Continuing Education and University Curricula of Rubberized Asphalt Concrete and Civil Engineering Application of Waste Tires

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STATE OF CALIFORNIA

Jerry Brown
Governor

John Laird
Secretary, California Natural Resources Agency

DEPARTMENT OF RESOURCES RECYCLING AND RECOVERY

Mark Leary
Acting Director

Department of Resources Recycling and Recovery
Public Affairs Office
1001 I Street (MS 22-B)
P.O. Box 4025
Sacramento, CA 95812-4025
www.calrecycle.ca.gov/Publications/
1-800-RECYCLE (California only) or (916) 341-6300

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Abstract: California generates about 40 million waste tires per year. Waste tires can cause significant public health, safety, and environmental concerns. Through research and marketing efforts, the CIWMB has increased the usage of waste tires in Rubberized Asphalt Concrete and other Civil Engineering Applications. These are great ways to turn a waste material into a valuable product. However, successful usage of waste tires in the RAC and Civil Engineering applications is not easily accomplished. Only trained and experienced engineers can ensure that these products can be successfully used in this type of application. To promote sustainability and the proper usage of waste tires in the above applications, the CIWMB funded this research to educate professionals, and university students.

Teaching materials were developed to educate undergraduate students who will become the future engineers and decision makers. As a part of this project, a series of lecture materials for eleven different courses were developed. These lecture modules cover topics from the freshman to senior level classes. Each lecture has been presented in a real class environment at CSU, Chico. The lectures greatly enhanced the students' knowledge of using waste tires in civil and transportation engineering applications.

Professor training workshops were given at three different locations, Sacramento, Pomona, and San Luis Obispo. About 40 professors from 16 different universities attended these workshops. These universities included representatives from the UC system, California State University system, private universities, and community colleges. The educational materials and other useful project information are summarized at the following website: http://www.ecst.csuchico.edu/cp2c/ciwmb/education/.

Practical presentations were also given for professionals at conferences or workshops including Transportation Research Board (TRB) meeting, California Asphalt Paving Association (CalAPA) meeting, California Maintenance Superintendent Association (MSA) meeting, APWA northern California section, American Society for Engineering Educators, and 4th Rubber Modified Asphalt Conference. These were well received and were useful in stimulating interest in using recycled tires in a variety of applications.

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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The content does not necessarily reflect the official views or polices of the California Integrated Waste Management Board or the State of California.

NOTE: Subsequent to the completion of this curriculum and the preparation of this report, legislation (SB 63, Strickland) signed into law by Gov. Arnold Schwarzenegger eliminated the California Integrated Waste Management Board (CIWMB) and its six-member governing board effective Dec. 31, 2009.

CIWMB programs and oversight responsibilities were retained and reorganized, effective Jan. 1, 2010, and merged with the beverage container recycling program previously managed by the California Department of Conservation.

The new entity is known as the Department of Resources Recycling and Recovery (CalRecycle) and is part of the California Natural Resources Agency. It is no longer part of the California Environmental Protection Agency (Cal/EPA), which is referenced throughout this report.

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1.0 INTRODUCTION

1.1 Background

The United States generates about 300 million waste tires each year. Some of these tires end up in stockpiles, both legally and illegally. Stockpiled waste tires pose significant public health and environmental issues. The curved shape of a tire retains rain water which creates an ideal breeding ground for mosquitoes and rodents, which transmit diseases, such as the West Nile virus. Tires are combustible materials and when placed in stockpiles can ignite resulting in tire fires that are difficult to extinguish. One passenger car tire equivalent (PTE) is estimated to contain the same amount of energy as over two gallons of oil (RPA, 2003). Although the Environmental Protection Agency (EPA) does not consider scrap tires to be a hazardous waste, tire fires release hazardous compounds which pollute the air, soil and water (EPA, 2008). Public agencies and private companies have spent millions of dollars cleaning up tire fires across the country.

Many states have instituted stockpile abatement programs, which have helped to reduce the number of tires in stockpiles significantly. In 1994, it was estimated that about 700 to 800 million waste tires were stockpiled. Today, the number of waste tires in stockpiles has been reduced to less than 200 million. Civil engineering projects can sometimes utilize stockpiled tires that are generally dirtier than “fresh” scrap tires helping to reduce stockpiles.

Based on the report by the Rubber Manufacturing Association (RMA), the recycling and reusing of waste tires in the United States has improved significantly (RMA, 2006). For example, in 2005, about 78 percent of the total number of waste tires generated were recycled and re-utilized, while only 10 percent of the total waste tires were reused in 1990. Waste tires can be consumed in a variety of ways. The major markets are tire derived fuel, civil engineering applications, and ground rubber applications including rubberized asphalt. Tire derived fuels accounted for 52 percent of scrap tires nationwide in 2005, which consumed about 155 million tires. Civil engineering applications, which is the second largest market, consumed more than 49 million tires in 2005. Ground rubber used in rubberized asphalt consumed about 12 percent of the total number of waste tires. However, about 10 percent of waste tires generated each year still go to landfills, which means these tires are not beneficially used and instead occupy valuable landfill space.

Civil engineering applications include using tire-derived aggregate (TDA) in: road construction, landfill applications, septic leach fields, gas and leachate collection systems, retaining wall backfill, lightweight embankment fill, vibration and sound control applications. Waste tire products possess many beneficial properties that are useful in these applications. Tire-derived aggregate (TDA), which is shredded tires, are light weight, have very good thermal insulation and high permeability, and have good vibration damping characteristics (Humphrey, 2003).

Ground rubber and crumb rubber markets have been growing for the past several years. Asphalt rubber or rubberized asphalt concrete (RAC) is the largest market for ground rubber. According to the Rubber Pavement Association, since 1990 more than 30 million tires have been used in asphalt rubber pavement, which equate to 40 times the distance from the earth to the moon when one tire is stacked on another (RPA, 2008). Crumb rubber can beneficially modify the physical performance of asphalt concrete. It has been demonstrated that, properly used, rubberized asphalt

can increase pavement service life, reduce maintenance, lower life cycle costs, reduce road noise, increase drainage, increase safety, and help improve the environment.

Using waste tires in civil and transportation engineering applications is a complex and challenging proposition. There have been some failed projects in the past, such as embankment fires in Washington State and Colorado due to the internal heating of TDA in 1995 (Baker et. al., 2003). Engineers need to be educated in order to know how to use these special construction products properly. To promote sustainability in the use of waste tires in civil and transportation engineering, the major goal of this study was to develop and disseminate appropriate university curricula materials which can be used to educate future engineers.

1.2 Objectives

The objectives of this research were to:

- Synthesize the state-of-the-art of utilizing waste tires in civil and transportation engineering applications.
- Develop and disseminate effective teaching materials to educate university faculty and students about utilizing waste tire products in civil engineering.
- Promote sustainability by using waste tires in civil engineering applications through university education.
- Continuing education of professionals on how to use waste tire products in civil and transportation engineering applications through publication and presentations at conferences and workshops.

To ensure the above objectives were met, the work tasks were identified as follows:

Task 1. Identify key sources of resource information

Task 2. Develop detailed course outlines

Task 3. Mock class presentations and feedback

Task 4. Identify locations for course delivery and development of course brochure

Task 5. Prepare and deliver presentations for professionals

Task 6. Evaluations

Task 7. Develop detailed outlines for each teaching module

Task 8. Develop the lecture materials/visual aids for the modules

Task 9. Introduce material to freshman or sophomores at community colleges

Task 10. Work with Private College, California State University, and University of California Faculty to introduce course modules.

Task 11. Project evaluation, and

Task 12. Preparation of final report.

In consultation with CIWMB staff, the above tasks were modified to put more emphasis on university curricula development than on continued education of professionals. The number of university classes for which teaching materials were developed was increased from the proposed eight courses to eleven different courses in civil engineering.

This report is organized as follows. In section 2, the results of a comprehensive literature review that was conducted is presented. Section 3 discusses the continuing education of professionals from training material development to presentations at various workshops and conferences. Section 4 discusses the development of university curricula to teach undergraduate students how to utilize waste tires in civil and transportation engineering applications. Section 5 describes how the teaching materials developed were disseminated to other universities or colleges within California. Section 6 shows conclusions of this project and recommendations for future work.

2.0 LITERATURE REVIEW

This task involved obtaining the latest state-of-art and state-of-practice information on the use of waste tires in civil and transportation engineering projects. The information collected or knowledge gained was then synthesized and utilized to develop course teaching modules and presentations for teaching RAC and CE applications utilizing waste tires. The researchers have created a project folder on the Civil Engineering server to share this information with project team members. By completing the literature review and contacting key experts, we have identified the following major sources of information on the use of recycled tire rubber in RAC and CE applications. The detailed publications can be found on the web at the following link: http://www.ecst.csuchico.edu/cp2c/ciwmb/TireProjectLiteratureIndex.html. Much of this information is copyrighted, so it can not be made generally available. What follows is a brief description of the major resources by category.

2.1 Rubberized Asphalt Concrete (RAC)

Rubberized Asphalt Concrete, which Caltrans now refers to as Rubberized Hot Mix Asphalt began to be used in the 1970s. Numerous useful references are available on this subject. The following constitute the major ones:

1. Rubberized Asphalt Concrete Pilot Training Course by Caltrans – June 2006
   - Presentations
     - RAC Prelude
     - RAC Introduction
     - RAC Structural Design
     - RAC Materials and Design
     - RAC Construction
     - RAC Inspection Guide
     - RAC Summary

- References
    - Asphalt Rubber Design and Construction Guide Vol I
    - Caltrans Asphalt Rubber Usage Guide
    - Feasibility of Recycling RAC
    - RAC Synthesis
    - RAC-G SSP Version 12-12-05
    - RAC-O SSP Version 12-12-05
    - Rehab Manual – June 2001
    - Structural Design Considerations

2. Use of Scrap Tire Rubber 2-8-2005
3. Rubberized Asphalt Concrete Projects – Caltrans Flexible Pavements

    - Dist 1 RAC Project Photos
    - Firebaugh Field Pictures
    - 5 year warrantee projects

4. RAC 101 – Use of Asphalt Rubber in Pavement
5. RAC 105 – Construction Inspection Overview
6. Management of Scrap Tires – EPA (Web)
7. Rubber Pavement Association
8. MACTEC-work for Caltrans and the CIWMB

2.2 Civil Engineering (CE) Applications of Waste Tires

A substantial amount of literature is available on utilizing scrap tires in civil engineering applications. Most of this literature is topic specific and is listed as reference material at the end of each modules chapter. Some of the most significant reference materials are as follows:

1. Civil Engineering Applications using Tire Derived Aggregates (TDA) – Report by Dana Humphrey
2. Recycling Materials Resource Center (RMRC)
3. Civil Engineering Applications of Scrap Tire – EPA
4. References
    - Subgrade Fill and Embankments
    - Backfill for Wall and Bridge Abutments
    - Subgrade Insulation for Roads
    - Landfills
    - Septic System Drain Fields
    - Gravel Substitute
    - Drainage around Building Foundations and Building Foundation Insulation

5. RCC Scrap Tire Workgroup
6. Scrap Tire News (Web)
7. Dana Humphrey – University of Maine

- Civil Engineering Application of Tire Chips (Web)
- Work for CIWMB

8. Tire Derived Aggregate (TDA)
9. CIWMB Publications (Web)
10. ASTM Standards

3.0 CONTINUING EDUCATION OF PROFESSIONALS

3.1 Development of presentations

The authors developed training materials for professionals and delivered them at several locations. For RAC, presentations were developed for Asphalt Rubber 101 in 2 hour, 4 hour, and 6 hour timeframe formats. For the use of tire derived aggregate (TDA) in civil engineering applications presentation materials from Kennec, Inc. and other researchers have been , incorporated and used during the professional presentations. As an example, the presentation for asphalt rubber 101 for professionals and TDA in California from Kennec, Inc. are included in appendix A.

3.2. Accomplishments for Continuing Education

This effort on the continuing education of professional was reduced once it was determined that student work was more effective. Presentations have given at various professional conferences and workshops. The following table summarizes the times and locations of these conferences and workshops:

TABLE 1. Presentations to Professionals at Conferences or Workshops

Conference or Workshop	Date	Location
California Asphalt Paving Association (CalAPA) Technical Meeting	Aug 5, 2008	Oakland, CA
California Maintenance Superintendent Association (MSA) annual meeting	Aug 27, 2008	Rohnert Park, CA
Transportation Research Board (TRB) Annual Meeting	Jan 12, 2009	Washington, D.C.
America Society for Engineering Educators PSW Conference	March 20, 2009	San Diego, CA
America Public Works Associations (APWA) northern CA chapter workshop	April 24, 2009	Chico, CA
4th Rubber Modified Asphalt Conference	May 7, 2009	Akron, OH
Asphalt Rubber 2009	Nov, 2009	Nanjing, China

To disseminate this knowledge nationally, papers were published in TRB and ASEE. Another paper regarding asphalt rubber was accepted for Asphalt Rubber 2009 to be held in China in November 2009. A list of the papers presented is summarized in Table 2.

TABLE 2. Papers to Professionals at Conferences or Workshops

Paper Title	Conference Name	Date	Location
Promoting Sustainability through Educating Undergraduate Students on Applications of Waste Tire Products in Civil Engineering and Transportation	Transportation Research Board (TRB) Annual Meeting	Jan 12, 2009	Washington, D.C.
Curricula for Using Waste Tires in Civil Engineering Applications	America Society for Engineering Educators PSW Conference	March 20, 2009	San Diego, CA
Promoting Asphalt Rubber Application through Education	Asphalt Rubber 2009	Nov, 2009	Nanjing, China

4.0 DEVELOPMENT OF LECTURE MATERIALS FOR UNIVERSITY CURRICULA

4.1 Background

Utilizing waste tires in civil and transportation engineering applications is a multi-disciplinary subject. No single class currently available in civil engineering can cover all the aspects of this broad topic. At the beginning of the project, two different approaches were compared:

- Developing one new class to include all aspects of waste tire applications
- Adding teaching modules at different class levels in a variety of related civil engineering classes. After considerable discussion this method was chosen because it is more flexible and can reach more students.

For each teaching module PowerPoint presentations, assignments, and reference materials has been created. This allows for instructors to more easily incorporate these modules into their own courses.

Therefore, waste tire applications teaching modules for a variety of civil engineering courses from freshman level to senior level were developed. Each module contains one or more lectures. Figure 1 illustrates the courses that training modules were developed for. A chapter (or narrative) for each course module has been prepared in draft form to give the instructor additional background material on each topic.

By offering teaching modules for waste tire applications at different levels in higher education, more students can be reached than any single elective class could. By the time, a student graduates, they will have conceivably seen waste tire applications multiple times. This was chosen as a more effective way of teaching undergraduate students about utilizing unconventional materials, such as waste tire products.

The teaching modules were developed to be independent of each other. Each module emphasizes a different aspect of waste tire applications. Some discuss geotechnical engineering applications, while others may illustrate pavement material modification. In addition, they do not need to be offered together. The format of the training materials is flexible so professors and instructors can tailor the teaching modules to their teaching needs as they please. The teaching modules including PowerPoint presentations, assignments, and some student sample projects are available at the project website: http://www.ecst.csuchico.edu/cp2c/ciwmb/education/. The teaching modules and lecture presentations can also be found in the Appendix B of this report.

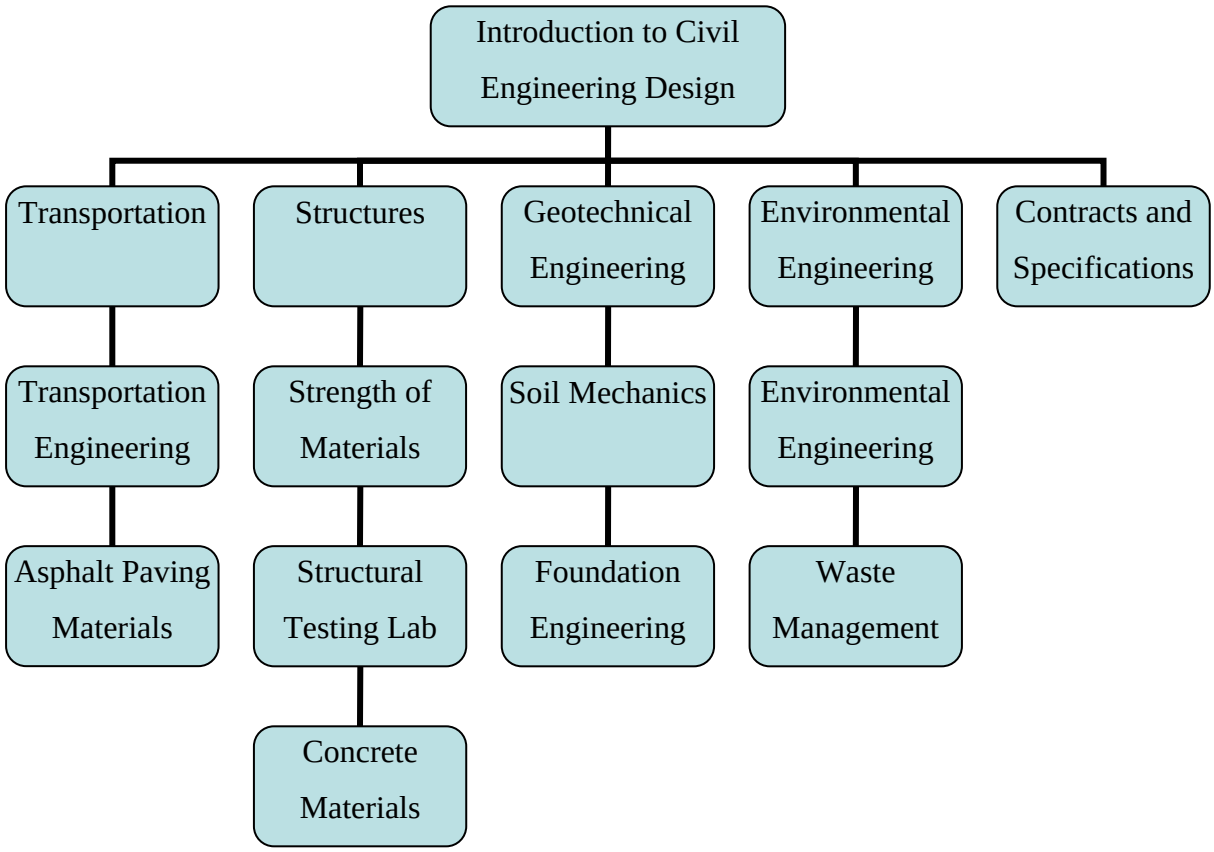

FIGURE 1. Roadmap for Teaching Waste Tire Applications in Civil Engineering Curricula

4.2 Summary of Teaching Modules

To assist in the teaching of these modules, companion materials in a chapter format have been developed in draft format. Each class or module is discussed in its own chapter. The following

sections describe the objectives, scope, and major components of each chapter. The detailed chapter contents are in Appendix C. The following sections provide a brief summary of the modules developed.

4.2.1 Introduction to Civil Engineering Design

The goal of this lecture is to introduce university students to waste tires and give them an overview of utilizing waste tire products in a variety of types of civil engineering applications. It is important to introduce students to the significance of utilizing recycled materials to remove them from the waste stream and to preserve valuable natural resources. Students should understand the significance of protecting the environment. They should also learn to promote healthy and sustainable development for society.

The lecture introduces waste tire materials by mentioning the negative environmental impacts if waste tires are not properly managed. Each year, about 300 million waste tires were generated in the United States with about 40 million waste tires generated in California alone. Although the majority of the waste tires were recycled and reused, a significant number of waste tires were put into landfills or stockpiles. In 1983, a tire fire burned about 7 million tires in Rhinehart, Virginia. The fire burned for nine months, polluting water with poisons, such as lead and arsenic. In 1998, a grass fire ignited an estimated 7 million tires at an unlicensed tire disposal facility in Tracy, California. It was extinguished after 26 months with water and foam. In September 1999, lightning ignited stockpiled tires in the little town of Westley, California. The fire burned for three months. It took seven years to clean up and cost about 20 million dollars. Figure 3 shows a picture of the Westley tire fire.

The lecture also covers the benefits and challenges of using waste tire derived products in civil and transportation engineering applications. It discusses physical properties of waste tire derived aggregate. More importantly, it gives an overview of the major applications in civil and transportation engineering, including TDA as backfill materials for retaining walls and bridge abutments, lightweight fill for embankments, insulation layer for roadway base, vibration damping materials for rail lines, and rubberized hot mix asphalt for pavement. It also gives students a roadmap of civil engineering classes that potentially include waste tire applications.

FIGURE 2. Tire Fire in Westley California in September 1999

(From Earth-Link Web, 2008)

4.2.2 Strength of Materials

This lecture mainly covers the physical properties of tire derived aggregates. TDA are pieces of shredded tires that are generally between 1 inch and 12 inches in largest dimension. The properties of TDA that affect engineering performance are: gradation, specific gravity, absorption capacity, compressibility, resilient modulus, time dependent settlement of TDA fills, shear strength, hydraulic conductivity, and thermal conductivity.

This lecture also covers a general model which is a combination of Maxwell and Kelvin models using spring and dashpot elements. The model can be used to analyze the energy dissipation and vibration mitigation characters of TDA. TDA has been used as a vibration damping material for a light rail line by Valley Transit Authority (VTA) in California's Bay Area. The results show that it is a very cost effective vibration attenuation material. As shown in Figure 3, the average vibration level of a light rail line has been reduced by about 10 dB for the 63 to 250 Hz range compared with a control section. This is a significant reduction because dB is a log scale so 10 dB's represents a order of magnitude reduction in transmitted vibration. The project also saved VTA approximately $1 to $2 million compared with a floating slab vibration mitigation technique.

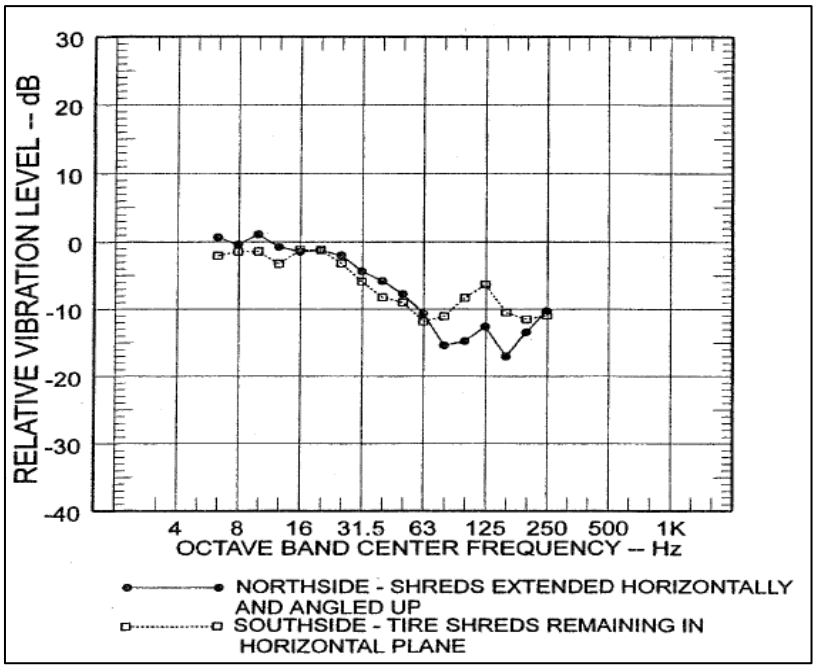

FIGURE 3. Relative Vibration Reduction for VTA Light Rail by Using TDA

(Humphrey, 2003)

4.2.3 Structural Testing Lab – Shear Strength

The lecture part of the structural testing lab on TDA discusses the stress-strain relationship for TDA. This lecture introduces the common methods of measuring shear strength of granular materials, including soil, crumb rubber, and tire buffing. The lab portion of the class allows students to test the shear strength of crumb rubber using direct shear apparatus.

A literature review and comparison of shear strength parameters from many different sources was conducted. The shear strength of the TDA mainly depends on: (a) size and shape of the tire rubber pieces, (b) density of packing, (c) magnitude of the compressive normal loading, (d) gradation, and (e) orientation of tire shreds.

4.2.4 Contract and Specifications

This lecture has two modules. One is on ASTM international standards; the other is for specifications on rubberized hot mix asphalt. A series of ASTM standards related to waste tire applications are covered. The major one is ASTM D6270, which has detailed definitions on tire rubber, material characterization, usage, construction practices, guideline for fills, and leachate etc. The lecture also provides students the necessary background on ASTM International.

The specification lecture starts with various types and aspects of specifications. As examples, standard specifications were illustrated using Caltrans standard specification on RHMA – O (open graded rubberized hot mix asphalt) and RHMA – G (gap graded rubberized hot mix asphalt).

4.2.5 Soil Mechanics

Tire Derived Aggregate (TDA) has many unique physical properties that can be used in Geotechnical engineering. The in-place density of TDA ranges from 45 lb/ft^3 to 58 lb/ft^3, which is about 1/3 the unit weight of soil. TDA can be used as a lightweight material to construct embankments on weak, compressible foundation soils. TDA has high permeability, more than 1 cm/sec, which can replace conventional aggregate to be used as gas collection media or leachate collection material. TDA is a good thermal insulation material, which has a thermal insulation 8 times greater than the gravel. In cold climates, placing a 6 to 12 inch tire shred layer under the road can prevent the subgrade soils from freezing. In addition, excess water may be released when subgrade soils thaw in the spring. The high permeability of tire shreds allows water to drain from beneath the roads, preventing damage to road surfaces.

In the lecture material, the Dixon Landing interchange project at the intersection of I-880 and Dixon Landing Road is used as a case study to illustrate the design, construction, and cost benefit of the project. The embankment for the interchange needed to be constructed on top of about 30 feet of San Francisco Bay mud, which is a highly compressible soil. It required using lightweight fill material for most fill sections to reduce total settlement. For most projects building on a soft clay type of soil, using TDA as a lightweight fill material is significantly cheaper than other alternatives. The Dixon Landing interchange project used 6,627 tons or 662,700 passenger tire equivalents (PTE) of TDA. The cost savings to Caltrans was $447,000 compared to using lightweight aggregate for the project. When the purchase price of the TDA is subtracted, the cost savings is still $230,000. Figure 4 shows the TDA compaction for the construction of Dixon Landing interchange.

FIGURE 4. Dixon Landing Interchange Embankment Fill, Compacting TDA

(Kennec, Inc. 2008)

Another case study for soil mechanics class is using TDA as subgrade insulation for Witter Farm Road, Orono, Maine. Frost in this cold climate region can cause heaving of the road and can

crack the asphalt, while the thawing weakens the road subbase leading to rutting of the gravel and cracking of the asphalt. From the testing results, the frost depth was reduced from 55 inches in control section to about 30 inches in a TDA fill section.

The lecture also introduces using TDA for Marina Drive slope repair in Ukiah, CA. As shown in Figure 5, a road slide damaged the Marina Drive making it unusable. Using TDA as lightweight backfill material replacing typical backfill soil, less excavation is necessary and a more cost effective design can be utilized. The project used about 2,000 ton or 200,000 PTE tires.

FIGURE 5. Landslide Damaged Section of Marina Drive, Ukiah, CA

4.2.6 Concrete Materials

Rubber included concrete or rubberized concrete consists of mixing tire rubber into Portland cement concrete mixes by replacing a portion of the mineral aggregate with crumb rubber. It changes the physical properties of concrete.

One of the most important factors about the rubberized concrete material is the mix design. From the literature review shown in Table 3, the major mix design factors are proportions of crumb rubber by volume or by weight of mix, water-cement ratio, rubber type, and rubber content.

TABLE 3. Summary of Rubberized Concrete Mix Designs from Literature

Author	Rubber Type	Rubber Content	Method of Mix Design
Kaloush et. al.	1mm Crumb Rubber	0, 50, 100, 150, 200, and 300 lb/cuyd	Replaced fine aggregate with crumb rubber by weight, increased w/c ratio
Fedroff et. al.	Super fine powder	0, 10, 20, and 30%	By weight of cement in mix adjusted w/c ratio to get 3 to 5 inches of slump
Tantala et.al.	Buff Rubber	5 and 10%	Replaced 5% and 10% of coarse aggregate with buff rubber by volume
Schimizze et.al.	Fine/Coarse Reclaimed Rubber	5% of mix design by weight	Lowered both 1. fine aggregate and 2. fine and coarse aggregate to get 5% rubber by weight
Biel and Lee	3/8" minus rubber droppings	0 to 90% in 15% increments	Replaced fine aggregate with crumb rubber by volume gave 0 to 25% rubber by volume in mix
Eldin et.al.	Ground tire chips, fine crumb rubber	0,25,50,75,100% by volume	Test specimens replacing either coarse or fine aggregate

A fair amount of research has been done in using waste tire particles in Portland cement concrete. Although compressive strength and stiffness of concrete mixes decrease dramatically with increasing rubber content, the ductility, toughness, and tensile strain have been shown to increase with small amounts of rubber particles. Rubberized concrete may be more flexible and crack resistant for lightweight paving. It may provide vibration damping and sound transmission mitigation. It can be used for energy absorption due to dynamic force, such as earthquakes. It may also increase the freeze-thaw durability of concrete.

4.2.7 Foundation Engineering

Lateral earth pressure is the pressure exerted by a fill material on the wall of a structure like a retaining wall. It can be determined from the coefficients of lateral earth pressure, which are calculated by dividing horizontal stress by vertical stress. TDA can also reduce lateral earth pressure up to 50 percent compared to conventional soil backfill material. It also has good drainage properties to prevent water build up behind the wall. Therefore, TDA is a very good

material as backfill for retaining walls and bridge abutments. It can reduce the design thickness of the wall and use less reinforcing steel.

This lecture introduces a full scale retaining wall testing at the University of Maine. The testing facility has four walls and a reinforced concrete foundation. The size of the testing facility is 16 ft. high by 15 ft. long by 14.7 ft. wide. The lateral earth pressure, horizontal displacement, interface friction between the wall and TDA, were measured during the test. It was found that the horizontal stress at rest for TDA is 45 percent less than that of conventional granular fill. Figure 6 shows a picture of loading TDA fill into the constructed wall testing facility.

FIGURE 6. Full Scale Retaining Wall Testing Using TDA as Backfill

(Humphrey 2003)

The lecture also introduces a case study of constructing of a real world retaining wall with TDA. Figure 7 shows a picture of the project. Caltrans and the CIWMB constructed 300 linear feet of retaining wall, along Wall 119, with TDA as lightweight backfill material along route 91, in Riverside, California. The retaining wall is 12 ft. tall, with 9.8 ft. of compacted TDA enclosed in a geotextile membrane. It has about 2 feet of soil cover. At designated locations, the forces were measured using pressure cells; the strains in the reinforcing steel were measured with strain

gauges; temperature of the tire shred materials were measured using temperature sensors; and the displacement of the wall was monitored with a tilt meter. The retaining project was very successful and it used 837 tons of TDA. The following picture shows the construction of Wall 119.

FIGURE 7. TDA as Backfill for Retaining Wall 119 in Riverside, CA

(Kennec, 2008)

4.2.8 Environmental Engineering

This lecture focuses on the environmental aspects of utilizing waste tires in civil and transportation engineering applications. First, it introduces the negative impact if waste tire materials are not recycled and managed properly. Then, it describes the engineering properties of TDA and rubberized asphalt. It shows the beneficial usage of waste tire materials in civil engineering applications, such as lightweight fill, landfill applications, vibration damping, and rubberized asphalt pavement.

Consequently, it addresses the environmental assessment research on using TDA and rubberized asphalt. Significant amounts of research, both laboratory evaluations and field tests, have been conducted on various environmental impacts. It provides students the knowledge of what environmental factors that they should pay attention to when they use waste tires. Generally, recycled rubber derived from scrap tires is a safe recyclable material. It is important to recognize that the impact of scrap tires on the environment varies according to the local water and soil conditions, especially pH values. Scrap tire products may not be safe to use in applications where the pH is too high or too low.

4.2.9 Transportation Engineering

The goal of the transportation engineering lecture is to inform students of the history, benefits, limitations and practice of using asphalt rubber (AR) as a paving material. This lecture is divided into four modules, each dealing with a different aspect of asphalt rubber applications.

The students are first introduced to the history of asphalt rubber being used as a paving material. Case studies of full scale AR overlay projects in California are presented. These studies outline the strategy of using AR as an overlay to repair existing distressed pavements, as well as discussing the design and results of the AR overlays. The benefits of using AR pavements as a replacement for conventional asphalt are also included. The second module discusses the structural design of AR pavements. A 2005 Caltrans study is referenced in this module to discuss the revised practices of using AR in new pavements as well as an overlay. Students are informed about the recommended design strategy for new pavements and overlays using AR. An overview of the revised practice for using AR in overlays and new pavement is also presented. This module also discusses cost analysis comparing AR and conventional asphalt.

Students are introduced to the manufacturing and construction process of AR in the third module. The module discusses the general paving process with an emphasis on the different practices between AR and conventional asphalt. An overview of the manufacturing process informs students how AR is produced and also highlights the operational differences when dealing with AR such as the laydown and compaction temperatures for successful placement of AR. The last module of the lecture goes into detail about the AR binder production, AR mix production, inspection of paving and troubleshooting. Some or all of these modules could be included in this class.

4.2.10 Asphalt Paving Materials

This lecture consists of asphalt rubber (AR) binder design, the different types of AR mixes and the cautions of using AR. The lecture defines the different types of asphalt rubber binders and discusses how each type is produced. Crumb Rubber Modifiers (CRM) are the form of waste tires added to the binder. The interaction between the CRM, the asphalt and the affecting factors are explained. When designing an AR blend, it is necessary to develop a binder profile which evaluates the compatibility, interaction, and stability of materials over a period of time.

The students are introduced to the most commonly used types of rubberized hot mix asphalt concrete, including Rubberized Hot Mix Asphalt – Gap graded (RHMA-G), Rubberized Hot Mix Asphalt – Open graded (RHMA-O), and Rubberized Hot Mix Asphalt – Open graded – High Binder content (RHMA-O-HB). The mix design, advantages, and standard specifications are described for each rubberized asphalt mixture type. For example, Figure 8 shows RHMA-O can reduce splashing during rainy season and improve safety.

FIGURE 8. Free-Draining RHMA-O Next To DGAC

(Caltrans 2003)

4.2.11 Solid Waste Management

This lecture covers the application of Tire Derived Aggregates (TDA) in landfills. The construction of modern mechanized landfills requires large quantities of material which possess the same material properties as TDA. TDA can be used in many landfill applications.

Federal guidelines require landfills to employ a layer of material with a high void content to sit in between the waste and the impermeable layer of a landfill in order to contain leachate until removal. This layer is known as the operations or drainage layer. TDA is a good alternative material for gravel for this application due to its high permeability. It is necessary that all leachate produced in a landfill is collected due to its toxic nature. Landfills have leachate collection systems which require a high permeable material such as TDA. Many landfills have low points or sumps where leachate is allowed to drain and collected for removal. TDA has been used as a collection media for the leachate. TDA has been utilized in as needed leachate recirculation systems too. In these cases, TDA is used to insulate perforated pipes which deliver the leachate back into the fill area of a landfill. Landfills use toe drains to collect leachate from the base of landfills. In this application TDA is used as a collection media, where leachate is allowed to drain into a trench with a perforated pipe on the bottom and filled with TDA. The TDA allows the leachate to freely drain into the trench and insulates the perforated pipe to prevent blockage and damage while the leachate flows into the pipe.

Federal and state guidelines also require landfills to control and collect methane gas produced during the anaerobic digestion of organic wastes. The methane generated within the landfill tends to follow the path of least resistance. TDA is an excellent material for gas control systems due to its high permeability. Landfills use gas collection trenches to extract and capture the methane gas. Vertical trenches passing through the impermeable landfill cap allows methane gas to vent out of the landfill into a collection system. The vertical trench is composed of perforated pipe

surrounded by TDA. This system allows the methane to vent out of the landfill into a collection system. Landfills also use trenchless gas collection systems. In these systems, methane is allowed to vent through the non permeable cap at the toe, located at the bottom of the lift. TDA is placed atop the toe to allow the methane to enter a perforated collection pipe.

Due to TDA's high permeability and durability it can also be used to protect and insulate parts of the gas collection systems. TDA is used to insulate horizontal collection pipes as well as protect gas well heads.

4.3 Student Feedback

All these lectures have been taught at the undergraduate level at the California State University, Chico. The outcomes showed that students are happy with the teaching modules. They understand the importance of promote sustainability and using recycled materials. They are happy that they can add waste tire products in their civil engineering application toolbox. They have greatly improved their knowledge on waste tire material applications. They were able to demonstrate their knowledge and interests of waste tire applications through their term projects, lab reports, presentations, and homework assignments.

As an example, the following outcomes were evaluated at the Spring 2008 Soil Mechanics class:

a. Ability to design and analyze data, as well as to interpret results for a slope stability problem using waste tires.
b. Knowledge of the engineering properties of waste tire derived aggregate, and application of the properties in their engineering analyses.
c. Understanding the importance and benefits of utilizing recycled materials such as waste tires in civil engineering applications.

The students were formed into lab groups. Each group was assigned a slope stability problem for an embankment project. They needed to use simplified bishop method and ordinary method of slices to design the slope and choose materials used for the embankment. They needed to compare the conventional fill materials with tire derived aggregates. Student groups were required to submit a formal lab report and give a presentation on their findings. Figure 9 shows slope stability analysis results by students on TDA as embankment fill materials.

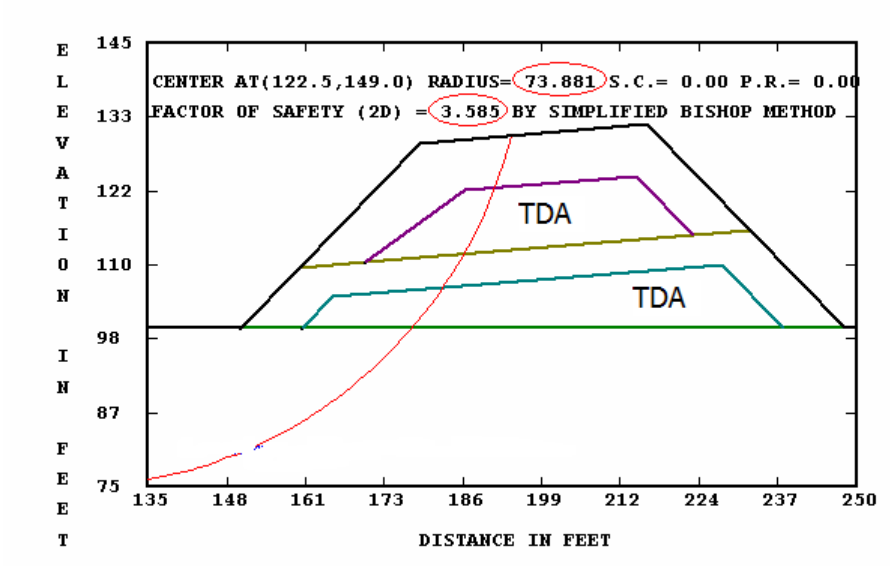

FIGURE 9. Sample Slope Stability Analysis Results using Simplified Bishop Method

Student proficiency is measured by the score on lab report and presentation. Generally, 90 to 100 percent would represent mastery, 80 percent above adequate proficiency, 70 percent adequate proficiency, and below 70 percent would be indicative that the student lacks proficiency. Figure 10 shows the scores of the lab groups in this project. Students learned the subjects very well.

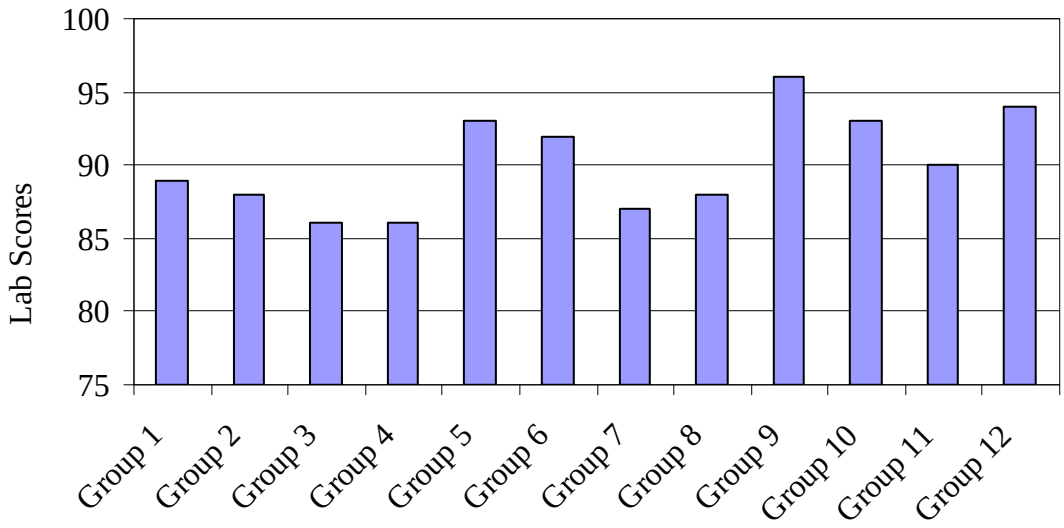

Figure 10. Lab Scores of Using Waste Tires as Embankment Fill in Slope Analysis

4.4 Student Recognition by the Board

On April 14, 2009, two Chico State students gave a presentation about their student project on using waste tire in rubberized asphalt pavement, and using tire derived aggregates as retaining

wall back fill materials on a hypothetical SH 99 widening project. The board members were very pleased with the student' work and gave very positive comments about their presentation. Figure 10 shows the CIWMB board members awarding two students a certificate of appreciation.

FIGURE 10. CIWMB Board Members Award Chico Students Certificate of Appreciation

(Left to right: Sheila Kuehl, Rosalie Mulé, John Laird, Students Julian Storelli and Cody Menefee, and Carole Migden)

5.0 DISSEMINATION OF KNOWLEDGE TO UNIVERSITIES AND COMMUNITY COLLEGES IN CA

5.1Training materials and Instructor Workshops

A training manual relating to university curricula and along with the most relevant references was developed. Invitations were then sent to civil engineering faculty at universities in California who were interested in teaching one or more of the waste tire applications related classes.

Three professor training workshops were given to professors teaching classes related to the use of waste tire applications in California. One professor training workshop was conducted in Sacramento, CA on December 19, 2008 for the universities in the northern California. Another professor training workshop was held in Pomona, CA on January 5, 2009 for the universities in the southern California. Fourteen professors from 11 different universities attended these two workshops. The third workshop was held at the San Luis Obispo on April 17, 2009. This workshop was very successful with 22 professors from 9 different universities. A list of those attending the workshops is given in Table 4.

The professors were asked to rate the quality of the materials and the presentations at the workshops. They believed the teaching materials are very useful and can be incorporated into their classes. The presentations from the workshop are available at the following website: www.ecst.csuchico.edu/cp2c/ciwmb/education.

TABLE 4. List of Professors Attending the Professor Training Workshops

Num	Last Name	First Name	Department	University
1	Al-Manaseer	Akthem	Civil & Environmental Engineering	San Jose State University
2	Andrei	Dragos	Civil Engineering	Cal Poly Pomona
3	Chai	Rob Y. H.	Civil and Environmental Engineering	University of California, Davis
4	Estrada	Hector	Civil Engineering	University of the Pacific
5	Farran	Hany	Civil Engineering	CAL POLY POMONA
6	Hanson	James	Civil and Environmental Engineering	California Polytechnic State University
7	Jia	Xudong	Civil Engineering Department	Cal Poly Pomona
8	Khatri	Sikandar	Civil Engineering	San Francisco State University
9	Kim	Uksun	Civil and Environmental Engineering	California State University, Fullerton
10	Larralde	Jesus	Civil Engineering	Cal State University, Fresno
11	Lee	Luke	Civil Engineering	University of the Pacific
12	Lepech	Michael	Department of Civil and Environmental Engineering	Stanford University
13	Li	Yuwei	Volvo Center for Future Urban Transportation	University of California at Berkeley
14	Liu	Lubo	Civil and Geomatics Engineering	California State University Fresno
15	Mathias	Darlene	Engineering	Consumes River College
16	Mitra	Nilanjan	Civil Engineering	CalPoly San Luis Obispo
17	Mitra	Sudeshna	Civil Engineering	CalPoly San Luis Obispo
18	Mosallam	Ayman	CIVIL & ENVIROMENTAL ENGINEERING	University of California, Irvine
19	Nelson	Yarrow	Civil & Environmental Engineering	Cal Poly, SLO

Num	Last Name	First Name	Department	University
20	Nilsson	Tonya	Civil Engineering	San Jose State
21	Oskoorouchi	Ali	Civil & Environmental Engineering	San Jose State University
22	Pande	Nurag	Civil and Environmental Engineering	Cal Poly Sal Luis Obispo
23	Porbaha	Ali	Civil Engineering	CSU_Sacramento
24	Putcha	Chandrasekhar	Civil and Environmental Engineering	California State University, Fullerton
25	Putnam	Jim	Civil and Environmental Engineering	UCDavis
26	Qu	Bing	Civil and Environmental Engineering	California Polytechnic State University
27	Rahim	Ashraf	Civil and Environmental Engineering	CalPoly State University
28	Reginato	Justin	Civil Engineering & Engineering Management	University of the Pacific
29	Saadeh	Shadi	Civil Engineering	CSULB
30	Shafizadeh	Kevan	Civil Engineering	CSU Sacramento
31	Tarakji	Ghassan	Civil Engineering, School of Engineering	San Francisco State University
32	Tiwari	Binod	Civil and Environmental Engineering	California State University, Fullerton
33	Vigil	Sam	Civil & Environmental Engineering Department	Cal Poly
34	Vucetic	Mladen	Civil and Environmental Engineering	University of California, Los Angeles (UCLA)
35	Xiao	Ming	Civil and Geomatics Engineering	California State University, Fresno
36	Yesiller	Nazli	Civil and Environmental Engineering	California Polytechnic State University

5.2 Presentations

Guest lectures at a few select community colleges in Northern California were given. On May 1, 2009, an introduction to civil engineering design lecture was given to about 30 college students in Shasta College, Redding CA. Students and faculty showed interest in this topic. Based on the feedback from the instructor (Joe Polin of the Shasta College), the students talked among themselves for quite a while after the presentation. They enjoyed the topic and applications of waste tire products. On May 8, 2009, Dr. Joel Arthur gave a presentation to a lower division engineering class at the College of the Siskiyous. The contact person at College of the Siskiyous

is Michael Read. The students thought the presentation and information were very valuable and worthwhile.

A presentation was given at a conference for the America Society for Engineering Educators for Pacific Southwest Division in San Diego on March 20, 2009. Many university faculty from California attended this conference. The attendees asked questions about the sustainability of using waste tires. They were interested in the teaching materials and the website.

A presentation was given at the 88 Annual Conference of the Transportation Research Board on January 11-15 2009 in Washington D.C. The TRB meeting covered all the areas in transportation and attracted more than 10,000 transportation professionals including academia from all over the world. It was an excellent opportunity to promote waste tire applications in civil and transportation engineering. For example, University of New York at Buffalo requested the web access to the teaching materials and training manual from CIWMB and CSU, Chico.

Finally, a presentation about life cycle cost analysis of asphalt rubber materials was given in Akron, OH in May 2009. People were very interested in the topic and the information is very useful for people in selecting appropriate pavement treatments including asphalt rubber. This presentation is included in Appendix D.

5.2 Instructor workshop Feedback and Evaluations

At each professor training workshops, professors filled out evaluation forms and provided suggestions for the project. The sample evaluation form is included in Appendix E.

The following table gives a summary of feedback from University Professors attending the workshop. The ratings are from 1-5 with 1 as poor and 5 as excellent:

TABLE 5. Summary Ratings from University Professor Training Workshops

Training Quality	Average Rating	Standard Deviation
1. What is your overall rating of this Workshop?	4.27	0.62
2. This training will be beneficial to you in teaching waste tire applications?	4.32	0.63
3. Overall speakers' knowledge of the subjects.	4.32	0.70
4. overall speakers' presentation style	4.18	0.83
5. The topics were presented in logical order	3.82	0.78
6. Usefulness of Seminal Material	4.36	0.71

The attendees praised the workshop as being successful and meaningful. The followings are summaries of sample answers to questions at the professor training:

1. What do you think were the strengths of the workshop?

[Very good introduction to the subject], [It's a new topic and new area where we can start research on], [Excellent presenters. Excellent notes. Very gracious host], [Lot of good examples in terms of research studies as well as actual construction projects.], [Introduction of a new material in a good manner in different perspective applications], [Very good overview of the use of tire waste products. Good interaction with audience. Speakers are very knowledgeable], [Good Selection of slides, good coverage of background materials for the most part], [Relevant and Timely subjects], [New idea and practical value], [Course structure is very usable for interested instructors, very timely as sustainability in an emerging issue], [Archive of materials very helpful. Running through teaching modules good, but could accelerate for faculty members. Good you generally stayed on time], [Good: overview of TDA and RHMA, examples, classroom interactions], [Presenters working in the industry had good, practical knowledge], [Good examples and practical applications], [Excellent speakers and graphics], [The development of course material was fantastic. Having Joaquin Wright was very useful to fully understand construction uses].

2. What do you think were the weaknesses of this Workshop?

[Short duration. One day is too short to get all aspects of this subject; two days may be better], [It was short, we could have more discussions], [None], [Some examples from other states as well as abroad.], [Much more research should have been presented], [Would like more about testing and design with materials. For example, for geotechnical engineering, there is a lot of lab data on hydraulic, shear strength and compressibility and the tire chip and soil/tire chip mixes that can be included in the module], [Some technologies discussed were not reliantly developed].

3. How would you suggest the workshop be improved? Do you think an online or web-based seminar helpful?

[A 2-day workshop, numbered page handout. Yes web-based course/seminar], [Web might be useful to incorporate other researchers working in the area], [I feel that the material presented in the binned volume is extensive and very clear. Very professional presentations],[Put them in study material so that interested readers can refer to.], [Do more research, put enough resources for more research and more University-Industry collaboration. Online is good.], [web-based seminars would be an excellent follow-up to the seminar],[in person much better than on-line version, especially for this length of course(all day)], [Yes very much, maybe "Webinar" would be a more regular fixture as we implement it in our teaching], [face-face interaction is valued, larger room, more discussion time, it would be helpful for an open faculty discussion time], [ask CIWMB to make presentation on goals and priorities], [Would like Gary Hick's Slides], [Ensure that all presentations are in handouts], [More crowd control for inappropriate questions].

4. I would like to have additional information on the following subjects.

[Other applications], [Current research in geotechnical applications], [Structural testing of asphalt rubber pavements], [Studies on transportation engineering: both in terms of pavement materials and implication on operation or safety], [Material models for this new material], [Show more long-term performance do structures built with the tire products], []Extensive reference list categorized by specialty topic], [The locations in CA where RAPM have been used], [Supply Chain/ value chain of waste tires].

5. How did you hear about this seminar?

[Email], [Call from Dr. Cheng], [Dr. Joel Arthur], [Email from Dr. Cheng], [Email], [Email], [Email and from Stacy Patenaude], [Email], [Email from depth. chair], [Call from Dr. Arthur].

6. Will you use some of the materials here into your teaching? If not, why?

[Yes], [Yes], [As relevant to my Concrete Testing Laboratory, yes. At least inform the students that this technology exists.], [Yes],[Yes],[Will try to incorporate material into class lectures], [Helpful modules, I should be able to use them], [Yes], [Yes], [Yes, very helpful to have full modules], [Probably], [Yes], [Yes will use in Solid Waste and Sustainability Classes].

7. Do you have any other comments or questions?

[No], [I would like to follow up on current research trends], [I am thankful for giving me a chance to learn more about pavement structural materials.], [it was good, keep up the good work. Educate more people],[Include student perspectives, especially from students who have taken such a course],[Make sure that the participants understand that this is material intended to be used for teaching. This is not a research conference; we are not discussing research results. The room was too small. Include soil/chip mixtures, need to expand on get tech applications], [Larger room. A panel discussion with all speakers would be great platform for open discussion], [Check for repetitive information for each speech].

6.0 CONCLUSIONS AND RECOMMENDATIONS

This was a very challenging and rewarding project. University level teaching materials were developed which can help society in several ways, including:

- Environmental benefits
- Waste tire utilization in civil engineering applications as tire derived aggregates
- Waste tire in utilization transportation engineering application as rubberized asphalt concrete
- Educate university students about sustainability and using recycled materials

Specific conclusions and recommendations are as follows.

6.1 Conclusions

- Waste tire applications cover a wide range of civil engineering areas, including geotechnical, environmental, structural, and transportation.

- The teaching modules or lecturing materials were developed to cover freshman level to senior level classes. The freshman class gives students an introduction and overview of waste tire products and their applications. Junior classes cover the material properties, testing, and standards. Senior classes cover the waste tire applications in civil and transportation engineering.

- The outcomes show that it is an effective way to teach waste tire applications and to reach more students. Students have demonstrated knowledge and interest on the sustainable usage of waste tire materials through out their school work.

- Education of students is the most important way of training future engineers. University students are more inclined to learn new technologies such as applying the use of waste tire products in their future projects.

- Incorporating waste tire application projects into University curricula is a great green way to sustain the usage of waste tires. Through the pilot classes conducted at CSU Chico, students learned to turn the waste tire products into valuable materials after the proper education of RAC or other CE applications for waste tires. Now, as a part of their knowledge base, they are much more aware of green waste tire applications as well as conventional civil engineering materials, such as steel, concrete, asphalt, and wood.

- After consulting with CIWMB staff, the workshops for continuing education were given. Most of the effort was spent on the development of university curricula and undergraduate education on waste tire applications in civil and transportation engineering.

6.2 Recommendations

The following recommendations are presented as possible future work. They include;

- More studies are needed to explore new innovative ways to apply waste tire products in civil and transportation engineering. In civil engineering applications, more research is needed to be study material properties including shear strength parameters, constitutive relationships, material models for vibration damping, and TDA performance under seismic loading. In rubberized asphalt concrete, the emerging techniques, such as warm mix and asphalt rubber, terminal blend, will bring broader and better applications of asphalt rubber into roadway pavement applications.

- A follow up study is recommended two or three years after the completion of this project. It is important to know the needs and lessons learned from various universities. A follow up study will ensure the long term and sustainable education of waste tire civil engineering applications.
- With more research results and projects coming up, the teaching materials stored in the CSU Chico website need to be updated in the future.
- The chapters developed in the appendices of this report are preliminary. They need to be refined and revised to provide more suitable support to the university curricula on waste tire applications in civil and transportation engineering.
- More outreach to community colleges is recommended so resources can be given to faculty for inclusion in their classes.

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APPENDICES

Appendix A

Sample Presentation for professionals

(See Volume II of the Final Report for Details)

Appendix B

University Curricula Lecture Presentations

(See Volume II of the Final Report for Details)

Appendix C

University Curricula Chapter Lectures

(See Volume II of the Final Report for Details)

Appendix D

Presentation at the 4th Rubber Modified Asphalt Conference

(See Volume II of the Final Report for Details)

Appendix E

Sample Workshop Evaluation Form

(See Volume II of the Final Report for Details)

Continuing Education and University Curricula of RAC and CE Application of Waste Tires

Final Report

Report Number: CP2C- 2009 – 101

Volume II

(Appendices)

May 15, 2009

California Pavement Preservation Center

25 Main Street, Suite 202

California State University

Chico, California 98929-0930

(530) 898-5981

PROJECT SUMMARY PAGE	Tech Report: 2009 – 101
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Authors: Ding Cheng, R. Gary Hicks, and Joel Arthur	
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Abstract:

This is the second volume of the CIWMB education project final report. In this volume, the following appendices are included:

Appendix A: Sample presentations for Rubberized Asphalt Concrete and Tire Derived Aggregate Applications in Civil Engineering

Appendix B: Presentations from the university curricula for using waste tire products in civil and transportation engineering

Appendix C: Lecture chapters as supplement for the university curricula

Appendix D: Presentations at the 4th Rubber Modified Asphalt Conference

Appendix E: Sample workshop evaluation form

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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The content does not necessarily reflect the official views or polices of the California Integrated Waste Management Board or the State of California.

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Module 6 CIVL 415 Reinforced Concrete **239**
Module 7 CIVL 431 Environmental Engineering **263**
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D Presentation at the 4th Rubber Modified Asphalt Conference **312**

E Sample Evaluation Form **321**

Appendix A

Sample Presentation for Professionals

USE OF ASPHALT RUBBER IN PAVEMENTS

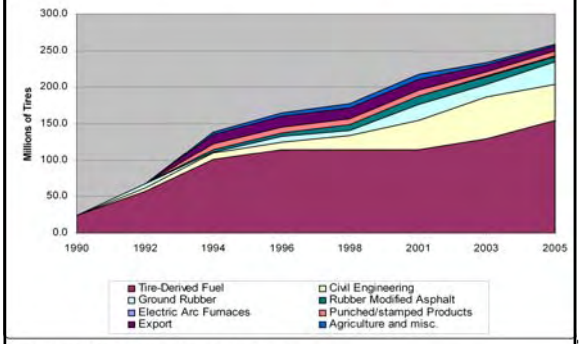
April 17, 2009

PRESENTATION TOPICS

1. ASPHALT RUBBER-RHMA "101"
2. HISTORY OF ASPHALT RUBBER
3. RHMA APPLICATIONS
4. RHMA USAGE GUIDELINES
5. BENEFITS AND LIMITATIONS
6. IMPLEMENTATION

2

U.S. Scrap Tire Market Trends, 1990-2005



© Rubber Manufacturers Association, 2006.

WHAT IS ASPHALT RUBBER ? Section 1

AR101

ASPHALT RUBBER ASTM D8

A blend of asphalt cement, reclaimed tire rubber and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles.

RELATED SPECIFICATION: ASTM D 6114

Standard Specification for Asphalt Rubber Binder.

High viscosity material that typically requires agitation to keep CRM particles dispersed.

4

Asphalt Rubber Types 1

AR101

WET PROCESS-with agitation

Adding graded rubber to asphalt and mixing and reacting-requires agitation

Wet PROCESS – No Agitation

Adding fine rubber typically < #30 to asphalt at the terminal-generally little or no agitation. Often referred to as terminal blend

DRY PROCESS

Use CRM as substitute for 1-3% of Aggregate by mixing crumb rubber directly with aggregate used for asphalt concrete

5

Wet Process-with Agitation 1

AR101

- Method of modifying asphalt cement with CRM and other components
- Most widely used in California, Arizona, Florida and Texas
- Contains 18-22 % crumb rubber – agency spec vary
- Particle size ranges from # 8 to #10 top size
- Type 1 Asphalt Cement and tire rubber (AZ, FL and TX)
- Type 2 Asphalt, tire rubber, high natural CRM + extender oil (CA)

6

Wet Process-with Agitation

1

AR 101

- Thoroughly mix CRM & other components with hot (400-425ºF) asphalt cement
- Interact at 350-375ºF for designated period (typical minimums 45-60 minutes)
- CRM particles swell, exchange oils with AC
- Rotational Viscosity is discriminator for appropriate use

7

Wet Process-No Agitation

1

AR 101

- Contains from <5%-15 % crumb rubber
- Particle size ranges from 40 to 80 mesh top size
- Can also contain polymers
- Used in Arizona ,Florida, Texas, and California
- Often referred to as Terminal Blend

8

Wet Process-Agitation vs. No Agitation

1

AR 101

9

Dry Process

1

AR 101

- Substitutes CRM for 1 to 3% of aggregate in hot mix
- Not considered to modify binder, although some interaction with CRM may occur in place over time (absorbs light fractions)
- CRM gradations have ranged from coarse (-1/4") to fine (-#80)

10

Asphalt Rubber Binder

1

AR 101

COMPONENTS

- Crumb Rubber (including HNR)
- Asphalt Cement
- Additives
- Blended to meet specific specs

11

Crumb Rubber Modifier - CRM

1

AR 101

Produced from grinding up whole scrap tires, tread buffings, and other waste rubber products. Crumb rubber comes in a variety of grades and designations presented by particular size and/or source.

12

CRM Used For Wet Process

1

AR 101

CRM Product

13

Asphalt Cements

1

AR 101

Come in a variety of grades

Typically a softer binders is used for RHMA than for conventional hot mix

	PG 64-10
Hot climates	PG 64-16 (AR-4000)
Moderate climates	PG 58-22 (AR-4000)
Cold climates	PG 52-28 (AR-2000)

14

Additives

1

AR 101

Used in conjunction with the CRM to enhance interaction and produced desirable properties

- Extender oils
- Anti-strip agents
- High natural rubber (HNR)
- Polymers – typically limited to no agitation

15

Interactions Depend On

1

AR 101

1. Asphalt Cement Source & Grade
2. Rubber Type/Source
3. Amount Of Rubber
4. Gradation Of Rubber
5. Interaction Time
6. Interaction Temperature

16

Advantages of High Viscosity AR Binder

1

AR 101

- Allows higher binder content and increased film thickness-resulting in increased durability (moisture resistance and aging resistance)
- Improves aggregate retention
- Minimizes drain-down problems
- Increases resistance to fatigue and reflection cracking
- Increases resistance to bleeding, flushing and deformation

17

HISTORY OF ASPHALT RUBBER

Section 2

History of AR Use

- Used since the 1960's
- Used in chip seals, inter-layers, and HMA
- Use extensively in Arizona, California, Florida and Texas
- Design and construction guides now available from some agencies

18

Ravendale Project

2

History of AR Use

First CA project to use reduced thickness RHMA when compared to the conventional AC design thickness

Different thickness test sections of RHMA, dry process, and conventional AC mixes

Performance monitored for nearly 20 years

19

CALTRANS Reduced Thickness Design

2

History of AR Use

- CALTRANS developed the interim guidelines in 1992
- Based on laboratory and long-term field data (two decades)
- Supported by research efforts

20

Design Of RHMA Overlays

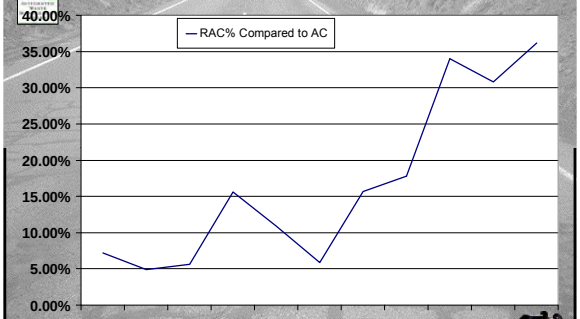
2

History of AR Use

- Uses a deflection based design method
- Up to 50 % reduction in thickness compared to conventional AC design thickness
- Over 200 reduced thickness projects

21

Caltrans RHMA Usage (% of AC Used)



22

Findings

2

History of AR Use

Thickness of RHMA rubber mixes can be reduced by a factor of 2 and still give the same performance for resistance to reflective cracking

Reduced thickness first incorporated into the Caltrans design process in 1992

Adopted in Rehabilitation manual in 2002

23

AR Applications

3

AR Applications

ASPHALT RUBBER

SPRAY APPLICATIONS

- Chip Seals
- AR Interlayers

HOT MIX ASPHALT

- Dense-Graded HMA (RHMA-D) (Use with no agitation only)
- Gap-Graded HMA (RHMA-G)
- Open-Graded HMA (RHMA-O)
- Open-Graded High Binder HMA (RHMA-O-HB)

24

Rubberized Asphalt Concrete *RHMA*

3

AR Applications

High viscosity AR binder most effective in gap and open-graded mixes used in upper 60 mm of pavement

For resisting reflective cracking, Caltrans allows reduced thickness for gap-graded RHMA overlays of structurally sound pavements

25

Hot Mix Asphalt *HMA*

3

AR Applications

USES

GAP GRADED MIXES RHMA-G

OPEN GRADED MIXES RHMA-O

DENSE GRADED MIXES RHMA-D

RHMA-D Only with no agitation binders

Used primarily in Arizona, California, Florida and Texas

Reduced thickness only by Califronia

26

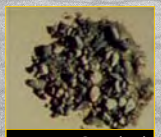
Aggregate Gradation Comparison

3

RHMA Applications

Open Graded

Gap Graded



Dense Graded

27

Dense-Graded HMA *RHMA-D*

3

RHMA Applications

EARLY USE

Limited performance improvements vs. cost

Inadequate void space to accommodate sufficient AR binder to modify behavior

Discontinued use with high viscosity binder

28

Gap Graded Mixes *RHMA-G*

Currently the workhorse mix in CA

Normally used in thicknesses from 30 to 60 mm

Thickness reduction allowed when this mix is employed

29

HOT MIXES *RHMA-O*

3

RHMA Applications

Open-Graded

Widely used in California as surface course

Free draining with reduced splash and spray

Does not add any structural value

30

HOT MIXES *RHMA-O-HB*

3

RHMA Applications

Open-Graded High Binder

Widely used in Arizona as surface course

Also used in Caltrans as surface course

Not as free draining, but improved durability

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AR USAGE GUIDELINES

Section 4

RAC USAGE GUIDELINES

A DESIGN

B PRODUCTION & EQUIPMENT

C CONSTRUCTION

D SAMPLING & TESTING

32

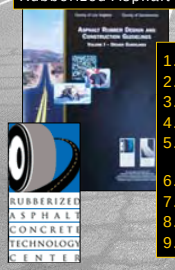
Design Guide-Contents

Design 4

RAC USAGE GUIDELINES

Rubberized Asphalt Concrete Technology Center (RACTC)

www.rubberizedasphalt.com



1. Introduction
2. Asphalt Rubber
3. AR Design Considerations
4. AR Materials Issues
5. AR Construction Issues-HMA & Chip Seals
6. Pre-construction meeting
7. Environmental considerations
8. Current/Future Developments
9. References

33

Caltrans Design Guide

Design 4

RAC USAGE GUIDELINES

1. Introduction
2. Asphalt rubber product design, selection and use
3. Production of AR binders and mixtures
4. Construction and inspection guides
5. References

www.dot.ca.gov/

34

Where and Why Used?

4

RAC USAGE GUIDELINES

1. Replaces conventional mixes where paving temperatures and haul distances are favorable
2. More resistant to cracking and fatigue

Particularly Reflection Cracking

35

AR Design Considerations

Design 4

RAC USAGE GUIDELINES

1 BINDER DESIGN

2 STRUCTURAL DESIGN

36

Asphalt Rubber Blend Profile

Design 4

RAC USAGE GUIDELINES

Developed to evaluate compatibility between materials used

Checks for stability of the blend over time

Should be required for each project

37

Binder Design

Design 4

RAC USAGE GUIDELINES

ASPHALT RUBBER

TEST	MINUTES OF REACTION 45	90	240	360	1,440	SPEC. LIMITS @ 45 MINUTES (CALTRANS 7/2002)
VISCOSITY, CP HAAKE@ 190C	2400	2800	2800	2800	2100	1500 - 4000
RESILIENCE@ 25C (% REBOUND)	27	--	33	--	23	18 Minimum
R & B SOFTENING PT., C (ASTM D36)	59.0	59.5	59.5	60.0	58.5	52 - 74
CONE PEN @ 25C (ASTM D217)	39	--	46	--	50	25 – 70

38

Asphalt Rubber Tests

Design 4

RAC USAGE GUIDELINES

CONE PENETRATION

RESILIENCE

R&B SOFTENING POINT

FIELD VISCOSITY

39

Cone Penetration

Design 4

RAC USAGE GUIDELINES

ASTM D 217

40

Resilience

Design 4

RAC USAGE GUIDELINES

ASTM D 5329

Formerly ASTM D 3407

41

R&B Softening Point

Design 4

RAC USAGE GUIDELINES

ASTM D 36

42

Field Viscosity

Design 4

RAC USAGE GUIDELINES

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Pavement Structural

Design 4

When RHMA-G is used as overlay material

- Design for conventional HMA thickness
- Determine RHMA-G overlay thickness according to FPRM
- RHMA-G overlay thickness generally half that of the HMA overlay thickness

New pavements

- Caltrans does not reduce thickness for the use of RHMA in new pavement construction

44

AR Binder Production

4

RAC USAGE GUIDELINES

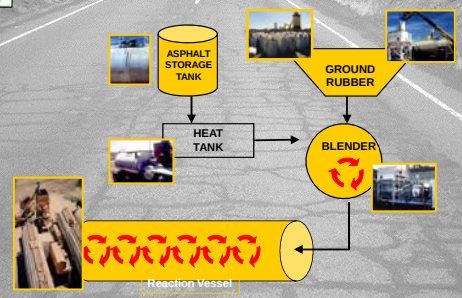
1. Overview of process
2. Hold over and reheating issues
3. Documentation
4. Sampling & Testing requirements

45

AR Blending Schematic

Production 4

RAC USAGE GUIDELINES



46

AR BINDER Process

Production 4

RAC USAGE GUIDELINES

47

AR Binder Process

Production 4

RAC USAGE GUIDELINES

48

Holdover and Preheating Issues

4

RAC USAGE GUIDELINES

Production Set Up

Caltrans Specs

1. Heating must be discontinued 4 hrs after 45 minute reaction period
2. Two reheat cycles are allowed
3. Specification compliance
4. Restoring viscosity

Documentation

Certificate of compliance
AR binder design
AR binder production log

49

Uses for High Viscosity Binders- Hot mixes

INCREASES COST SO USE WHERE MOST EFFECTIVE

1. Most effective in gap-graded and open-graded mixes
2. Most effective in relatively thin surface lifts (max 60 mm)
3. Gap-graded is used as structural layer, equivalent to DG
4. Open-graded is used as surface friction course
5. Increased resistance to rutting, fatigue and reflective cracking a function of binder content
6. Not suitable for DGAC

50

AR Hot Mixes

Production 4

RAC USAGE GUIDELINES

RHMA - G

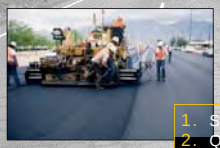
- Similarities to conventional DGAC
- Mix production
- Importance of temperature
- Sampling and testing requirements
- Construction

51

AR Good Practices

Construction 4

RAC USAGE GUIDELINES



1. Same as DGAC
2. Quality Control
3. Inspection

Troubleshooting

Segregation
Smoke
Appearance

Good Practices

Production
Delivery
Placement
Compaction

52

Preparation for Paving

Construction 4

RAC USAGE GUIDELINES

Crack Sealing

Minimal Application-Excess will work through overlay and cause fat spots

Patching

Tack Coat

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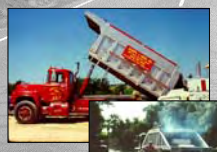
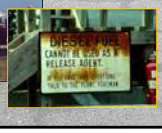
AR Delivery Equipment

Construction 4

RAC USAGE GUIDELINES





ITEMS TO WATCH FOR

1. Release agents
2. Plant production
3. Mix delivery
4. Placement
5. Compaction
6. Balanced production

54

AR Placement

Construction 4

RAC USAGE GUIDELINES

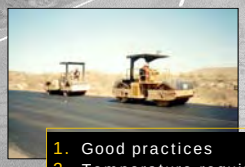
Minimum Handwork and Raking

55

Hot Mix Compaction

Construction 4

RAC USAGE GUIDELINES



1. Good practices
2. Temperature requirements
3. Factors affecting compaction
4. Test strips and rolling patterns
5. Finishing

56

Factors that Affect Compaction

Construction 4

RAC USAGE GUIDELINES

For all AC and RHMA mixes:

1. Lift thickness
2. Air temperature
3. Pavement/base temp.
4. Mix temperature
5. Wind velocity
6. Sunlight or lack thereof

57

SAMPLING AND TESTING

Construction 4

RAC USAGE GUIDELINES

STANDARD PRACTICES AS PER HMA

QC TESTING REQUIREMENTS
- Tests
- Frequency

QA TESTING REQUIREMENTS
- Tests
- Frequency

VISCOSITY OF BINDER CONTENT
- Field GO NO-GO Test

58

AR Benefits

5

BENEFITS

- Improved durability as surface layer
- Resistance to fatigue cracking
- Resistance to reflection cracking
- Resistance to aging
- Can be used in reduced thickness
- Reduced noise
- Lower life cycle costs
- Environmental

59

Improved Performance

5

BENEFITS

Cracking resistance

Durability-aging resistance

60

Increased Cracking Resistance

5

BENEFITS

8" of Conventional Overlay After Twelve Years of Performance

5" of Asphalt Rubber Overlay After Twelve Years of Performance

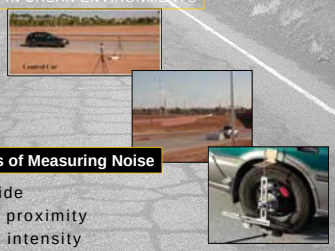
61

Reduced Noise

5

BENEFITS

IMPORTANT IN URBAN ENVIRONMENTS



Methods of Measuring Noise

- Wayside
- Close proximity
- Noise intensity

62

How Is *Noise* Controlled ?

5

BENEFITS

At the Source

Vehicle & Tire Emissions

Through Distance

3 dBA Reduction for Each Doubling of Distance
25ft=70dBA, 50ft=67dBA, 100 ft=64

Through Obstructions

Berms, Walls, and Combination of Both

63

Noise Levels By

5

BENEFITS

SURFACE TYPE-CPX MEASUREMENT

104.9	Random Transverse (Wisconsin Method)
102.5	Uniform Transverse (ADOT Method-3/4")
99.1	Longitudinal (ADOT Method-3/4")
95.5	Whisper Grind (Industry Method)
91.8	ARFC (ADOT Method)

64

LCCA Study by Hicks and Epps

5

BENEFITS

- Establish strategies for analysis period
- Establish M&R activity timing
- Estimate agency costs
- Estimate user and non-user costs
- Develop expenditure streams
- Compute net-present value
- Analyze results

65

LCCA Results *Deterministic Approach*

5

BENEFITS

Scenario	Present Worth ($/yd)	
Preservation – Chip Seal		
▪ Conventional	18.39	
▪ AR	15.87	2.25

66

LCCA Results *Probabilistic Model*

5

BENEFITS

Scenario	% of times savings result
Preservation - chip seal	86
Preservation - thin HMA	82
Structural Overlay	86

67

Environmental Benefits

5

BENEFITS

1. Reduces landfill problems
2. Tire stockpiles
3. Value added products
4. Recycling of wastes
5. Noise abatement

Linear tire fill

68

RAC Limitations

5

LIMITATIONS

- Increased initial costs must be offset by improved performance
- Not amenable to raking
- Higher temperatures for placement and compaction
- Environmental issues - air quality and odor concerns
- Knowledge of users and good HMA practices

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Cost Considerations

5

LIMITATIONS

HOT MIX

could be cheaper with high oil price

Offset if used in thinner layers

Offset by increased service life

70

Construction Considerations

5

LIMITATIONS

Control of temperature is most important
Handwork is more difficult
Material is stickier

Cold or wet weather
Considerable handwork
Long haul
Temperature considerations

71

Climatic

5

LIMITATIONS

72

Environmental Concerns

5

LIMITATIONS

ENVIRONMENTAL - AIR QUALITY

Smoke issue in parts of CA

Can be controlled

HEALTH & SAFETY

No increased risk per numerous studies

RECYCLING OF AR MIXES

Stockpile uniformity – per conventional HMA

No indication of problems with Air Quality

73

Frequently Asked Questions ?

5

LIMITATIONS

Frequently Asked Questions

1. Is the use of AR technically sound and cost effective? YES
2. AR be used in cold weather climates? YES
3. Can AR be rehabilitated and/or recycled? YES
4. Why isn't AR more widely used by other agencies? Education

74

Implementation

6

IMPLEMENTATION

- Educating users
- Benefits of AR
- Identifying best places to use AR
- Understanding the Limitations
- Successes and no failures

75

Conclusions

6

- AR has been used since the 1960's in chip seals and thin hot mix overlays
- AR design and construction guides are now available
- AR has proven to be a cost effective treatment for pavement maintenance and rehabilitation
- Despite the many successes, its use is still limited to a few states

76

Conclusions

6

- Good standard practices and understanding of the materials are required for design, production, and construction of AC and RHMA pavements.
- AR is a cost effective treatment for pavement maintenance and rehabilitation

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Contact details see next page

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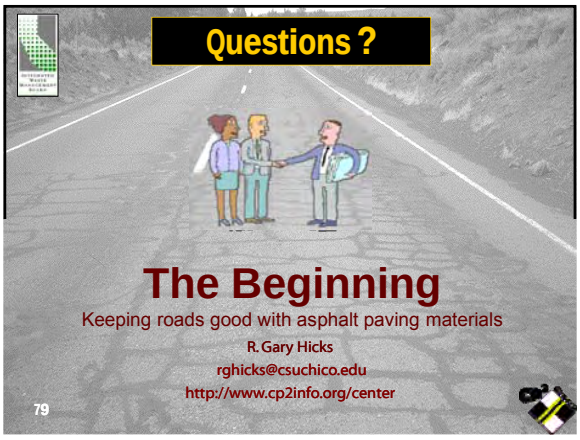

Questions ?
The Beginning
Keeping roads good with asphalt paving materials
R. Gary Hicks
rghicks@csuchico.edu
http://www.cp2info.org/center
79

Civil Engineering Applications
Using Tire-Derived Aggregate (TDA)
Selected California Projects

Civil Engineering Applications
Using Tire-Derived Aggregate (TDA)
Selected California Projects
Presented for The California State University, Chico, California Pavement Preservation Center

Presented By:
KENNEC, INC
Joaquin Wright, Principal

TDA Presentation Summary
Pavement Preservation Center,
April 17th 2009

- Beneficial properties of TDA
- Construction management aspects of building with TDA
- Embankment projects
- Slide repair projects
- Retaining wall backfill projects
- Vibration Attenuation projects
- Retaining wall backfill projects
- Landfill Applications

KENNEC, INC

Beneficial Properties of Tire Derived Aggregate (TDA) in Civil Engineering Applications

Tire Derived Aggregate (TDA) has properties that civil engineers, public works directors & contractors need

- Lightweight
- Free Draining/High Permeability
- Low earth pressure
- Good thermal insulation
- Durable
- Compressible
- May be cheapest solution

Help solve significant environmental problems
Conserve natural aggregate resources

KENNEC, INC

Uses for Tire Derived Aggregate (TDA)

- Lightweight Embankment Fill
- Lightweight TDA for slide repair

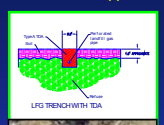
KENNEC, INC

Uses for Tire Derived Aggregate (TDA)

- Lightweight TDA for Retaining Walls

- TDA for vibration attenuation

- TDA in Landfill Applications



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CM Aspects for TDA Projects

- Pre–Construction
- Construction

KENNEC, INC

Pre- Construction Activities

- Design and Overall Project Understanding
  - Develop Comprehens ve Understanding
    - Communication w th team for Des gn, Construction, and Construction Management expectations
    - Del very methods and rates
      - Material quality/ve ification
      - Stockpile location
- Regulatory Agency Outreach
  - Education and Communication
    - Local Water Board
    - Local F re Department
    - nteragency Agreements Ca Trans/C WMB

KENNEC, INC

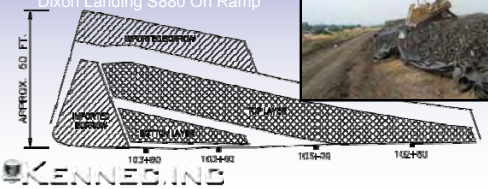
Construction Activities

- Construction Understanding
  - Communication w th team at k ck off meeting, TDA Construction, when, where and team expectations
  - P acement techniques
    - Rates of Delivery, number of suppliers
    - q/a of material
    - Advantageous changes in techniques
    - Documentation of wo k
- As-builts
  - Documentation of changes
    - Data retr eva methods and ver cation
    - Draw ngs of TDA ocation, sensors etc., future work

KENNEC, INC

Embankment Fill Application DIXON LANDING

Lightweight Embankment Fill
Dixon Landing S880 On Ramp



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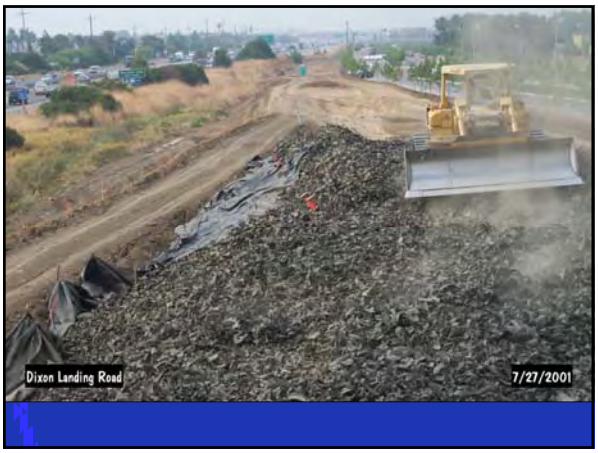
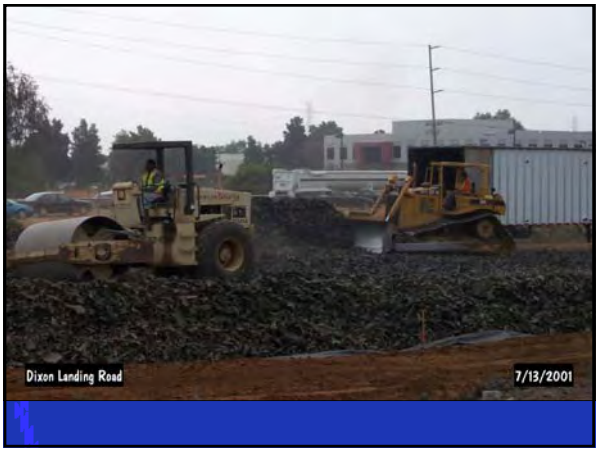
Dixon Landing Embankment Fill

KENNEC, INC

Dixon Landing Road
7/27/2001


Dixon Landing Road
7/27/2001

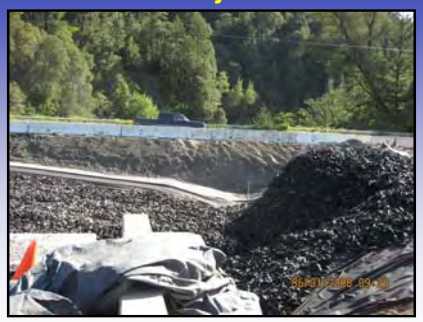

Dixon Landing Road
7/13/2001

Dixon Landing Road
7/12/2001

660,000 Tires

Savings to the State $240,000

Confusion Hill Embankment Project



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Confusion Hill Backfill Project

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Confusion Hill Existing alignment

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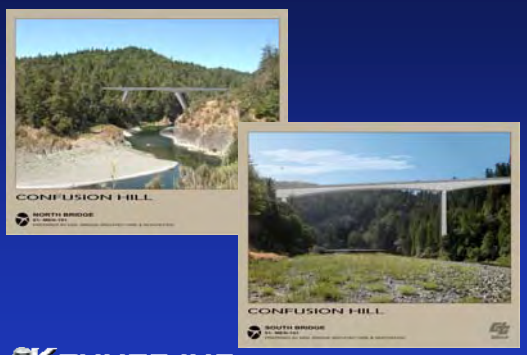
Confusion Hill bridges



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Confusion Hill TDA Embankment fill

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Light Weight TDA Fill for "Slip outs"

Lightweight Fill for "Slip Out"
Road Slide Repair
Mendocino and Sonoma Counties

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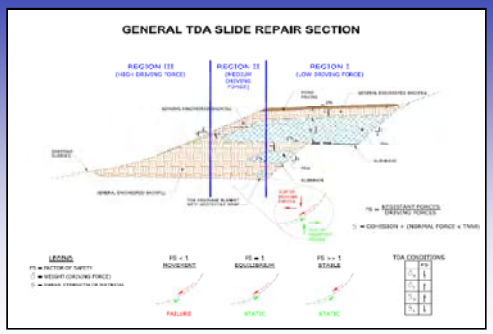
General view of tda slide repair



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Marina Drive slide repair

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Marina Drive slide repair

KENNEC, INC

Geysers road slide repair

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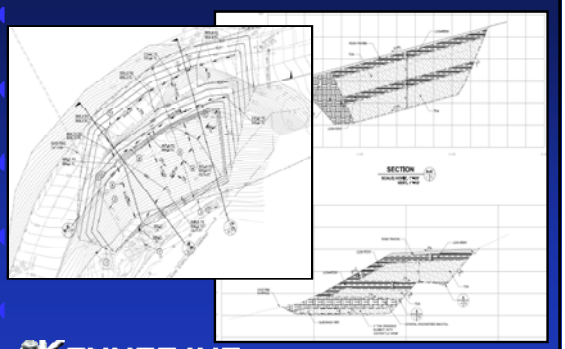
Geysers road slide repair



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Geysers road slide repair

KENNEC, INC

Geysers road slide repair

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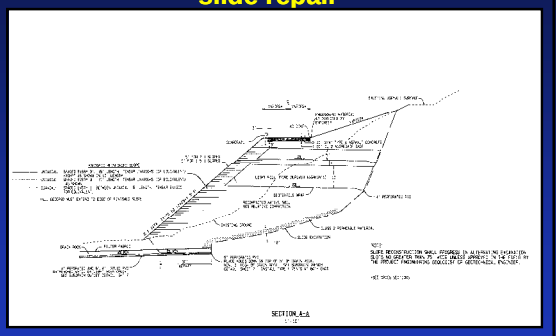
Sonoma Mountain Road slide repair



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Sonoma Mountain Road slide repair

KENNEC, INC

Sonoma Mountain Road slide repair

KENNEC, INC

Sonoma Mountain Road slide repair

KENNEC, INC

Sonoma Mountain Road slide repair

KENNEC, INC

Sonoma Mountain Road slide repair

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Sonoma Mountain Road slide repair

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Light Weight Backfill behind retaining walls

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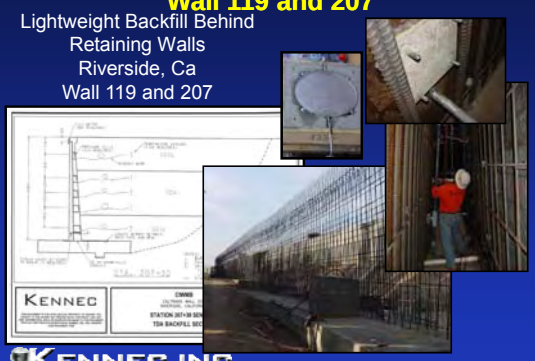
Light Weight Application Wall 119 and 207

Lightweight Backfill Behind
Retaining Walls
Riverside, Ca
Wall 119 and 207



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Wall 119 Riverside, Ca

Back cut of slope prior to retaining wall foundation installation

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Wall 119 Riverside, Ca

Wall foundation installed
rebar cage under construction

Strain Gauge Installation

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Wall 119 Riverside, Ca

Grinding rebar Preparation for strain Gauge Installation

Spot welding strain gauge to rebar

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Wall 119 Riverside, Ca

Spot welding strain gauge

Installed strain gauges (typical)

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Wall 119 Riverside, Ca

Installation of strain gauge cover

Covers installed and sealed

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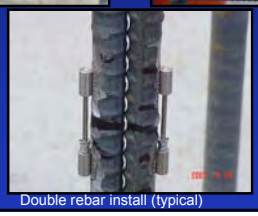
Wall 119 Riverside, Ca

Installed strain gauge (typical)



Double rebar install (typical)

Wall 119 Riverside, Ca

Placement of foundation soil

Compaction of foundation soil

Unloading TDA

Wall 119 Riverside, Ca

Installed TDA

Typical Station

Pressure cell installed

Wall 119 Riverside, Ca

TDA placement

TDA placed and compacted

Data collection during construction

Wall 119 Riverside, Ca

Final lifts of TDA, notice Geotextile wrap on both sides of TDA

TDA compaction

Wall 119 Riverside, Ca

Final geo-textile wrap

Wall 119 Riverside, Ca

Cover soil delivery, placement, and compaction

Wall 119 Riverside, Ca

Completed cover soil installation, 2 feet

Typical gravel/soil section

Road way backfill

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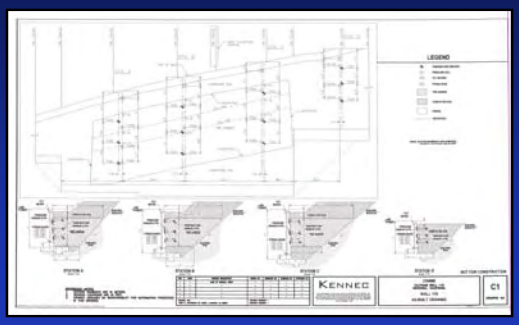
Wall 119 Riverside, Ca

Wall 207 Riverside, Ca

150,000 Tires

Wall 119 & 207 Riverside, Ca

As- Builts!



Vibration Attenuation

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Conventional Vibration Mitigation Technology $800+/ft

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TDA Vibration Mitigation $150/ft

VTA-Vasona Line Extension 2001

100,000 TIRES

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Use of TDA in Landfills

- Landfill Gas Pipe Protection
- Landfill Bio-Reactor System
- Drainage Layers in Landfill Covers
- Landfill Gas Extraction Trenches
- Daily and Intermediate Alternative Cover

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Why use TDA in landfill systems?

- High Permeability/Free Draining
- Compressible
- Lightweight
- Cost savings
- Recycling (100 Tires = 1.5 cy)

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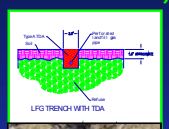
Landfill Gas Collection Trenches, Replace Gravel w/Type A TDA



- Type A for Gravel Replacement
- Oversize Auger for Vertical Wells
- Geo-textile separator between TDA and Soil or Fine Material

LFG TDA Trenches Typical Construction

- Typical excavation & relocation of refuse
- Typical equipment, End Dump, Excavator, Skip loader, Air monitor

LFG TDA Trenches Typical Construction

- Remove refuse/soil place pipe bedding, place pipe, cover with TDA
- Geo-textile separator between TDA and Soil or Fine Material

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LFG TDA Trenches Typical Construction

- Geo-textile separator between TDA and Soil or Fine Material

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LFG TDA Trenches Typical Construction

- Geo-textile separator between TDA and Soil or Fine Material
- Replace cover material, fill operations as usual, draw from system when appropriate

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What is Type A TDA?

Type A TDA Typical, Three inch minus,

- 1 Ton 1.4 cubic yards
- 1 Ton 100 tires (PTE)
- In Place Density 45 58 lb/ft³
- Permeability › 1 cm/sec for many applications

Uses Drainage material, septic leach fields, Vibrations dampening layers under light rail tracks. Gas collection media, Leachate collection material

Dana Humphrey, 2005

What is Type B TDA?

Type B TDA Typical, 12 inch minus,

- 1 Ton 1.5 cubic yards
- 1 Ton 100 tires (PTE)
- In Place Density 45 50 lb/ft³
- Permeability › 1 cm/sec for many applications

Uses Lightweight fill for embankments, Lightweight fill behind retaining walls, Gas collection media, Leachate collection material

Dana Humphrey, 2005

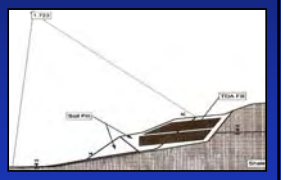
Size of TDA

Dana Humphrey, 2005

TDA Civil Applications

- Lightweight Embankment Fill

- Lightweight Backfill Behind Retaining Walls
- Lightweight fill for road slide repairs



•Vibration Attenuation
•Landfill Applications

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Questions ?

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Appendix B

University Curricula Lecture Presentations

Today decides tomorrow!!!

Applications of Waste Tire Products in Civil Engineering

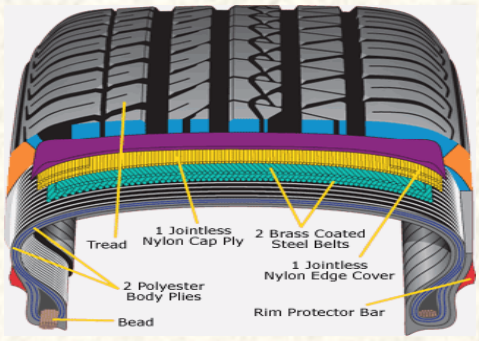
Introduction to Civil Engineering Design

CSU, Chico

Introduction

- Background
- Benefits of Using TDA
- Civil Engineering Applications
  - Lightweight Fill
  - Retaining Wall Backfill
  - Drainage Filter Material
  - Rubberized Asphalt Paving Materials
  - Others
- Challenges and Barriers
- Other Courses Related to Waste Tire Applications

Tire Composition



Problems

Millions of used tires are already piled up in huge stockpiles: both legally …

Problems

… and illegally

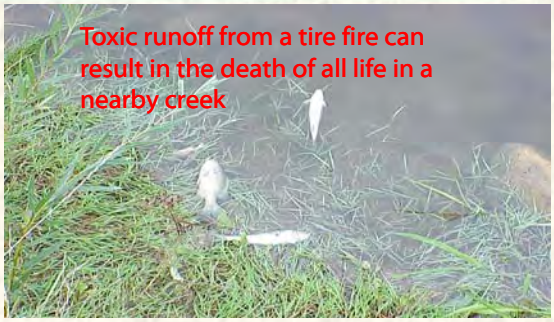
Environmental Issues

Environmental Issues

Tire fires release heavy metals and other hazardous compounds that run into streams and seep into shallow wells

- Arsenic
- Chromium
- Lead
- Manganese
- Nickel
- Mercury
- Cadmium
- Oil

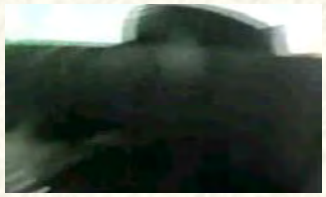
Environmental Issues



Use of Waste Tires in California

- **40.2 million reusable and waste tires are generated each year and an estimated 1.5 million waste tires have been illegally dumped or stockpiled**
- **CE applications of waste tires in California include:**
  - **Tire Derived Aggregate (TDA)**
  - **Rubberized Hot Mix Asphalt (RHMA)**
  - **Others**

Tire Shredding Process



ECOTIRE scrap tire recycling

Tire Derived Aggregate (TDA)

Benefits of TDA

- **TDA has properties that civil engineers need:**
  - **Lightweight**
  - **Low lateral earth pressure**
  - **Good thermal insulation**
  - **Good drainage/hydraulic conductivity**
  - **Compressible**

Benefits of TDA

Can use lots of tires!!!

- 75 tires per C.Y. of TDA fill
- 100 tires per ton
- 2000 tires per lane mile of rubberized asphalt pavement
- 662,700 tires for Dixon Landing Embankment, Milpitas, CA
- 83,700 tires for 300 ft Retaining Wall 119, Route 91, CA

Range of Civil Engineering Applications

- Rubberized Asphalt Paving Materials
- Lightweight fill for highway embankments
- Retaining wall backfill
- Vibration damping layers beneath rail lines
- Insulation layer to limit frost penetration in roadways
- Landfill and environmental application

Benefits of Rubberized Asphalt Concrete

- Improves traction
- Improves durability
- Reduces noise
- Reduces vibration
- Lowers maintenance needs
- Reduces the spray/splash when raining
- Uses waste tire chips (2000 waste tires per lane mile)

Reduced Noise and Vibration

Reduced Splash/Spray effect

Civil engineering Applications in the United States

- The fastest growing use for scrap tires
- Approximately 60 million tires per year are used in CE applications

Lightweight Fill for Highway Embankments

- Tire shreds are viable in this application due to their light weight.
- For most projects, using tire shreds as a lightweight fill material is significantly cheaper than other alternatives
- Highway embankment in Virginia used 1.7 million tires!

Retaining Wall Backfill

- The weight of the tire shreds allows construction of thinner, less expensive walls
- TDA can reduce problems with water and frost build up behind the wall, because TDA is free draining and is a good thermal insulator.

Vibration Damping Layers Beneath Rail Lines

TDA is a good way to dampen the annoying vibrations caused by passing trains

Insulation Layer to Limit Frost Penetration in Roadways

- Placing a tire shred layer under the road can prevent the subgrade soils from freezing
- In addition, the high permeability of tire shreds allows water to drain from beneath the roads, preventing damage to road surfaces.

Landfill and Environmental Application

- Daily and Intermediate Alternative Cover
- Landfill Gas Pipe Protection
- Drainage Layers in Landfill Covers
- Leachate Collection and Removal System
- Landfill Gas Extraction Trenches

Barriers to Using Recycled Materials: Civil Engineering Aspects

- Engineering properties not well established
- Lack of long term performance data
- Lack of design standards or manual
- Civil engineers are risk adverse

Barriers in Using Recycled Materials: Environmental Concerns

- Chemical composition is complex
- Long term environmental effects unknown
- Public perception – it is a waste, so it must be bad!
- Convoluted regulatory approval process
- Environmental regulators are risk adverse

Barriers to Using Recycled Materials: Construction Issues

- New procedures and equipment may be required
- Difficult to estimate "in-place" cost
- Supply is uncertain – both quantity & quality
- Sometimes more expensive than conventional construction
- Contractors are risk adverse

Overcoming Barriers

- Lab studies to determine engineering properties
- Lab studies to determine environmental impacts
- Pilot construction projects (full or nearly full scale)
- Monitor long term engineering and environmental performance
- Modify specifications, etc. as needed
- Develop national and/or regional standards
- Education – address concerns head on and focus on the benefits

TDA Sizing and Applications

Type A (Less than 3 inches) - drainage, insulation, vibration damping

Type B (Less than 12 inches) - lightweight fill

Types of Rubberized Hot Mix Asphalt

RHMA-O – Open Graded Asphalt Concrete

RHMA-G – Gap Graded Asphalt Concrete

RHMA-D – Dense Graded Asphalt Concrete

RHMA-O RHMA-G RHMA-D

Guidelines Available

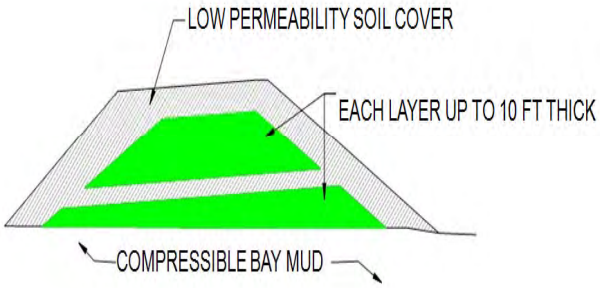
- ASTM D6270 "Civil Engineering Applications of Scrap Tires"
- FHWA guidelines to limit heating in fills
- EPA studies on environmental impacts

Successful TDA Embankment Project

Dixon Landing Interchange

- **PROBLEM: Embankment Constructed on Bay Mud**
- **SOLUTION: Use TDA for the core of the embankment**
- **CHEAPEST SOLUTION: saved $230,000**

Typical Cross Section



Preventing Embankment Heating

- **No TDA contaminated with gasoline, oil, grease, etc.**
- **Limit fine sized TDA**
- **Max TDA layer thickness is 3 meters (10 ft)**
- **Minimize access of fill to water & air**

Unloading TDA

Spreading with Bulldozer

Compacting with 10-ton Roller

Unit Costs

- Placement costs of TDA (including geotextile) = $3.74/yd^3
- Purchase & delivery costs of TDA = $23.66/yd^3
- In-place cost for TDA = $27/yd3
- In-place cost for lightweight aggregate = $50/yd^3

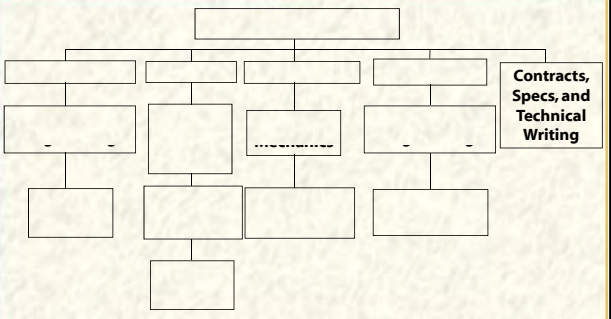
Cost Savings

- Cost savings to CALTRANS with TDA provided at no cost by CIWMB = $477,000
- Cost savings to state less purchase price of TDA = $230,000

Sample Problems

- If we need 5000 yd^3 of the Compacted Fill, what is the TDA volume that is needed from the borrowing pit? The expansion factor is 1.5 for this problem.

Roadmap for CIVL Curricula Related to Waste Tire Applications



Conclusions

- Barriers to using recycled materials can be overcome
- TDA has properties that engineers need
- Civil engineering applications are the fastest growing use for scrap tires in U.S.
- Certain specifications and guidelines are available
- Manageable Environmental effects

THANK YOU

Today decides tomorrow!!!

MATERIAL MODELS FOR CRUMB RUBBER AND TDA

California State University, Chico

Waste Tire Products for CE Applications

- Whole Tires
- Tire Shreds (TDA)
- Crumb Rubber/Tire Buffings

Whole Tires

TIRE DERIVED AGGREGATE (TDA)

Definition:

Pieces of shredded tires that are generally between 25mm (1 in.) and 300mm (12 in.) in largest dimension.

Small Shred Size

Large Shred Size

Crumb Rubber Sample

Rubber Tire Buffings

Side by Side Comparison

CIVIL ENGINEERING APPLICATIONS: Whole Tires

- Crash Barriers
- Retaining walls
- Fences
- Culverts
- Others?

CIVIL ENGINEERING APPLICATIONS: Tire Derived Aggregate (TDA)

- Subgrade and Embankment Fill
- Backfill for Wall and Bridge Abutments
- Subgrade Insulation for Roads
- Lateral Edge Drains
- Vibration Damping Layer Beneath Rail Lines
- Landfill Daily Cover and Drainage
- Septic System Drain Fields

CIVIL ENGINEERING APPLICATIONS: Crumb Rubber/Tire Buffings

- Rubberized Asphalt Concrete
- Rubberized Portland Cement Concrete
- Running Tracks
- Others?

Engineering Properties of TDA
(After Humphrey, 2003)

1. Gradation
2. Specific Gravity and Absorption Capacity
3. Compressibility
4. Resilient Modulus
5. Time Dependent Settlement of TDA Fills
6. Lateral Earth Pressure Characteristics
7. Shear Strength
8. Hydraulic Conductivity (Permeability)
9. Thermal Conductivity

Mechanics of Materials Background

- Continuum Mechanics
  - Uniform distribution of matter
  - No voids
  - Cohesive (all portions are connected together, and have no breaks, cracks, or separations)
- Crumb Rubber and TDA
  - Discrete material
  - Contains air voids
  - "Cohesionless"
  - Similar properties to sands and gravels

Continuum Mechanics

- Deformable bodies develop both Normal (tension and compression) and Shear Stresses when acted on by applied loads
- Brittle materials fail in tension perpendicular to the maximum tensile stress
- Ductile materials fail in shear parallel to the maximum shear stress
- Poisson's ratio relates the transverse contraction to the longitudinal elongation (or vice versa) 0.25< μ < 0.34 for most CE materials

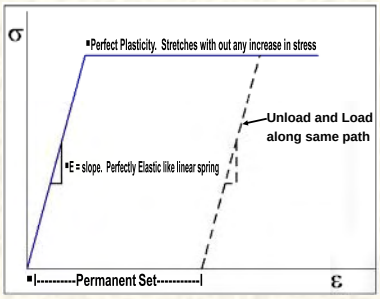
TDA STRENGTH

TDA can support compressive but not tensile stresses and typically fails in shear

The Shear Strength of TDA is affected by five factors:

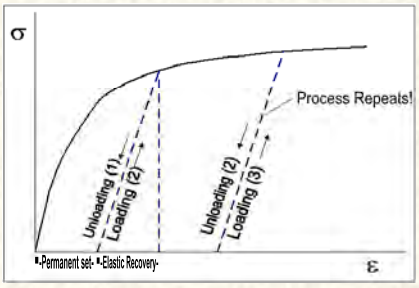
1. Size and shape of the tire shreds
2. The density (packing) of the sample at the beginning of the test
3. Magnitude of the compressive normal loading
4. The orientation of the tire shreds in the specimen
5. "Cohesion"

Material Model: Elastoplastic



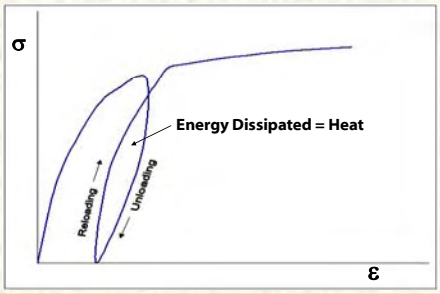
More General Material Model

Nonlinear Inelastic Model



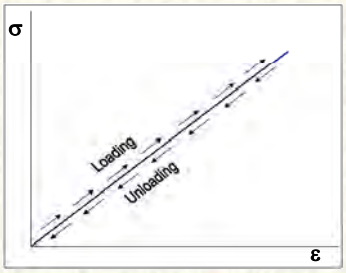
More Realistic General Model

Energy is lost in unloading and reloading process (hysteresis)



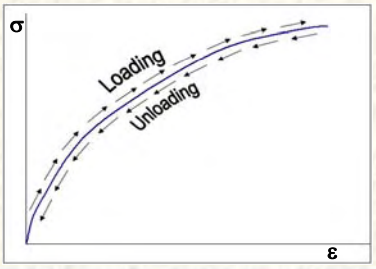
Closer Look at Elasticity

- Linear Elastic Behavior- makes things easy
- True up to Elastic Limit



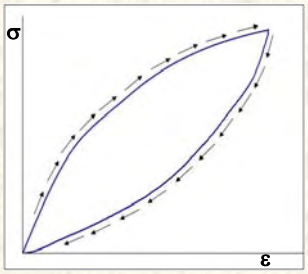
Non-Linear Elastic (Rubber)

- Nonlinear load path
- Still loads and unloads along same path



Anelastic Behavior

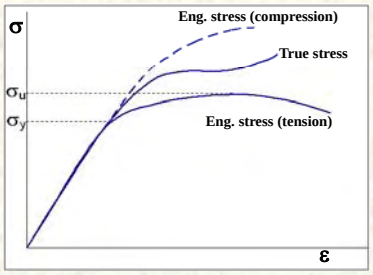
- Does not load and unload along the same path
- Thermal energy- Dissipates to the surroundings without damaging material
- Useful for vibration damping
- Examples
  - Mounts for motors and other rotating machinery
  - Subbase under railroads (TDA application)



- Just think about applications for earthquakes if we could get concrete to behave this way by adding waste tire rubber

Poisson Effect

- After Yielding, values of engineering and true stress deviate appreciably



Possible Material Models

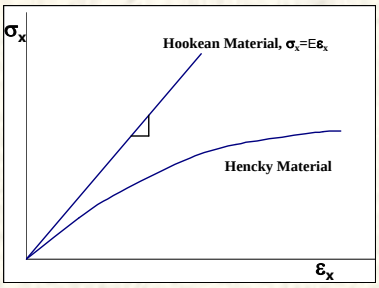
- Hookean

Linear Elastic

E = Spring Constant

- Hencky Material

Nonlinear Spring



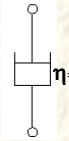
In either case, energy is conserved if Loading and Unloading curves coincide

Viscous Materials

- Named viscous because of fluid-like behavior
- Material is viscous if stress determines strain *rate*
- i.e. strain rate is a function of stress
  - $d\varepsilon/dt = \dot{\varepsilon}_x = g(\sigma_x)$
- Strain is *not* recovered upon removal of stress

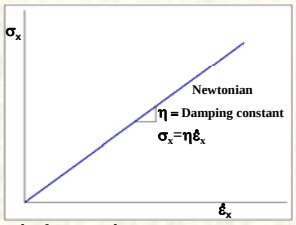
Viscous Materials

- If stress is a linear function of the strain rate, then we call it a Newtonian fluid.
  - Use linear dashpot to model behavior:



η=Damping constant

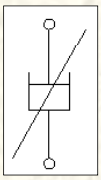
Ideal Viscous (Newtonian)



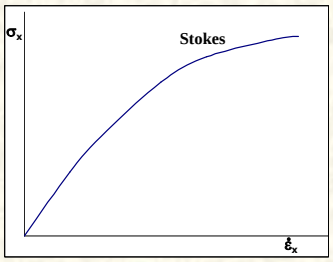
- In this model, we consider σ_x to be the force on the system while $\dot{\varepsilon}_x$ is the speed of the piston. Therefore η = Damping constant

When Force and Speed are Not Linearly Related

- We have a Non-Newtonian or Quasi-Viscous case.
- Also referred to as a "Stoke's" Material



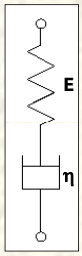
Quasi-viscous (Stokes)



Viscoelastic Materials

- Materials that posses viscous and elastic properties
- Many materials are viscoelastic
  - Examples:
    - Structural Metals and Rock at high temperatures
    - Plastics at room temperature
- Use *combinations* of springs and dashpots to model viscoelastic materials

Linear Maxwell Model

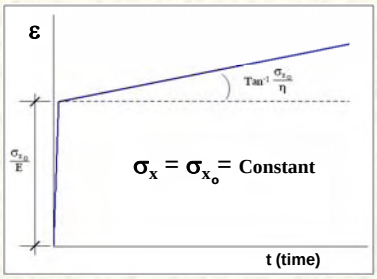


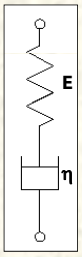
- Linear spring and dashpot in series, therefore $F_{spring}=F_{dashpot}$
- Strain rate composed of two parts
  1. Strain rate in spring, $\dot{\varepsilon}_x=\dot{\sigma}_x/E$
  2. Strain rate in dashpot, $\dot{\varepsilon}_x=\sigma_x/\eta$
- Add them using superposition to get total strain rate of system

$\dot{\ } = \dot{\ }$

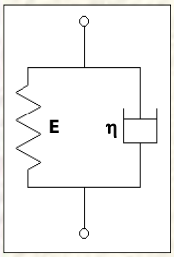
Graphical Linear Maxwell Model Constant Stress

- Constant stress gives a nearly instantaneous spring displacement plus a constant strain-rate from the dashpot





Kelvin Model



- Spring and dashpot are in parallel
- Strains are equal, but forces are not
- Stress components:

$\sigma_{spring} = E\varepsilon_x$

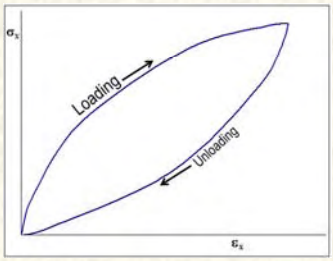
$\sigma_{dashpot} = \eta\dot{\varepsilon}_x$

Therefore, by superposition

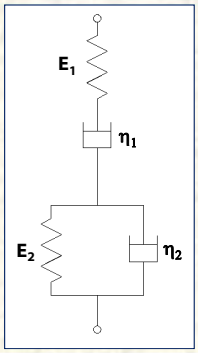
$\sigma_{total} = E\varepsilon + \eta\dot{\varepsilon}$

Kelvin Relaxation

- When the spring relaxes, energy is dissipated in the dashpot

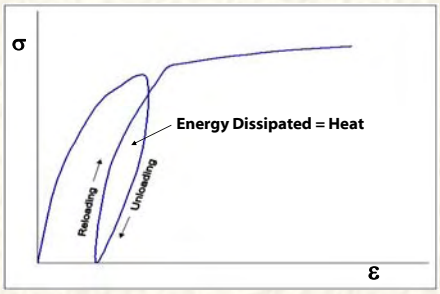


More General Model (Burgers Fluid)

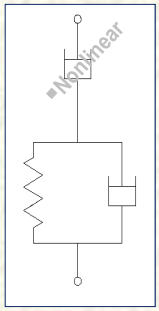


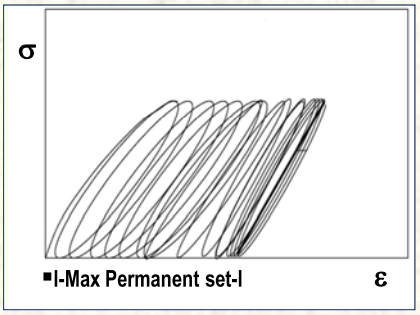
- Combine Maxwell and Kelvin model in Series
  - Some permanent deformation
  - Some perfect elasticity
  - Some vibration damping
- Many additional spring-dashpot combinations possible

General Model Behavior



General Model- Kelvin Model in Series with Nonlinear Dashpot





Potential Applications

- Energy Dissipation
  - Earthquake Energy Absorption
- Vibration Mitigation
  - Machinery Mounts
  - Train and Truck Traffic Loads

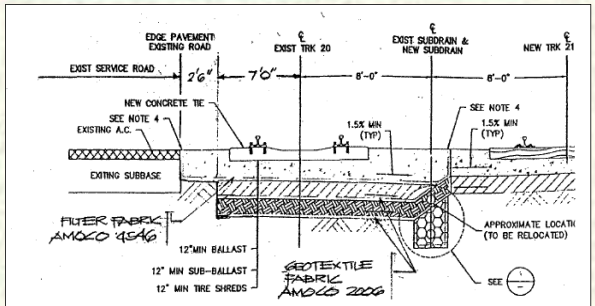
Vibration Mitigation Application- Vasona Light Rail Line and Test Track

- TDA used as subbase beneath train track ballast
- Goal: Reduce vibration for local residence and businesses

Case History VTA Light Rail Project

- Reduce ground borne vibrations that affect adjacent businesses and residences
- 12" of Type A Tire Shreds below 12" of subballast and 12" of ballast for 1591 feet of track
- Tests indicated a significant reduction in vibration with TDA section

Test Track Cross-Section



Cross section of tire shred test section.

TDA Test Track Construction

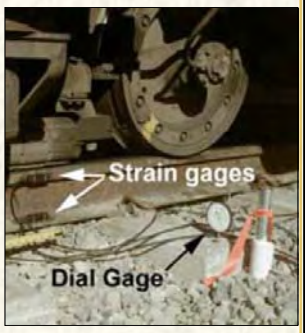
Test Track Construction

Finished Test Track

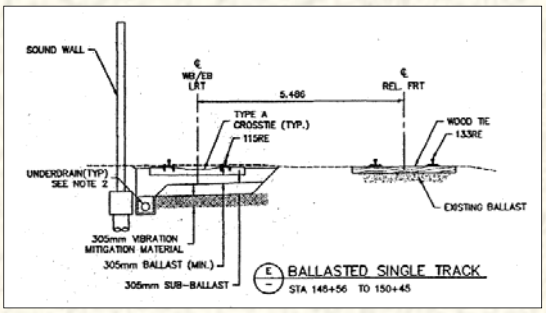
Vibration Sensor Mounted Under Ground

Measuring Devices

- **Strain gages to measure strains in rail**
- **Dial gage to measure deflections**

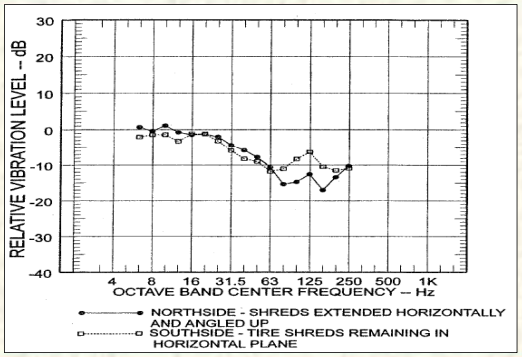


Rail Line Cross Section Drawing



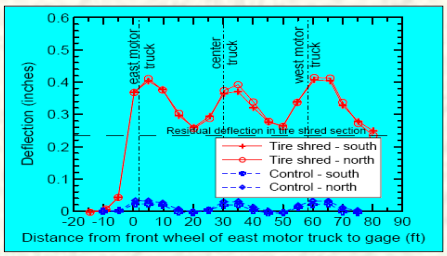
Rail Line Construction Pictures

Results - Vibration



Tie Deflections

- **Elastic Deflections in ties less than 0.2 in. Which is acceptable**
- **Minor permanent deflection may mean more frequent releveling of the ties.**



Cost Savings

- **Cost of conventional track = $100 per track-ft**
- **Cost of track with TDA vibration mitigation = $121 per track-ft**
- **Cost of floating slab vibration mitigation = $600-1000 per track-ft**
- **Cost savings = $479-$879 per track-ft**
- **Total savings = $1 to $2-million**

Summary

- **Presented practical material models applicable to TDA for vibration mitigation**
- **TDA can save money in these applications**
- **More data and studies are needed to calibrate these material models**

THANK YOU

Questions?

References

- Elastic and Inelastic Stress Analysis, Irving H. Shames, Francis A. Cozzarelli. Prentice Hall, Englewood Cliffs, New Jersey
- Civil Engineering Applications Using Tire Derived Aggregate. Presented by Dr. Dana Humpherey. Sponsored by: California Integrated Waste Management Board
- E Wall System at Kembla Grange: http://www.azom.com/details.asp?ArticleID=3069

Today decides tomorrow!!!

Shear Strength of Tire Derived Aggregate (TDA)

California State University, Chico

Background Information

- At the end of 2005, the U.S. generated approximately 300 million scrap tires
- Historically, these scrap tires took up space in landfills or provided breeding grounds for mosquitoes and rodents when stockpiled or illegally dumped
- Fortunately, markets now exist for 82% of these scrap tires-up from about 17% in 1990
- These markets-both recycling and beneficial use-continue to grow
- The remaining scrap tires, however, are still stockpiled or landfilled

Background Information

Waste tires were used as follows:

- 155 million (52%) were used as fuel (TDF)
- 49 million (16%) were recycled or used in civil engineering projects
- 30 million (10%) were converted into ground rubber and recycled into products
- 7.4 million (2.5%) were converted into ground rubber and used in rubber-modified asphalt
- 6.9 million (2.3%) were exported
- 6.1 million (2.0 %) were recycled into cut/stamped/punched products
- 3 million (1%) were used in agricultural and miscellaneous uses

Scrap Tire Markets

- The 3 largest scrap tire markets are:
  - Tire derived fuel
  - Civil engineering applications
  - Ground rubber applications/ rubberized asphalt concrete
- Both recycling and beneficial use of scrap tires has expanded greatly in the last decade through increased emphasis on recycling and beneficial use by state, local and Federal governments, industry, and other associations
- Unfortunately, even with all of the reuse and recycling efforts underway, not all scrap tires are being used beneficially

Civil Engineering Applications

- The civil engineering market encompasses a wide range of uses for scrap tires
- Scrap tire material typically replaces other material currently used in construction such as lightweight fill materials, drainage aggregate, or even soil
- A considerable amount of tire shreds for civil engineering applications come from stockpile abatement projects
- Tires that are reclaimed from stockpiles are usually dirtier than other sources of scrap tires and are typically rough shredded

Tire Derived Aggregate (TDA)

Definition:

Pieces of processed tires that have a consistent shape and are generally between 25mm (1 in.) and 300mm (12 in.) in size.

Small Shred Size

Large Shred Size

Crumb Rubber Sample

Rubber Buffings

Size Comparison

Civil Engineering Applications

- Subgrade Fill and Embankments
- Backfill for Retaining Walls and Bridge Abutments
- Subgrade Insulation for Roads
- Lateral Edge Drains
- Vibration Damping Layer Beneath Rail Lines
- Landfill Applications
- Septic System Drain Fields

Subgrade Fill and Embankments

- Tire shreds can be used to construct embankments on weak, compressible foundation soils
- Tire shreds are viable in this application due to their light weight
- Using tire shreds as a lightweight fill material may be significantly cheaper than alternatives
- Subgrade fill and embankment applications include: protecting roads from erosion, enhancing the stability of steep slopes along highways, and reinforcing shoulder areas

Backfill for Walls and Bridge Abutments

- The light weight of the tire shreds reduces horizontal pressures and allows for construction of thinner, less expensive walls
- Tire shreds can also reduce problems with water and frost build up behind walls because tire shreds are free draining and provide good thermal insulation

Engineering Properties of TDA (After Humphrey, 2003)

1. Gradation
2. Specific Gravity and Absorption capacity
3. Compressibility
4. Resilient Modulus
5. Time Dependent Settlement of TDA Fills
6. Lateral Earth Pressure
7. Shear Strength
8. Hydraulic Conductivity (Permeability)
9. Thermal Conductivity

Mechanics of Materials Background

- Continuum Mechanics
  - Uniform distribution of matter
  - No voids
  - Cohesive (all portions are connected together, and have no breaks, cracks, or separations)
- Crumb Rubber and TDA
  - Discrete Material
  - Contains air voids
  - Possesses cohesion
  - Similar Properties to sands and gravels

Continuum Mechanics

- Deformable bodies develop both normal (tension and compression) and shear stresses when acted on by applied loads
- Brittle materials fail in tension perpendicular to the maximum tensile stress
- Ductile materials fail in shear parallel to the maximum shear stress
- Poisson's ratio relates the transverse contraction to the longitudinal elongation (or vice versa) $0.25 < \mu < 0.34$ for most CE materials

CRUMB RUBBER STRENGTH

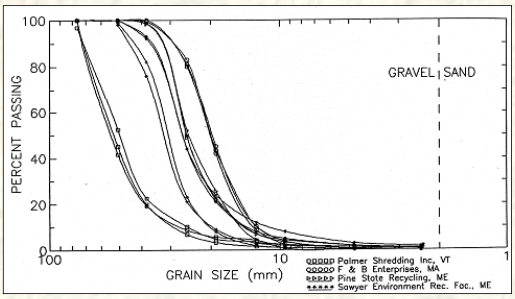
- Crumb Rubber can support compression but not tension stresses and typically fails in shear
- We will consider three factors affecting the Shear Strength of Crumb Rubber:
  1. Size and shape of the rubber pieces
  2. The density (packing) of the sample at the beginning of the test
  3. Magnitude of the compressive normal loading

1. Size and Shape of the Particles

- Our crumb rubber sample is "uniformly graded" i.e. all the particles are nearly the same size and are approximately cubical in shape
- TDA (Tire shreds) are also fairly uniformly graded but are irregularly shaped
- The following plots show typical gradation curves for TDA, crumb rubber, and rubber buffings

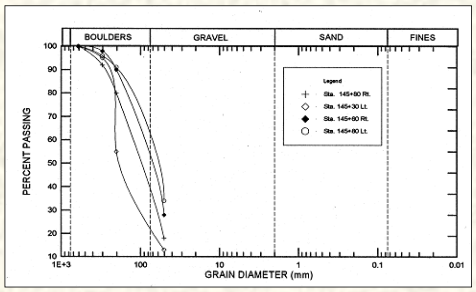
TDA Gradation

3" Maximum Size:

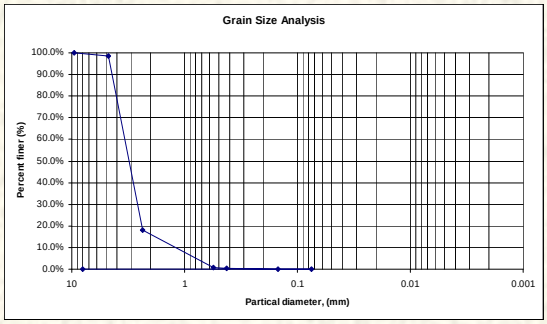


TDA Gradation

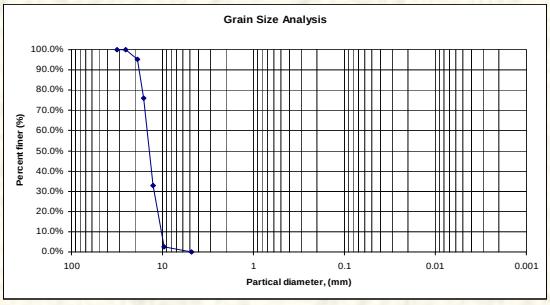
12" Maximum Size:



Crumb Rubber Gradation



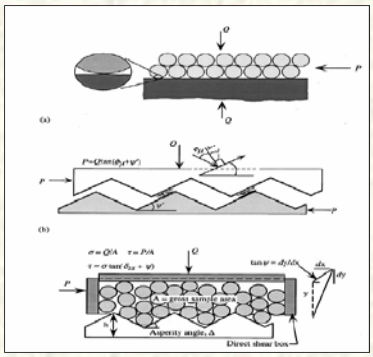
Rubber Buffing Gradation



2. Effects of Density or Packing

- **The preparation of the sample may influence the shear stress/strain behavior**
- **Initially loose samples will decrease in volume as the sample is sheared**
- **Initially densely packed samples will "Dilate" or expand as the sample is sheared**
- **Need to measure displacement perpendicular to the direction of loading to determine what you have**

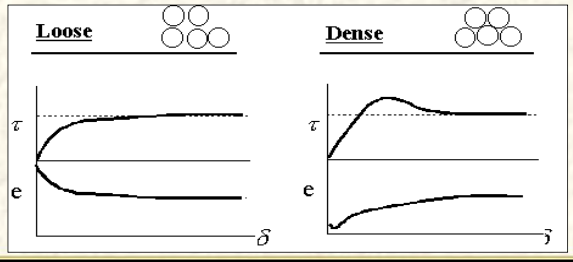
2. Effects of Density or Packing



Effects of Density or Packing

For Uniform Spheres:

(e = void ratio, defined as volume of voids/ volume of solids)



3. Magnitude of the compressive normal loading

- As the normal force is increased on the sample, the shear stress of the sample increases
- The relationship between the normal stress and the shear stress for a granular material like crumb rubber and TDA is given by Mohr-Coulomb failure criteria:

$$\tau = c + \sigma * \tan\phi$$

$\tau = c + \sigma \tan\phi$

- τ = shear stress on the failure plane
- σ = normal stress on the failure plane
- C = the cohesion intercept (=0 for most granular materials)
- ϕ = angle of internal friction (slope of the line relating shear strees to normal stress

We are interested in Shear Strength

Can be determined in the Lab using one of two common tests:

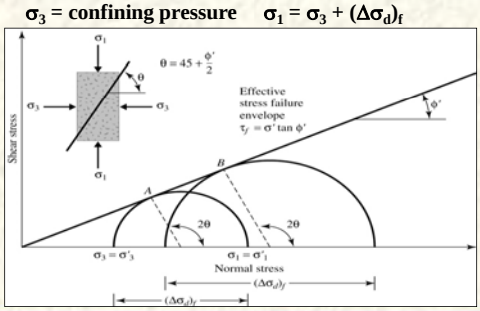
- Triaxial Test
- Direct Shear Test

Triaxial Test Machine

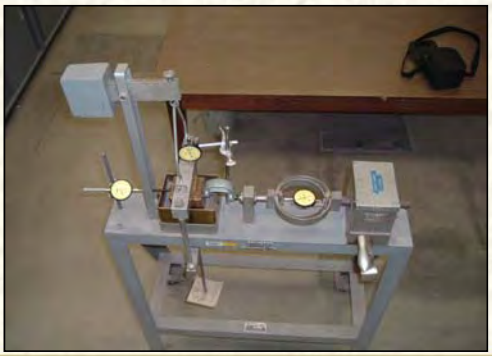
Example Failure Envelope from Triaxial Test

Principal stresses at failure for drained test:

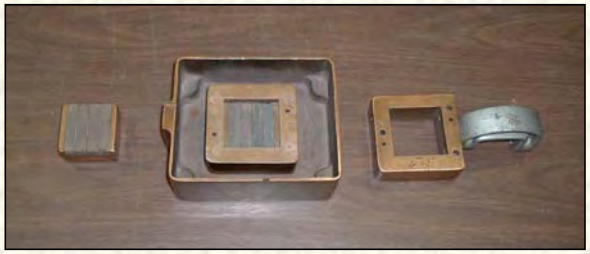
σ_3 = confining pressure $\quad \sigma_1 = \sigma_3 + (\Delta\sigma_d)_f$



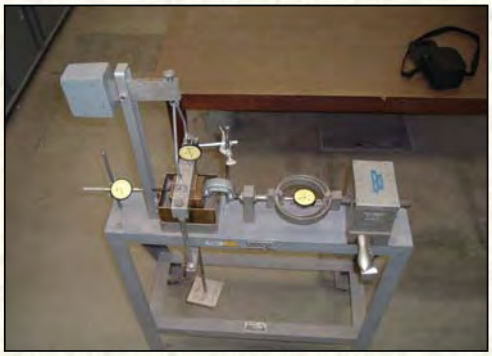
Direct Shear Test Machine



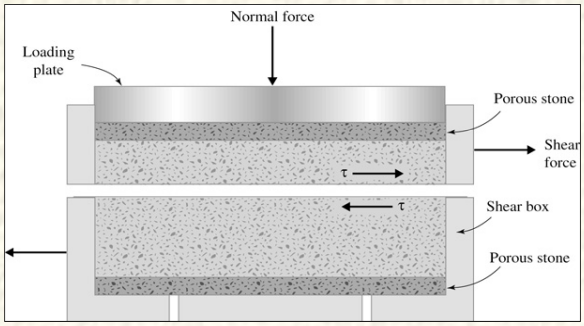
Shear Box



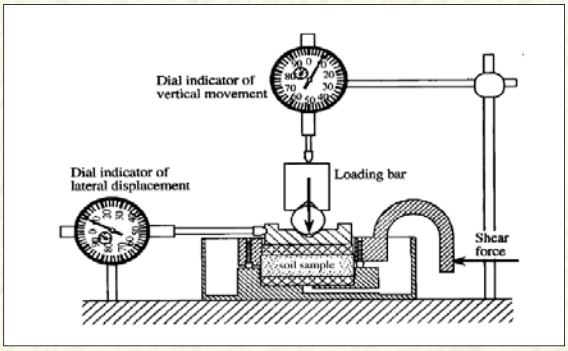
Direct Shear Test Machine



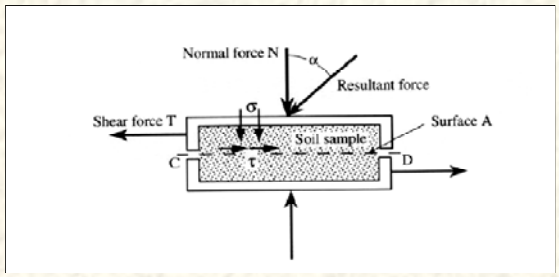
Direct Shear Test



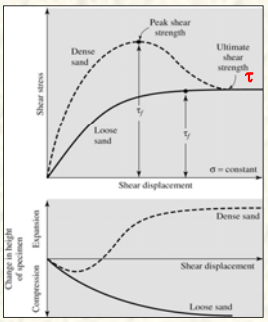
Schematic Showing Direct Shear Equipment



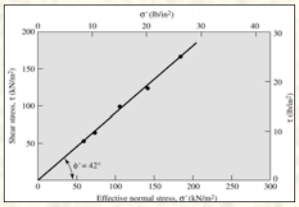
Crumb Rubber Sample in the Direct Shear Box



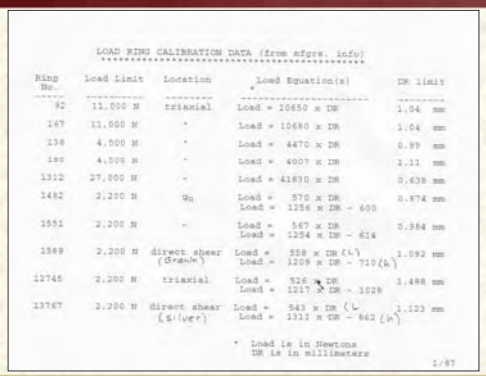
Example direct shear test curves



Example failure envelope (dry sand, note *c* is zero)



Proving Ring Calibration Data



LOAD RING CALIBRATION DATA (from mfgrs. info)

Ring No.	Load Limit	Location	Load Equation(s) *	DR limit
92	11,000 N	triaxial	Load = 10650 x DR	1.04 mm
167	11,000 N	"	Load = 10680 x DR	1.04 mm
138	4,500 N	"	Load = 4470 x DR	0.99 mm
180	4,500 N	"	Load = 4007 x DR	1.11 mm
1312	27,000 N	"	Load = 41830 x DR	0.638 mm
1482	2,200 N	W_n	Load = 570 x DR Load = 1256 x DR - 600	0.874 mm
1551	2,200 N	"	Load = 567 x DR Load = 1254 x DR - 614	0.984 mm
1589	2,200 N	direct shear (Grasuk)	Load = 558 x DR (L) Load = 1209 x DR - 710 (h)	1.092 mm
12746	2,200 N	triaxial	Load = 526 x DR Load = 1217 x DR - 1028	1.488 mm
13767	2,200 N	direct shear (Silver)	Load = 543 x DR (L) Load = 1312 x DR - 862 (h)	1.123 mm

* Load is in Newtons
DR is in millimeters

1/87

Advantages and Disadvantages of Direct Shear Test

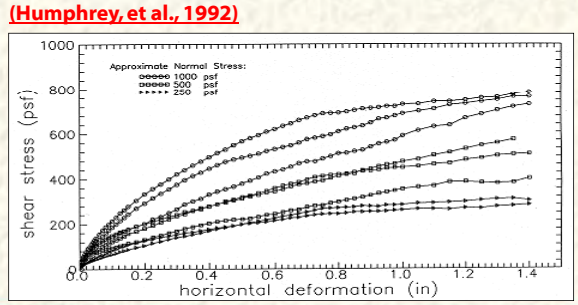
- **Disadvantages:**
  - **Soil is forced to fail along the plane of split of the shear box, instead of along a natural weak plane**
  - **The distribution of shear stress is not uniform, but assumed to be uniform**
- **Advantages:**
  - **Simple to perform**
  - **Good for testing shear strength along contacting surfaces of different materials (e.g., soil and foundation materials)**

Shear Strength

- **A direct shear apparatus or a triaxial shear apparatus can be used to measure the shear strength of tire shreds**
- **However, apparatuses large enough for TDA are rare, so tests are generally completed on 1-in or smaller tire shreds**
- **The triaxial test shouldn't be used for tire shreds with protruding steel belts**

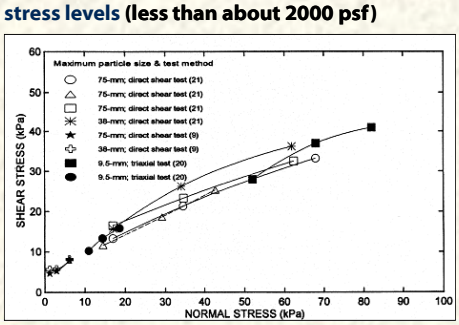
Shear Strength

Shear stress vs. horizontal deformation for Pine State Recycling tire shreds tested in direct shear box (Humphrey, et al., 1992)



Shear Strength

Comparison of failure envelopes of TDA at low normal stress levels (less than about 2000 psf)



References:
(21) Humphrey, et al, 1992
(9) Cosgrove, 1995
(20) Benda, 1995

Shear Strength

- **These failure envelopes are non-linear and concave down**
- **Tests on 0.5-in and 1-in tire shreds at higher stress levels produce failure envelopes that are approximately linear**
- **For high stress tests, using a failure criteria of 15% axial strain, Ahmed (1993) obtained cohesion intercepts from 572 to 689 psf and friction angles from 15.9 to 20.3 degrees**

Summary

- In order to determine the strength properties rubber tire particles, lab tests need to be conducted
- The most appropriate method is the direct shear test
- Like soil, the shear strength of rubber particles increases as normal stress increases
- Under normal loading, TDA develops an apparent cohesion

THANK YOU

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Contracts Specifications and Technical Writing

ASTM INTERNATIONAL

Outline

- Module 1:

  ASTM International Standards
- Module 2:

  Specifications and Special Provisions

Module 1: Outline

- Background of ASTM
- What is ASTM
- Why we need ASTM standards
- ASTM standards for using waste tires in CE applications
- Summary

Background of ASTM

- Originally known as the American Society for Testing and Materials, now ASTM International
- The organization's headquarters is in West Conshohocken, Pennsylvania, about 5 miles northwest of Philadelphia
- A group of scientists and engineers, led by Charles Benjamin Dudley formed the *American Society for Testing and Materials* in 1898 to address the frequent rail breaks plaguing the fast-growing railroad industry

What is ASTM?

- ASTM International is one of the largest voluntary standards developing organizations in the world
- ASTM's members, representing producers, users, consumers, government, and academia from over 100 countries, develop technical documents that are a basis for manufacturing, management, procurement, codes, and regulations
- Committees develop more than 12,000 ASTM standards that can be found in the 77-volume Annual Book of ASTM Standards

ASTM Sections

1. Iron and Steel Products
2. Nonferrous Metal Products
3. Metals Test Methods and Analytical Procedures
4. Construction
5. Petroleum Products, Lubricants, and Fossil Fuels
6. Paints, Related Coatings, and Aromatics
7. Textiles
8. Plastics
9. Rubber
10. Electrical Insulation and Electronics
11. Water and Environmental Technology
12. Nuclear, Solar, and Geothermal Energy
13. Medical Devices and Services
14. General Methods and Instrumentation
15. General Products, Chemical Specialties, and End Use Products

Section 4 - Construction

- Volume 04.01 - Cement, Lime; Gypsum
- Volume 04.02 - Concrete and Aggregates
- Volume 04.03 - Road and Paving Materials; Vehicle-Pavement Systems
- Volume 04.04 - Roofing and Waterproofing
- Volume 04.05 - Roofing, Waterproofing, and Bituminous Materials
- Volume 04.06 - Thermal Insulation; Environmental Acoustics
- Volume 04.07 - Building Seals and Sealants; Fire Standards; Dimension Stone
- Volume 04.08 - Soil and Rock (I): D 420 to D 5779
- Volume 04.09 - Soil and Rock (II): D 5780 - latest; Geosynthetics
- Volume 04.10 - Wood
- Volume 04.11 - Building Construction
- Volume 04.12 - Building Constructions (II): E 1672 - latest; Property Management Systems

Section 9 - Rubber

- Volume 09.01 - Rubber, Natural and Synthetic -- General Test Methods; Carbon Black
- Volume 09.02 - Rubber Products, Industrial - Specifications and Related Test Methods: Gaskets; Tires

Why do we need ASTM?

- ASTM International has no role in requiring or enforcing compliance with its standards
- They may become mandatory when referenced by an external contract, corporation, or government

Why do we need ASTM?

- Other governments (local and worldwide) also have referenced ASTM standards
- Corporations doing international business may choose to reference an ASTM standard

ASTM Membership

- Membership in the organization is open to anyone with an interest in its activities
- Standards are developed within committees, and new committees are formed as needed, upon request of interested members
- As of 2007, there are more than 30,000 members, including over 1100 organizational members, from more than 120 countries

ASTM Spec for Waste Tires

ASTM D6270

Standard Practice for

Use of Scrap Tires in Civil Engineering Applications

Designation: D 6270 – 98 (Reapproved 2004)

ASTM D6270: Significance and Use

This Standard covers the following scrap tire products:

- **tire chips or tire shreds comprised of pieces of scrap tires**
- **tire chip/soil mixtures**
- **tire sidewalls**
- **whole scrap tires**

used in civil engineering applications

ASTM D6270: Significance and Use

Tire derived products are used in the following CE applications:

- **lightweight embankment fill**
- **lightweight retaining wall backfill**
- **drainage layers**
- **thermal insulation layer to limit frost penetration beneath roads**
- **insulating backfill to limit heat loss from buildings**
- **replacement for soil or rock in other fill applications**

ASTM D6270: Significance and Use

Uses of whole scrap tires and tire sidewalls include:

- **fill when whole tires are compressed into bales**
- **retaining walls**
- **drainage culverts**

ASTM D6270: Apparatus

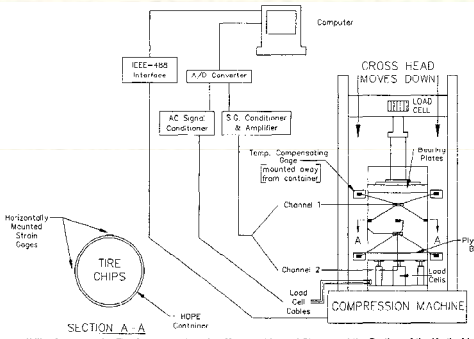


FIG. 1 Compressibility Apparatus for Tire Shreds Designed to Measured Lateral Stress and the Portion of the Vertical Load Transferred by Friction from Tire Shreds to Container (8)

ASTM D6270: Apparatus

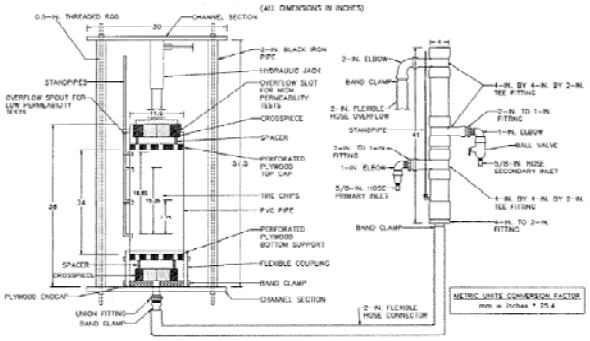


FIG. 2 Hydraulic Conductivity Apparatus for Tire Shreds with Provisions for Application of Vertical Stress (10)

ASTM D6270: Benefits

- **1/3 to 1/2 of the dry density of typical soil**
- **8 times greater thermal resistivity than typical soil**
- **Lateral earth pressures reduced by 50%**
- **High hydraulic conductivity**

ASTM D6270: Construction Uses

- Two different sizes are commonly used (Type A: <3in, Type B: <12in)
- Large tire shreds should be compacted by a tracked bulldozer, sheepsfoot roller, or smooth drum vibratory roller
- Should be covered with a sufficient thickness of soil
- Where pavement will be placed over the tire shreds and in drainage applications, the tire shreds should be wrapped completely by a geotextile material

ASTM D6270: Calculations

$$\rho_s = S_a(\rho_w) \quad (1)$$

where:
S_a = apparent specific gravity, and
ρ_w = density of water.

$$M_R = A\Theta^B \quad (2)$$

where:
Θ = first invariant of stress (sum of the three principal stresses),
A = experimentally determined parameter, and
B = experimentally determined parameter.

$$K_O = \sigma_H / \sigma_v \quad (3)$$

$$\mu = K_O / (1 + K_O) \quad (4)$$

where:
σ_H = measured horizontal stress, and
σ_v = measured vertical stress.

ASTM D6270: Use of Scrap Tires in Civil Engineering Applications

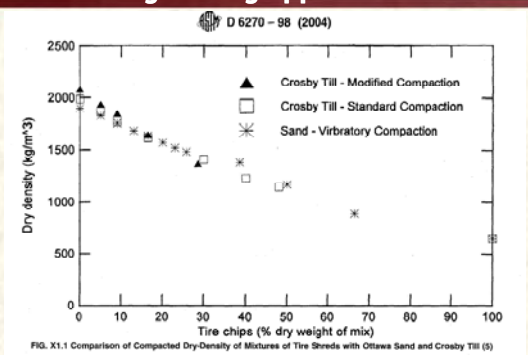


FIG. X1.1 Comparison of Compacted Dry-Density of Mixtures of Tire Shreds with Ottawa Sand and Crosby Till (5)

ASTM D6270: Use of Scrap Tires in Civil Engineering Applications

TABLE X1.3 Compressibility on Initial Loading

Particle Size Range (mm)	Tire Shred Type	Tire Shred Source	Initial Dry Density (kg/m³)	Vertical Strain (%) at Indicated Vertical Stress (kPa) 10	25	50	100	200
2 to 75	Mixed	Palmer	Compacted	7 to 11	16 to 21	23 to 27	30 to 34	38 to 41
2 to 51	Mixed	Pine State	Compacted	6 to 14	15 to 20	21 to 26	27 to 32	33 to 37
2 to 25	Glass	F and B	Compacted	5 to 10	11 to 16	18 to 22	26 to 28	33 to 35
2 to 51	Mixed	Sawyer	Compacted	5 to 10	13 to 18	17 to 23	23 to 30	29 to 37
	Mixed		Compacted	4 to 5	8 to 11	13 to 16	16 to 23	27
75 max	Mixed	Pine State	8 0 to 670	12 to 20	18 to 28	- - - -	- - - -	- - - -
2 to 51	Mixed	Pine State	Loose	18	34	41	46	52
2 to 25	Mixed	F and B	Loose	3	18	28	37	46
	- - - -		Loose	9	12 to 17	17 to 24	24 to 31	30 to 38

ASTM D6270: Use of Scrap Tires in Civil Engineering Applications

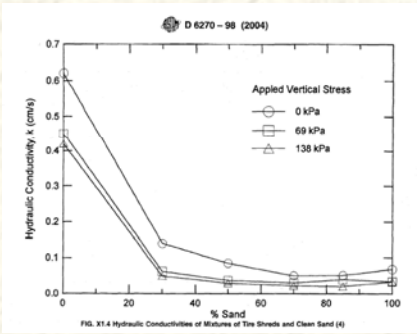


FIG. X1.4 Hydraulic Conductivities of Mixtures of Tire Shreds and Clean Sand (4)

ASTM D6270: Embankment Fill- Introduction

- Shredding of scrap tires produces chunks of rubber ranging in size from large shreds to smaller chips
- Tire shreds and tire chips have both been used as lightweight fill materials for roadway embankments and backfills behind retaining walls
- The shreds or chips can both be used by themselves or blended with soil

ASTM D6270: Embankment Fill- Introduction

- Tire shreds normally range in size from 12 in to 3 in
- Tire chips are usually sized from a maximum of 3 in down to a minimum of 1/2 in

ASTM D6270: Embankment Fill-Application

Embankments containing tire shreds or chips are constructed by completely surrounding the shreds or chips with a geotextile fabric and placing at least 3 ft of natural soil between the top of the scrap tires and the roadway.

ASTM D6270: Embankment Fill- Performance Record

- At least 15 states have utilized scrap tire shreds or chips as a lightweight fill material for the construction of embankments or backfills
- Some projects have used tire shreds or chips as embankment material, while other projects have blended tire chips with soil
- In 2004, more than 70 successful projects have been constructed on state, local, or private roads

ASTM D6270: Embankment Fill- Performance Record

- Aside from problems with puncturing of rubber tires on haul vehicles by the exposed steel in tire chips or shreds, there have been no other construction-related problems on scrap tire embankment projects
- Adequate compaction, which is always a prime concern on any embankment project, is of even greater concern on a tire shred or chip embankment project, where it is known that some consolidation will occur
- Some cracking of the roadway above a tire shred or chip embankment is possible because of long-term settlement or differential settlement

ASTM D6270: Embankment Fill- Performance Record

As of 2004, at least 15 states had completed scrap tire embankment projects, only six states (North Carolina, Oregon, Vermont, Virginia, Wisconsin, and Maine) had prepared specifications or some provisions for this use

ASTM D6270: Material Characteristics

- Specific Gravity
- Water Absorption Capacity
- Gradation
- Compacted Dry Density
- Compressibility
- Resilient Modulus
- Coefficient of Lateral Earth Pressure
- Poisson's Ratio
- Shear Strength
- Hydraulic Conductivity
- Thermal Conductivity

ASTM D6270: Embankment Fill- Properties

- Specific Gravity: 1.1 to 1.3
- Compacted Unit Weight: 20 lb/ft^3 to 45 lb/ft^3
- Friction Angle: 19° to 25°
- Cohesion value: 160 lb/ft^2 to 240 lb/ft^2
- Young's Modulus: 112 lb/in^2 to 181 lb/in^2
- Permeability: 1.5 to 15 cm/sec

ASTM D6270: Embankment Fill- Mix Design

- Tire chips can be mixed or blended with soil
- As the percentage of soil is increased, the unit weight of the blend increases
- Mix ratios are usually prepared on a volumetric basis
- A maximum 50:50 tire chip to soil ratio is suggested so that tire chip usage is not reduced too greatly
- If the unit weight of the fill is not a concern, then even small percentages (10 to 25 percent) of tire chips can be blended into the soil. This could improve the compactibility of the fill

ASTM D6270: Construction Practices and their Characteristics

- Lightweight Embankment Fill: Low-Compacted Dry Density
- Insulating Layer: Thermal Resistance
- Retaining Wall Backfill: Low-Compacted Dry Density, High-Hydraulic Conductivity, Low-Thermal Conductivity
- Drainage Application: High-Hydraulic Conductivity

ASTM D6270: Embankment Fill- Construction Procedures, Material Handling:

- The number of tires to be processed into shreds or chips is directly related to the intended volume of the tire chip portion of the embankment
- It is estimated that every cubic yard of volume will require about 75 automobile tires that have been shredded into shreds or chips and compacted into an embankment

ASTM D6270: Embankment Fill- Construction Procedures, Site Preparation:

- The site of the embankment should be prepared in essentially the same manner as though common earth were being used for fill material
- If there is a high water table or swampy area that will be at the base of the embankment, it may be advisable to construct a drainage blanket
- If there is a natural flow of runoff through the area where the embankment is to be constructed, provisions should be made to pipe the runoff beneath the embankment

ASTM D6270: Embankment Fill- Construction Procedures, Mixing:

- When tire shreds or chips are to be blended or mixed with soil, the mixing should be performed volumetrically, using bucket loads from a front end loader and blending the materials together as well as possible with the bucket
- As another option to the mixing of tire shreds or chips and soil, alternate layers of the tire shreds or chips and the soil can be constructed

ASTM D6270: Embankment Fill- Construction Procedures, Placing

- Tire chips should be spread across a geotextile blanket using a tracked bulldozer
- A minimum 2 foot layer or lift should be spread out over the geotextile
- A recommended maximum 3 foot lift thickness can still be spread and compacted

ASTM D6270: Embankment Fill- Construction Procedures, Compaction:

- Compaction may be achieved by at least three passes of the tracked bulldozer over the layer of tire chips
- The chip particles align themselves with each other and settle fairly readily
- The weight of the bulldozer passing over the tire chips is enough to readily compact the layer of chips
- For larger chips or thicker layers, as many as 15 passes of a bulldozer may be required to achieve compaction

ASTM D6270: Embankment Fill- Construction Procedures

- The top layer of a tire chip embankment should be kept at least 3 ft below the base or subbase layer of the pavement that will be on top of the embankment
- Each layer of a tire chip embankment must be fully compacted before the next layer is placed
- When the top layer of tire chips has been fully compacted, the sides and top of the tire chips should be fully wrapped and enclosed by the geotextile

ASTM D6270: Embankment Fill- Construction Procedures

- A minimum of 3 ft of compacted soil should be placed on top of the geotextile and tire chips
- The soil should be compacted in thinner layers 6 in. to 12 in. in thickness
- The tire chip embankment will experience further deflection during placement and compaction of the soil cover

ASTM D6270: Embankment Fill- Unresolved Issues

- The first and most pressing unresolved issue is to determine the cause or causes of the exothermic reactions that resulted in three scrap tire embankment fires that occurred during 1995
- Other tire shred or tire chip embankment projects, especially the thick fills, including those that have caught on fire, should be more closely monitored, possibly by installing temperature probes and gas sampling wells

ASTM D6270: Embankment Fill- Unresolved Issues

- The pH of any water leaching from scrap tire fills should be measured
- Laboratory investigations should also be undertaken under varying conditions and temperatures to pinpoint under which conditions exothermic reactions may be initiated

Some ASTM Standards Relevant to Waste Tires in CE Applications

- ASTM D422: Particle Size Analysis of Soils
- ASTM D575: Test Methods for Rubber Properties in Compression
- ASTM D698: Test Methods for Compaction Characteristics of Soil Using Standard Effort
- ASTM D5084: Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter
- ASTM D3080: Direct Shear Test of Soils Under Consolidated Drained Conditions

ASTM D422: Particle Size Analysis of Soils

The following is the quantitative determination of the distribution of particle sizes in soils:

- Distribution of particle sizes larger than 75 µm is determined by sieving
- Distribution of particle sizes smaller than 75 µm is determined by a sedimentation process, using a hydrometer to secure the necessary data.

ASTM D575: Test Methods for Rubber Properties in Compression

- Covers two test methods that are useful in comparing stiffness of rubber materials in compression
- Can be used by rubber technologists to aid in development of materials for compressive applications
- Compression Test of Specified Deflection: The force required to cause a specified deflection is determined
- Compression Test of Specified Force: A specified mass or compressive force is placed on the specimen and the resulting deflection is measured

ASTM D698: Test Methods for Compaction Characteristics of Soil Using Standard Effort

- A soil at a selected water content is placed in three layers into a mold of given dimensions
- Each layer is compacted by blows of a rammer dropped from one foot high
- The resulting dry unit weight is determined
- The procedure is repeated for a sufficient number of water contents to establish a relationship between the dry unit weight and the water content for the soil
- When plotted the data represents a relationship known as the compaction curve
- The values of optimum water content and standard maximum dry unit weight are determined from the curve.

ASTM D5084: Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter

- Apply to one-dimensional, laminar flow of water within porous materials such as soil and rock
- Hydraulic conductivity of porous materials generally decreases with an increasing amount of air in the pores of the material
- Assume that Darcy's law is valid and that the hydraulic conductivity is unaffected by hydraulic gradient

ASTM D5084: Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter

- Validity of Darcy's law may be evaluated by measuring the hydraulic conductivity of the specimen at three hydraulic gradients; if all measured values are similar (within about 25%), then Darcy's law may be taken as valid
- When the hydraulic gradient acting on a test specimen is changed, the state of stress will also change, and, if the specimen is compressible, the volume of the specimen will change

ASTM D3080: Direct Shear Test of Soils Under Consolidated Drained Conditions

- Test method consists of placing the test specimen in the direct shear device
- Predetermined normal stress is applied
- Measures the shearing force and horizontal displacements as the specimen is sheared

Summary

- Discussed the origin, background, and purposes of ASTM standards
- Reviewed ASTM standards for use of waste tires in civil engineering applications
- Discussed the application of TDA in embankment fill according to ASTM D6270

Questions ?

The Beginning

Keeping roads good with asphalt rubber paving materials

http://www.cp2info.org/center

"Today decides tomorrow!!!

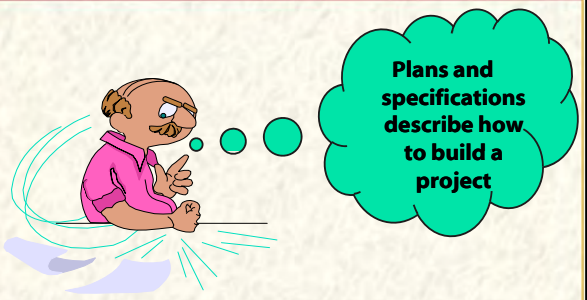
CIVL 402 Contract Spec and Technical Writing

Rubberized Hot Mix Asphalt

Module 2: Outline

- Standard Specifications
- Standard Special Provisions
- Asphalt rubber definitions
- Asphalt rubber binder
- Asphalt rubber binder design
- Types of mixes
- Cautions

Plans and Specifications



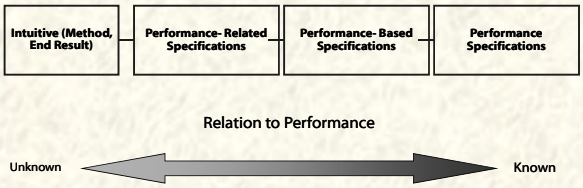
Plans and Specifications

- Plans
  - Provide layout and dimensions
- Specifications
  - Describe project specific requirements for:
    - Materials
    - Workmanship
    - General & special provisions

Types of Specifications

- Proprietary
- Method
- QC/QA
- End Result
- Performance-Related (PRS)
- Performance-Based (PBS)
- Performance (e.g., Warranty/Guarantees)
- Design/Build
- Design/Build/Operate

Specifications



Statistical Methods in Specifications

These can be statistically based:

- Method
- QC/QA
- End Result
- PRS and PBS

Proprietary Specifications

- Brand/Product/Process/Manufacturer Specific
  - (e.g., Patented Products or Processes)
- Difficult to use in Competitive Bidding Process
  - "or equivalent" commonly used

Method Specifications

- Detailed description of materials and procedures to be used to construct final product
- Procedural
- Prescriptive
- Require continuous on-site inspection
- Historically, most commonly used method

QC/QA Specifications

- 35 states
- Commonly used
- Falls between method and end result specifications

Elements of QC/QA Specifications

- Definitions
- Materials
- Construction Process
- Construction Equipment
- Mix Design
- Acceptance:
  - Lot and Sublot
  - Sampling
  - Testing
- Pay Factors / Method of Payment
- Training, Certification, and Accreditation

End Result Specifications

- Specify minimum in-place material properties (e.g., density)
- Do NOT specify construction methods - *Contractor freedom and Innovation*
- May or may not include material specifications
- Gaining popularity (use)

Statistically Based End Result Specifications

- Consider BOTH Agency or Owner and Producer or Contractor risk
- Require both QC and QA
- Third party - Independent Assurance?
- Very common today

Performance-Related and Performance-Based Specifications

- Commonly used in equipment and machinery manufacturing industries
- Being introduced to construction as well as other Industries
- FHWA strongly supporting development of performance-related specs
  - HMA - WesTrack
  - PCC - ERES/Illinois

Performance-Related and Performance-Based Specifications

- Require functional spec's for materials and in-place properties
- Tight quality control/quality assurance (QC/QA) required
- Must have dependable relationships between material properties and actual pavement performance - KEY!

Elements of the "Ideal" Performance Based Specification

- Reproducible test methods
- Well defined construction variability
- Existence of robust relationships between tests (measured properties) and pavement performance
- Definable and measurable pavement performance

Performance Specifications

- Specify minimum level of performance over a specified period
- Examples:
  - Less than 5% fatigue cracking after 10 years of service
  - Rut depths less than 13 mm (1/2 in) after 15 years of service
- Warranties

AR Definitions

Asphalt Rubber Definition: ASTM D8

A blend of asphalt cement, reclaimed tire rubber and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles.

Definitions

Related Specification: ASTM D 6114

Standard Specification for Asphalt Rubber Binder

High viscosity material (usually field-blended) that typically requires agitation to keep CRM particles dispersed.

Asphalt Rubber Binder

Components:

- Crumb Rubber Modifier (CRM)
  - Scrap Tire Rubber
  - High Natural Rubber Content Scrap Rubber
- Asphalt Cement
- Extender oil - Caltrans

Caltrans Specifications for High Viscosity (Field Blend) AR Binders

- Asphalt modifier: Extender oil at 1 to 6% by mass of asphalt (For chip seal binders, CT may continue to require minimum 2.5% extender oil)
- Asphalt + extender oil: 78-82% by total mass of AR binder
- Total CRM: 18-22% by total mass of AR binder, of which:
  - Scrap tire CRM = 73-77% of total CRM
  - High natural CRM = 23-27% of total CRM

Crumb Rubber Modifier (CRM)

- CRM is produced from grinding whole scrap tires, tread buffings, and other waste rubber products. CRM comes in a variety of grades and size designations from various suppliers and/or sources
- CRM gradation and content affects not only AR binder properties, but also influences the voids structure of RHMA-G mixes
- Gradation limits used by Caltrans and ADOT are broad and allow considerable variation; changes are being considered
- Check project special provisions to verify CRM gradation limits in effect for specific projects

Crumb Rubber Modifier (CRM)

Crumb Rubber Modifier (CRM)

- High natural rubber CRM is used to improve adhesion and flexibility, chip seal aggregate retention, and to compatibilize asphalt and CRM interactions
- It has a high natural rubber content (40-48% by mass) and may be made from scrap tires or other non-tire sources
- Caltrans also requires that "high natural" be used in binders for RHMA mixes

Asphalt Cements

- Asphalt cements come in a variety of grades and designations
- AR-4000 was used to make asphalt rubber in the past
- Caltrans adopted the Performance Graded (PG) system in 2006
- Do not use modified asphalts as the base asphalt cement for CRM modification

PG Asphalt Cements

- For high mountain and high desert areas, use PG 58-22 as the base asphalt
- For other areas (coastal, inland valleys, low and south mountain, and desert) use PG 64-16 as base asphalt

Additives

- Extender oils: aid in the interaction of the crumb rubber and asphalt by providing aromatics which are absorbed by the rubber, and help with dispersion by chemically suspending the rubber in the asphalt. Required by Caltrans
- Anti-stripping agents: used to improve adhesion of binder to aggregate

Asphalt Rubber Blend Design Submittals

- Supplier and identification (or type) of scrap tire and high natural CRM
- Typical gradation of each type of CRM material used in the asphalt rubber binder design
- Percentage of scrap tire and high natural CRM by total mass of the asphalt-rubber blend
- If CRM from more than one supplier is used, info will be required for each CRM supplier used
- Laboratory test results for test parameters shown in the special provisions

Asphalt Rubber Blend Design Submittals

- Base asphalt PG binder grade, supplier, and Certificate of Compliance
- Percentage of the combined blend of asphalt and asphalt modifier by total mass of asphalt rubber binder
- Asphalt modifier type, supplier, identification, and test results demonstrating conformance to specs
- Percentage of asphalt modifier by mass of asphalt
- Design profile
- Minimum interaction time and temperature
- Material Safety Data Sheets for everything

Asphalt Rubber Blend Design Profile

- A design profile is developed to evaluate the compatibility between materials used, compliance of component interaction properties, and to check for stability of the AR blend over time
- A 24-hour design profile will be required for each project, for hot mix and spray applications
- Previous AR blend designs may be validated with currently available materials and may be submitted for more than one project

Asphalt Rubber Blend Design Example Design Profile

	Minutes of Reaction					Spec. Limits @ 45 minutes (Caltrans 12/2005)
TEST	45	90	240	360	1,440	
Viscosity, cP Haake@ 190°C	2400	2800	2800	2800	2100	1500 - 4000
Resilience@ 25°C (% Rebound) (ASTM D 5329)	27	--	33	--	23	18 Minimum
R & B Softening Pt., °C (ASTM D36)	59.0	59.5	59.5	60.0	58.5	52 – 74 (125-165°F)
Cone Pen @ 25°C (ASTM D217)	39	--	46	--	50	25 – 70

Types of Rubberized Asphalt Concrete (RHMA) Hot Mixes

- Dense-graded (limited usage by Caltrans)
- Gap-graded
- Open-graded
- Open-graded (High Binder, HB)

Aggregate Gradation Comparison

Open Graded Gap Graded Dense Graded

Dense-Graded Mixes (RHMA-D)

- Early use
  - Limited performance improvements vs. cost
  - Inadequate void space to accommodate sufficient AR binder to modify mix behavior
- Discontinued use with high viscosity (field blend) binders
- Suitable for use with no agitation CRM-modified binders (terminal blend) such as MB

Gap-Graded Mixes (RHMA-G)

RHMA-G is the most commonly used RHMA mix type

Purpose – Structural mix that provides increased resistance to:

- Rutting
- Fatigue
- Reflective cracking
- Oxidative aging

Gap-Graded Mixes (RHMA-G)

Standard Special Provisions for RHMA-G with high viscosity (field blend) AR binder are currently being updated to address PG binder implementation.

Revisions include:

- Remove test methods from body of SSP, develop corresponding CT Lab Procedures for CRM sieve analysis and measuring rotational viscosity of AR binder
- Format SSP for inclusion in Section 39 of Caltrans Standard Specifications

Gap-Graded Mixes (RHMA-G)

- Adjustments to Hveem Mix Design Method (CT 367), including:
  - Modify (coarsen) aggregate gradation requirements, particularly for 600 µm sieve, to facilitate achieving minimum VMA (18%)
  - Add maximum VMA limit of 23%
  - Test 3 briquettes at each binder content, use average values for calculations and plots

Gap-Graded Mixes (RHMA-G)

- Adjustments to Hveem Mix Design Method, cont'd
  - Design air voids content may range from 3 to 5% based on traffic index and climate, and as designated by the Engineer in project special provisions
  - Still requires minimum AR binder content of 7.0% by weight of dry aggregate to provide durability (Must have sufficient binder content to provide expected performance benefits)

Gap-Graded Mixes (RHMA-G)

Adjustments to Hveem Mix Design Method, cont'd

- Use Caltrans Laboratory Procedures LP-1 through LP-4 for volumetric calculations
- Report Voids Filled with Asphalt (VFA) and Dust Proportion for information only
- Plot average unit weight, stability, % air voids, VMA, and VFA, versus asphalt rubber binder content

Open-Graded Mixes (RHMA-O, RHMA-O-HB)

- Standard Special Provisions for RHMA-O and RHMA-O-HB are also currently being updated to incorporate PG binder implementation
- Changes are similar to those for RHMA-G, but with less impact on mix design method
- Effects of CRM gradation and content in binder have relatively little effect on voids structure of open-graded mixes

Open-Graded Mixes (RHMA-O)

- RHMA-O is designed to provide a free-draining surface (reduced splash, spray, and hydroplaning) that maintains good frictional characteristics in wet or dry conditions
- Such mixes are not considered to be structural elements and no thickness reduction applies
- RHMA-O is typically placed in thin lifts, nominally 24 to 30 mm thick

Open-Graded Mixes (RHMA-O)

- Do not use open-graded mixes where there is a significant amount of stop and go traffic or turning vehicles, such as city streets or in parking lots
- These porous low modulus pavements are susceptible to tire scuffs from simultaneous braking and turning motions, and to damage from leaking vehicle fluids
- Caltrans does not use RHMA-O in snow country

RHMA-O Mix Design

- RHMA-O mixture design is performed according to California Test 368, with asphalt rubber binder content set at 1.2 times the optimum bitumen content for the designated PG binder grade
- A check test is used to verify that binder drain down is not excessive
- If long hauls are anticipated, drain down should also be checked in the laboratory for the expected haul time

Open-Graded Mixes (RHMA-O-HB)

- RHMA-O-HB mixes have higher binder contents (1.6 times demand for PG asphalt instead of 1.2)
- HB provides improved friction course durability and performance due to thicker AR binder films
- Drain down check is more critical for high binder mixes
- RHMA-O-HB does not drain as freely as RHMA-O due to higher binder content, but still drains more freely than DGAC

SSP – Standard Special Provisions

- Standardized language used with construction contracts to amend, supplement, and incorporate the Caltrans Standard Specifications
- Standard Special Provisions are always being created and updated to reflect new understanding of materials, workmanship, and new products or procedures.

Open-Graded Mixes

- RHMA-O and RHMA-O-HB provide safety benefits, and also have proved to:
  - Provide smooth ride
  - Significantly reduce tire noise
- Joint Caltrans/ADOT/FHWA studies are in progress to measure and document noise reduction over a ten-year period

SSP – RHMA-O

1. General
2. Materials
3. Proportioning and mix design
4. Review of RHMA mix design
5. Contractor QC, sampling, and testing

SSP – RHMA-O

6. Equipment for production of asphalt-rubber binder
7. Proportioning of binder, aggregates
8. Spreading and compacting
9. Measurement and payment

Caution

- The specifications and mix design methods discussed in this presentation apply to use of high viscosity asphalt rubber binders (field blend) in gap- and open-graded RHMA mixes
- No agitation binders (low viscosity, terminal blend) should never be directly substituted for high viscosity binders in any RHMA mix
- The two different types of CRM-modified binders have very different viscosity ranges and behave very differently from each other in asphalt concrete hot mixes

Summary

- Introduction of plans and specifications for construction projects
- Caltrans specifications for RHMA-G, RHMA-O, and RHMA-O-HB
- Caltrans SSPs

Questions ?

The Beginning

Keeping roads good with asphalt rubber paving materials

http://www.cp2info.org/center

"Today decides tomorrow!!!

Waste Tire Applications in Geotechnical Engineering

By
CP2 Center
And
CSU Chico

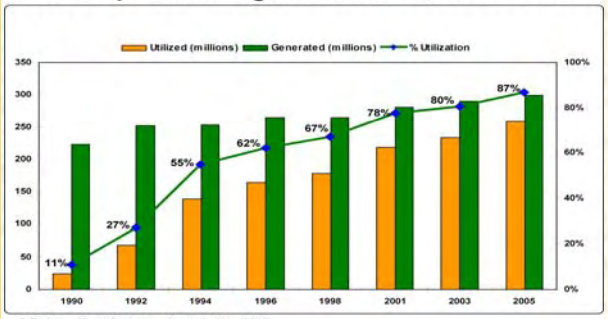
CIVL 411 Soil Mechanics

Outline

- Background
- Benefits of Using Waste Tire Materials
- Physical Properties of Tire Chips or Tire Shreds
- Waste Tire Applications in Geotechnical Engineering
- Sample Case Studies
- Summary

Background

U.S. Scrap Tire Management Trends, 1990 - 2005



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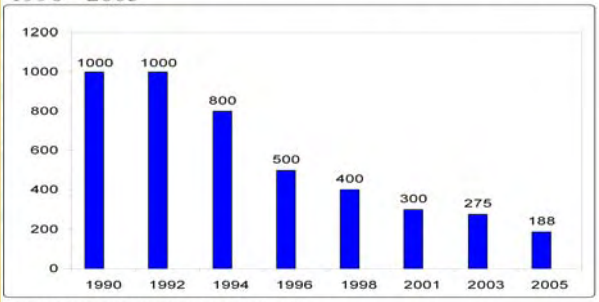
Background

Millions of Scrap Tires Remaining in U.S. Stockpiles, 1990 - 2005



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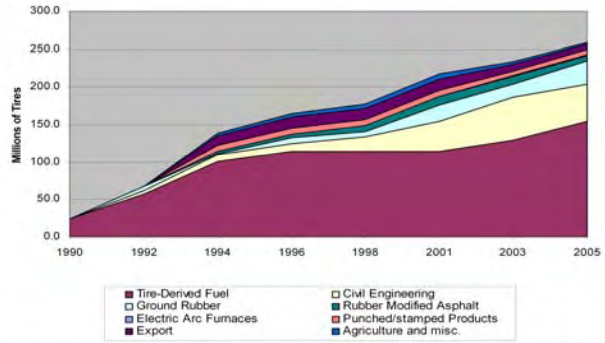
Tire fires release heavy metals and other hazardous compounds

- Arsenic
- Chromium
- Lead
- Manganese
- Nickel
- Mercury
- Cadmium
- Pyrolytic Oil

U.S. Scrap Tire Market Trends, 1990-2005



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Tire Derived Aggregate (TDA)

Pieces of processed tires that have a consistent shape and are generally between 25mm (1 in.) and 300mm (12 in.) in size.

Physical Properties of TDA

- Lightweight (1/3 soil)
- Low earth pressure (1/2 soil)
- Good thermal insulation (8 times better)
- Good drainage (10 times better)
- Compressible
- Durable

The Benefits of Using Waste Tires

- Help get rid of waste tires
- Prevent waste tire fires and protect environment
- Preserve valuable aggregate
- Utilize unique engineering properties of waste tire materials

Geotechnical Engineering Applications

- Backfill for retaining walls and bridge abutments
- Lightweight embankment fill and subgrade fill
- Subgrade insulation for roads
- Slope repair

Subgrade Fill and Embankments

- Tire shreds can be used to construct embankments on weak, compressible foundation soils
- Tire shreds are viable in this application due to their light weight
- For most projects, using tire shreds as a lightweight fill material is significantly cheaper than other alternatives
- Subgrade fill and embankments include protecting roads from erosion, enhancing the stability of steep slopes along highways, and reinforcing shoulder areas

Backfill for Walls and Bridge Abutments

- The light weight of the tire shreds reduces horizontal pressure and allows for construction of thinner, less expensive walls
- Tire shreds can also reduce problems with water and frost build up behind walls, because tire shreds are free draining and provide good thermal insulation

Subgrade Insulation for Roads

- In cold climates, excess water is released when subgrade soils thaw in the spring
- Placing a 6 to 12-inch thick tire shred layer under the road can prevent the subgrade soils from freezing
- In addition, the high permeability of tire shreds allows water to drain from beneath the roads, preventing damage to road surfaces

Slope Repair

- When a road landslide occurs:
  - Often it is necessary to excavate the sliding road material down to more stable soil
  - Then rebuild the slope and road in shallow, compacted sections called lifts
  - Drainage improvements are usually made to the slope to increase its stability
- TDA has properties that civil engineers, public works directors and contractors need:
  - Lightweight TDA requires less excavation
  - More cost effective design can be utilized

Case Study for Retaining Wall Backfill

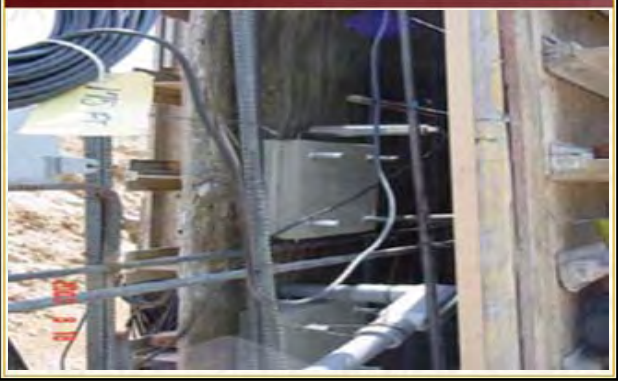
Wall 119, Riverside, CA

- PROBLEM: Widening the West bound side of Route 91 using TDA, is it as effective as typical backfill soil? YES!!!
- Instrumentation: Installation of four types of gauges, strain gauge, pressure cell, temperature sensor, and tilt meter

Wall 119, Retaining Wall Construction

Wall 119, Strain Gauge Installation

Wall 119, Pressure Cell Installation



Wall 119, Temperature Sensor Installation

Wall 119, Tilt Meter Installation

Wall 119, TDA Placement

Wall 119, TDA Compaction

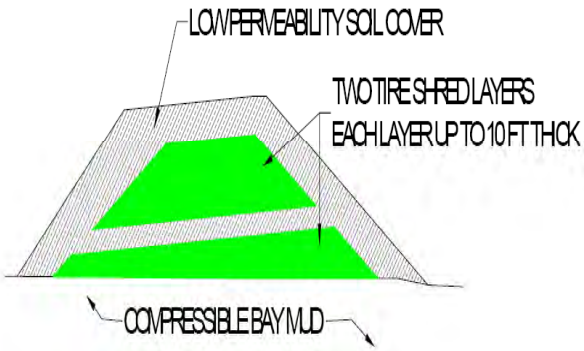
Wall 119, Completed

Case Study for Lightweight Embankment fill

Dixon Landing Interchange

- **PROBLEM: Embankment Constructed on Bay Mud**
- **SOLUTION: Use TDA for the core of the embankment**
- **CHEAPEST SOLUTION: saved $230,000**

Dixon Landing Interchange, Cross Section



Dixon Landing Interchange, Dumping TDA

Dixon Landing Interchange, Spreading TDA

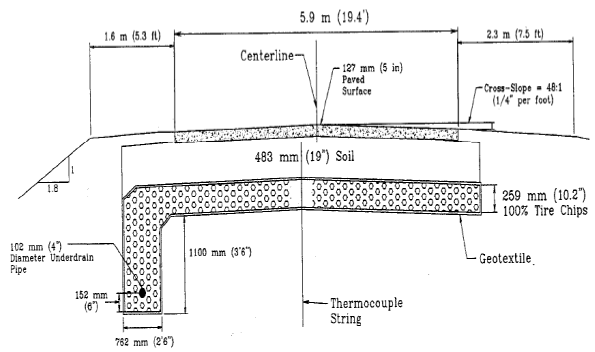
Dixon Landing Interchange, Compacting TDA

Subgrade Insulation for Roads

Witter Farm Road, Orono, Maine

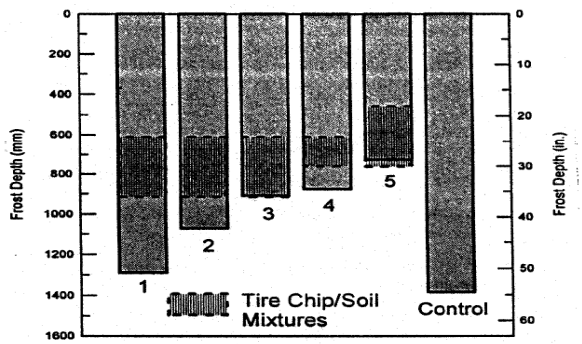
- **PROBLEM: Frost in cold climates cause heaving of the road and can crack the asphalt, when the ice melts the water weakens the road subbase leading to rutting of the gravel and cracking of the asphalt**
- **SOLUTION: Use TDA as subgrade, because it has eight-times better insulating material then gravel and is more permeable**

Witter Farm Road, Typical Cross Section



Witter Farm Road, Placing and Compacting TDA

Witter Farm Road, Frost Penetration for winter of 1996/7



Case Study for Slope Repair

Marina Drive, Ukiah, CA

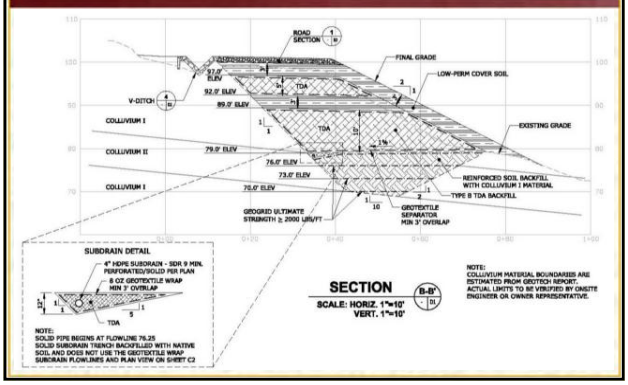
- **PROBLEM: Road slide damaged the road making it unusable**
- **SOLUTION: Use TDA as replacement to typical backfill soil**

Marina Drive, Damaged Section of Road

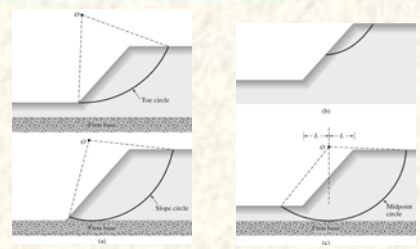
Marina Drive, Damaged Section of Road

Marina Drive, Damaged Section of Road

Marina Drive, Proposed Drawing



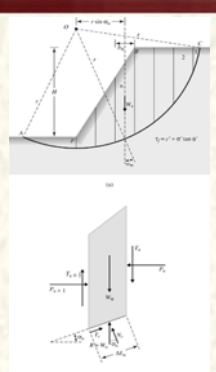
Mode of Circular and General Failure



(a) Slope failure (toe circle, slope circle)
(b) Shallow slope failure
(c) Base failure (midpoint circle)

Methods of analysis:
1. Mass procedure
2. Method of slices

Ordinary Method of Slices



Let driving and resisting moment about O be equal:

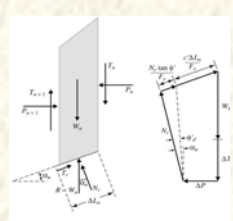
$$\sum_{n=1}^{p} W_n r \sin\alpha_n = \sum_{n=1}^{p} \frac{1}{F_s}\left[c' + \frac{W_n \cos\alpha_n}{\Delta L_n}\tan\phi'\right](\Delta L_n)(r)$$

$$F_s = \frac{\sum_{n=1}^{p}\left[c' + \frac{W_n \cos\alpha_n}{\Delta L_n}\tan\phi'\right](\Delta L_n)(r)}{\sum_{n=1}^{p} W_n r \sin\alpha_n}$$

$$= \frac{\sum_{n=1}^{p}\left[c'\Delta L_n + W_n \cos\alpha_n \tan\phi'\right]}{\sum_{n=1}^{p} W_n \sin\alpha_n}$$

Need trial and error to find failure surface with smallest F_s

Simplified Bishop's Method



Shear resistance:

$$T_r = N_r(\tan\phi_R') + c_R'\Delta L_n = N_r\frac{(\tan\phi')}{F_s} + \frac{c'\Delta L_n}{F_s} \quad (1)$$

Normal force (solve by summing vertical forces in the force polygon shown:

$$N_r = \frac{W_n + \Delta T - \frac{c'\Delta L_n}{F_s}\sin\alpha_n}{\cos\alpha_n + \frac{\tan\phi'\sin\alpha_n}{F_s}} \quad (2)$$

Let driving and resisting moment about O be equal:

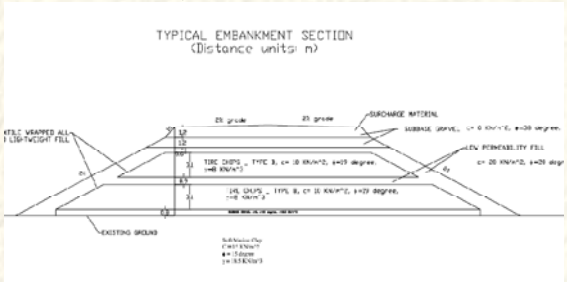
$$\sum_{n=1}^{p} W_n r \sin\alpha_n = \sum_{n=1}^{p} T_r r \quad (3)$$

Substitution of Eqx. (1) and (2) into (3) and solve for Fs:

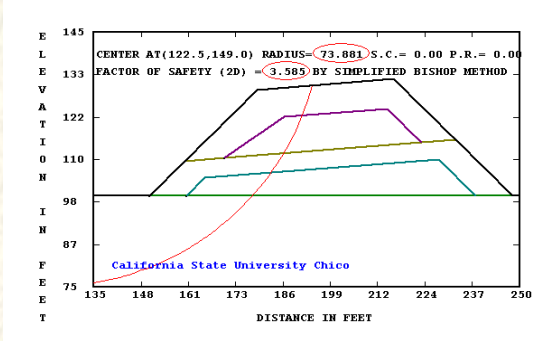
$$F_s = \frac{\sum_{n=1}^{p}(c'b_n + W_n \tan\phi')/m_{\alpha(n)}}{\sum_{n=1}^{p} W_n \sin\alpha_n}, \text{ where } m_{\alpha(n)} = \cos\alpha_n + \frac{\tan\phi'\sin\alpha_n}{F_s}$$

Sample Student Problem on Slope Analysis on a Embankment Fill

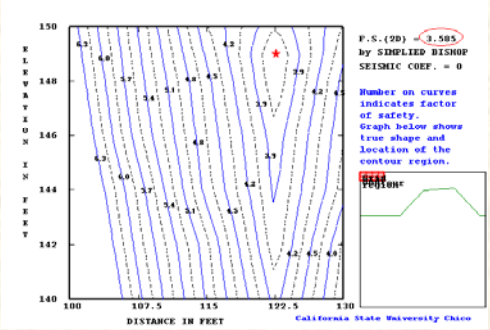
Find the factor of safety for the slope in the following embankment:



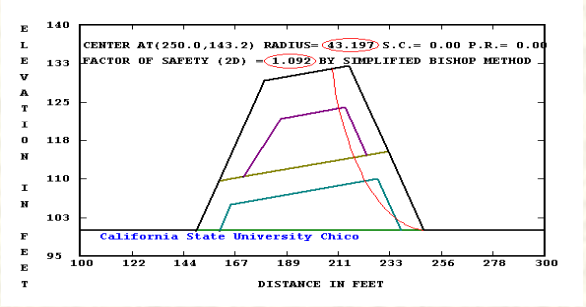
Left side analysis using SBM



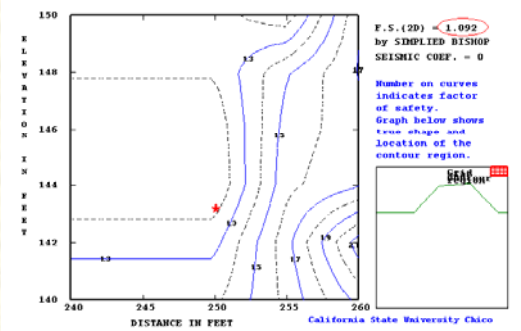
Left side analysis using SBM



Right side analysis using SBM

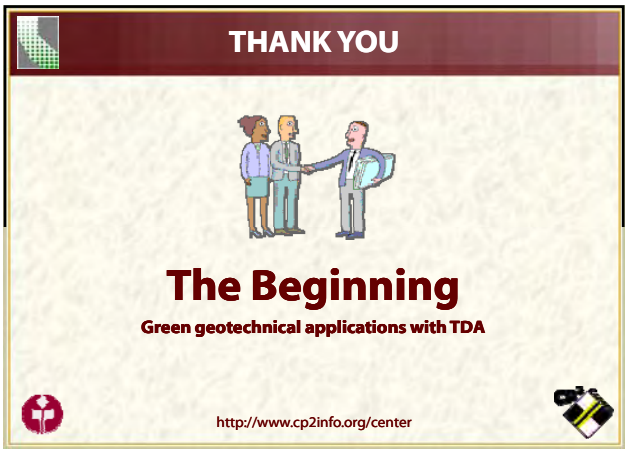


Right side analysis using SBM



SUMMARY

- Introduction of TDA applications
- TDA applications in geotechnical engineering
- Successful TDA projects
- Sample problem


THANK YOU
The Beginning
Green geotechnical applications with TDA
http://www.cp2info.org/center

Has Many Names in the Literature

- Crumb Rubber Concrete (CRC)
- Rubber Included Concrete (RIC)
- Rubberized Concrete
- Rubcrete
- Tire Rubber-Filled Concrete

Potential Effects of Adding Rubber to Concrete

- Reduces Compressive Strength
- Can Increase Ductility
- Increases Toughness (ability to absorb energy)
- May Reduce Cracking
- Reduces Unit Weight of the Concrete
- Reduces Thermal Expansion/Contraction
- May Replace Air Entraining Agent in Cold Environments
- Improves Insulation (but Decreases Thermal Mass)
- Reduces Sound Transmission

Potential Applications of Rubber Included Concrete

- Tire rubber may replace air entraining in cold weather applications
- RIC may be more flexible and crack resistant for light weight paving
- RIC may provide vibration damping and sound transmission mitigation

Mix Design

The mix design should be based on an absolute volume method, replacing mineral aggregate with tire particles of similar size characteristics (gradation). This is accomplished by utilizing the specific gravity of the aggregates.

Mix Design Parameters - RIC

- Type of Rubber Particles
- Size of Rubber Particles and Aggregate
- Gradation of Rubber Particles
- Specific Gravity of Rubber Particles
- Fineness Modulus (Fine Aggregate)
- Rubber Content for Mix
- Water-Cement Ratio

Sample of Mix Designs from Literature

Author	Rubber Type	Rubber Content	Method of Mix Design
Kaloush et. al.	1mm Crumb Rubber	0, 50, 100, 150, 200, and 300 #/cuyd	Replaced fine aggregate with crumb rubber by weight, increased w/c ratio
Fedroff et. al.	Super fine powder	0, 10, 20, and 30%	By weight of cement in mix adjusted w/c ratio to get 3 to 5 inches of slump
Tantala et.al.	Buff Rubber	5 and 10%	Replaced 5% and 10% of coarse aggregate with buff rubber by volume
Li et. al.	Cyrogenic Ground Rubber<2mm	33%	Replaced 33% of fine aggregate by volume
Schimizze et.al.	Fine/Coarse Reclaimed Rubber	5% of mix design by weight	Lowered both 1. fine aggregate and 2. fine and coarse aggregate to get 5% rubber by weight
Biel and Lee	3/8" minus rubber droppings	0 to 90% in 15% increments	Replaced fine aggregate with crumb rubber by volume gave 0 to 25% rubber by volume in mix
Eldin et.al.	Ground tire chips, fine crumb rubber	0,25,50,75,100% by volume	Test specimens replacing either coarse or fine aggregate

Difficulties Interpreting Literature Results

- **Different types of tire particles**
- **Different methods of mix design**
- **Different pretreatment of tire particles**
- **Different testing procedures**

Only general conclusions can be drawn from the results published in the literature!

Summary of Engineering Properties of Rubberized Concrete from the Literature

- **Compressive Strength**
- **Tensile (Split Cylinder) Strength**
- **Flexural (Modulus of Rupture) Strength**
- **Unit Weight**
- **Air Content**
- **Stiffness**
- **Ductility**
- **Toughness**
- **Coefficient of Thermal Expansion**
- **Durability**
- **Damping characteristics**

Rubberized Concrete Compressive Strength

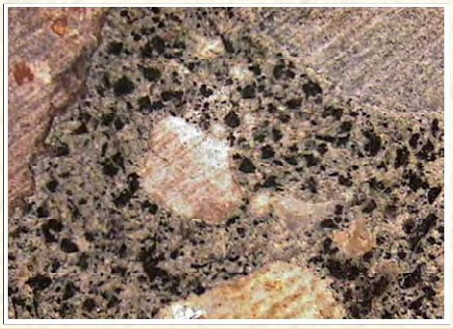
- **Rubber is weaker and less rigid than the mineral aggregate that they replace, which reduces the compressive strength**
- **Increasing rubber content has been found to increase the air content, which also reduces the compressive strength**
- **The bond characteristics between the cement paste and the rubber may also reduce the compressive strength**
- **As always, w/c ratio, unit weight, workmanship, and curing affect compressive strength**

Mix Ingredients for Crumb Rubber Concrete (Kaloush et. al. 2004)

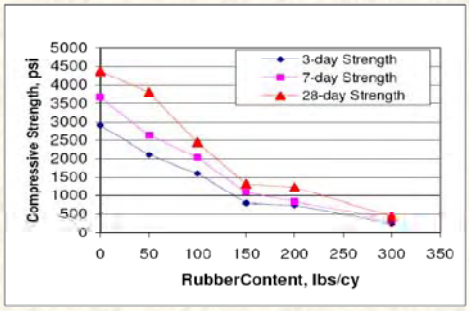
Project / Mix ID #	*Unit Weight lbs/cu ft*	*W/C ratio*	*Dry weight of materials, (lbs/Cyd)*		
			Cement	*FA*	*CA*
0 lbs per Cyd *(Trial)*	147.8	0.42	525	1417	1731
50 lbs per Cyd *(Trial)*	140.1	0.44	525	1367	1731
100 lbs per Cyd *(Trial)*	135.7	0.45	525	1317	1731
150 lbs per Cyd *(Trial)*	125.7	0.46	525	1267	1731
200 lbs per Cyd *(Trial)*	126.5	0.47	525	1217	1731
300 lbs per Cyd *(Trial)*	109.2	0.48	525	1117	1731

Cross-sectional View of Concrete Samples (Kaloush et. al. 2004)

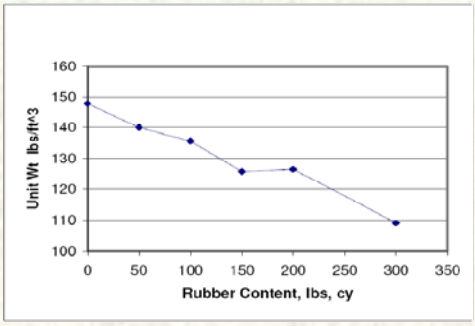
Microscopic View of Crumb Rubber Distribution in 400 lbs CR/ Cyd. Mix (Kaloush et. al. 2004)



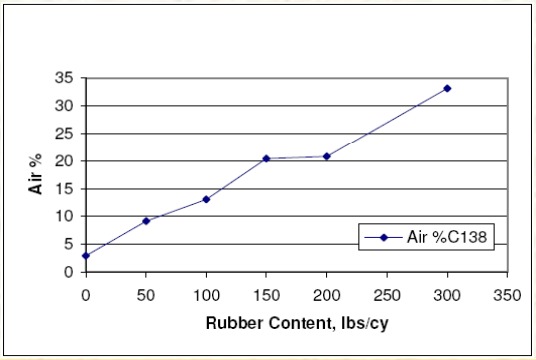
Effect of Rubber Content on Compressive Strength (Kaloush et. al. 2004)



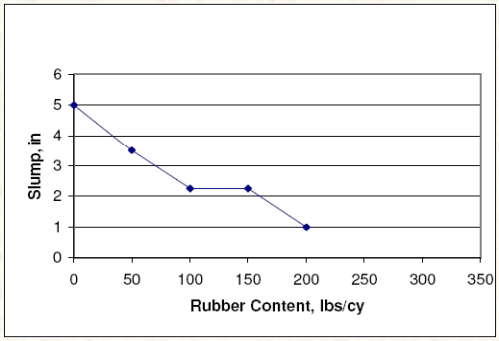
Effect of Rubber Content on Concrete Unit Weight (Kaloush et. al. 2004)



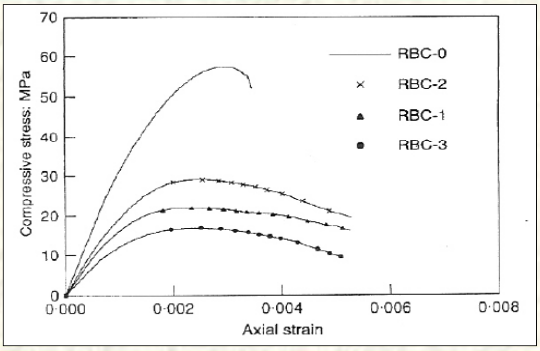
Effect of Rubber Content on Concrete Air Content (Kaloush et. al. 2004)



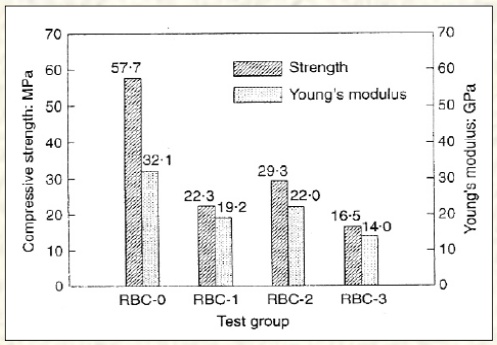
Effect of Rubber Content on Concrete Slump (Kaloush et. al. 2004)



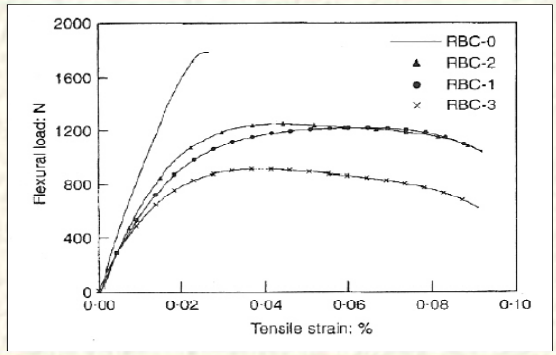
Compressive Stress Strain Curves (Li et. al. 1998)



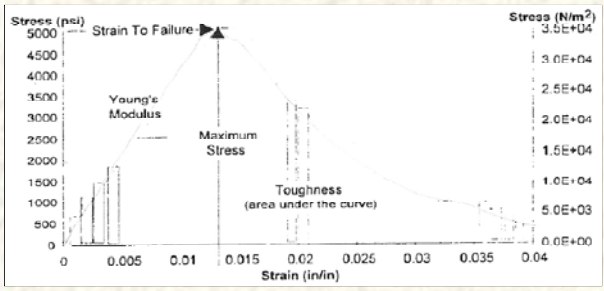
Compressive Strength and Stiffness
(Li et. al.1998)



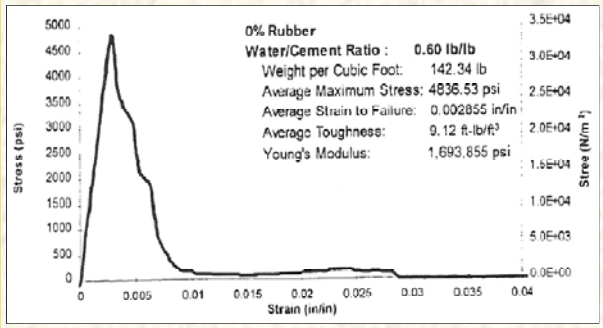
Flexural Strength
(Li et. al. 1998)



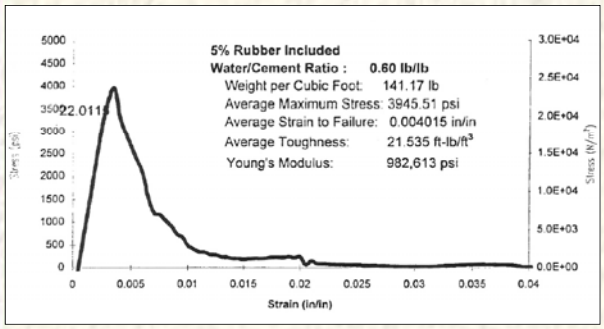
Typical Concrete Compression Stress-Strain Curves
(Tantala et. al. 2002)



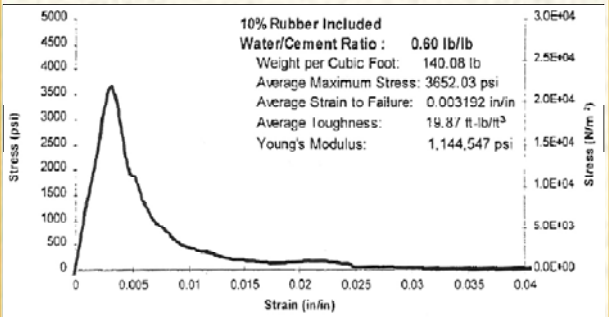
Stress-Strain Curves Ordinary Concrete
(Tantala et. al. 2002)



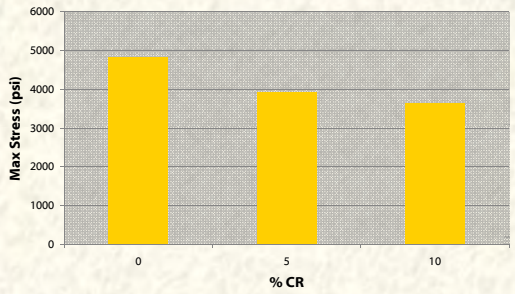
Stress-Strain Curves 5% Rubber Concrete
(Tantala et. al. 2002)



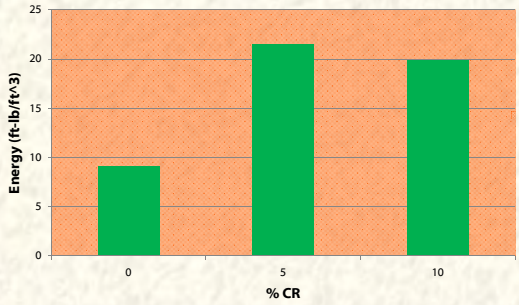
Stress-Strain Curves 10% Rubber Concrete
(Tantala et. al. 2002)



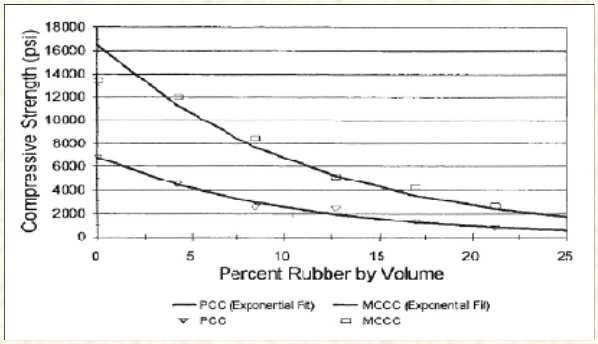
Maximum Compressive Stress



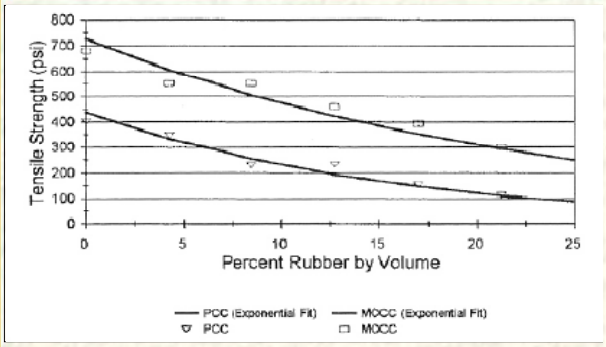
Toughness



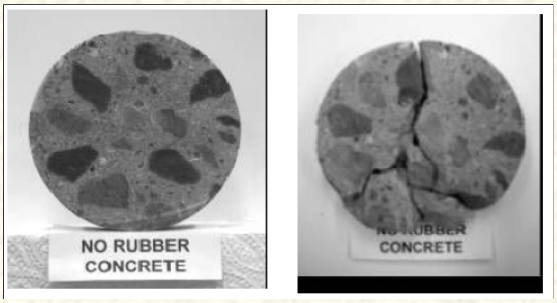
Compressive Strength vs. Rubber Content (Biel et. al. 1994)



Split Cylinder Strength vs. Rubber Content (Biel et. al. 1994)

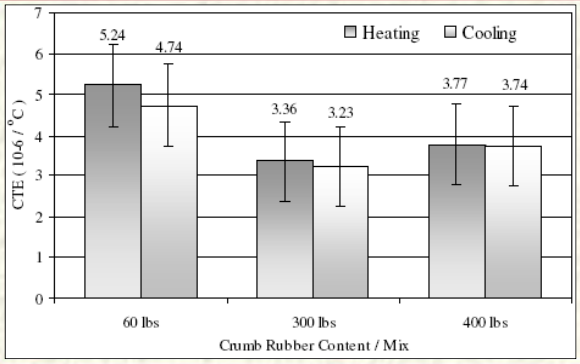


A Tensile Strength Failure of Ordinary Concrete (Kaloush et.al. 2004)



Tensile Strength Failures Crumb Rubber Concrete (Kaloush et.al. 2004)

Coefficient of Thermal Expansion - CRC
(Kaloush et.al. 2004)

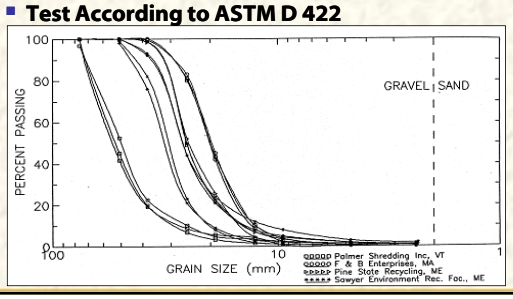


Engineering Properties of Tire Rubber for Concrete Mix Design

- Gradation (Generally Uniformly Graded)
- Specific Gravity
- Absorption Capacity
- Unit Weight

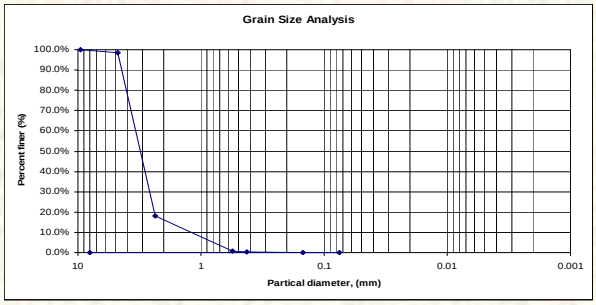
Gradation

- Generally Uniformly Graded (Same Size)
- Max Size Varies According to Manufacturing
- Test According to ASTM D 422



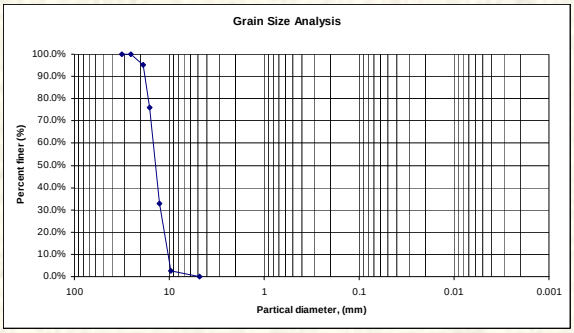
Crumb Rubber Sample

GSD Crumb Rubber



Tire Buffings Sample

GSD Tire Buffings



Specific Gravity and Absorption Capacity

Tire shred type	Specific gravity			Water Absorption capacity (%)	Reference
	Bulk	Saturated surface dry	Apparent		
Glass belted	----	----	1.14	3.8	Humphrey et al. (1992)
Glass belted	0.98	1.02	1.02	4	Manion & Humphrey (1992)
Steel belted	1.06	1.01	1.10	4	Manion & Humphrey (1992)
Mixture	1.06	1.16	1.18	9.5	Bressette (1984)
Mixture (Pine State)	----	----	1.24	2	Humphrey et al. (1992)
Mixture (Palmer)	----	----	1.27	2	Humphrey et al. (1992)
Mixture (Sawyer)	----	----	1.23	4.3	Humphrey et al. (1992)
Mixture	1.01	1.05	1.05	4	Manion & Humphrey (1992)
Mixture	----	0.88 to 1.13	----	----	Ahmed (1993)

Patented Concrete Mix Design

- 100 parts by weight of cement
- 100-200 parts by weight of sand
- 200-400 parts by weight of coarse aggregates
- 15-30 parts by weight of shredded particulates comprising rubber, fibers and steel obtained from whole waste tires
- 20-70 parts by weight of water
- Fly ash
- Super-plasticizer

Reinforced Concrete Lab

- Lab is required of all CE majors as part of a capstone design class in reinforced concrete design
- Conducted experiments with varying water-cement ratios of 0.4, 0.55, and 0.7
- Each of three labs assigned a different rubber percentage: 10, 20 and 30% by volume
- Replaced fine aggregate with crumb rubber, and coarse aggregate with rubber buffings by volume assuming a specific gravity of 1 for the tire rubber.

Lab Objectives

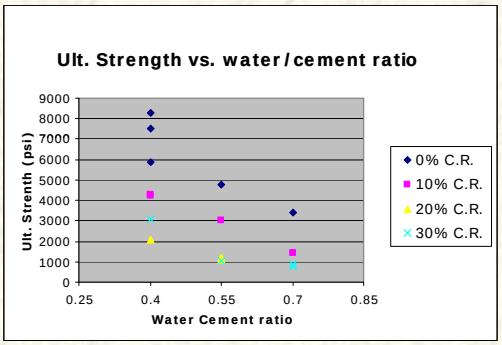
Study the effects of adding tire particles to assigned mix. Try to determine:

1. Compressive Strength
2. Modulus of Elasticity
3. Poisson's Ratio
4. Air Content
5. Comment on workability/segregation

Results

- Results were generally consistent with the findings in the literature
- Incomplete data sets as they were assigned the same mix design that was given in class for ordinary concrete, and some results were not recorded

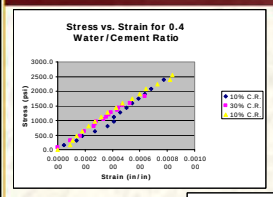
Concrete Lab Results

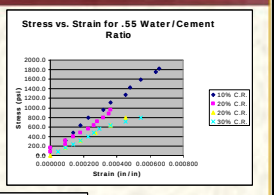


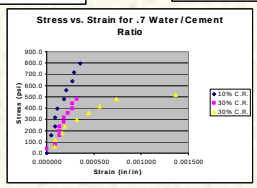
Compressometer for E and μ

- UTM for applying Load and measuring Force
- Dial gages for Longitudinal and Transverse strain

Stress-Strain Curves







Other Results

- Summary of comments
- No lateral strain data, hence, no Poisson's ratio results
- Need another lab cycle…

Summary

- A fair amount of research has been done in using waste tire particles in Portland cement concrete
- Concrete compressive strength and stiffness decrease dramatically with increasing rubber content
- However, tensile strain, ductility, and toughness have been shown to increase with small amounts of rubber particles

Potential Applications

- Light duty paving (sidewalks, etc.)
- Vibration mitigation
- Energy absorption (earthquake)
- Increase freeze/thaw durability
- Others?

References

- **Civil Engineering Applications Using Tire Derived Aggregate. Presented by Dr. Dana Humpherey. Sponsored by: California Integrated Waste Management Board**
- **Properties of Crumb Rubber Concrete Kamil E. Kaloush, Ph.D, P.E., Assistant Professor Arizona State University ,Department of Civil and Environmental Engineering**
- Mechanical Properties of Concrete with Ground Waste Tire Rubber. David Fedroff, Shuaib Ahmad, and Banu Zeynep Savas
- Properties of Concrete Incorporatign Rubber Tyre Particles. Z. Li, F. Li, and J. S. Magazine of concrete Research, 1998, 50, No. 4, Dec., 297-304
- Use of Waste Rubber in Light-Dudy Concrete Pavements. Richard R. Shimizze, S.M.ASCE, James K. Nelson, M.ASCE, Serji N. Amirkhanian, M.ASCE and John A. Merden, A.M. ASCE.
- Rubber-Tire particles as Concrete Aggregate. Neil N. Eldin, Ahmed B. Senouci. Journal of Materials in Civil Engineering, **5** (1993) 478-96.
- Quasi-Elastic Behavior of Rubber Included Concrete (RIC) Using Waste Rubber Tires. Michael W. Tantala, University of Pennsylvania, John A Lepore, Ph.D., P.E, University of Pennsylvania, Iraj Zandi, Ph.D., P.E., University of Pennsylvania, Philadelphia, Pennsylvania, USA.
- Use of Recycled Tire Rubbers in Concrete. Biel T.D. and Lee H. Infrastructure: New Materials and Methods of Repair. Proceedings of the Third Materials Engineering Conference, San Diego, 1994, 351-358

"Today decides tomorrow!!!

Environmental Issues of Waste Tires in Civil Engineering

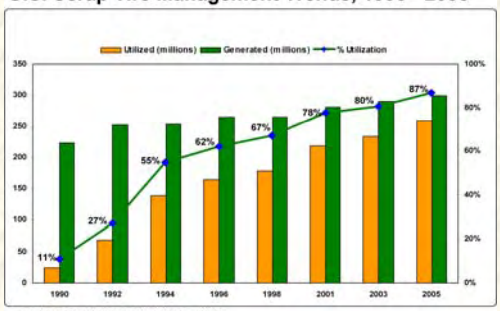
Department of Civil Engineering,
California State University, Chico

Outlines

- Introduction
  - Stockpiles
  - Tire Fires
- Waste Tire CE Applications
- Environmental Assessment Research
  - Lab Evaluations
  - Field Tests
- Conclusions and Recommendations

Background

U.S. Scrap Tire Management Trends, 1990 - 2005



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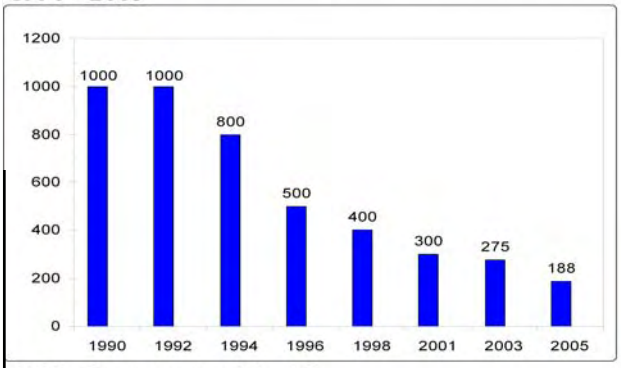
Millions of Scrap Tires Remaining in U.S. Stockpiles, 1990 - 2005



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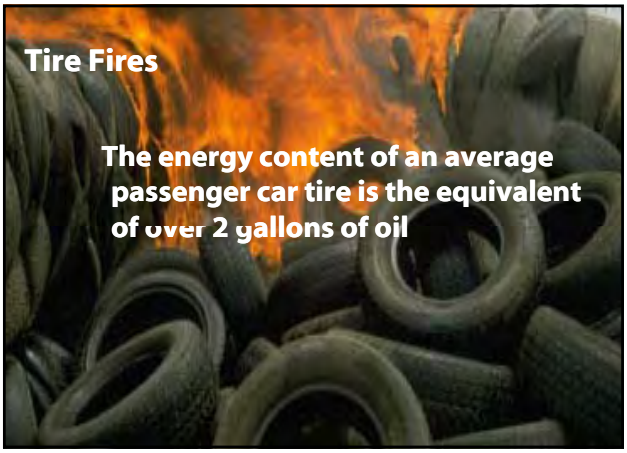
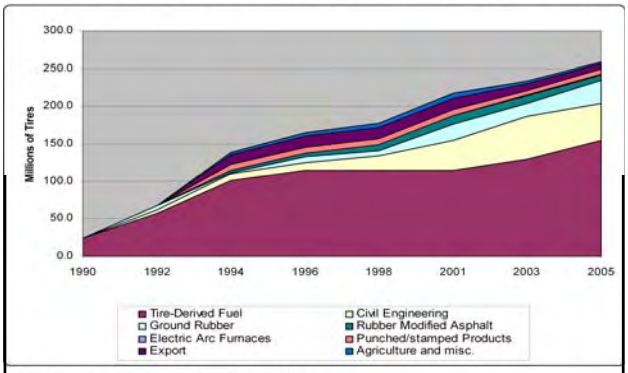


Toxins Released During Tire Fires

- Tire fires release heavy metals and other hazardous compounds that run into streams and seep into shallow wells
  - Arsenic
  - Chromium
  - Lead
  - Manganese
  - Nickel
  - Mercury
  - Cadmium
  - Pyrolytic Oil

U.S. Scrap Tire Market Trends, 1990-2005



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Properties of TDA in Civil Engineering Applications

Size	*2 to 12 inches*
Weight	*1/3 to 1/2 weight of soil*
Volume	*1 cubic yard ≈75 tires*
Drainage	*10 times better than well graded soil*
Insulation	*8 times better than gravel*
Lateral Foundation Wall Pressure	*1/2 that of soil*

Civil Engineering Applications

- Lightweight Fill
- Retaining Wall Back Fill
- Embankment Fill and Slope Repairs
- Subgrade Insulation Layer
- Landfill Applications
- Septic System Drain Field
- Vibration Damping

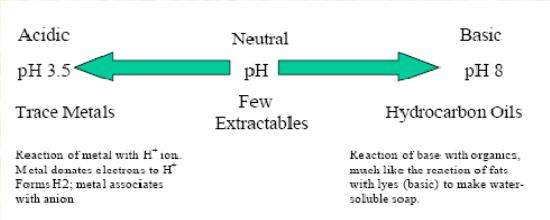
Environmental Concerns of CE Applications

- Groundwater Contamination
- Fire Hazard
- Long Term Performance
- Lab Test Results
- Field Test Results

Lab Testing on Tire Leaches

- Toxicity Characterization Leaching Procedure (TCLP)
- Extraction Procedure Toxicity (EP Tox)
- Scrap tires are usually pre-cut into a designated dimension and submerged into different solutions, then the leachate is analyzed
- Lab tests can be used as an indicator of the types of contaminants that a scrap tire may produce

Minnesota Pollution Control Agency



Results of the Study

- None of the laboratory leachate samples exceed the EP toxicity criteria or the TCLP criteria
- For some samples and some leaching conditions, arsenic, cadmium, chromium, selenium, and zinc exceeded the Recommended Allowable Limits (RALs) set by the Minnesota Department of Health for drinking water

Recommendation From the Study

- The study recommended that use of scrap tires in roadway construction be limited to the unsaturated zone
- The roadway design should limit infiltration of water through the scrap tires and should promote surface water drainage away from the scrap tire subgrade

Virginia Department of Transportation Final Report on Leachable Metals in Scrap Tires

- The study consisted of two parts: one-year leaching and TCLP testing
- Leaching for two weeks results in a leachate that is approximately seven times more concentrated than usual TCLP extracts
- However, the stronger leach may be wholly or partially offset by the use of larger particles than the method calls for
- The concentrations of metals in the leachate were well below the TCLP regulatory limits

Illinois Department of Energy and Natural Resources Study

- Shredded tires were subjected to EP toxicity testing by DTC Laboratories Inc.
- In their results, levels of the organic compounds analyzed were below the detection limits in all cases
- None of the metals were above the EP toxicity limits for the EP TOX test

Conclusions from Lab Tests

- All lab results with various leaching conditions showed that higher concentrations of metals tend to appear at lower pH (acidic) conditions
- Higher levels of organics appear under high pH (basic) conditions
- Both the metallic components and the organics were well below the TCLP standards and the EP standards
- In total, these laboratory tests indicate scrap tires are not a hazardous waste.

Field Studies

- Scrap tires cut into various sizes, were used in designated positions in the road
- The soil and water were sampled at various times
- Studied the impact of scrap tires on the environment

Field Studies for Scrap Tire Applications

- Impact on Air
  - Releases volatile and semi-volatile organic compounds (VOC and SVOC) when hot
  - However, similar or less than that of asphalt
  - Slows down once the asphalt-rubber cools to the service temperature
  - Latex allergens may also be released from tire chips, but it should be a manageable amount

Impact on Soil

Minnesota Pollution Control Agency (1991)

- Field studies did not identify significant differences between waste tire areas and control areas for soil samples and for a biological survey
- No evidence was reported of the extractables found in previous laboratory tests under extreme pH conditions

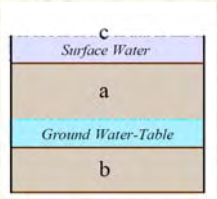
Impact on Soil

Department of Geology, Kent State University (1997)

- Soil-tire mixtures can be safely used as a light-weight fill material and in situations where improvement in drainage characteristics is required

Impact on Water

- When considering the impact of scrap tires on water, three locations for the tire chips are traditionally considered.



- a: above ground water table
- b: below ground water table
- c: surface water

Above Groundwater Table

Wisconsin Department of Transportation Study

- There is little or no likelihood of significant leaching of tire chips for substances that are of specific public health concern, such as lead or barium
- The lead, zinc, and manganese levels were elevated

Above Groundwater Table

Chenette Engineering, Inc.

- Shredded tires were installed in place of crushed stone in a replacement on-site disposal system
- This system was installed in December 1991 and a two-year follow-up was reported on in 1993
- As anticipated, iron and lead started out at elevated levels; both metal concentrations quickly dropped below Vermont groundwater standards

Above Groundwater Table

University of Maine (1997)

- Better monitored by control wells
- There was no evidence that tire chips increased the level of substances above the primary drinking water standard
- There was no evidence that tire chips increased the levels of aluminum, zinc, chloride or sulfate, which are included in the secondary (aesthetic) drinking water standards
- Iron and magnesium may exceed their secondary standards under some cases
- Results were below the detection limit for all compounds

Below Groundwater Table

- Increased the iron concentration at three test sites
- Within the tire chip trench, iron content was up to two orders of magnitude higher than the secondary drinking water standard
- The iron did not appear to have migrated downward at any of the sites

Below Groundwater Table

- Manganese content was also increased by the tire chips
- Manganese levels consistently exceeded the secondary drinking water standard in the test well within the tire chip trench
- Unlike iron, the manganese was observed to migrate downwards with groundwater flow

Below Groundwater Table

- Zinc content was also increased by the tire chip installations, however, the concentration was well below the drinking water standard
- Chromium concentrations were increased by the tire chips, but only at the peat site
  - The chromium levels were all below the primary drinking water standard

Conclusions on Groundwater Contamination

- Iron levels exceeded the Recommended Allowable Level (RAL). However, considering that iron is a secondary allowable drinking water element, it does not pose severe problems to the environment
- Among other metallic and organic compounds, there seems to be some disagreement; it may depend on the local soil pH conditions, the water infiltration conditions, and other pedological factors
- A maximum allowable steel content for recycled tire rubber should be established

Biological Survey

Minnesota Pollution Control Agency Biological Surveys (1990)

- No observable difference in either of the study areas when compared to the control areas
- Toxicity Characteristics Tests (TCT) concluded that future biological surveys would likely indicate no observable differences at tire sites when compared to background sites

Toxicity Survey

- Abernethy (1994)
  - Zinc levels were found to be 0.023~0.025 mg/L, which is consistent with the chemical makeup of tires
- Nelson (1994)
  - Zinc was found to be present at potentially toxic levels
  - Cadmium, copper and lead were also present at levels significantly above background sites

Conclusions

- Generally, recycled rubber derived from scrap tires is a safe recyclable material
- A common concern is that the Fe and Mn levels are often elevated. These elements are specified in the secondary drinking water standard based on aesthetic reasons (taste)
- Levels of metallic contaminants tend to increase under low pH values, while the level of organic compounds increases under high pH value

Recommendations

- Generally, reasonable to recommend use of recycled scrap tires in civil engineering applications
- It is important to recognize that the impact of scrap tires on the environment varies according to the local water and soil conditions, especially pH values

Environmental Benefits of Waste Tire Applications

- Prevents pollution and waste generation
- Saves money through prevention of waste tire disposal
- Creates new recycling industries
- Reduces landfill disposal and expansion

Summary
Environmental Advantages

THANK YOU
The Beginning
Keeping roads good with asphalt rubber
http://www.cp2info.org/center

Objectives

- Module 1: Introduction of Asphalt Rubber (AR)
- Module 2: Structural Design of Rubberized Hot Mix Asphalt (RHMA)
- Module 3: Construction
- Module 4: Inspection

Module 1: Introduction Outline

- History of Asphalt Rubber (AR)
- Caltrans Experience with RHMA
- Advantages of RHMA
- Primary References

History of Asphalt Rubber

- Used since the 1960's
- Used in chip seals, inter-layers, overlays, wearing courses, and hot mix asphalt pavements
- Used extensively in Arizona, California, Florida and Texas
- Design and construction guides now available from some agencies

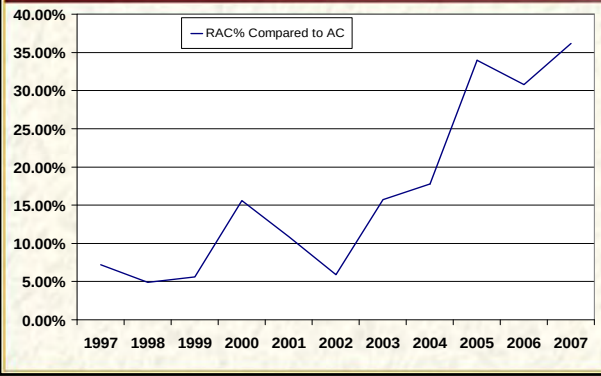
History of Asphalt Rubber (Cont.)

- Variable results in early years
- Most effective in retarding reflection cracking as a thin surface layer
- Mixes perform satisfactorily if properly designed and constructed

Caltrans Use of RHMA

- Largest Use
  - Thin overlays (RHMA-G) (Gap Graded)
  - Mitigate reflective cracking
  - Reduced thickness
- Other Uses
  - Friction course (RHMA-O) (Open Graded)
  - Durable sacrificial course (RHMA-O-HB) (Open Graded, High Binder)
- Performance
  - Successful in all applications
  - Problems generally due to construction issues

Caltrans RHMA Usage (% of AC Used)



Rubberized Bonded Wearing Course (RBWC) on I-5

MB and HVS

- 10 pilot projects using Rubberized Modified Binder (RMB) (1997 - 2000)
- Performance: *8 good, 1 fair*, and 1 poor**
- HVS Sites – UC Berkeley
  - *45 mm RHMA-G, Field Blend*
  - *45 mm Type G Modified Binder (MB), Terminal Blend (TB)*
  - *90 mm Type G (MB), TB*
  - *45 mm MB 15%, TB*
  - *90 mm MB 15%, TB*
  - *90 mm DGAC Type A (Control)*
- HVS Performance: Exceeding expectations

* Not materials related

RHMA 5-Year Warranty Projects

- 5 Projects Constructed in 2002 - 04
  - 4 – Wet Process (Fresno-33, Ventura-150, Merced-140, San Deigo-75)
  - 1 – MB-D (terminal) (Lassen-395)
- Level Playing Field
  - 15% CRM
  - Open specifications
  - 5-Year Performance Warranty Criteria include
    - > Rutting > Cracking > Delaminating
    - > Bleeding > Potholing
- Regular Review and Evaluation

Fresno-33

- Fresno-33 (Firebaugh, 9 test sections, June 04)
  - DGAC (90 mm)
  - RHMA-G (45 mm, 90 mm)
  - RUMAC (45 mm, 90 mm)
  - MB-G (45 mm, 90 mm)
  - MB-D (45 mm, 90 mm)

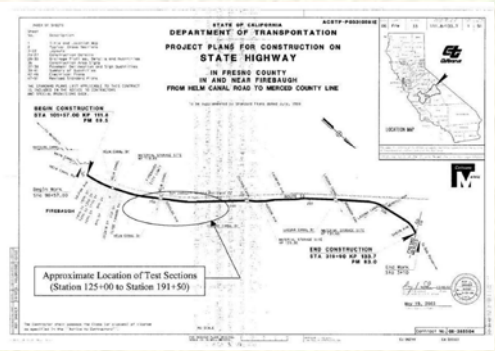
- *Performance evaluation sections*
- *Laboratory performance tests*
- *Comparison to HVS*

Firebaugh Background

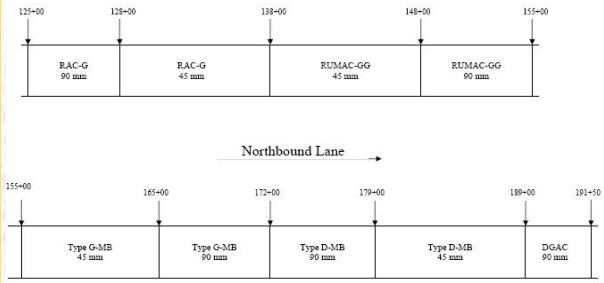
- In 2004 Caltrans, with funding provided by the California Integrated Waste Management Board (CIWMB) launched a full scale experimental design and construction project using rubberized asphalts as an overlay on existing distressed pavement sections.

- The main focus of this project was to observe the field performance of various mixes of RHMA with different thicknesses, and to evaluate the constructability of the RHMA mixes.

Fresno-33 (Firebaugh)



Fresno-33 (Firebaugh), Test Sections



Test Section Mixes

Material Type	Section	Process	Thickness (mm)	Length (m)	Test Section		PES Location	
					Begin	End	Begin	End
RAC-G	1	Wet	90	300	70.956	71.143	70.985	71.080
	2		45	1000	71.143	71.764	71.391	71.486
RUMAC	3	Dry	45	1000	71.764	72.386	72.100	72.195
	4		90	700	72.386	72.821	72.495	72.590
MB-G	5	Terminal	45	1000	72.821	73.442	73.000	73.095
	6		90	700	73.442	73.877	73.500	73.595
MB-D	7	Terminal	90	700	73.877	74.312	74.055	74.150
	8		45	1000	74.312	74.934	74.500	74.595
DGAC	9	Control	90	13000	74.934	83.069	75.000	75.095

- (RAC-G) – Rubberized Asphalt Concrete, Gap Graded (Wet Process)
- (RUMAC) - Rubber Modified Asphalt Concrete, Gap Graded (Dry Process)
- (MB-G) - Type-G Modified Binder (terminal blended wet process)*
- (MB-D) - Type-D Modified Binder (terminal blended wet process)*

* - The project specifications required the MB binders to have at least 15% rubber by weight of asphalt.

Fresno-33 (Firebaugh) Existing Pavement Distresses

Firebaugh Construction

- **Paving began in April 2004 and was concluded in June of 2004**

Heating of Type D-MB Transverse Joint with a Blowtorch prior to Paving Type G-MB

Windrow of Type G-MB

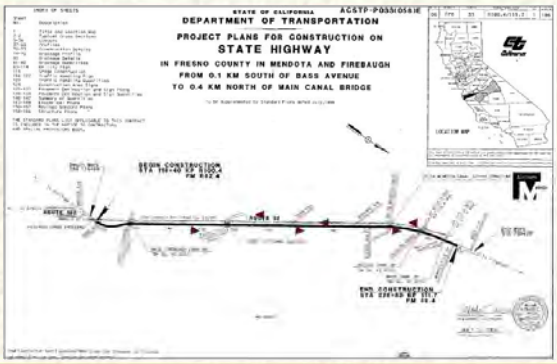
Evaluation of Field Results

- **Three rounds of post-construction performance monitoring were conducted on the project. FWD (Falling Weight Deflectometer) testing was performed during all three rounds.**
- **Within each project, four to nine 152-meter performance evaluation sections (PESs) were established for long-term performance monitoring.**

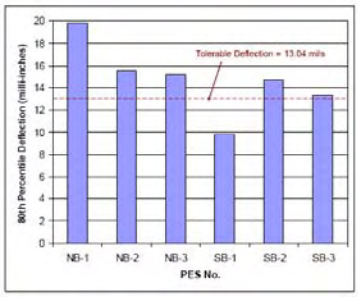
Evaluation of Field Results

- **A condition survey took place during the last round of the three round evaluations.**
- **Detailed pavement condition surveys – Distress surveys were conducted according to standard Caltrans definitions for distress type, severity, and extent.**
- **The surveys involved measurements of rutting, cracking, raveling, flushing, and other distresses as well as digital photographs.**
- **The tests and surveys serve as key components of the performance monitoring program.**

Firebaugh Test Section Locations

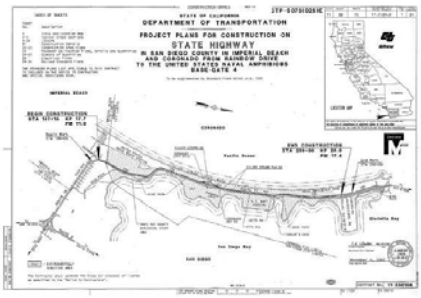


Firebaugh Results



- The bar graph compares the 80th percentile deflections with the tolerable value.
- Those that have an 80th percentile deflection greater than the tolerable value are considered structurally inadequate and less likely to survive the 10-year design period.

SAN DIEGO COUNTY, HIGHWAY 75



The San Diego RAC Warranty project is located along the two southbound lanes and shoulders of State Highway 75, District 11, San Diego County, between Coronado and Imperial Beach, CA. The project extends 6.4 miles.

Highway 75 Distressed Pavement

San Diego 75, Design Considerations

- The project area is located within the Caltrans "South Coast" climatic area. Precipitation, temperature, and traffic volume data were the key factors used to develop a mix design and pavement thickness.

San Diego Temperature and Precipitation Data

Element	Annual
Average Max Temp (°F)	69.9
Average Min Temp (°F)	56.4
Average Total Precipitation (in)	10.22
Average Total Snow Fall (in)	0.0
Average Snow Depth (in)	0.0

San Diego 2003 Annual Average Daily Truck Traffic Data (AADT)

Post Mile	Kilo Post	Leg	Description	Vehicle AADT Total	Truck AADT Total	Truck % Total Vehicle	EAL 1-Way (1000)	Year Ver/Est
9	14.5	A	SD JCT RTE 5	71000	2130	3	151	85V
18.47	29.7	B	CORONADO POMONA AVE	30000	570	1.9	51	86E
19.586	31.5	B	JCT RTE 282	32000	768	2.4	46	84V
19.586	31.5	A	JCT RTE 282	26000	884	3.4	81	86E

Ver=Verified, Est=Estimated

Structural Design Considerations

- Caltrans engineers determined a 60 mm gap-graded rubberized asphalt concrete (RAC-G) overlay was necessary to achieve desired results

Materials and Mix Design

- The asphalt rubber binder was an AR-4000 with 20% CRM (75% scrap tire and 25% high natural) and 3% extender oil

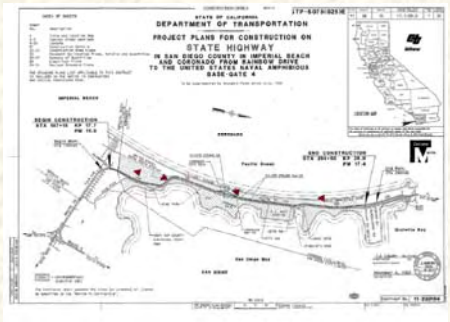
San Diego 75, Construction

- Paving took place between April 25 2003 and May 15 2003.
- The Equipment used is shown in the table bellow.

San Diego RAC Paving Equipment

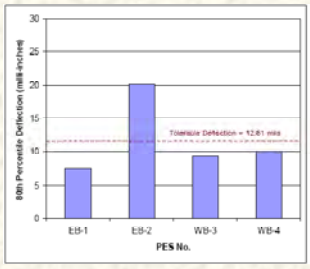
Make	Type	Model
Merle Husky/Cat	Vibratory Paver	Model AP 1055B
Caterpillar	Steel Wheel Vibratory Roller	Model CAT 364C
Ingersoll Rand	Steel Wheel Vibratory Roller	Model DD110
Teamstar	2000 gal Tack Truck	
Terra Gator	Sanding Truck	1603T
	R/T Backhoe w/ Spreader Box	
Brace	Brace Broom	BD250B

Field Observations and Results



- Location of PESs

Field Observations and Results



- The graph indicates that three of the four PESs have 80th percentile deflections that clearly satisfy the tolerable deflection criteria.
- The pavement can be expected to provide good structural performance over the 10-year design period.

Advantages of AR

- Good durability – in terms of resistance to cracking and aging
- Environmental friendly – make value-added use of a waste material, reduce traffic noise
- Versatility – can be used in most maintenance and rehabilitation activities, often at reduced thickness for resistance to reflective cracking
- Longer lasting color – for better contrast with striping and marking
- Reduced maintenance – for both chip seals and hot mix asphalts

Primary References

- Asphalt Rubber Usage Guide
- Use of Scrap Tire Rubber – State of the Technology and Best Practices
- Synthesis of Caltrans Rubberized Asphalt Concrete Projects
- Feasibility of Recycling Rubber-Modified Paving Materials
- Study on Structural Design Considerations
- Flexible Pavement Rehabilitation Manual
- Asphalt Rubber Design and Construction Guidelines
- RHMA-G SSP Version (12-12-05)
- RHMA-O SSP Version (12-12-05)

http://www.dot.ca.gov/hq/esc/Translab/fpmlab/Caltrans_CIWMB%20Project%20T021%20Deliverables.htm

Summary of Module 1

- Course Objectives and Content
- History of RHMA
- Caltrans Experience with RHMA
- Advantages of RHMA
- References

Module 2: Structural Design

New Pavements and Overlays

Module 2: Outline

- Terminology
- Caltrans Practices
- 2005 Study
- Revised Caltrans Practices
- RHMA Project Selection
- Cost Analysis

Terminology

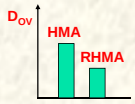
- Hot-mix asphalt (HMA) replaces the term dense-graded asphalt concrete (DGAC)
- Caltrans Highway Design Manual (HDM)
- Caltrans Flexible Pavement Rehabilitation Manual (FPRM)
- Asphalt Rubber Usage Guide (AR Guide)
- Mechanistic-empirical (M-E) based analysis and design

Caltrans Practice – Overlays

- Based on FPRM (2001)
- Uses deflection reduction to a tolerable level
- Design for HMA overlay thickness based on TI and existing HMA layer thickness
- Check also for reflective cracking and ride quality prior to pavement design

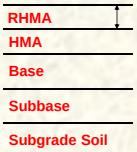
Caltrans Practice Overlays

- When RHMA-G is used as overlay material
  - Design for conventional HMA thickness
  - Determine RHMA-G overlay thickness according to FPRM
    - Table 3 – Based on structural equivalencies
    - Table 4 – Based on reflection crack retardation
  - RHMA-G overlay thickness generally half that of the HMA overlay thickness



2005 Study

- How should RHMA be used in new pavements?
- Can RHMA-G thickness be increased more than 60 mm?
- Does 2:1 thickness reduction for RHMA-G provide adequate structural equivalency in overlays?

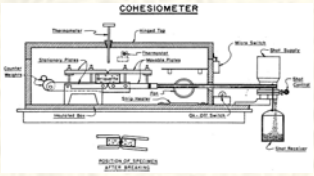


2005 Study

- Joint effort between Caltrans, UCPRC, and MACTEC
- Both new pavements and structural overlays
- Laboratory tests (Cohesiometer)
- Theoretical (M-E) analysis with lab-developed models

Primary Findings – New Pavements

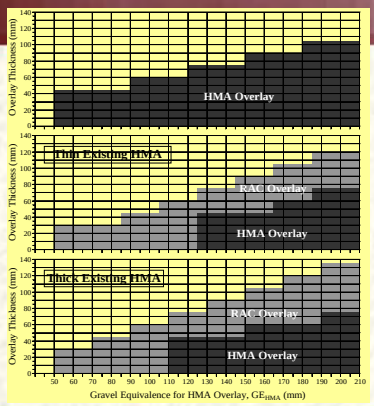
- Limited cohesiometer test results indicate that G_f for RHMA and HMA are similar.



Primary Findings Structural Overlays

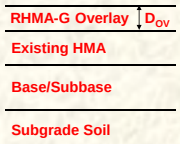
- Based on M-E analysis, the structural benefit of the RHMA-G overlay varies with the thickness placed. The greatest benefit occurs in a thin layer of 30 mm to 60 mm thick as compared to HMA of the same thickness.
- The use of reduced thickness for RHMA-G overlay is valid; however, not to the extent previously employed by Caltrans.

Simplified Overlay Thickness Design Charts

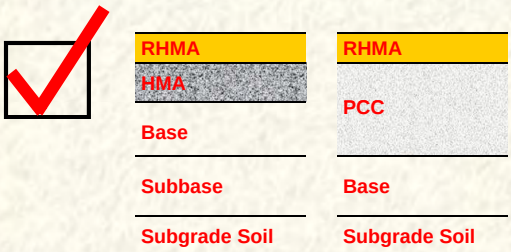


Recommendations – Structural Overlays

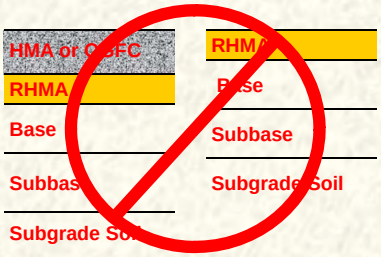
- Calculate GE for HMA using current methodology and determine structural overlay
- Design RHMA-G overlay in a range of 30 to 60 mm to achieve most structural benefit



RHMA Usage in New Pavements



RHMA Usage in New Pavements

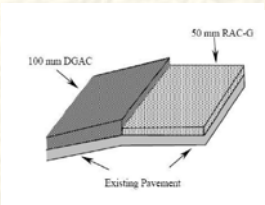


RHMA Usage in New Pavements

Material Type	Max Thickness
RHMA-G	60 mm
RHMA-O	45 mm
RHMA-O on RHMA-G	45 mm on 60 mm

Revised Practice New Pavements

- Place on top of conventional HMA or PCC. Do not place directly over aggregate base (treated or non-treated), subbase, or native soil.



Revised Practice New Pavements

- Place gap-graded RHMA (RHMA-G) no thicker than 60 mm and open-graded RHMA (RHMA-O) no thicker than 45 mm. Up to 45 mm of RHMA-O may be placed on top of 60 mm of RHMA-G.

Revised Practice – New Pavements

- Do not place underneath conventional HMA or open graded friction course (open-graded HMA).
- Do not reduce the overall pavement thickness when RHMA is used. Pavement thicknesses for rehabilitation can be reduced with RHMA for reflective cracking only. Reflective cracking is not an issue for new construction.

Revised Practice Overlays

- Overlay design procedure is now incorporated into new HDM
- Rehabilitation strategies are divided into three categories:
  - Overlay
  - Mill and Overlay
  - Remove and Replace
- Rehabilitation designs are governed by one of the following three criteria:
  - Structural adequacy
  - Reflective cracking
  - Ride quality

Revised Practice Overlays

- Overlay procedures for flexible over existing flexible pavement
  - Structural adequacy
    - Principle of reducing deflection to a tolerable level is still the basis
    - The required overlay thickness is determined by dividing gravel equivalency (GE) by gravel factor (G_f)
  - Reflective cracking (table for equivalencies)
  - Ride quality can be evaluated based on the pavement's smoothness

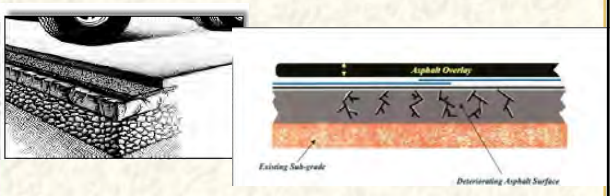
Layer Thickness Equivalencies for Reflective Crack Retardation

HMA	RHMA-G	RHMA-G on SAMI-R
45 mm	30 mm	
60 mm	30 mm	
75 mm	45 mm	
90 mm	45 mm	
105 mm	▪ 45 mm, if CW < 3 mm ▪ 60 mm, if CW ≥ 3 mm, or if underlying material is CTB, LCB, or PCC	▪ N/A for CW < 3 mm ▪ 30 mm, if CW ≥ 3 mm and underlying material is untreated ▪ 45 mm, if CW ≥ 3 mm and underlying material is CTB, LCB, or PCC

Note: CW = Crack Width

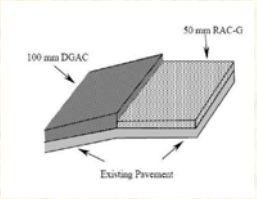
RHMA Project Selection – Overlays

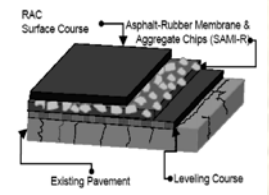
- Overlay projects are the best candidates for the use of RHMA mixes because existing pavement helps satisfy cover requirements



RHMA Project Selection –Overlays

- If existing pavement is structurally sound and surface cracking is the predominant distress, RHMA-G thickness may be reduced up to half of the designed HMA thickness for controlling reflective cracking





RHMA Project Selection
Mill & Overlay with RHMA

- Projects in which a certain amount of the existing HMA surface is to be removed and replaced are valid candidates for RHMA
- Follow the mill and overlay procedure in HDM, check for:
  - Structural adequacy
  - Reflective cracking
  - Ride quality (sufficient)

Cost Analysis Initial Cost

- 2008 unit costs: $96/ton for HMA vs. $115/ton for RHMA.
- Costs for both HMA and RHMA will be higher in 2009.
- In general, initial costs are high; however, reduced layer thickness results in lower costs
- Experienced contractors and engineers help keep cost of RHMA low and quality high

Cost Analysis LCCA

- LCCA – life cycle cost analysis
- Available information indicates that RHMA is (in general) cost-effective in the majority of cases when compared to conventional HMA rehabilitation and maintenance strategies.

Cost Analysis LCCA

- Caltrans has developed a LCCA procedure based on the RealCost Model developed by FHWA
- Caltrans procedure has typical M&R schedule for California
  - By various climate region (e.g., coast, valley, desert, and mountain) and for Districts
  - By surface type (e.g., HMA, RHMA)
  - By M&R design life

Cost Analysis LCCA

- Caltrans procedure also includes overall rehabilitation construction unit cost for various strategies
- The Caltrans LCCA procedure was ready for use by the end of June 2006

Summary of Module 2

- Caltrans Practices
- 2005 Study
- Revised Caltrans Practices
- RHMA Project Selection
- Cost Analysis

Module 3: Construction

Manufacture, Delivery, Placement, and Compaction

Module 3: Outline

- Construction Overview
- Surface Preparation
- Manufacture
- Mix Delivery (Hauling)
- Placement
- Compaction
- Specifications/SSPs

Construction Overview

FOCUS: RHMA surface courses

- RHMA-G, RHMA-O, and RHMA-O-HB
- RHMA placement very similar to typical dense-graded AC overlays, except:
  - Typically requires higher placement and compaction temperatures
  - For RHMA-G, use vibratory mode for breakdown passes and get 95% of required compaction during breakdown
  - Not amenable to handwork
- Good practices are required for RHMA production and construction, as for HMA.

Surface Preparation

GOAL: Provide surface conditions that promote performance of the new RHMA surface.

Same activities as for HMA:

- Address existing distress
  - Seal cracks
  - Remove and replace failed pavement
- Improve smoothness
  - Fill ruts, level, restore or adjust profile
- Assure bond with underlying layers

Surface Leveling

- Techniques
  - Cold milling, cold planing, grinding
  - Leveling course (HMA)
  - Rut filler

Clean and Sweep

- To promote good bonding, mill or grind surface, and remove debris from repaired areas prior to placing overlay
- Wash if necessary
- Make sure surface is dry before overlaying

Apply Tack

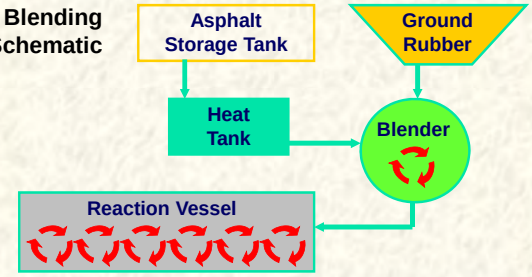
Purpose is to bond pavement layers together. Paving grade asphalt binder preferred for RHMA.

Manufacture

- **Primary difference from normal AC plant operations is on-site manufacture of high viscosity asphalt rubber binder.**

AR Binder Production Process

Blending Schematic



CRM comes in nominal 2,000 lb "Supersacks"

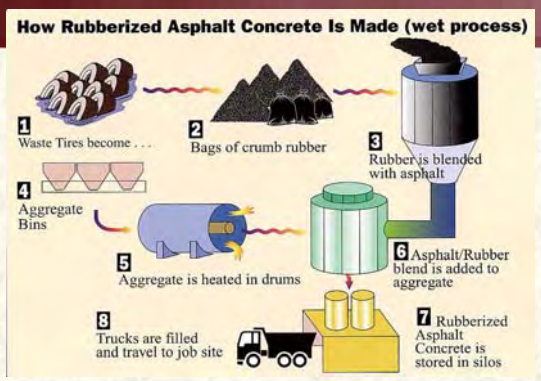
CRM is weighed in hopper

CRM is blended with hot asphalt cement

AR Blending Equipment & Interaction Tank

RHMA Mix Production

- Asphalt rubber binder feed is substituted for normal asphalt cement feed, interlocked and metered into the AC plant
- Little impact on AC plant operations
  - More than one AR binder plant can be used to maintain RHMA production at normal tph rate
  - Primary differences from HMA are in mixing and discharge temperatures
    - Aggregate mixing temperature range 300 - 325°F
    - AR binder added at ≈ 375°F



Mix Delivery (Hauling)

- RHMA mix temperature is critical for placement and compaction
  - Trucks hauling RHMA mixes must be tarped for a long haul
  - Spread temperature 280-325°F per Caltrans
  - Minimum temperature for start of breakdown rolling is 275°F per Caltrans
  - Generous compared to other specifications: Green Book requires higher temperatures

Mix Delivery

As for HMA, to promote quality, smoothness, and uniform compaction, must balance all aspects of:

- Mix production (AC plant)
- Mix delivery (trucking)
- Paving operations (non stop)
- Compaction (keep up with the paver)

Mix Segregation

- Aggregate (particle size) segregation
  - RHMA-G may look segregated due to low fine's content – mix texture may look coarse and somewhat open.
    - Sample, test binder content and gradation to verify
  - Segregation causes non-uniform gradation and compaction, may yield interconnected air voids
  - Sources include mix loading/unloading and paver operation

Mix Segregation

- Techniques to reduce aggregate (particle size) segregation
  - Better mix gradations – not much help for RHMA-G or RHMA-O
  - Improved loading and unloading practices
  - Use material transfer vehicle – not always feasible

Thermal Segregation

- Often accompanies particle size segregation
- Results in non-uniform compaction
- Sources include:
  - Processes that result in uneven cooling (hauling, windrows)
  - Managing paver wings
  - Delays in mix delivery and/or placement

Thermal Segregation

- Techniques to reduce thermal segregation
  - Minimize time between loading and placement
  - Truck insulation and tarping
  - Proper paving procedures
  - Material transfer vehicle

Issues Related to Haul Trucks

- Types and characteristics
  - End dump
  - Belly (bottom) dump – do not use windrows when site temperatures are marginally cold
  - Horizontal discharge (live bottom)
- Insulation – tarps required
- Cleaning (truck bed) – NO SOLVENTS!
  - Soap for surfactant
- Truck maintenance

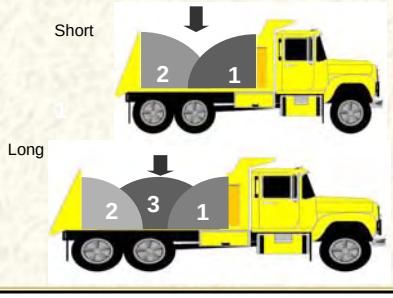
Truck Loading Practices

- Primary goal – Avoid segregation!

- What makes a mix prone to segregation?
  - Range of particle sizes, limited fines

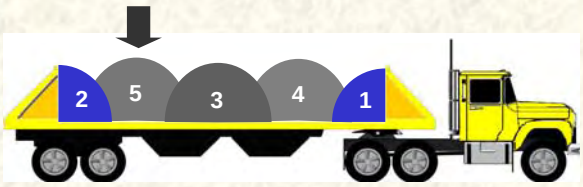
Truck Loading Practices

Preferred practice for end dump trucks:



Truck Loading Practices

Preferred practice for belly dump trucks:



Placement (Laydown)

- Purpose – Place mix smoothly at a uniform specified thickness conforming to plan slopes and grades at temperatures above a specified minimum
- Equipment – same as for HMA
  - Tractor unit (paver)
  - Screed unit
- Paver operation - same as for HMA
- Joints – good practices essential

Paver Operation

Use good practices!

References:

- National Highway Institute (NHI) HMA Construction Course
- HMA Paving Handbook 2000
- Caltrans Construction Manual

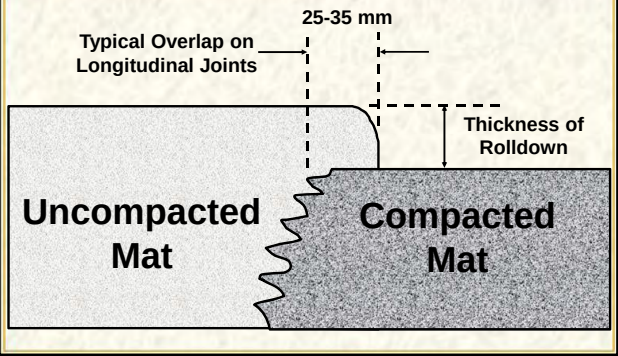
Handwork

- Minimize as much as feasible
- Coarse gradation, stiff binder make handwork difficult
- High temperatures necessary to maintain RHMA workability
- Typically yields coarse, open and rough looking appearance due to limited fines
- Minimize raking and luting
- Do not broadcast excess material

Joints

- Use good practices
- Difficult to feather RHMA mix due to limited fines
- Assume compaction reduces machine placement thickness by ≈ ¼-inch per inch
  - For hand placement, use 3/8-inch per inch difference
- Some raking unavoidable
  - Minimize as possible
  - Rake excess to hot side, not cold side

Joint Overlap



Compaction

Adequate compaction is required to achieve good pavement performance

- Improves resistance to rutting
- Reduces moisture/air penetration and related environmental damage
  - Oxidative aging (embrittlement, raveling)
  - Moisture damage (stripping)
- Improves fatigue resistance
- Reduces low temperature cracking potential
- Improves durability

Compaction

Key factors influencing compaction include:

- Lift thickness
- Air temperature
- Base temperature
- Spread temperature of RHMA mix
- Wind velocity, humidity, & other site factors
- Sunlight or lack thereof
- Mix properties including binder content

Temperature is the key to achieving RHMA compaction!

Compaction Temperature (RHMA)

- When air temperature is ≥55°F,
  - Minimum temperature for starting breakdown rolling is 280°F
  - Breakdown must be completed before mat temperature drops below 260°F
- When air temperature is ≥ 65°,
  - Minimum temperature for starting breakdown rolling is 275°F.
  - Breakdown must be completed before mat temperature drops below 250°F

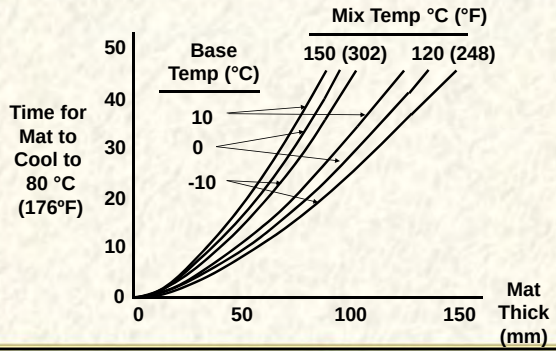
Compaction Temperature

- Specify the same temperatures for RHMA-O and RHMA-O-HB mixes as for RHMA-G
- Working at the minimum temperatures may cause problems with achieving adequate compaction of RHMA-G mixes

Compaction Temperature

- Suggest applying the higher temperature range for open-graded RHMA
  - Based on experience of others, may still be marginally low to provide desired performance
  - Primary problems with low temperature placement of open-graded mixes are raveling and delaminating

Time Available for Compaction



Compaction Requirements

- Caltrans has implemented compaction requirements for RHMA-G mixes
  - Acceptance based on pavement cores
  - Proposed lower limit is 91% of maximum theoretical density (equivalent to maximum 9% in-place air voids)
- No compaction requirements for open-graded RHMA mixes, present or future

Compaction Equipment

- Roller types
  - Static steel wheel rollers
  - Pneumatic-tired rollers – do not use with RHMA
  - Vibratory steel wheel rollers – required for breakdown
- Rolling sequence
  - Breakdown – immediately behind paver in vibratory mode
  - Intermediate
  - Finish

Compaction Equipment

Roller Pattern

- Selection of compaction equipment
- Width of paving
- Width of roller(s) – for RHMA need enough breakdown rollers to cover placement width
- Number of passes needed
- Nuclear gauges for relative density
- Cores for correlation of gauges with in-place density, i.e. air voids content

Specifications/SSPs

- Specifications for RHMA-G, RHMA-O, and RHMA-O-HB can be found in Section 39 of Caltrans standard specifications.
- Follow requirements in project special provisions to assure use of appropriate version

Summary of Module 3

- Construction Overview
- Surface Preparation
- Manufacture
- Mix Delivery (Hauling)
- Placement
- Compaction
- Specifications/SSPs

Module 4: Inspection Guide

Hot Mix Asphalt Plant Operations

Plant operations during RHMA mix production are essentially the same as for standard HMA production. CT 109 requirements apply.

<u>Differences</u>

- Production and monitoring of the asphalt rubber binder for wet process mixes.
- Plant mixing temperatures of 300-325°F may be slightly higher than usual.

AR Binder Production

<u>Required Documentation</u>

- AR Binder Design Profile, including
  - Component identification and proportions
  - CRM gradations
  - AR test results showing compliance with specifications
- Certificates of Compliance for components
  - Asphalt Cement
  - Asphalt Modifier (Extender Oil)
  - Scrap Tire CRM
  - High Natural CRM

Asphalt Rubber Blend Design Example Design Profile

	Minutes of Reaction					Spec. Limits @ 45 minutes (Caltrans 12/2005)
TEST	45	90	240	360	1,440	
Viscosity, cP Haake@ 190°C	2400	2800	2800	2800	2100	1500 - 4000
Resilience@ 25°C (% Rebound) (ASTM D 5329)	27	--	33	--	23	18 Minimum
R & B Softening Pt., °C (ASTM D36)	59.0	59.5	59.5	60.0	58.5	52 – 74 (125-165°F)
Cone Pen @ 25°C (ASTM D217)	39	--	46	--	50	25 – 70

AR Binder Production

Inspection items

- Batch sheets or production logs for AR binder that show the amounts (typically by mass) of the components used. Check proportions of:
  - Asphalt Cement
  - Extender oil
  - Scrap tire CRM
  - High natural CRM

AR Binder Production

The AR binder production logs or viscosity testing logs should indicate when the CRM was added.

Before adding AR binder to the aggregate:

- Verify minimum AR interaction time of 45 minutes has elapsed
- Verify AR binder viscosity meets or exceeds the minimum 1500 cPs requirement at 375°F
- Continue to monitor viscosity hourly during RHMA mix production

AR Binder Production

- As long as interaction time and viscosity meet or exceed minimum requirements, the AR binder may be added to the aggregate, even if viscosity differs from values shown in the design profile.

- The design profile serves as a guide, not as a specification. If viscosity during production differs from design profile by 400 cPs or more for corresponding interaction interval, obtain a binder sample for compliance testing.

RHMA Mix Production

<u>Required Documentation</u>

- RHMA Mix Design including:
  - Individual and combined aggregate gradations
  - Results of individual and combined aggregate quality tests
  - Aggregate source(s) and blend proportions
  - Theoretical maximum specific gravity/density
  - Design AR binder content
  - Design air voids content
  - Design Voids in Mineral Aggregates (VMA)
  - Hveem Stability

RHMA Mix Production

- Verify AC plant complies with CT 109 requirements
- Check aggregate bins
- Sample aggregate cold feed or hot bins as appropriate and verify gradation. Test Sand Equivalent as required
- Verify RHMA mixing and discharge temperatures

RHMA Mix Production

- Visually inspect the RHMA mix in the haul truck before it leaves the plant
- Sample and test RHMA mix according to the project special provisions.
- Tests include gradation, AR binder content, maximum theoretical specific gravity, lab-compacted air voids, and Hveem stability
- Verify that haul trucks are tarped.

RHMA Mix Production

- Maintain inspector's log of pertinent information, including but not limited to:
  - List of samples obtained
  - Plant test results (aggregates and mix)
  - Quantities of AR binder and RHMA mix
  - Binder production temperatures and viscosity measurements, etc.
  - Other required information

Inspection at Paving Site

Before Overlay Placement:

- Verify surface preparation is complete
  - Cracks treated or sealed?
  - Damaged areas repaired?
  - Milling properly completed (if applicable)?
  - Surface clean and swept?
  - Tack coat properly applied?
- Verify ambient and pavement temperatures are at least 55°F and rising

Inspection at Paving Site

- Equipment
  - Verify that paver and rollers meet size requirements, are in good working condition, and qualified operators are on-site
  - Verify sufficient steel-wheeled rollers are available for breakdown and intermediate compaction.
  - Breakdown rollers must have vibratory capability
- Delivery method: Do not use windrows if ambient temperature is marginally cold.

Inspection at Paving Site

Caltrans requirements for RHMA-G, ambient temperature between 55 and 65°F:

- RHMA-G spread temperature 290-325°F
- Minimum temperature for breakdown rolling is 280°F
- Vibratory mode is required for RHMA-G breakdown
- Complete breakdown before RHMA mat temperature drops below 260°F

Inspection at Paving Site

- Less stringent for ambient temperature ≥ 65°F
- Other jurisdictions recommend minimum 290°F for breakdown rolling or completion thereof
- Compaction requirements have been implemented for RHMA-G mixes, with acceptance based on cores

Inspection at Paving Site

Caltrans placement temperature requirements for RHMA-O and RHMA-O-HB ambient temperature between 55 and 65°F are the same as for RHMA-G.

Other jurisdictions do not recommend placing RHMA-O at temperatures <65°F.

For open-graded RHMA mixes, use static mode for breakdown compaction. Do not use vibratory mode.

Percent compaction is not a requirement for open-graded mixes.

Inspection at Paving Site

During RHMA placement:

- Collect load tickets and track tonnage placed
- Measure placement thickness and calculate yield
- Observe coordination between RHMA delivery and placement – record if trucks or paver are waiting
- Note any rejected loads of RHMA
- Observe delivery operations - are good practices being used?

Inspection at Paving Site

- Record if windrows are used.
- Monitor RHMA temperatures at spread and during breakdown and intermediate compaction.
- Observe paver operations – note discrepancies from good practice that might impact quality of joints or ride (smoothness).
- Joints at proper locations?
- Observe raking, luting, handwork. Broadcasting of excess mix or over-raking will damage the appearance of the finished pavement.

Inspection at Paving Site

- Observe compaction operations – note discrepancies from good practice that might impact in-place density
  - Breakdown roller(s) following immediately behind paver?
  - Breakdown roller(s) using vibratory mode?
  - Sufficient breakdown rollers operating to keep up with paver?
  - Intermediate static roller(s) keeping up?
  - Finish rollers effective?

Inspection at Paving Site

Rules of Thumb for RHMA-G compaction:

- Need to get 95% of minimum required density with breakdown coverage to achieve adequate compaction.
- Mix temperature is critical for adequate compaction of RHMA-G materials

After Paving

- Check the appearance of the finished surface for roller marks, scuffs, gouges, or other irregularities
- Check smoothness as required in project special provisions

- Visually evaluate quality of paving joints and identify any areas that may need to be sealed.
- Identify core locations for compaction acceptance

Troubleshooting

- If any type of RHMA mix problem is suspected, obtain samples immediately and test for compliance with project special provisions.
- Log full description of problem and related activities and report to the RE.

Troubleshooting

Possible Problems to Watch For:

- Segregation: Particle size segregation may be difficult to identify in coarse graded RHMA-G mixtures. May appear segregated even if not, due to small percentage of fines included.
  - When in doubt, sample
  - ID and record affected truckloads and corresponding placement areas
- Size segregation is often accompanied by temperature segregation

Troubleshooting

- Temperature segregation may be identified using a heat gun or infrared camera
  - To measure actual mix temperature without surface effects, use a 6-inch long thermometer
- Indicate hot and cold spots in the mix that can cause differences in compaction
  - Can see areas in haul trucks and pavers where mix is not circulating and has cooled
  - Shows when material from paver wings is dumped into the hopper and where it comes out behind the screed

Troubleshooting

- Smoke
  - Blue smoke means that the mix is too hot and plant operating temperature needs to be adjusted
  - White smoke is steam - too much moisture in the mix. May make mix tender and interfere with compaction. Aggregate needs to be dried longer before mixing with the AR binder.

Troubleshooting

- Stiff appearance: Too cool or possibly somewhat low AR binder content. Check temperature and get a mix sample for further testing if needed.
- Dull, flat appearance: Low AR binder content and/or excessive fines. Localized areas may indicate insufficient mixing or segregation. Get sample and test for gradation and AR binder content.

Troubleshooting

- Slumped and shiny appearance typically indicates high AR binder content.
  - RHMA-O and especially RHMA-O-HB may look this way and still meet specifications
  - Old descriptive term is "wormy" – mix seems to almost crawl while watched
  - Some complying RHMA-G mixes may also be wormy
  - Visually check for binder drain down in the haul truck bed, sample and test for AR binder content and gradation

Summary of Module 4

- Monitor AR binder production and viscosity results
- Sample AR binder and individual component materials for verification and acceptance
- Observe RHMA temperature and compaction operations
- Compaction acceptance can be based on core samples

Questions ?

The Beginning

Keeping roads good with asphalt paving materials

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"Today decides tomorrow!!!

TDA in Foundation Engineering

Foundation Engineering
CSU, Chico

Prepared for the CIWMB

Introduction

- Background
- Civil Engineering Applications
- Full Scale Test of TDA as Retaining Wall Backfill
- Case Study
- Conclusion

Basic Information

- Each year, the U.S. generated approximately 300 million scrap tires
- Historically, these scrap tires took up space in landfills or provided breeding grounds for mosquitoes and rodents when stockpiled or illegally dumped
- Fortunately, markets now exist for 82% of these scrap tires-up from about 17% in 1990
- These markets-both recycling and beneficial use-continue to grow
- The remaining scrap tires, however, are still stockpiled or landfilled

Whole Tires and Cut, Stamped, and Punched Products

- Scrap tires may be recycled by:
  - Cutting, punching, or stamping them into various rubber products after removal of the steel bead
- Recycled products include:
  - Floor mats, belts, gaskets, shoe soles, dock bumpers, seals, muffler hangers, shims, and washers
- Whole tires may be recycled or reused as:
  - Highway crash barriers, for boat bumpers at marine docks, and for a variety of agricultural purposes

Scrap Tire Markets

- The 3 largest scrap tire markets are:
  - Tire derived fuel
  - Civil engineering applications
  - Ground rubber applications/ rubberized asphalt concrete
- Both recycling and beneficial use of scrap tires has expanded greatly in the last decade through increased emphasis by state, local and Federal governments, industry, and other associations
- Unfortunately, even with all of the reuse and recycling efforts underway, not all scrap tires can be used beneficially

Tire Derived Fuel

- Tires can be used as fuel either in shredded form - known as tire derived fuel (TDF) - or whole, depending on the type of combustion device
- Scrap tires are typically used as a supplement to traditional fuels such as coal or wood
- In 2003, 130 million scrap tires were used as fuel (about 45% of all generated) - up from 25.9 million (10.7% of all generated) in 1991
- There are several advantages to using tires as fuel:
  - Tires produce the same amount of energy as oil and 25% more energy than coal
  - The ash residues from TDF may contain a lower heavy metals content than some coals
  - Results in lower NOx emissions when compared to many U.S. coals, particularly the high-sulfur coals

Civil Engineering Applications

- The civil engineering market encompasses a wide range of uses for scrap tires
- In almost all applications, scrap tire material replaces some other material currently used in construction such as lightweight fill materials, like expanded shale or polystyrene insulation blocks, drainage aggregate, or even soil fill
- A considerable amount of tire shreds for civil engineering applications come from stockpile abatement projects
- Tires that are reclaimed from stockpiles are usually dirtier than other sources of scrap tires and are typically rough shredded
- Rough tire shreds can be used as embankment fill and in landfill projects

Tire Derived Aggregate (TDA)

Definition:

Pieces of processed tires that have a consistent shape and are generally between 1 and 12 inches in size

Civil Engineering Applications

- Civil engineering applications include:
  - Subgrade Fill and Embankments
  - Backfill for Retaining Walls and Bridge Abutments
  - Subgrade Insulation and Lateral Edge Drains for Roads
  - Vibration Damping Layer Beneath Rail Lines
  - Landfill Applications
  - Septic System Drain Fields

Subgrade Fill and Embankments

- Tire shreds can be used to construct embankments on weak, compressible foundation soils
- Tire shreds are viable in this application due to their light weight
- For most projects, using tire shreds as a lightweight fill material is significantly cheaper than other alternatives
- Subgrade fill and embankment applications include: protecting roads from erosion, enhancing the stability of steep slopes along highways, and reinforcing shoulder areas

Backfill for Retaining Walls and Bridge Abutments

- The lower weight of the tire shreds reduces lateral earth pressures and allows for construction of thinner, less expensive walls
- Tire shreds can also reduce problems with water and frost build up behind walls because tire shreds are free draining and provide good thermal insulation

Subgrade Insulation for Roads

- In cold climates, excess water is released when subgrade soils thaw in the spring
- Placing a 6 to 12-inch thick tire shred layer under the road can prevent the subgrade soils from freezing
- In addition, the high permeability of tire shreds allows water to drain from beneath the roads, preventing damage to road surfaces

Landfills

- Landfill construction and operation is a growing market application for tire shreds
- Scrap tire shreds can replace other construction materials that would have to be purchased
- For Instance, scrap tires may be used as a lightweight backfill in gas venting/collection systems, in leachate collection systems, and in operational liners
- They may also be used in landfill capping and closures, and as a material for daily cover

Septic System Drain Fields

- Some states—Alabama, Florida, Georgia, South Carolina, and Virginia—allow tire shreds to be used in construction of drain fields for septic systems
- Tire-derived material replaces traditional stone backfill material, but reduces the expense and labor to build the drain fields
- Tire chips can also hold more water than stone and can be transported more easily due to their light weight

Other Civil Engineering Applications

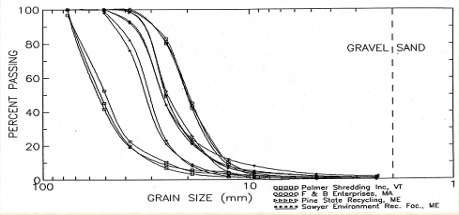
- Playground surface material
- Gravel substitute
- Drainage around building foundations and building foundation insulation
- Erosion control/rainwater runoff barriers (whole tires)
- Wetlands/marsh establishment (whole tires)
- Crash barriers around race tracks (whole tires)

Engineering Properties of TDA (After Humphrey, 2003)

1. Gradation
2. Specific Gravity and Absorption capacity
3. Compressibility
4. Resilient Modulus
5. Time Dependent Settlement of TDA Fills
6. Lateral Earth Pressure
7. Shear Strength
8. Hydraulic Conductivity (Permeability)
9. Thermal Conductivity

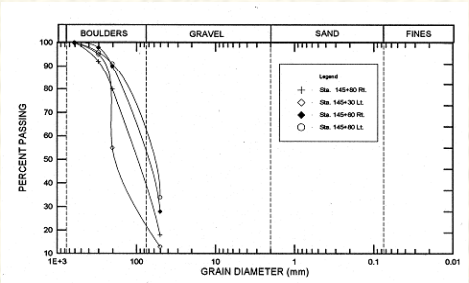
Gradation

- Generally uniformly graded (same size)
- Max size varies according to manufacturing
- Test according to ASTM D 422



Gradation

- 12" Maximum Size:



Specific Gravity and Absorption Capacity

Tire shred type	Specific gravity			Water Absorption capacity (%)	Reference
	Bulk	Sat. surf. dry	Apparent		
Glass belted	----	----	1.14	3.8	(1)
Glass belted	0.98	1.02	1.02	4	(2)
Steel belted	1.06	1.01	1.10	4	(2)
Mixture	1.06	1.16	1.18	9.5	(3)
Mixture (Pine State)	----	----	1.24	2	(1)
Mixture (Palmer)	----	----	1.27	2	(1)
Mixture (Sawyer)	----	----	1.23	4.3	(1)
Mixture	1.01	1.05	1.05	4	(2)
Mixture	----	0.88 to 1.13	----	----	(4)

Compacted Unit Weight

- Loose 21.3 to 30.9 pcf (no compaction)
- 50 to 60% of Standard 38.3 to 40.1 pcf
- Standard 39.5 to 40.7 pcf
- Modified 41.2 to 42.7 pcf
- Range of dry compacted = 38 to 43 pcf
- Soil typically 125 pcf
- Data also available for TDA/Soil mixtures

Compressibility (3 Reasons)

1. Settlement that will occur during and in the first month or two after placement of fill
2. In-place unit weight of fill varies with compaction effort
3. Deflections caused by temporary loading (e.g. wheel loads) may need to be considered

Compressibility

Definition: The susceptibility of a material to volume change due to changes in stress

Due to its porosity and high rubber content, TDA is highly compressible under loaded conditions.

TDA can compress by as much as 50% under high normal loads.

Lateral Earth Pressure

- Lateral earth pressure is the pressure exerted by a fill material on the wall of a structure like a retaining wall
- It can be determined by coefficients of lateral earth pressure, which are calculated by dividing horizontal stress by vertical stress
- Poisson's ratio, μ, relates horizontal deformation to vertical deformation
- The following table lists values for the coefficient of lateral earth pressure and Poisson's ratio:

Lateral Earth Pressure

Particle size range (in.)	Tire shred type	Source of tire shreds	K_o	μ	Reference
2	Mixed	Sawyer Environmental	0.44	0.30	(1)
3	Mixed	Palmer Shredding	0.26	0.20	(2)
2	Mixed	Pine State Recycling	0.41	0.28	(2)
1	Glass	F & B Enterprises	0.47	0.32	(2)
----	----	----	----	0.3 to 0.17	(3)
2	Mixed	Maust Tire Recycles	0.4[a]	0.3	(4)

Notes: a. For vertical stress less than 25 psi.

References:
(1) Manion and Humphrey (1992); Humphrey and Manion (1992)
(2) Humphrey, et al. (1992, 1993); Humphrey and Sandford (1993)
(3) Edil and Bosscher (1992, 1994)
(4) Drescher and Newcomb (1994)

Shear Strength

- A direct shear apparatus and ASTM D 3080 or a triaxial shear apparatus can be used to measure the shear strength of tire shreds
- When testing tire shreds, larger sample sizes have to be used than are necessary for other soils. This is due to the larger particle size of tire shreds
- Large triaxial shear apparatuses only have limited availability, so tests are generally completed on 1-in or smaller tire shreds
- The triaxial shear apparatus also shouldn't be used for tire shreds with protruding steel belts

Permeability

The permeability of tire shreds is much greater than most granular soils, with experimental values ranging from 0.58 cm/s to 23.5 cm/s. Often times the permeability of TDA exceeds the flow capacity of the test equipment!

The table in the next slide lists hydraulic conductivity (permeability) values for tire shreds:

Summary of reported hydraulic conductivities of TDA

Particle size (in.)	Void ratio	Dry density (pcf)	Hydraulic conductivity (cm/sec)	Reference
2.5		29.0	5.3 to 23.5	Bressette (1984)
2.5		37.9	2.9 to 10.9	
2		29.3	4.9 to 59.3	
2		38.1	3.8 to 22.0	
1.5	----	----	1.4 to 2.6	Hall (1990)
0.75	----	----	0.8 to 2.6	
2	0.925	40.2	7.7	Humphrey, et al.
2	0.488	52.0	2.1	(1992, 1993)
3	1.114	37.5	15.4	
3	0.583	50.1	4.8	
1.5	0.833	38.8	6.9	
1.5	0.414	50.4	1.5	
1.5		0.653	0.58	Ahmed (1993)
1.5	0.693	42.0	7.6	Lawrence, et al.
1.5	0.328	53.6	1.5	(1998)
3	0.857	41.7	16.3	
3	0.546	50.1	5.6	

Thermal Conductivity

- The thermal conductivity of tire shreds is lower than typical soils and varies depending on the size of the tire shreds
- As particle size increases, and more air can circulate in the voids, thermal conductivity increases, and the tire shreds become less effective as insulators
- For insulation projects, tire shreds with a maximum size of 3 inches should be used
- The following slide gives thermal conductivity as a function of density and void ratio:

Apparent thermal conductivities of air dried tire shreds

Sample	Density (pcf)	Density (Mg / m³)	Void Ratio	Apparent thermal conductivity (Btu / hr-ft-°F)	Apparent thermal conductivity (W / m-°C)	Surcharge
gravel	117.6	1.88	0.41	0.295	0.510	none
	121.6	1.95	0.36	0.326	0.563	half
	123.0	1.97	0.34	0.345	0.596	full
F&B-g	38.5	0.62	0.85	0.120	0.207	none
	43.3	0.69	0.64	0.113	0.195	half
	45.4	0.73	0.56	0.114	0.197	full
F&B-s	39.1	0.63	0.85	0.145	0.251	none
	42.8	0.69	0.69	0.130	0.225	half
	45.3	0.73	0.60	0.134	0.232	full
Palmer	39.7	0.64	0.998	0.159	0.275	none
	45.1	0.72	0.76	0.119	0.206	half
	48.5	0.78	0.63	0.125	0.216	full
Pine State	39.2	0.63	0.97	0.158	0.273	none
	45.4	0.73	0.7	0.139	0.240	half
	49.6	0.79	0.56	0.114	0.197	full
Sawyer	36.0	0.58	1.13	0.184	0.318	none
	41.0	0.66	0.87	0.148	0.256	half
	43.7	0.70	0.76	0.156	0.270	full

Why Use TDA

- Tire Derived Aggregate (TDA) has properties that civil engineers, public works directors & contractors need
  - ✓Light weight
  - ✓High permeability
  - ✓Low earth pressure
  - ✓Good thermal insulation
  - ✓Durable
  - ✓Compressible
  - ✓May be cost effective
- Help solve significant environmental problem
- Conserve natural aggregate resources

What is Type A TDA?

Type A TDA - Typical, Three inch minus,
1 Ton = 1.4 cubic yards
1 Ton = 100 tires (PTE)
In Place Density = 45-58 lb/ft³
Permeability › 1 cm/sec

Uses - Drainage material, septic leach fields, vibrations dampening layers under light rail tracks, gas collection media, leachate collection material

What is Type B TDA?

Type B TDA - Typical, 12 inch minus,

- 1 Ton = 1.5 cubic yards
- 1 Ton = 100 tires (PTE)
- In Place Density = 45-50 lb/ft³
- Permeability › 1 cm/sec for many applications

Uses - Lightweight fill for embankments, lightweight fill behind retaining walls

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ASTM D 6270 Fill Types

Class I Fills:

-TDA placed in layers less than 1m (~3') thick.

Have a maximum of 50% (by weight) passing the 38 mm (~1.5") sieve.

Have a maximum of 5% (by weight) passing the 4.75 mm (~.19") sieve.

Sample Applications of Class I Fills are typically utilized in landfill leachate and gas control applications.

ASTM D 6270-98 Fill Types

Class II Fills:

-TDA placed in layers ranging from 1m (~3') to 3m (~10') thick.

Have a maximum of 25% (by weight) passing the 38 mm (1.5") sieve.

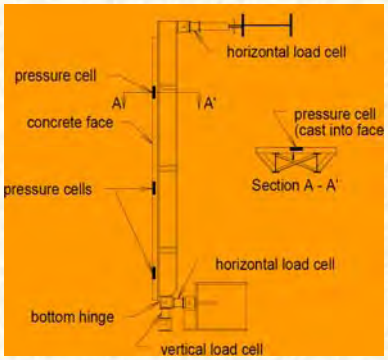
Have a maximum of 1% (by weight) passing the 4.75 mm (~.19") sieve.

Sample applications of Class II Fills are retaining wall back fills, embankment fills, and slope repairs.

UMaine Test Wall- Introduction

- **World's 2nd largest retaining wall test facility (16 ft high, 15 by 15 ft plan area, surcharge of 750 psf)**
- **Used tire shreds that were 3-in. max and had no removal of steel belts and 1.5-in. max and had most of the steel belts removed**
- **Tire shreds placed in 8-in. lifts and compacted with 2300-lb roller**

Full Scale Testing – UMain Test Wall



Construction of UMain Test Wall

Interior of UMaine Test Wall

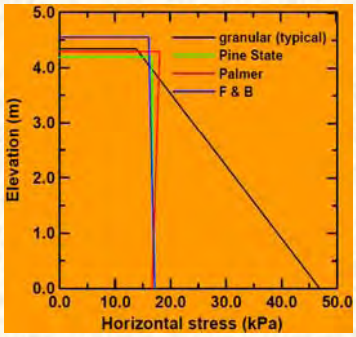
Loading TDA Fill

Compacting TDA

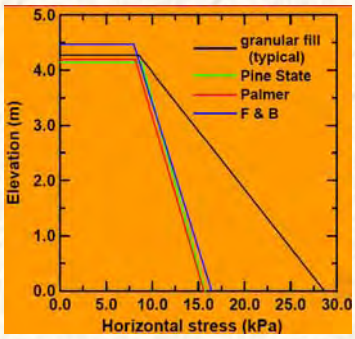
Surcharge Blocks

Fully Loaded Facility

At-rest stress distribution at 35.9 KPa surcharge



Stress at 35.9 KPa surcharge and 0.01H rotation



After removed backwall

Close-up of TDA

Removing TDA after Test

Benefits of TDA as Backfill

- Lower pressure on wall
- Lateral earth pressure coefficient is not constant, but varies with depth
- Results in nearly constant at rest lateral earth pressure as seen in previous slide
- Less rebar and/or thinner retaining wall
- Get rid of waste tires

TDA Applications

Lightweight Backfill Behind Retaining Walls, Riverside, CA

Case Study for Retaining Wall Backfill

Wall 119, Riverside, CA

- **PROBLEM: Widening the westbound side of Route 91 using TDA, is it as effective as typical backfill soil?**

Case History Route 91 Retaining Wall

- **Retaining Wall 12' tall, with 9.8' of TDA enclosed in a geotextile membrane to prevent soil intrusion**

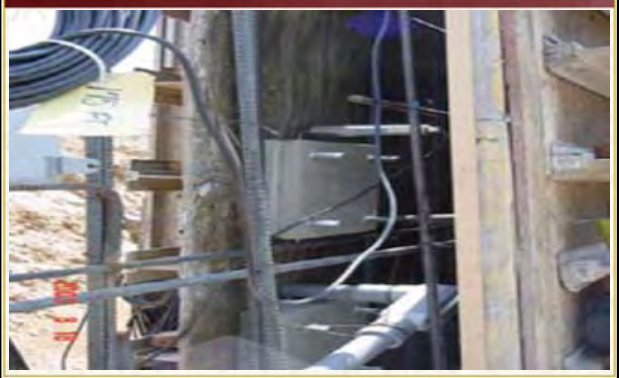
Testing

Measurement: Installation of four types of gauges, strain gauges, pressure cells, temperature sensor, and a tilt meter

Wall 119, Retaining Wall Construction

Wall 119, Strain Gauge Installation

Wall 119, Pressure Cell Installation



Wall 119, Temperature Sensor Installation

Wall 119, Tilt Meter Installation

Wall 119, TDA Placement

Wall 119, TDA Compaction

Wall 119, Completed

Project Summary

- Used 1130 cubic yards of type B tire shreds for 262 foot long fill.
- This equates to 76,500 PTE (passenger tire equivalents)
- Find more data at www.usetda.com

Summary

- Background
- TDA has properties that engineers need
- Full scale testing wall with TDA as backfill material
- Case studies
- Can use a lot of waste tires

THANK YOU

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Today decides tomorrow!!!

Teaching Modules

- Part One: Applications of Tire Derived Aggregates in Landfills
- Part Two: Environmental Engineering Considerations in the Use of TDA in Sanitary Landfills

Background

- In California, nearly 40.2 million waste tires are generated each year
- The California EPA estimates that 1.5 million of these tires are illegally dumped or stockpiled
- It is necessary to find applications for these tires in order avoid the potential dangers they pose to human health as well as the environment

Tire Derived Aggregates

Tire Derived Aggregates (TDA) are derived from rubber tires that have been processed into a consistent size and shape, generally between 1" and 12" in size.

Benefits of using TDA in Engineering Applications

- Tire Derived Aggregate (TDA) has properties that civil engineers, public works directors & contractors need
  - Lightweight
  - Free Draining/High Permeability
  - Low earth pressure
  - Good thermal insulation
  - Durable
  - Compressible
  - Maybe cheapest solution
- Help solve a significant environmental problem
- Conserve natural aggregate resources

TDA Type A Properties

- Typical Size – One to three inches
- Unit Weight – 1 ton = 1.4 cubic yards
- 1 ton of type A = 100 passenger car tires
- High Permeability, 1 cm/sec
- Uses - Drainage material, septic leach fields, Vibrations dampening layers under light rail tracks. Gas collection media, Leachate collection material.

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TDA Type B Properties

- Typical Size – Twelve inches or less
- Unit Weight – 1 ton = 1.5 cubic yards
- 1 ton of type B = 100 passenger car tires
- High Permeability, 1 cm/sec

- Uses - Lightweight fill for embankments, Lightweight fill behind retaining walls, Gas collection media, Leachate collection material

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ASTM D 6270 TDA Specifications

Class I tire shreds shall have a maximum of 50 percent (by weight) passing the 1-1/2 inch (38 mm) square mesh sieve, and a maximum of 5 percent passing the No. 4 (4.75mm) sieve

- Class I Fills are typically utilized in landfill leachate and gas control

Class II tire shreds shall have a maximum of 25 percent (by weight) passing the 1-1/2 inch (38 mm) square mesh sieve and a maximum of 1 percent passing the No. 4 (4.75 mm) sieve

- Class II fills are used when TDA is placed in layers ranging from 1m (~3') to 3m (~10') thick.)

ASTM Standards

ASTM 6270 as a basic guidelines

- A report by GeoSyntec Consultants, Inc. for the California Integrated Waste Management Board suggests that TDA used for gas collection should have a maximum dimension, measured in any direction, of 12-in. and conform to the this schedule:

SIEVE SIZE' IN. (MM)	MINIMUM PASSING (% BY WEIGHT)
12 (300)	100
6 (150)	95
3 (75)	50
#4 (4.75)	5

ASTM Recommendations

- "It is the responsibility of the design engineer to determine the appropriateness of using scrap tires in any particular application and to select applicable tests and specifications to facilitate construction and environmental protection."
- ASTM D6270 advises that tire derived aggregate projects not be greater than 3m (10') in thickness
- At this time, ASTM does not recommend the use of tire derived aggregates below the water table

TDA in Landfill Applications

- Landfill Operations/Drainage Layers
- Leachate Collection and Removal System
- Leachate Recirculation Trenches
- Landfill Gas Extraction Systems
- Landfill Gas Pipe Protection

Operations/Drainage Layer

- In landfills, the geomembrane, or impermeable layer, prevent water which has drained through the landfill, or leachate, from passing into the soil and groundwater
- The Operations Layer separates waste and provides protection to the underlying landfill containment system as well as allowing leachate to drain into a removal system
- TDA is an ideal candidate for use in an operation layer

Operations/Drainage Layer

- **The Code of Federal Requirements (Title 40, Part 258) requires MSW landfills to install a leachate drainage layer:**
  - ***"New MSWLF units and lateral expansions shall be constructed"…. With a composite liner… and a leachate collection system that is designed and constructed to maintain less than a 30-cm depth of leachate over the liner."***

TDA as an Operations/Drainage layer

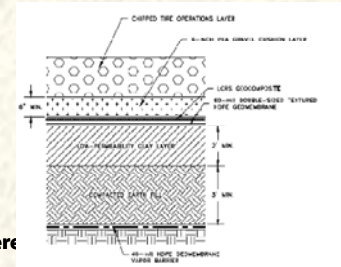
- **A full scale bioreactor landfill was constructed in Yolo county. The objective of the project was to manage municipal solid waste for a rapid decomposition of organic waste, maximum landfill gas generation and capture, and minimum long-term environmental consequences**

TDA as an Operations/Drainage layer

- **Three of the bioreactor cells constructed at Yolo county landfill had a baseliner design which utilized TDA**

- **This composite liner system was constructed in 1999 and was designed to exceed the Code of Federal Requirements (Title 40, Part 258) and Title 27 of the CCR, which require MSW landfills to install a leachate drainage layer. and Title 27 of the CCR.**

- **1.5 million waste tires were used in this project**



TDA as an Operations/Drainage layer

- **The TDA was placed in a 2 foot layer above 6 inches of pea gravel at the Yolo County landfill**
- **The TDA proved to be a cheap alternative to aggregates, while effectively utilizing a waste product with beneficial physical properties in landfill applications**

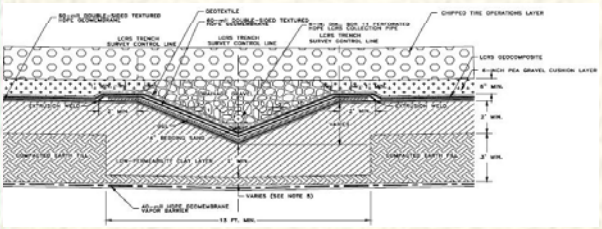
TDA as a Leachate collection media

- **Due to TDA's high permeability, it makes an excellent medium for the collection of leachate**

- **TDA has been used as a sump fill material where leachate drains to a low point filled with TDA. The high voids in the TDA allows large quantities of leachate to drain and collect for removal**

Leachate Collection System

- **The Yolo County bio reactor utilizes TDA in a leachate collection sump**
- **The voids in the TDA allows the leachate to flow into the depression for collection and removal**



Utilizing TDA in a Leachate Recirculation System

- In 2002, the Audubon County Sanitary Landfill, in Audubon, IA, constructed a leachate recirculation trench
- The system is used as an as-needed recirculation of leachate back into the landfill's fill area through the recirculation trench, when the head levels of the leachate storage lagoon are elevated to critical levels during the wet months
- TDA was utilized to backfill and insulate a perforated pipe located inside an excavated trench. The trench was excavated within the waste boundaries of the facility

Utilizing TDA in a Leachate Recirculation System

- The trench was excavated in the existing waste to allow the overflow leachate to drain back into the landfill
- TDA with a nominal size of 3 to 4 inches was backfilled in 3 to 5 foot layers
- The TDA insulated the pipe from damage as well as insuring the leachate drained freely through the pipe

Utilizing TDA in a Leachate Recirculation System

- The Metro Park East Landfill in Mitchellville, IA constructed a leachate recirculation trench system in 2003
- The system is an as-needed recirculation of leachate back into the landfill's waste fill area when the head levels of the leachate storage lagoon are elevated to peak levels during the wet months
- A 4 inch diameter perforated pipe was insulated with 2 feet of 3 to 4 inch nominal size TDA and backfilled with uncompacted clay

Leachate Recirculation System

- As needed, leachate is pumped from the holding lagoon and injected into the existing waste through the leachate recirculation trench

- Picture: Leachate Storage Lagoon

Utilizing TDA in a Leachate Toe Drain

- In 2002, the Des Moines County Regional Sanitary Landfill, in Burlington IA, constructed a leachate toe drain
- This structure utilized TDA as drainage media to collect leachate from the toe of the landfill
- A collection trench was excavated at the bottom of the landfill lift and a 4" HDPE perforated pipe was placed in the base of the trench
- The trench was backfilled with 1,004 tons of 4" to 6" nominal sized TDA
- 24" of uncompacted soil was placed above the TDA for vegetative growth to control erosion

Utilizing TDA in a Leachate Toe Drain

- Excavated trench at base of lift awaiting placement of perforated 4 inch pipe and TDA fill

Utilizing TDA in a Leachate Toe Drain

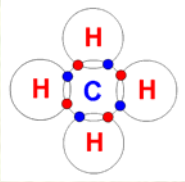
- A geotextile was placed on top of the TDA to serve as a filter. Two feet of uncompacted soil will be placed on top of the liner to allow vegetative growth

Landfill Gas

- A product of the decomposition of organic material in an anaerobic condition is methane gas
- Methane, as a green house gas, is 21 more times potent than carbon dioxide
- If allowed to collect in concentrations greater than 5%, methane gas has the potential to spontaneously combust
- It is necessary to vent and collect the methane gas

Federal Landfill Gas Guidelines

- The Code of Federal Requirements (Title 40, Part 258.23) requires MSW landfills to ensure that the concentration of methane gas does not exceed the lower explosive limit for methane at the facility property boundary.



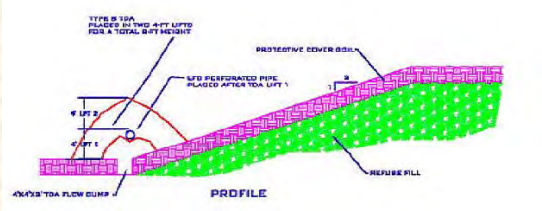
Landfill Gas Collection Systems

- TDA's properties make it an excellent candidate for the use in gas collection applications
- TDA has a high permeability, due to the voids in the material, creating an ideal medium in which methane can easily pass through
- 1.5 cubic yards of TDA utilizes 100 waste tires

Landfill Gas Collection Trenches

- The high permeability of the TDA makes it an ideal material for the insulation of the gas collection pipes
- Vertical trenches passing through the impermeable landfill cap allows methane gas to vent out of the landfill into a collection system

Gas Collection System, Trench-less

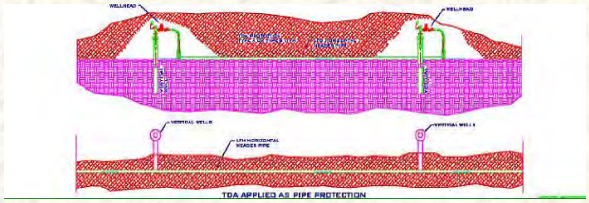


- Methane is allowed to vent through the non permeable cap at the toe, located at the bottom of the lift. TDA is placed atop the toe to allow the methane to enter a perforated collection pipe
- TDA type B is recommended

Landfill Gas Collection system Protection

- Landfill gas can be collected in horizontal collection pipes. These pipes are perforated to allow the gas to pass through. TDA is placed on op of the pipes to allow gas to pass through while preventing solid waste from clogging and damaging the pipe

Landfill Gas Pipe Protection



- Gas collection wellheads protected by TDA type B

Gas Collection System Protection

- Gas collection system protected by TDA type B

TDA as an Alternative Daily Cover

- After every day of operation, it is necessary that landfills apply a cover material to contain the waste
- This is necessary to:
  - Improve the access to the landfill
  - Reduce the amount of trash that can blow away
  - Reduce the risk of disease (birds, animals and insects feeding on waste)
  - Reduce odors
  - Reduce the chances of fire

Questions ?

Environmental Engineering Considerations in the Use of TDA in Sanitary Landfills

Overview

Use of TDA in lieu of sand or gravel aggregate
- Life cycle assessment of GHG emissions
- Engineering aspects of TDA versus aggregate
- Water quality aspects
- Landfill impacts and potential market

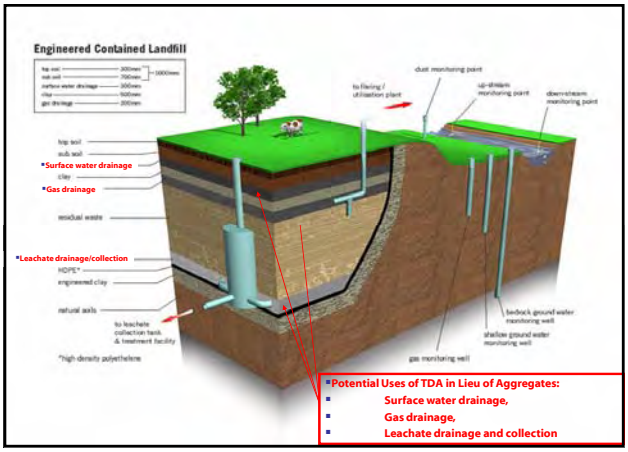
Use of TDA for alternative daily cover (ADC)
- Life cycle assessment of GHG emissions
- Limitations of TDA as cover

Use of whole tires in landfills

Use of Tire Derived Aggregate (TDA) in Lieu of Sand or Gravel Aggregates

TDA can be used in lieu of sand or gravel for:

- **leachate collection systems,**
- **the primary drainage layer for a liner system**
- **the drainage layer within the final cover system, and**
- **the media for landfill gas venting systems**



*Landfill Sand Protective Cover Installation

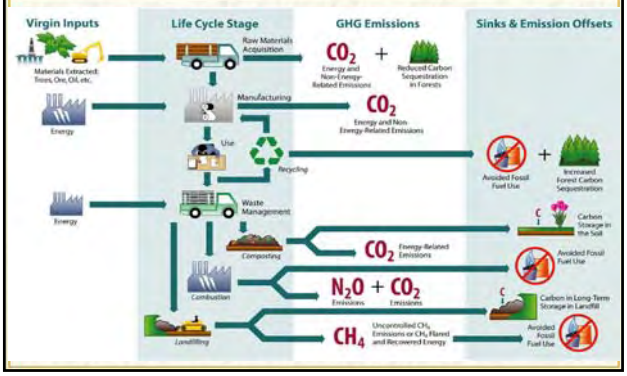
Landfill Gravel Protective Cover Installation

TDA Being Placed in a Leachate Collection System

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

Figure 1 shows GHG sources and sinks associated with the material life cycle.

Figure 1: GHG Sources and Sinks Associated with the Material Life Cycle



Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

Waste management decisions effect GHG emissions by the energy consumption associated with recycling.

This energy includes

- **Processing of recycled materials;**
- **Transporting materials**

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin aggregate

Recycling:

- **Recycled materials are used in place of virgin inputs in the manufacturing process.**
- **Material can be recycled in two ways:**
  - **Closed loop—material is recycled into the same product**
  - **Open loop—material is recycled into other products**

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

Recycling:

- **It is usually assumed that recycling decreases GHG emissions due to lower energy requirements compared to manufacture from virgin inputs.**
- **This may not always be true, however, especially with open loop recycling.**
- **As a result, a life cycle analysis should be performed to determine energy requirements and GHG emissions due to recycling processes.**

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

- **Because TDA is an open-loop recycled material, a life cycle assessment for energy consumption and GHG emissions should be performed to determine how the use of TDA compares to conventional aggregates—sand and gravel—commonly used in landfill design.**
- **The analysis can be divided into two parts:**
  - **Process energy requirements and GHG emissions**
  - **Transportation energy requirements and GHG emissions**

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

Process energy emissions

1. **Virgin Aggregate**

- **The EPA estimates that, nationwide, the average combustion energy to produce virgin aggregate from crushed stone is 0.0486 million Btu/Ton**
- **This gives total process emissions of 0.0009 MTCE/Ton**

Comparing GHGs

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are very different gases in terms of their heat-trapping potential. An international protocol has established CO_2 as the reference gas for measurement of heat-trapping potential (also known as global warming potential or GWP). By definition, the GWP of 1kilogram (kg) of CO_2 is 1.

CH_4 has a GWP of 21, which means that 1 kg of methane has the same heat-trapping potential as 21 kg of CO_2.

N_2O has a GWP of 310.

PFCs are the most potent GHG included in this analysis; GWPs are 6,500 for CF_4 and 9,200 for C_2F_6.

In this report, emissions of CO_2, CH_4, N_2O, and PFCs have been converted to their "carbon equivalents." Because CO_2 is 12/44 carbon by weight, 1 metric ton of CO_2 is equal to 12/44 or 0.27 metric tons of carbon equivalent (MTCE). The MTCE value for 1 metric ton of each of the other gases is determined by multiplying its GWP by a factor of 12/44. (All data provided here are from The Intergovernmental Panel on Climate Change (IPCC), *Climate Change 1995: The Science of Climate Change*, 1996, p. 121.)

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

Process energy emissions

2. TDA

- **Tire shred process data were calculated assuming the tire shredder is an electric 225 kW Saturn shredder, one of the most commonly used models (M. Hinsley, personal communication). This tire shredder produces approximately 7 tons/hr of TDA.**
- **At 70% load with 10% additional input for conveyors and screeners, the shredder will consume approximately 25 kW-hr/ton, or 85,325 Btu/ton, or 0.0853 million Btu/ton.**
- **This gives total process emissions of 0.0014 MTCE/Ton**

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

Process Energy Emissions

Material	Energy Consumption For Aggregate Production (million BTU/Ton)	Total Process Energy Emissions (MTCE/Ton)
Virgin aggregate[1] (crushed stone)	0.0486	0.0009
Tire Shreds[2]	0.0853	0.0014

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

Transportation energy emissions

- **The EPA estimates that the average combustion energy to transport one ton-mile of material in diesel trucks is 0.00623 million Btu.**
- **This gives transportation emissions of 0.00012 MTCE/Ton-mile**
- **Transportation emissions per ton-mile are assumed to be the same for both virgin aggregate and TDA as shown in the following table.**

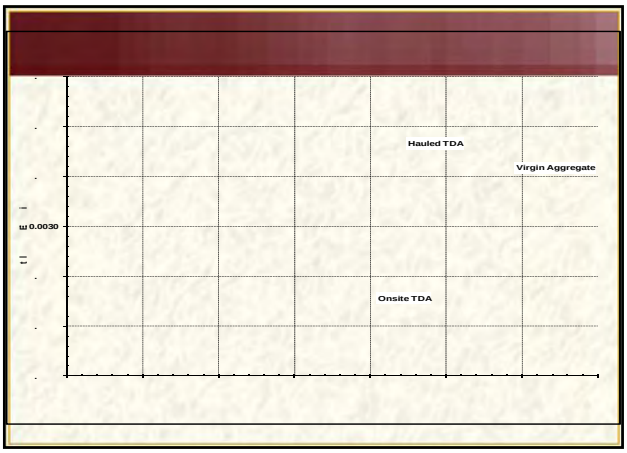
Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

Transportation Energy Emissions

Material	Energy Consumption for Aggregate Transport (million BTU/Ton-mile)	Total Transport Energy Emissions (MTCE/Ton-mile)
Virgin aggregate[1] (crushed stone)	0.00623	0.00012
Tire Shreds[3]	0.00623	0.00012

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

- **Since TDA has a higher process energy requirement than virgin aggregate per ton of material produced, it is concluded that transportation emissions will be the decisive factor as to whether the use of TDA will have more or less of an environmental impact than virgin aggregate per ton of production.**
- **Figure 2 shows the relationship between GHG emissions and haul distance to the landfill for both virgin aggregate and TDA produced onsite (at the landfill) and hauled.**



Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

- **Figure 2 shows that, on a weight basis, TDA should be produced onsite or as close to the landfill as possible if it is to be used as an alternative to virgin aggregate. Indeed, aggregate will likely produce less emissions than onsite TDA up to a haul distance of 5 miles on a weight basis.**
- **Otherwise, the use of TDA could easily produce more GHG emissions than virgin aggregate.**

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

- **TDA, however, has a much lower specific weight than stone or sand aggregate, thus a lower weight of TDA will be used in applications than the virgin aggregates.**

$\gamma_{aggregate}$ 105 lb/ft^3
γ_{TDA} 25 lb/ft^3

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

- **The emission data for processing and transportation are converted to a volume basis in the following tables and plotted in Figure 3.**

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

Process Energy Emissions Based on Volume

Material	Energy Consumption For Aggregate Production (million BTU/ft^3)	Total Process Energy Emissions (MTCE/ft^3)
Virgin aggregate[1] (crushed stone)	0.00255	0.0000427
Tire Shreds[2]	0.00106	0.0000175

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

Transportation Energy Emissions Based on Volume

Material	Energy Consumption for Aggregate Transport (million BTU/ft^3-mile)	Total Transport Energy Emissions (MTCE/ft^3-mile)
Virgin aggregate[1] (crushed stone)	0.0003271	0.0000063
Tire Shreds[2]	0.0000779	0.0000015

Total Energy Emissions per Cubic Foot Versus Haul Distance for Virgin Aggregate and TDA

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

- **Figure 3 shows that, on a volume basis, TDA produces less GHG emissions than virgin aggregate for both process and transportation energy.**
- **These results are due solely to the differences in specific weights between conventional aggregates and TDA, which allows less TDA to be used in aggregate application in landfills.**

Life Cycle Assessment of Energy Consumption and GHG Emissions for TDA and Virgin Aggregate

- **Because TDA is highly compressible, as will be discussed below, it is possible that more TDA will have to be utilized in a given application than its loose volume. This could occur, for example, in a leachate drainage application at the bottom of a landfill.**
- **A life cycle assessment of energy and emissions should therefore be performed for each specific application of TDA at landfills.**

Engineering Aspects of TDA Versus Aggregate

Hydraulic Conductivity
Compressibility
Compatibility with Geosynthetics and Liners
Combustibility
Storage Issues
Uniformity and Quality

Engineering Aspects of TDA Versus Aggregate

Hydraulic Conductivity

- **TDA hydraulic conductivity has been measured in a range from 0.0005 to 59.3 cm/sec.**
- **This wide range may be attributed to differences in shred size distribution, composition, and compaction level.**

Engineering Aspects of TDA Versus Aggregate

Hydraulic Conductivity

- The lower range of conductivities has been stated to be due to smaller shreds under greater vertical stress.
- Conductivity also decreases significantly as the percentage of soil in TDA increases.

Engineering Aspects of TDA Versus Aggregate

Compressibility

- TDA is highly compressible under loaded conditions.
- Under high loads, TDA can compress by as much as 50%.

Engineering Aspects of TDA Versus Aggregate

Compressibility

- The compressibility should be considered in the use of TDA for the leachate drainage and collection layer in a landfill.
- Research has shown that a 12 inch TDA leachate layer could compress 30% under 75 feet of waste, leaving an effective thickness of 8.7 inches.

Engineering Aspects of TDA Versus Aggregate

Compatibility with Geosynthetics and Liners

- Exposed wire from TDA presents a significant puncture hazard for any geosynthetic layer used in a landfill.
- It is recommended that a granular cushion layer be used between TDA and geomembrane layers to provide puncture protection.

Engineering Aspects of TDA Versus Aggregate

Combustibility

- TDA has a flash point of about 580 °F.
- Under the right conditions, TDA has the potential to create an internal heating reaction that could lead to a fire.

Engineering Aspects of TDA Versus Aggregate

Combustibility

- Potential causes of internal heating reactions:
  - Oxidation of exposed steel belts
  - Oxidation of rubber
  - Microbial action

Engineering Aspects of TDA Versus Aggregate

Combustibility

- Conditions that may lead to internal heating reactions in TDA in landfills:
  - Access to air
  - Access to water
  - Retention of heat
  - Large fill thickness
  - Large amounts of exposed steel belts
  - Smaller TDA sizes and large amounts of granulated rubber particles
  - Presence of inorganic and organic nutrients

Engineering Aspects of TDA Versus Aggregate

Combustibility

- ASTM recommends that TDA not be used in layers greater than 10 feet thick.

Engineering Aspects of TDA Versus Aggregate

Storage Issues

- A major impediment to use of TDA in landfills is the ability to store sufficient quantities to keep up with landfill construction activities.
- Landfills will often need to stockpile and store TDA in an onsite staging area, and thus must plan ahead for storage and deployment activities.

Engineering Aspects of TDA Versus Aggregate

Storage Issues

- TDA used as a substitute for aggregate should be stored in piles where
  - Vertical dimension does not exceed 15 ft.
  - Length is less than 100 ft.
  - Width is less than 50 ft.
  - Volume of pile is less than 75,000 ft^3.

Engineering Aspects of TDA Versus Aggregate

Storage Issues

- TDA in stored in piles should also
  - Be located away from potential ignition sources
  - Be located 50 ft away from combustible materials
  - Have a 50 ft fire lane between piles
  - Have a 20 lb Class ABC dry chemical fire extinguiser available within 100 ft radius of storage area
  - Have the site graded to prevent standing pools of water and limit stormwater runoff.

Engineering Aspects of TDA Versus Aggregate

Storage Issues

- Other TDA storage concerns
  - Use of temperature probes to monitor internal temperatures
  - Control of wind blown debris and other contaminates
  - Water truck to cool down piles as necessary
  - Care with moving TDA to avoid contamination with underlying soils.

Water Quality Concerns with TDA

- The Toxicity Characteristics Leaching Procedure (TCLP) used by ASTM showed that TDA was below all regulated metals and organics.
- TDA therefore is not classified as a hazardous waste at the federal level.

Water Quality Concerns with TDA

- Studies have shown that a low pH trace metals can leach from TDA.
- At high pH hydrocarbon oils can leach from TDA.

Water Quality Concerns with TDA

- The pH of landfill leachate is can be acidic in new landfills, and has been reported to range from from 4.5 to 7.5.
- It is thus possible that some metals could be leached from TDA used in lechate collection systems.

Water Quality Concerns with TDA

- Landfill gas is corrosive, and it is also possible that metals could be leached from TDA where it is used in gas drainage systems.

Use of TDA for Alternative Daily Cover (ADC)

- Daily cover is defined as cover material placed on the entire surface of the active face at the end of each operating day.
- It's purpose is to control:
  - Vectors
  - Fire
  - Odors
  - Windblown litter
  - Scavenging

Use of TDA for Alternative Daily Cover (ADC)

- Commonly used ADC materials in landfills include:
  - Tarps (geosynthetic blankets)
  - Green waste
  - Compost
  - Wastewater sludges or biosolids
  - Construction and demolition materials
  - Foams

Use of TDA for Alternative Daily Cover (ADC)

- From a landfill operational perspective, the purpose of the use of ADC instead of soil is to
  - Save airspace (volume)
  - Minimize heavy equipment use by minimizing the volume of soil required for operations

Use of TDA for Alternative Daily Cover (ADC)

TDA has the following major constraint that limit its use as ADC.

- Life cycle emissions for production and application as ADC are higher than soil, especially if soil is excavated onsite, the most common case at landfills.

Use of TDA for Alternative Daily Cover (ADC)

Life cycle assessment of emissions using TDA as ADC.

- Daily cover is typically excavated onsite at landfills using an excavator, which is the most efficient form of excavation, as shown in the following photos.

- Onsite Production of Daily Cover with Excavator and Dump Truck

Use of TDA for Alternative Daily Cover (ADC)

Life cycle assessment of emissions using TDA as ADC.

- **The life cycles emissions of excavation and transportation of cover can be calculated as follows:**

Use of TDA for Alternative Daily Cover (ADC)

A. Energy Consumption for Conventional Cover Excavation

Caterpillar 345 Series II Excavator, 321 hp, 2.0 yd^3 bucket.
Fuel consumption = 11.0 gallons/hr @ medium load
Cycle time = 20 seconds
Production = 360 yd^3/hr
Soil density = 2,500 lb/yd^3 (loose)

$$\text{Production} = (360\ yd^3/hr)\cdot(2{,}500\ lb/yd^3)\cdot\left(\frac{1\ ton}{2{,}000\ lb}\right) = 450\ tons/hr$$

$$\text{Btu Value of Diesel Consumed} = \frac{(11.0\ gal/hr)(129{,}500\ Btu/gal)}{450\ tons/hr} = 3{,}165\ Btu/ton$$

$$\text{Energy Consumption for Soil Cover Excavation} = \frac{3{,}165\ Btu/ton}{10^6} = 0.00316\ \text{million Btu/ton}$$

Energy Emissions =
(0.00316 million Btu/ton)(0.01987 MTCE/million Btu) = 0.000063 MTCE/ton

Use of TDA for Alternative Daily Cover (ADC)

Life cycle assessment of emissions using TDA as ADC.

- **The emission data for processing and transportation are shown in the following tables and plotted in Figure 4.**

Use of TDA for Alternative Daily Cover (ADC)

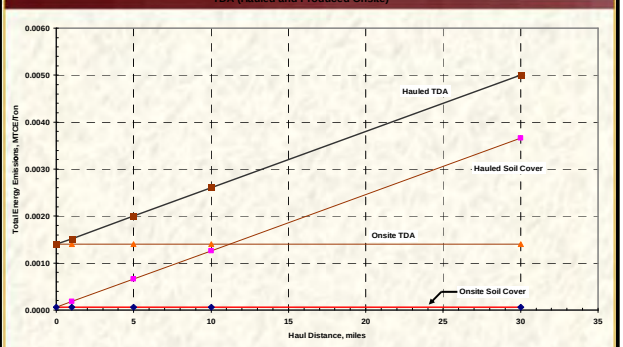
A. Process Energy Emissions

Material	Energy Consumption For Aggregate Production (million BTU/Ton)	Total Process Energy Emissions (MTCE/Ton)
Excavated Soil	0.00316	0.000063
Tire Shreds	0.0853	0.0014

B. Transport Energy Emissions

Material	Energy Consumption for Aggregate Transport (million BTU/Ton-mile)	Total Transport Energy Emissions (MTCE/Ton-mile)
Excavated Soil	0.00623	0.00012
Tire Shreds	0.00623	0.00012

Figure 4
Total Energy Emissions Versus Haul Distance for Soil Cover and TDA (Hauled and Produced Onsite)



Use of TDA for Alternative Daily Cover (ADC)

Life cycle assessment of emissions using TDA as ADC.

- **Figure 4 shows that, on a weight basis, even if TDA were produced onsite, it cannot compete with soil excavated onsite, or hauled soil up to a distance of 10 miles from the landfill.**

Use of TDA for Alternative Daily Cover (ADC)

Life cycle assessment of emissions using TDA as ADC.

- **TDA, however, has a much lower specific weight than soil, thus potentially a lower weight of TDA could be used in ADC applications.**

γ_{soil} 93 lb/ft^3

γ_{TDA} 25 lb/ft^3

Use of TDA for Alternative Daily Cover (ADC)

Life cycle assessment of emissions using TDA as ADC.

- **The emission data for processing and transportation are converted to a volume basis in the following tables and plotted in Figure 5.**

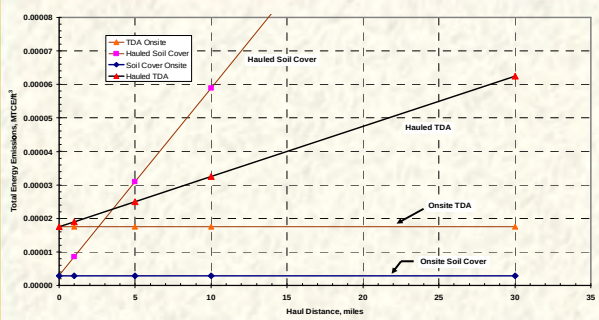
Use of TDA for Alternative Daily Cover (ADC)

c) Process energy emissions per ft^3

Material	Energy Consumption For Aggregate Production (million BTU/ft^3)	Total Process Energy Emissions (MTCE/ft^3)
Excavated Soil[1]	0.00255	0.0000427
Tire Shreds[2]	0.00106	0.0000175

Material	Energy Consumption for Aggregate Transport (million BTU/ft^3-mile)	Total Transport Energy Emissions (MTCE/ft^3-mile)
Excavated Soil[1]	0.0003271	0.0000063
Tire Shreds[2]	0.0000779	0.0000015

Figure 5
Total Energy Emissions per Cubic Foot Versus Haul Distance for Soil Cover and TDA (Hauled and Produced Onsite)



Use of TDA for Alternative Daily Cover (ADC)

Life cycle assessment of emissions using TDA as ADC.

- **Figure 5 shows that, on a volume basis, TDA produces more GHG emissions than soil for onsite production and can never compete if with soil cover that is excavated onsite.**
- **TDA potentially could, however, produce less GHG emissions than hauled soil, especially if the TDA is produced onsite or near the landfill.**

Use of TDA for Alternative Daily Cover (ADC)

Life cycle assessment of emissions using TDA as ADC.

- **These results are due solely to the differences in specific weights between soil and TDA.**
- **Because TDA is less dense than soil, it is likely that more TDA would have to be utilized in a given ADC application.**
- **This further limits the possibilities on the use of TDA as ADC.**

Use of TDA for Alternative Daily Cover (ADC)

In addition to life cycle emissions, the following characteristics also limit the use of TDA as ADC:

- It will not control infiltration of rainwater.
- It will not prevent fire hazards.
- It will not control the migration of landfill gas.
- It is more difficult to apply and compact, requiring more operating hours of heavy equipment.
- Tire shreds will more consume landfill airspace than compacted soil or other forms of ADC.

Conclusions on the Use of TDA in Landfills

TDA Use in Lieu of Virgin Aggregates

- The use TDA in lieu of stone or sand aggregate in drainage systems for water, leachate, or gas is feasible as long as the shredding machinery is onsite or close to the landfill. Otherwise GHG emissions can be higher than the use of virgin aggregates.
- In this case the volume of TDA used replaces the volume of aggregate that would have been used, and does not consume landfill airspace.

Conclusions on the Use of TDA in Landfills

TDA Use a ADC

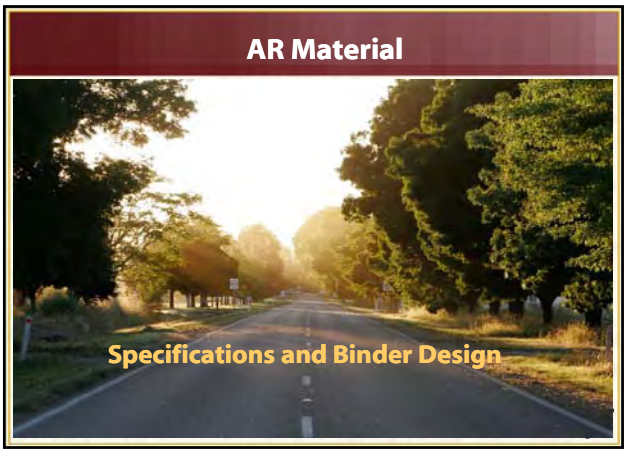
- The use TDA as ADC will likely consume more energy and produce more GHG emissions than soil cover excavated onsite or hauled close distances.
- TDA's physical characteristics preclude it from performing as a daily cover should (controlling infiltration, gas migration, fire hazards), and they also make it more difficult to spread and compact with machinery.
- TDA used as ADC will consume more landfill airspace than soil cover or other types of ADC, especially tarps.

Use of Whole Tires in Landfills

Use as a Base of Drainage Channel

THANK YOU
QUESTIONS?
http://www.cp2info.org/center

AR Material



Outline

- Definitions
- Asphalt rubber binder
- Asphalt rubber binder design
- Types of mixes
- Cautions

AR Definitions

Asphalt Rubber Definition:
ASTM D 8

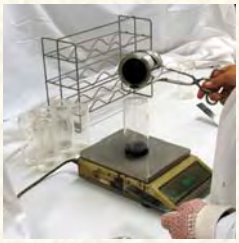
A blend of asphalt cement, reclaimed tire rubber and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles.

AR Definitions

Related Specification: ASTM D 6114

Standard Specification for Asphalt Rubber Binder

High viscosity material (usually field-blended) that typically requires agitation to keep CRM particles dispersed.



Definitions

The Wet Process can produce a wide variety of CRM modified binders from high viscosity (field blend) to no agitation (terminal blend) types

- **Rotational Viscosity is the discriminator for appropriate use, although rotational viscosity of terminal blends is not typically measured**
- **May be blended in field or at terminal**

Definitions

Wet Process

Method of modifying asphalt cement with scrap tire CRM and other components

- Most widely used approach (AZ, CA, TX, FL, others)
- Thoroughly mix CRM & other components with hot (400-425°F) asphalt cement
- Interact at 350-375°F for designated period (typical minimums 45-60 minutes)
  - CRM particles swell, exchange oils with asphalt binder

Definitions

Terminal Blends are:

- Low viscosity, no agitation
- Typically ≤ 10% CRM content, some @ 15%
- May include polymers and/or other modifiers
- Content in hot mixes is similar to neat asphalt cement

High Viscosity (Field Blend) vs. No Agitation (Terminal Blend)

Definitions

Dry Process

Substitutes CRM for 1 to 3% of aggregate in hot mix

- Not considered to modify binder, although some asphalt-CRM interaction may occur in place over time
- CRM gradations have ranged from coarse (1/4") to fine (#80)
- Mixed performance history – limited current use
  - May be related to mix design – need to account for long term absorption without starting out too rich
  - Not widely used in CA

Asphalt Rubber Binder

Components:

- Crumb Rubber Modifier (CRM)
  - Scrap Tire Rubber
  - High Natural Rubber Content Scrap Rubber
- Asphalt Cement
- Extender oil - Caltrans

Caltrans Specifications for High Viscosity (Field Blend) AR Binders

- Asphalt modifier: Extender oil at 1 to 6% by mass of asphalt (For chip seal binders, CT may continue to require minimum 2.5% extender oil)
- Asphalt + extender oil: 78-82% by total mass of AR binder
- Total CRM: 18-22% by total mass of AR binder, of which:
  - Scrap tire CRM = 73-77% of total CRM
  - High natural CRM = 23-27% of total CRM

Crumb Rubber Modifier (CRM)

- CRM is produced from grinding whole scrap tires, tread buffings, and other waste rubber products; CRM comes in a variety of grades and size designations from various suppliers and/or sources
- CRM gradation and content affects not only AR binder properties, but also influences the voids structure of RHMA-G mixes
- Gradation limits used by Caltrans and ADOT are broad and allow considerable variation; changes are being considered
- Check project special provisions to verify CRM gradation limits in effect for specific projects

Crumb Rubber Modifier (CRM)

Tire Processing Video Clips

Clip 1

Clip 2

Clip 3

Crumb Rubber Modifier (CRM)

- High natural rubber CRM is used to improve adhesion and flexibility, chip seal aggregate retention, and to compatibilize asphalt and CRM interactions
- It has a high natural rubber content (40-48% by mass) and may be made from scrap tires or other non-tire sources
- Caltrans also requires that "high natural" be used in binders for RHMA mixes

Asphalt Cements

- Asphalt cements come in a variety of grades and designations
- AR-4000 was used to make asphalt rubber in the past
- Caltrans adopted the Performance Graded (PG) system in 2006
- Do not use modified asphalts as the base asphalt cement for CRM modification

PG Asphalt Cements

- For high mountain and high desert areas, use PG 58-22 as the base asphalt.
- For other areas (coastal, inland valleys, low and south mountain, and desert) use PG 64-16 as base asphalt.

Additives

- Extender oils:
  - Aid in the interaction of the crumb rubber and asphalt by providing aromatics which are absorbed by the rubber
  - Help with dispersion by chemically suspending the rubber in the asphalt (required by Caltrans)
- Anti-stripping agents:
  - Improve adhesion of binder to aggregate

Asphalt & Rubber Interactions

Depend On:

- Asphalt Cement Source and Grade
- Rubber Type/Source
- Amount of Rubber
- Gradation of Rubber
- Interaction Time
- Interaction Temperature

Asphalt Rubber Blend Design Submittals

- Supplier and identification (or type) of scrap tire and high natural CRM
- Typical gradation of each type of CRM material used in the asphalt rubber binder design
- Percentage of scrap tire and high natural CRM by total mass of the asphalt-rubber blend
- If CRM from more than one supplier is used, info will be required for each CRM supplier used
- Laboratory test results for test parameters shown in the special provisions

Asphalt Rubber Blend Design Submittals

- Base asphalt PG binder grade, supplier, and Certificate of Compliance
- Percentage of the combined blend of asphalt and asphalt modifier by total mass of asphalt rubber binder
- Asphalt modifier type, supplier, identification, and test results demonstrating conformance to specs
- Percentage of asphalt modifier by mass of asphalt
- Design profile
- Minimum interaction time and temperature
- Material Safety Data Sheets for everything

Asphalt Rubber Blend Design Profile

- A design profile is developed to
  - Evaluate the compatibility between materials
  - Check compliance of component interaction properties
  - Check for stability of the AR blend over time
- For hot mix and spray applications, a 24-hour design profile will be required

Asphalt Rubber Blend Design Example Design Profile

	Minutes of Reaction					Spec. Limits @ 45 minutes (Caltrans 12/2005)
TEST	45	90	240	360	1,440	
Viscosity, cP Haake@ 190°C	2400	2800	2800	2800	2100	1500 - 4000
Resilience@ 25°C (% Rebound) (ASTM D 5329)	27	--	33	--	23	18 Minimum
R & B Softening Pt., °C (ASTM D36)	59.0	59.5	59.5	60.0	58.5	52 – 74 (125-165°F)
Cone Pen @ 25°C (ASTM D217)	39	--	46	--	50	25 – 70

Types of RHMA

- Dense-graded (limited usage by Caltrans)
- Gap-graded
- Open-graded
- Open-graded (High Binder, HB)

Aggregate Gradation Comparison

Open Graded Gap Graded Dense Graded

Dense-Graded Mixes (RHMA-D)

- Early use
  - Limited performance improvements vs. cost
  - Inadequate void space to accommodate sufficient AR binder to modify mix behavior
- Discontinued use with high viscosity (field blend) binders
- Suitable for use with no agitation CRM-modified binders (terminal blend) such as MB

Gap-Graded Mixes (RHMA-G)

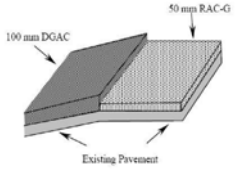
RHMA-G is the most commonly used RHMA mix type

Purpose – Structural mix that provides increased resistance to:

- Rutting
- Fatigue
- Reflective cracking
- Oxidative aging

Gap-Graded Mixes (RHMA-G)

Appropriate use: Most effective in relatively thin surface lifts (max 60 mm) as overlay of aged or distressed flexible or rigid pavements that are structurally sound. May be used as surface course for new construction. Suitable for wide range of traffic volumes and loadings.



Gap-Graded Mixes (RHMA-G)

- Thickness design
  - See Module 2 for details
  - New pavements
  - Overlays
- Overlay systems – two and three layer
  - SAMI-R, not SAMI-F

Gap-Graded Mixes (RHMA-G)

Standard Special Provisions for RHMA-G with high viscosity (field blend) AR binder are currently being updated to address PG binder implementation.

Revisions include:

- Remove test methods from body of SSP, develop corresponding CT Lab Procedures for CRM sieve analysis and measuring rotational viscosity of AR binder
- Format SSP for inclusion in Section 39 of Caltrans Standard Specifications

Gap-Graded Mixes (RHMA-G)

- Adjustments to Hveem Mix Design Method (CT 367), including:
  - Modify coarse aggregate gradation requirements, particularly for 600 µm sieve, to facilitate achieving minimum VMA (18%)
  - Add maximum VMA limit of 23%
  - Test 3 briquettes at each binder content, use average values for calculations and plots

Gap-Graded Mixes (RHMA-G)

- Adjustments to Hveem Mix Design Method, cont'd
  - Design air voids content may range from 3 to 5% based on traffic index and climate, and as designated by the engineer in project special provisions
  - Still requires minimum AR binder content of 7.0% by weight of dry aggregate to provide durability (Must have sufficient binder content to provide expected performance benefits)

Gap-Graded Mixes (RHMA-G)

Adjustments to Hveem Mix Design Method, cont'd

- Use Caltrans Laboratory Procedures LP-1 through LP-4 for volumetric calculations
- Report Voids Filled with Asphalt (VFA) and Dust Proportion for information only
- Plot average unit weight, stability, % air voids, VMA, and VFA, versus asphalt rubber binder content

Open-Graded Mixes (RHMA-O, RHMA-O-HB)

- Standard Special Provisions for RHMA-O and RHMA-O-HB have incorporated PG binder implementation
- Changes are similar to those for RHMA-G, but with less impact on mix design method
- Effects of CRM gradation and content in binder have relatively little effect on voids structure of open-graded mixes

Open-Graded Mixes (RHMA-O)

- RHMA-O is designed to provide a free-draining surface (reduced splash, spray, and hydroplaning) that maintains good frictional characteristics in wet or dry conditions
- Such mixes are not considered to be structural elements and no thickness reduction applies
- RHMA-O is typically placed in thin lifts, nominally 24 to 30 mm thick

Open-Graded Mixes (RHMA-O)

Appropriate Use:

RHMA-O may be used as an overlay or as a surface for new construction where traffic flow is essentially uninterrupted by signalization, such as freeways, and some rural and secondary highways.

Open-Graded Mixes (RHMA-O)

- Do not use open-graded mixes where there is a significant amount of stop and go traffic or turning vehicles, such as city streets or in parking lots
- These porous low modulus pavements are susceptible to tire scuffs from simultaneous braking and turning motions, and to damage from leaking vehicle fluids
- Caltrans does not use RHMA-O in snow country

RHMA-O Mix Design

- RHMA-O mixture design is performed according to California Test 368, with asphalt rubber binder content set at 1.2 times the optimum bitumen content for the designated PG binder grade
- A check test is used to verify that binder drain down is not excessive
- If long hauls are anticipated, drain down should also be checked in the laboratory for the expected haul time

Open-Graded Mixes (RHMA-O-HB)

- RHMA-O-HB mixes have higher binder contents (1.6 times demand for PG asphalt instead of 1.2)
- HB provides improved friction course durability and performance due to thicker AR binder films
- Drain down check is more critical for high binder mixes
- RHMA-O-HB does not drain as freely as RHMA-O due to higher binder content, but still drains more freely than DGAC

Open-Graded Mixes

- RHMA-O and RHMA-O-HB provide safety benefits, and also have proved to:
  - Provide smooth ride
  - Significantly reduce tire noise
- Joint Caltrans/ADOT/FHWA studies are in progress to measure and document noise reduction over a ten-year period

Caution

- The specifications and mix design methods discussed in this presentation apply to use of high viscosity asphalt rubber binders (field blend) in gap- and open-graded RHMA mixes
- No agitation binders (low viscosity, terminal blend) should never be directly substituted for high viscosity binders in any RHMA mix
- The two different types of CRM-modified binders have very different viscosity ranges and behave very differently from each other in asphalt concrete hot mixes

Summary

- Material Definitions
- Mix Design Profiles
- Material Testing
- RHMA-D
- RHMA-G
- RHMA-O, and RHMA-O-HB

Questions ?
The Beginning
Keeping roads good with asphalt paving materials
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Appendix C

University Curricula Chapter Lectures

Module 1 CIVL 131 Introduction to Civil Engineering Design
Module 2 CIVL 311 Strength of Materials
Module 3 CIVL 312 Structural Test Lab
Module 4-1 CIVL 402 Contracts and Specifications on Rubberized Asphalt Concrete
Module 4-2 CIVL 402 Contracts Specifications on ASTM Standards
Module 5 CIVL 411 Soil Mechanics
Module 6 CIVL 415 Reinforced Concrete
Module 7 CIVL 402 Environmental Engineering
Module 8 CIVL 441 Transportation Engineering
Module 9 CIVL 551 Foundation Engineering
Module 10 CIVL 575 Solid Waste Management
Module 11 CIVL 598 Asphalt Paving Materials

DISCLAIMER

The contents of these chapters are draft. They are intended for information only. The purpose of these chapters is to support the teaching modules in Appendix B. Please do not cite or reference this material in other publications. They reflect the views of the authors only. The content does not necessarily reflect the official views or polices of the California Integrated Waste Management Board or the State of California.

CIVL 131 Introduction to Civil Engineering Design

1.0 Introduction

According to the Rubber Manufacturers Association, the U.S. generated approximately 300 million scrap tires in 2005. Historically, these scrap tires took up space in landfills or provided breeding grounds for mosquitoes and rodents when stockpiled or illegally dumped. Fortunately, markets now exist for 87% of these scrap tires-up from about 17% in 1990. These markets-both recycling and beneficial use-continue to grow, and the California Integrated Waste Management Board (CIWMB) believes that the largest growing market for scrap tire products is in civil engineering applications. The remaining scrap tires, however, are still stockpiled or land-filled.

Nation wide, of the 300 million waste tires produced, most were used as follows:

- 155 million (52%) were used as fuel (TDF).
- 49 million (16%) were recycled or used in civil engineering projects.
- 30 million (10%) were converted into ground rubber and recycled into products.
- 7.4 million (2.5%) were converted into ground rubber and used in rubber-modified asphalt.
- 6.9 million (2.3%) were exported.
- 6.1 million (2.0 %) were recycled into cut/stamped/punched products.
- 3 million (1%) were used in agricultural and miscellaneous uses.

As can be seen, the three largest scrap tire markets, using about 78%, are:

- Tire derived fuel
- Civil engineering applications
- Ground rubber applications/ rubberized asphalt concrete

Both recycling and beneficial use of scrap tires has expanded greatly in the last decade through increased emphasis on recycling and beneficial use by state, local and Federal governments, industry, and other associations. Unfortunately, even with all of the reuse and recycling efforts underway, not all scrap tires are being used beneficially

California was the single largest contributing state, producing about 40 million of those tires. It is estimated on average each California resident produces about 1.1 tires each year. The California Integrated Waste Management Board (CIWMB) is tasked with diverting these scrap waste tires from the waste stream to be used in other beneficial applications. Civil engineering applications are the largest growing potential market for scrap tires.

1.1 Objectives

This chapter focuses on the materials that were developed to introduce first year engineering students to potential applications of scrap tires in civil engineering projects. It was developed for a course that is offered at most colleges and universities with engineering programs, often the course is called "Introduction to Engineering".

1.2 History

CIWMB has spent nearly two decades dealing with scrap tire issues in the State of California. They have not only been tasked with diverting scrap tires from the waste stream, but have been involved with reducing the number of scrap tires that have been stockpiled both legally and illegally, and in remediation efforts following devastating tire fires. CIWMB's Waste Tire Recycling Management Program has increased the annual diversion rate of waste tires from 34 percent in 1990 to about 75 percent in 2008 (CIWMB 2008). In addition, the program has cleaned up the majority of large tire piles in the state.

Abandoned waste tires pose potential threats to public health and safety, and to the environment. This is particularly true with respect to fire hazards and mosquito-borne diseases such as West Nile Virus. CIWMB has also completed remediation efforts at California's largest tire fire sites and worked on expanding the markets for tire-derived products.

1.3 Waste Tire Civil Engineering Applications

This module provides a general introduction to the problems related to the generation of waste tires in California and gives an overview of their applications in civil engineering projects. Benefits and problems encountered in using scrap tires as tire derived aggregate (TDA) and rubberized asphalt paving materials are discussed.

Tires are an engineered product with a complex composition. They contain steel belts and beads, polyester belts and both synthetic and natural rubber. They are engineered for toughness and durability, and are not easily recycled. Civil engineering projects can use waste tires in a variety of ways, from crumb rubber particles, to tire shreds, and to whole tires.

The use of scrap tire products in civil engineering applications can be broken down into three broad categories; tire derived aggregate, rubberized asphalt concrete (RAC) paving materials, and the use of whole scrap tires. TDA has many beneficial properties for certain civil engineering applications:

1. Lightweight, tire shreds weigh 1/3 to ½ as much as compacted soil and gravel.
2. Lower lateral earth pressure, about ½ or less than traditional backfill material.
3. Good thermal insulation characteristics, 8 times greater than gravel.
4. High permeability, greater than granular soils (sands).
5. Compressibility, useful for vibration mitigation.

RAC also has many desirable properties including the following:

1. Improves traction compared to traditional asphalt paving.

2. Improves durability of pavement section especially in overlays. Can typically use thinner overlays and get superior performance. Reduces reflection and surface tension cracking.
3. Reduces noise caused by vehicle traffic (noise pollution). Listen to the video on the PowerPoint presentation.
4. Reduces vibration felt in the vehicles.
5. Lowers maintenance costs because of longer service life typical of RAC.
6. Reduces spray/splash when raining. The video in the PowerPoint presentation dramatically demonstrates this effect.

RAC paving materials can improve the performance of the paving system while lowering material requirements due to thinner pavement overlay thicknesses. RAC paving systems have been proven to have lower life-cycle costs.

There are several beneficial applications of TDA in civil engineering projects. TDA can be utilized in several types of civil engineering applications:

1. Lightweight fill for embankments
2. Retaining wall backfill
3. Vibration damping layers under rail lines
4. Insulation layer to limit frost penetration in roadways
5. Landfill applications including daily cover, gas pipe protection, drainage layers, and leachate and gas collection and recovery systems.
6. Solving slope stability problems by replacing heavier soils, reducing the driving force behind slope stability failures.

Utilizing waste tire products in civil engineering applications makes use of the desirable characteristics of these products while helping to solve the environmental problems associated with their improper disposal. These civil engineering applications have the potential to utilize large quantities of waste tire products. For instance, about 75 tires are recycled for each cubic yard of TDA fill, and 2,000 tires are used per lane mile of RAC pavement. CIWMB believes that civil engineering applications represent the largest potential growth market for utilizing waste tires in California.

Several barriers exist to the mainstream use of scrap tires in civil engineering applications. These barriers have civil engineering aspects as well as environmental, regulatory, public perception, and construction issues. Civil engineers are risk adverse and are used to designing with conventional construction materials (soil, concrete, asphalt, timber and steel) that have standards and applicable code acceptance. The engineering properties of TDA are not as well established, and there is a lack of both long term performance data and design standards or manuals. In addition, the chemical composition of scrap tire products is complex as tires are engineered for

toughness, durability and consumer safety. The resulting long term environmental effects are unknown, and the engineer must overcome public perception – it is a waste, so it must be bad!

During design, the engineer is faced with a convoluted regulatory approval process, with many competing objectives (e.g. the EPA and water quality control regulatory groups). Environmental regulators are risk adverse and need reassurance about the impacts of using recycled products in civil engineering applications.

There are several construction issues to overcome as well. New procedures and equipment may be required as is the case for RAC paving systems, which require more controlled manufacturing, transporting and construction procedures. For TDA, it is often difficult to estimate "in-place" cost because of the variations in in-place density achieved and compaction effort to achieve it. Also, supply is uncertain – both in quantity & quality as the resulting TDA varies with the producer. Sometimes, the use of scrap tires may be more expensive than construction with conventional materials. Finally, like engineers, contractors are risk adverse.

However, many of the barriers can be overcome using the following strategies:

- Conducting lab studies to determine engineering properties, and environmental impacts.
- Undertake additional pilot construction projects (full or nearly full scale) utilizing waste tire products in civil engineering applications.
- Monitor long term engineering and environmental performance of these projects.
- Modify specifications, and develop national and/or regional standards, etc. as needed to mainstream the use of recycled products in civil engineering applications.
- Education by addressing concerns head on and focus on the benefits of utilizing these materials.

2.0 Case Studies

2.1 Stockpile fires

Two major tire fires have occurred recently in California, one at Tracy and another in Westley:

- Tracy - On August 7, 1998, a grass fire ignited an estimated 7 million tires at the unlicensed S.F. Royster Tire Disposal Facility in Tracy, California. It was extinguished, after 26 months, with water and foam in December, 2000. It was just recently cleaned up at a cost of 40 million dollars over the last 10 years.
- Westley - On September 22, 1999, lightning ignited stockpiled tires which burned until the fire was extinguished on October 26, 1999. An estimated 2 to 3 million tires burned and it cost an estimated $20 million to clean up.

Tire fires emit clouds of noxious black smoke, carbon black, volatile organics, semi-volatile organics, polynuclear aromatic hydrocarbons, oil, sulfur oxides, nitrogen oxides, carbonoxides, and airborne particulates, such as arsenic, cadmium, chromium, lead, zinc, and iron, which pose serious environmental problems to air, water and soil. Spraying water on tire fires often increases

the production of pyrolytic oil, provides a mode of transportation to carry oils off site, and aggravates contamination of soils and water.

The shape of a tire allows for easy entrance and containment of rainwater. This creates an ideal breeding habitat for mosquitoes and other pests. Tires are non-biodegradable and bulky, and not environmentally friendly looking when stored outside in piles.

2.2 Dixon Landing South 880 Onramp

CIWMB worked with Caltrans to utilize shredded tires (TDA) as lightweight fill on the Dixon Landing/I-880 interchange project in Santa Clara County. Light weight fill was identified as the cheapest option for this on ramp because it was to be built on bay mud, which was too weak to support the weight of traditional fill materials. Also, slope stability and settlement is a major concern when construction embankments on weak soils. TDA was chosen because it weighs one-third to one-half as much as traditional fill material, and TDA had a much lower delivered cost than competing light weight fill materials. The cross-sections of the fill, both perpendicular and parallel to the direction of vehicular travel are shown below:

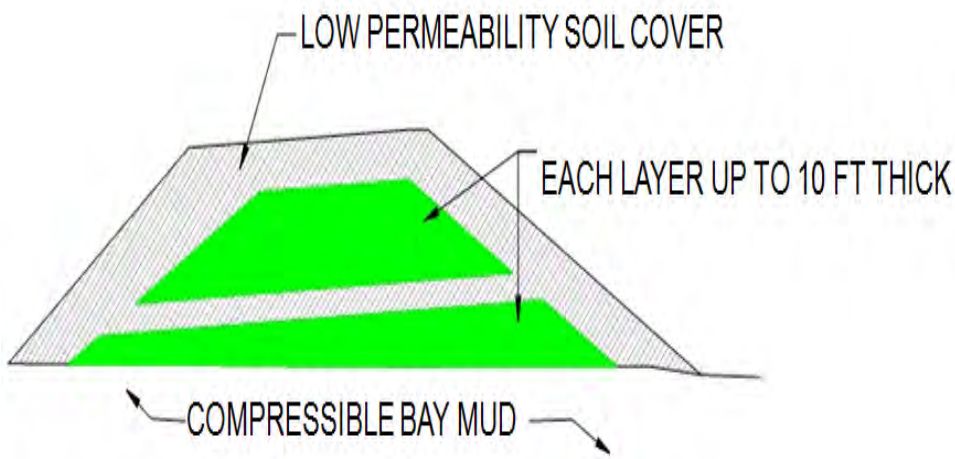

Figure 1. Cross Section View of Dixon Landing Embankment Fill Project with Two Layers of TDA

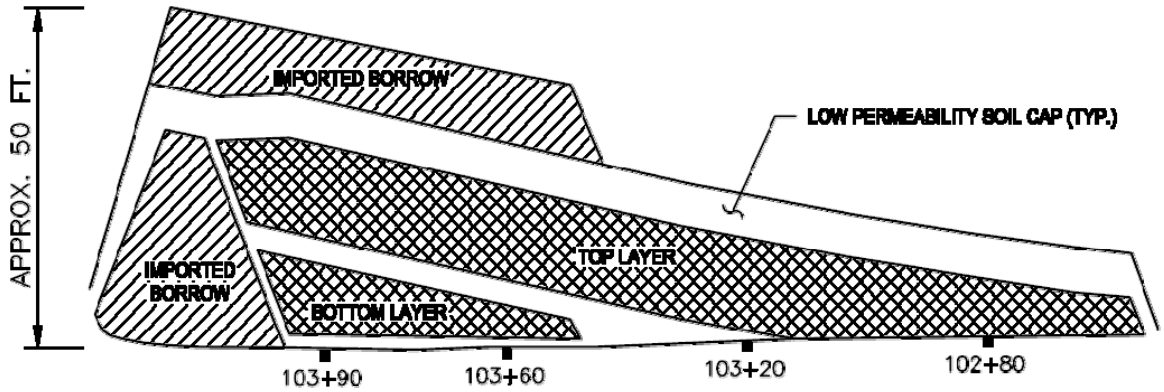

Figure 2. Dixon Landing TDA Embankment Project Profile

Tire shreds were placed in two layers, up to 10 feet thick, and were wrapped in geotextile fabric and separated by a three foot layer of low permeability soil. The 10 foot maximum TDA fill height was used to minimize internal heating that had lead to spontaneous combustion on earlier projects with a greater fill depth back in 1990s.

One such fire involved a TDA tire fill on Fall Springs Road in Garfield County, Washington in October, 1996. The engineers chose to fill a steep ravine with tire shreds instead of building a costly bridge. A few months after the project was completed, the fill began to smolder, followed by flames flaring up through cracks in the road surface with oil running out at the bottom of the ravine. Heavy equipment along with fire fighting crews were required to excavate the fill to full depth. When the ignited tire shreds were exposed to oxygen during excavation, flames erupted engulfing the construction equipment. It cost one million dollars to construct the fill and about three million dollars to remove the tire shreds and clean up the site.

According to ASTM D6270, embankment heating can be prevented by not allowing TDA contaminated with gasoline, oil, grease, etc., limiting fine sized TDA, limiting the max TDA layer thickness is 3 meters (10 ft), and minimizing access of fill to water & air.

On TDA construction projects, it is important to note that other than the haul units used to deliver TDA shown in Figure 3, no special construction equipment is required to spread and compact TDA fills. TDA has a much lower density than traditional fill materials. This means that haul trucks will be volume, not weight limited. This reduces the total number of trucks required to complete a fill project, which maybe an important issue where traffic congestion or limited site access is a concern.

Figure 3 Unloading TDA from Long Haul Truck

The material can be spread with bulldozers and compacted with standard (10 ton) rollers as shown in the Figures 4 and 5. ASTM D6270 specifies that TDA be placed in one foot lifts and be compacted by passing over each point in the fill a minimum of six times per lift. Note that traditional methods of determining in-place density like the sand cone and nuclear gages do no work with TDA. Estimates of in-place density may be obtained by surveying the volume of the fill and knowing the total weight of TDA placed.

Figure 4. Using Bulldozer to Spread TDA

Figure 5. Steel Roller was used to compact the TDA

Unit costs for the Dixon Landing project were as follows:

Placement costs of TDA (including geotextile)	= $3.74/yd3
Purchase & delivery costs of TDA	= $23.66/yd3
In-place cost for TDA	= $27/yd3
In-place cost for lightweight aggregate	= $50/yd3

Note that light weight aggregate was used for fill against the abutment as no data was available on the seismic response of TDA in that application. Cost savings to CALTRANS with TDA provided at no cost by CIWMB was $477,000. The cost savings to the State less the purchase price of TDA was $230,000. This is the amount that using TDA saved tax payers. This project was completed in August 2001, and has been monitored since with no performance problems to date. Figure 6 shows the completed embankment project using TDA.

Figure 6. Completed Dixon Landing TDA Light Weight Embankment Fill Project

3.0 Civil Engineering Waste Tire Education Curricula Roadmap

This module also covers an introduction to using scrap tires in civil engineering applications. The following chart shows a roadmap of how information on utilizing scrap tires was spread out through the undergraduate curriculum at CSU, Chico. Course teaching materials are available for each of the topics listed.

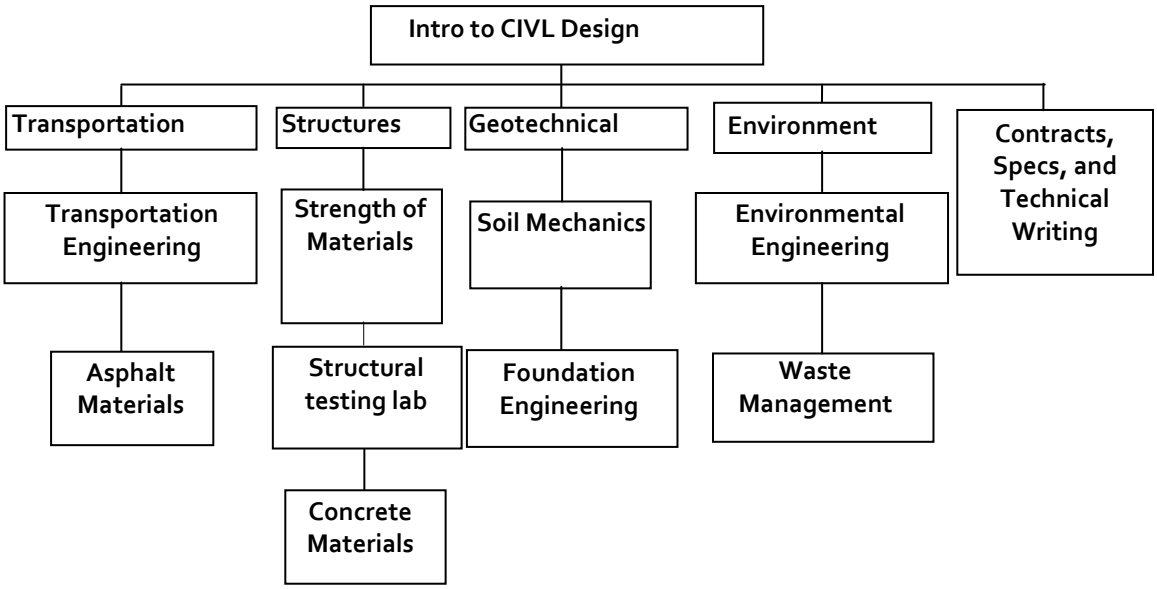

Figure 7. Roadmap of Teaching Waste Tire Applications in Civil Engineering

4.0 Summary and Recommendations

Although, there still remain barriers, Civil engineering applications are the fastest growing use for scrap tires in U.S. TDA has many desirable properties that make it an ideal material for use in a variety of civil engineering applications, while helping to divert waste tires from the waste stream. Although certain specifications and guidelines are available, more research and pilot projects are needed to gain confidence in the use of this recycled material. Long term studies are needed to monitor long term performance, and to determine the environmental impacts.

More work is needed both in terms of getting this material into the hands of educators and to incorporate new pilot project and research results that have been recently completed.

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CIVL 311 Strength of Materials

1.0 Introduction

Before an engineer can ever determine how an engineered system will behave, one must first gain an understanding of the behavior of the materials from which it is made. Knowing how materials behave helps engineers to choose the best materials for a particular project design, and, perhaps more importantly, to choose a project design that is best suited to the available materials. In the earliest engineering projects, materials were limited, so designers made do with what they had. For example, the Romans used arches to develop compressive forces in stone structures whose connections performed poorly in tension. As technology has advanced, many new materials have become available; however, the high cost of some of these materials makes them a poor selection for any project where cost effectiveness is a concern. As the field of engineering progresses, engineers find themselves not only looking at the financial cost of materials, but also at their cost to the environment. The challenge for engineers now is to design high quality projects that are both economically and environmentally efficient.

The first step for civil engineers in the design of high quality projects that are economically and environmentally efficient is to gain an understanding of low cost, environmentally friendly materials that work well for civil engineering applications. One such material is tire derived aggregate (TDA) and other similar products that can be derived from waste automobile tires, such as crumb rubber and tire buffings. As you can probably guess, waste tires are extremely cheap; in fact, many people get paid to take them, therefore the only costs are typically for processing and shipping, which are often included in the cost of other materials as well. In addition to being cheap, using waste tire products is environmentally friendly, as it helps reduce our ever-growing stockpiles of non-biodegradable waste, and waste tire products have many properties that are very useful in civil engineering applications.

1.1 Engineering Properties

Some of the engineering properties of TDA (and other tire derived products such as crumb rubber and tire buffings) that are important for design are: **Gradation**: the range and relative frequency of the particle sizes, **Specific Gravity**: the density of the particles in proportion to the density of water, **Absorption Capacity**: the measure of a materials capacity to absorb water, **Compressibility**: The susceptibility of a material to change volume due to changes in stress, **Resilient Modulus** (for linearly elastic materials): area under the elastic curve for (i.e. A measure of ability to absorb and return energy) **Resilient Modulus** (for subgrade materials): a measure of elastic modulus defined as amplitude of stress divided by recovered axial strain, **Time Dependent Settlement** of TDA Fills: change in volume verses time with consistent applied loading, **Shear Strength**: resistance to shear stress, **Hydraulic Conductivity (Permeability)**: the measure of how easily water moves through the material, **Thermal Conductivity**: how well heat transfers through the material.

In this chapter we will explore some general ways to examine properties like compressibility, settlement, and resilient modulus, that will allow us to gain a better understanding of some of the uses of TDA, but we will specifically emphasize how they relate to **vibration mitigation,** which

is the reduction of vibration by means of dissipating energy. First however, it is important to address some of the major differences between TDA and some of the materials which are typically analyzed in mechanics of materials classes.

1.2 Mechanics of Materials background (continuum versus discrete mechanics)

It is important to understand that the discipline of mechanics of materials can be categorized in different ways. One useful categorization to consider is continuum versus discrete mechanics. **Continuum Mechanics** deals with materials that have a uniform distribution of matter, do not contain voids, and are cohesive (meaning that all portions are connected together with no breaks, cracks, or separations). Most, if not all, of the work done in typical mechanics of materials classes falls into the category of continuum mechanics. Steel is an example of a material that should be analyzed using continuum mechanics.

Discrete Mechanics is the study of how discrete materials behave. Discrete materials (such as soils and TDA for example) are not continuous, often have voids, and typically have minimal cohesion. One must keep in mind that *TDA is a discrete material and therefore withstands compressive forces, but not tensile forces, and it often fails in shear*. The shear strength of TDA is affected by multiple factors including the orientation of the tire shreds, their size and shape, how well they are packed, the magnitude of compressive normal force acting on the TDA, and even the apparent cohesion of the tire shreds to one another.

2.0 Material Models

One of the ways that engineers deal with complex materials is to make less complex models of the materials that behave similar to the material of interest. In this section we will take a look at a few familiar material models that are easily understood. In the following section we will learn how to simulate far more complex material properties by utilizing combinations of the simple models we already understand.

2.1 Linear Elastic Material Model

The linear elastic material model (Figure 1) behaves like an **ideal** or **Hookean** spring (one with constant modulus of elasticity). It can be seen that stress and strain are always proportional to one another (the proportionality constant is the familiar Modulus of Elasticity of the material, the slope of the stress strain curve), it follows the same path for loading and unloading, (i.e. it exhibits elastic behavior) and is the same for every loading cycle. Further investigation shows that simple integration (finding the area beneath the line) allows us to calculate the energy per unit volume required for any given strain. It is important to note that the amount of energy returned when the material relaxes is exactly the same as the amount of energy required for the given deformation, therefore no energy is dissipated in the material; it is only stored and then returned mechanically.

$\sigma=\varepsilon E \quad E=\Delta\sigma/\Delta\varepsilon \quad F=\sigma A \quad \Delta L=\varepsilon L_o \quad V=AL_o$

Energy stored per unit volume$=\int\sigma\delta\varepsilon$ = area under stress-strain curve $=1/2\sigma_{max}\varepsilon$

Total energy stored$=V*\int\sigma\delta\varepsilon=\int\sigma A*\delta\varepsilon L_o=\int F\delta L$

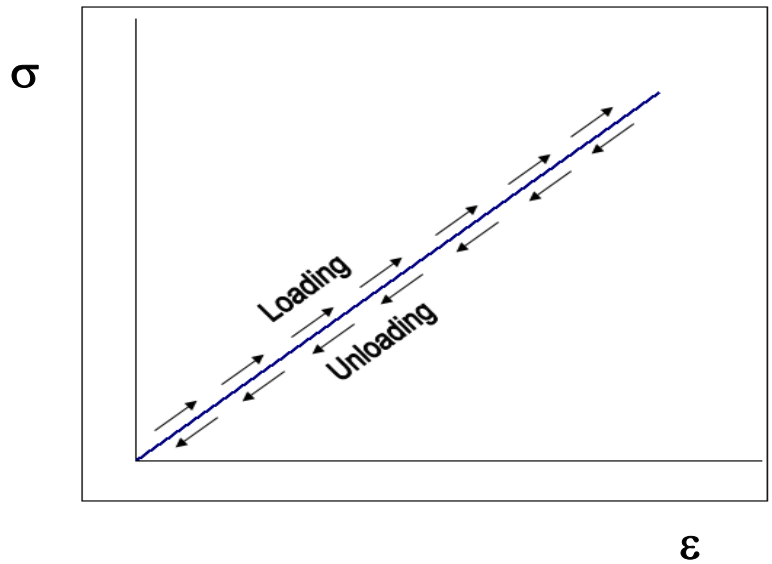

Figure 1. Linear Elastic Model

It is important to remind students that this linear elastic behavior results in two different phenomena that make their lives easy in elementary Mechanics of Materials. The first is that linear behavior gives rise to the nice linear equations that relate loading to stress (think bending stress = Mc/I and shear stress in torsion =Tc/J) and loading to deflection (think deflection of an axially loaded bar = PL/AE, or angle of twist of a shaft in torsion = TL/JG). The second key thing is that since the loading and unloading curve coincide and the material returns to its original undeformed shape and size following removal of the loading, one does not have to consider and keep track of the history of loading.

Another important elastic property in continuum mechanics is the relationship between longitudinal and transverse strain for uniaxial loading. For most structural materials this ratio is taken as a constant called Poisson's ratio (ν). It is interesting to note that theoretically Poisson's ratio varies from -1 to 0.5, but for most civil engineering materials it is in the range from 0.3 to 0.5. Poisson's ratio of zero implies no transverse strain in either direction, whereas a value of 0.5 represents an incompressible material or with constant volume in uniaxial compression or tension. Typical values for Poisson's ratio are: nearly zero for cork, about 0.1 for concrete, 0.27 to 0.3 for steel, 0.4 for nylon, and 0.45 to 0.5 for rubber! The students should be reminded of the mathematical relationship between the elastic constants, E, G, and ν is $G = 1/2E/(1+ \nu)$.

2.2 Elastoplastic Material Model

The elastoplastic material model (Figure 2) is an extension of the linear elastic model in that it accounts for yielding of the material. At the yield point it is assumed that the material cannot

take any additional stress and will continue to stretch without any increase in stress. Again, the area under the curve can be used to determine the energy required/released in loading and unloading. However, it must be noted that the any energy absorbed in the plastic range (beyond the yield point) will not be recovered upon unloading and therefore is dissipated as heat by the material. Each time the material is plastically deformed, the plastic portion of the deformation is permanent (only the elastic portion is recovered); therefore the next loading cycle begins at a new starting strain. This ideal model is very useful for analyzing many metals, such as steel, because it is a very simple, often relatively accurate, and generally conservative way of modeling their behavior.

Energy stored per unit volume $=\int\sigma\delta\varepsilon$ = area under stress-strain curve $=1/2\sigma_{max}\varepsilon$ where ε less than or equal to ε_y

Plastic Portion: $\sigma=\varepsilon_y E=\sigma_y$

Energy dissipated per unit volume$=\int\sigma\delta\varepsilon_{\varepsilon_y}^{\varepsilon}$area under plastic stress-strain curve

$=\sigma_{max}(\varepsilon-\varepsilon_y)$

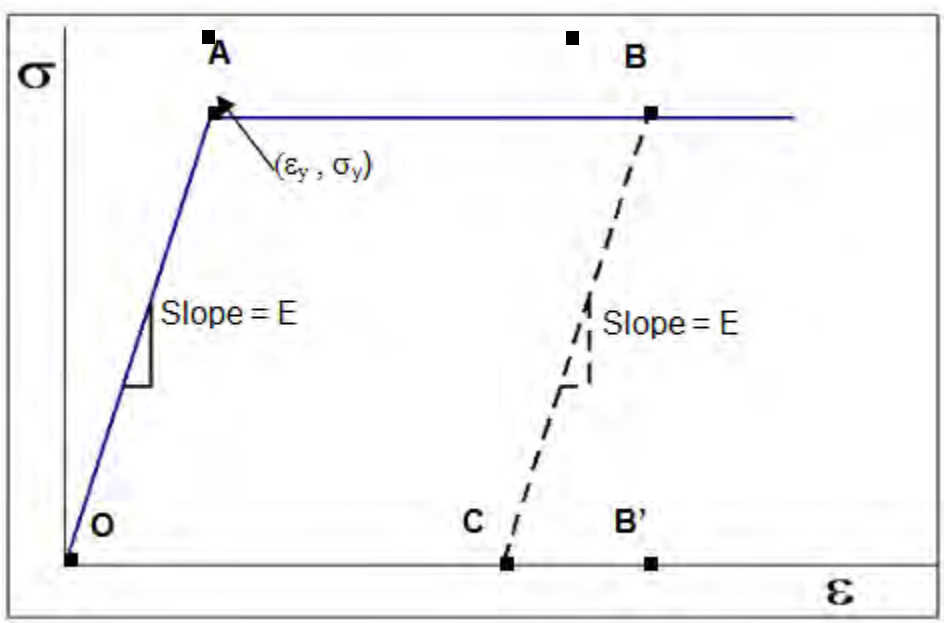

Figure 2. Elastoplastic Model

Material yields at (A). Dashed line represents unloading path if material is released from strain at (B).
Point (C) represents permanent deformation if material is released after reaching strain at (B).
If loaded until stress and strain at point (B): Area OABB'= energy input per unit volume, Area CBB'= energy returned per unit volume, and Area OABC= energy dissipated per unit volume.

2.3 Nonlinear Elastic Material Model

Nonlinear Elastic models (Figure3) describe the behavior of **Hencky materials,** materials in which the required stress increase for a given increase in strain is not constant (variable modulus

of elasticity, often referred to as the tangent modulus). It is important, however, to note that these materials still load and unload along the same path (hence the term 'elastic') and therefore no energy is dissipated these materials.

Energy stored per unit volume=$\int \sigma \delta \varepsilon$ = area under stress-strain curve.

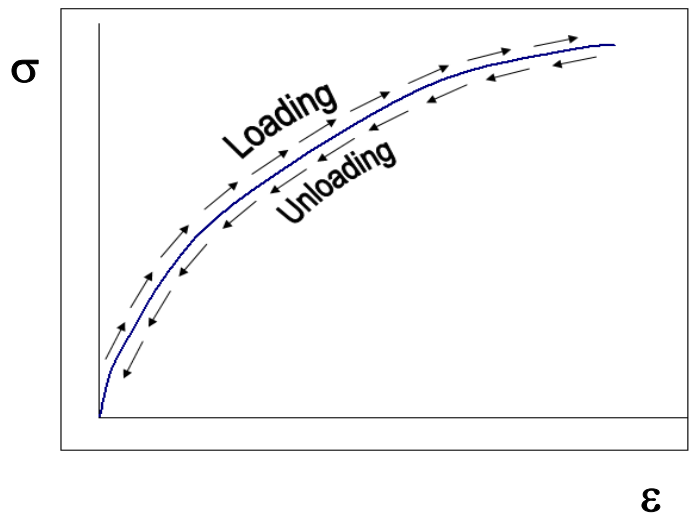

Figure 3. Nonlinear Elastic Model

2.4 Viscous Material Model

A viscous material is one in which stress determines strain *rate*. The model used for a viscous material is the **dashpot**, which is a hydraulic piston cylinder device and can also be called a damper. Ideal viscous materials (Figure 4), also known as **Newtonian fluids** are represented by the **linear dashpot**, which is a dashpot whose stress verses strain rate ratio, defined as its **damping constant**, does not change. Non-ideal viscous materials (Figure 5), known as **Stokes materials** are represented by nonlinear dashpots, simply meaning that the ratio of stress verses strain rate varies for different stress levels. It is important to remember that, for both linear and nonlinear dampers, *none of the strain is recovered*, which means that no mechanical energy is recovered, therefore *all the mechanical energy that acts on them is dissipated (converted to heat energy)*. Also, observe for the following equations that energy (force times distance) is proportional to how quickly deformation occurs, because force is proportional to strain rate.

Damping ratio: $\eta = F/(dL/dt)$= Force/elongation-rate OR $\eta = \sigma/(d\varepsilon/dt)$= stress/strain-rate

Total Energy dissipated=$\int F \delta L$

Energy dissipated per unit volume= $\int \sigma \delta \varepsilon$

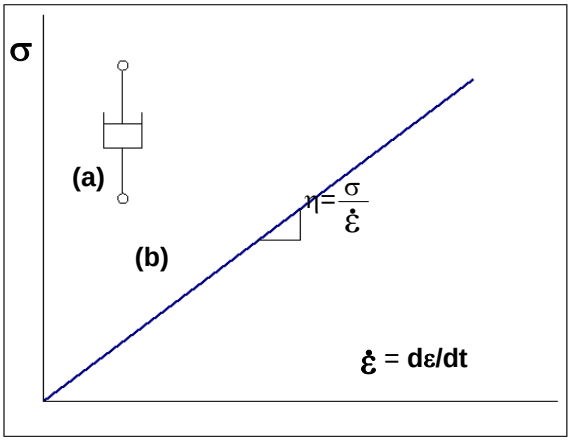

Figure 4. Ideal (Newtonian) Viscous Material

(a) Illustration of a dashpot (b) Graphical representation Newtonian viscous behavior

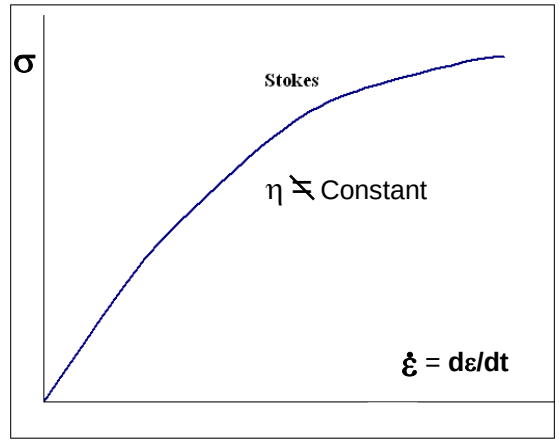

Figure 5. Non-Ideal (Stokes) Viscous Material

2.5 More complex Material Models

Most materials are neither wholly viscous nor wholly elastic. In fact, many materials can be classified as either **anelastic**, meaning that they load and unload along a different path and therefore dissipate energy, but return to the initial shape and size upon unloading, or **viscoelastic**, which means that they posses both viscous and elastic properties, and are therefore capable to dissipate energy as well, albeit with permanent deformation. In reality, virtually all solids are viscoelastic, but we generally only call them viscoelastic if they behave too viscously to be estimated as elastic or vise versa. In the following section, we will discuss a few basic types viscoelastic behavior and how to model them.

2.5.1 The Maxwell Model

Figure 6 illustrates a **Maxwell Model** of viscoelastic behavior. The Maxwell model is simply a spring and dashpot in *series*. Because the spring and dashpot are in series, they will always have the same force acting on them. However, the elongation in the spring depends only on the present force, whereas the strain in the dashpot is the integral product of force *and time*. Once each portion of the material model has been analyzed separately, they can be combined by superposition (i.e. just added together) to get the behavior of the model as a whole. Due to the fact that stress determines the magnitudes of the *total* spring displacement and the *rate* of the dashpot displacement, when a constant load is initially applied ($T=T_o$), the Maxwell model acts just like a spring, but for the remainder of the time ($T>T_o$) it behaves as a dashpot. Each time the load changes, the spring portion responds instantly by deforming in direct proportion to the load and then remains constant, whereas the dashpot simply undergoes a change in strain rate, but without recovering any past deformation. Notice that, because the dashpot is in series, the model will not return to its original position when it is unloaded, therefore energy is dissipated and not all deformation is recovered as shown below:

$$\Delta L \text{ (at time T)} = F_T/k + \int_{T_0}^{T} F/\eta \, dt \qquad \text{OR} \qquad \varepsilon \text{ (at time T)} = \sigma_T/E + \int_{T_0}^{T} \sigma/\eta \, dt$$

If Force/stress is held constant: $\Delta L = F/k + (F/\eta)*\Delta t$ OR $\varepsilon = \sigma/E + (\sigma/\eta)*\Delta t$

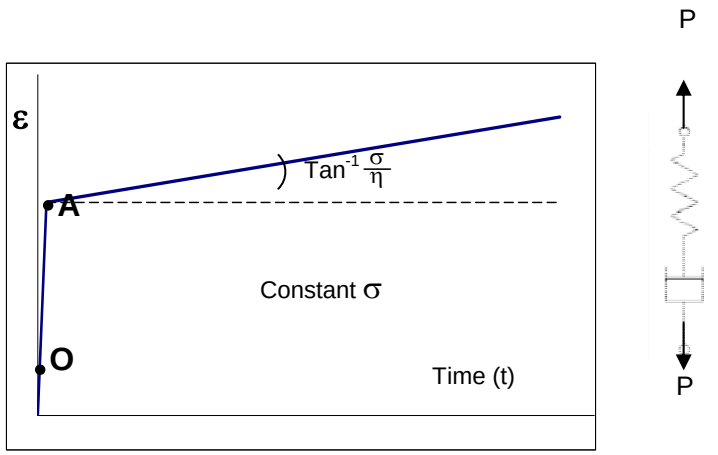

Figure 6. Maxwell Material Model

Graph on left above is general behavior of Maxwell Material subject to constant stress. Line OA is instantaneous elastic deformation, while the line beyond Point (A) represents viscous deformation with respect to time.

Picture on the right above is an illustration of a typical Maxwell Model with applied load (P).

2.5.2 The Kelvin Model

The **Kelvin model** (Figure 7) represents a spring and dashpot in parallel. As a result the spring and the dashpot always have the same strain, but often different forces. For any distinct load, the Kelvin Model has a corresponding distinct equilibrium position, which is exactly the same as that of the spring in the case that the dashpot was not even present. However, because the dashpot always resists strain change in either direction, it will always resist moving toward the new equilibrium position and therefore dissipate energy. It is important to recognize that the Kelvin and Maxwell Models both dissipate energy in the dashpot, but, in the Kelvin model, strain in the dashpot is recovered when the system is unloaded because the spring is connected in Parallel.

To further understand the Kelvin model, it is important to look at a couple of important limiting cases. The first such case is a very slowly applied load. As the rate of increase (or decrease) in load magnitude approaches zero, the rate of strain change approaches zero, which means that the force in the dashpot approaches zero. As the force in the dashpot approaches zero, the model becomes as if it were a spring only. Therefore, it can be concluded that very slowly applied loads are resisted mostly by the spring and not much energy is dissipated in the dashpot.

Conversely, a sudden brief load will result in a large force in the dashpot with very little force in the spring. This is because the dashpot, whose force is proportional to strain rate, forces the system to deform slowly. The spring, whose resistance is proportional to total strain, regardless of strain rate, will never offer much resistance because the system deforms very little under brief loading. In this case, virtually all the energy is dissipated in the dashpot.

From these two extreme cases, we can see that, in addition to the relative strengths of the spring and dashpot, the rate in which loading and unloading occurs is of great significance in determining the force in each and the amount of energy stored and dissipated.

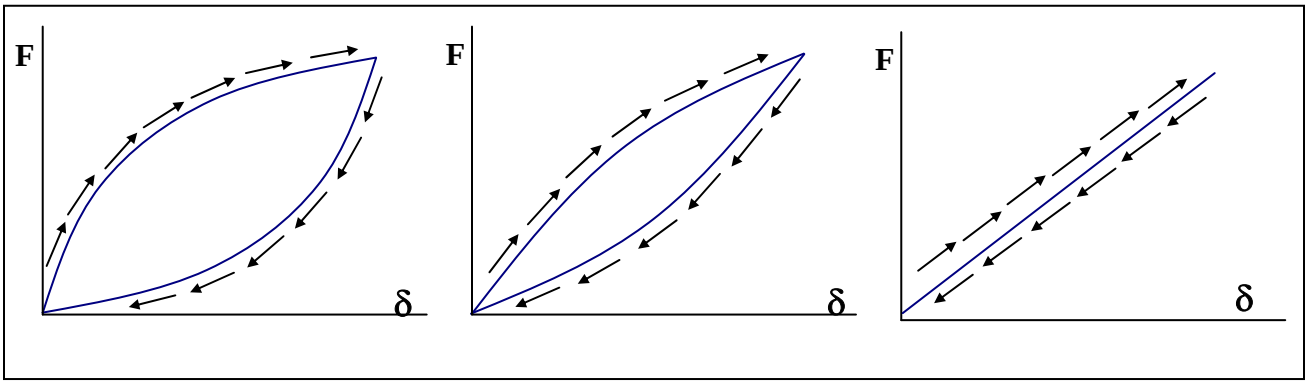

Figure 7. Kelvin Model – Area contained by each loop correlates to total energy dissipated by one loading cycle.

Left: Strong dashpot and/or quick loading and quick unloading = high viscous resistance **Middle:** Relatively slow loading and unloading and/or relatively weak dashpot = low viscous resistance

Right: Infinitely slow loading and unloading or infinitely weak (no) dashpot = no viscous force

2.5.3 The Burgers Fluid Model

A more general material model is the **Burgers Fluid Model** (Figure 8), which consists of a Kelvin model in series with a Maxwell model. This is a fairly general model in that it can simulate a material's ability to store and dissipate energy, deform elastically and viscoelasticaly and recover some, but not all of the strain caused from loading. This model includes all the most basic material properties in conjunction with each other and can be adjusted to represent a wide variety of materials. For higher accuracy, it may often be necessary to add nonlinear and/or elastoplastic springs and non-Newtonian dashpots, but the underlying concepts do not change. For example, TDA (and many soils) will slowly compress over time (settlement/consolidation), but the farther they compress, the slower the compression progresses until they virtually stop compressing. On a small scale, this is primarily due to a reduction in voids, but viewing the material on a larger scale allows us to simplify the analysis by imagining the material as having a nonlinear dashpot in series that 'bottoms out' at the point where the consolidation reaches its limit.

Just like Maxwell and Kelvin models, it is most natural to deal with Burgers Fluid models in terms of force and displacement, but these can easily be generalized to stress and strain to represent a material independently of its size.

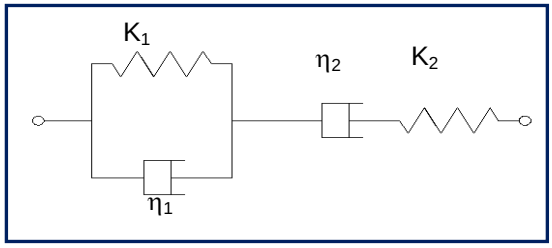

Figure 8. Illustration of Typical Burgers Fluid model

Linear springs and dashpots are used in this example, but they do not necessarily need to be linear

2.5.4 We've Presented the Models: Now What?

For engineers, it is important to understand the concepts of these material models. Although one is never likely face a situation in which they are required to analyze a material as a system of springs and dashpots in regular engineering practice, they are likely to work with viscoelastic materials and it is important to use their knowledge of material mechanics to predict things such as deflections, short and long term settlement, energy absorption, etc. For the remainder of this chapter we will examine one way in which engineers are using the knowledge of viscoelastic properties to utilize TDA in civil engineering projects.

3.0 Case Study: Vasona Light-Rail Project

3.1 What are we looking for?

Tire Derived Aggregate (TDA), because it is made of viscoelastic particles (rubber), has the possible benefit of mitigating vibration. However, to design an experiment to test only whether or not vibration is mitigated by TDA would fall far short of answering the bigger question which is, "Should we use TDA as subbase under the railway or not?" To answer the bigger question, it is important to weigh the benefits verses the costs. This raises several smaller questions such as; how *well* does the TDA mitigate the vibration? How great a benefit is there if the vibration is mitigated? How well does the TDA perform structurally compared to the alternative? What is the environmental impact? Will construction costs increase or decrease?

To answer these questions, the following experiment was conducted by the California Integrated Waste Management Board (CIWMB), the Valley Transit Authority (VTA), Korve Engineering, Wilson, Ihrig &Associates, and Dr. Dana N. Humphrey (University of Maine) at the VTA maintenance yard in San Jose, CA.

3.2 Experiment Design

A test track was constructed using a minimum of 12 inches of tire shreds as subbase wrapped in geotextile and laid horizontally on the south side and horizontally angled up on the North side and covered by a minimum of 12” of ballast and 12” of sub-ballast. The continuous steel rails were placed on concrete ties and connected to a control section with 8” of ballast and 8” of sub-ballast. Dial gauges with an accuracy of 0.001” were used to measure rail deflection while strain in the rails was monitored by strain gauges located at the top and bottom of the rails. Vibration transducers were mounted on spikes placed in the ground near the track in order to monitor vibration levels.

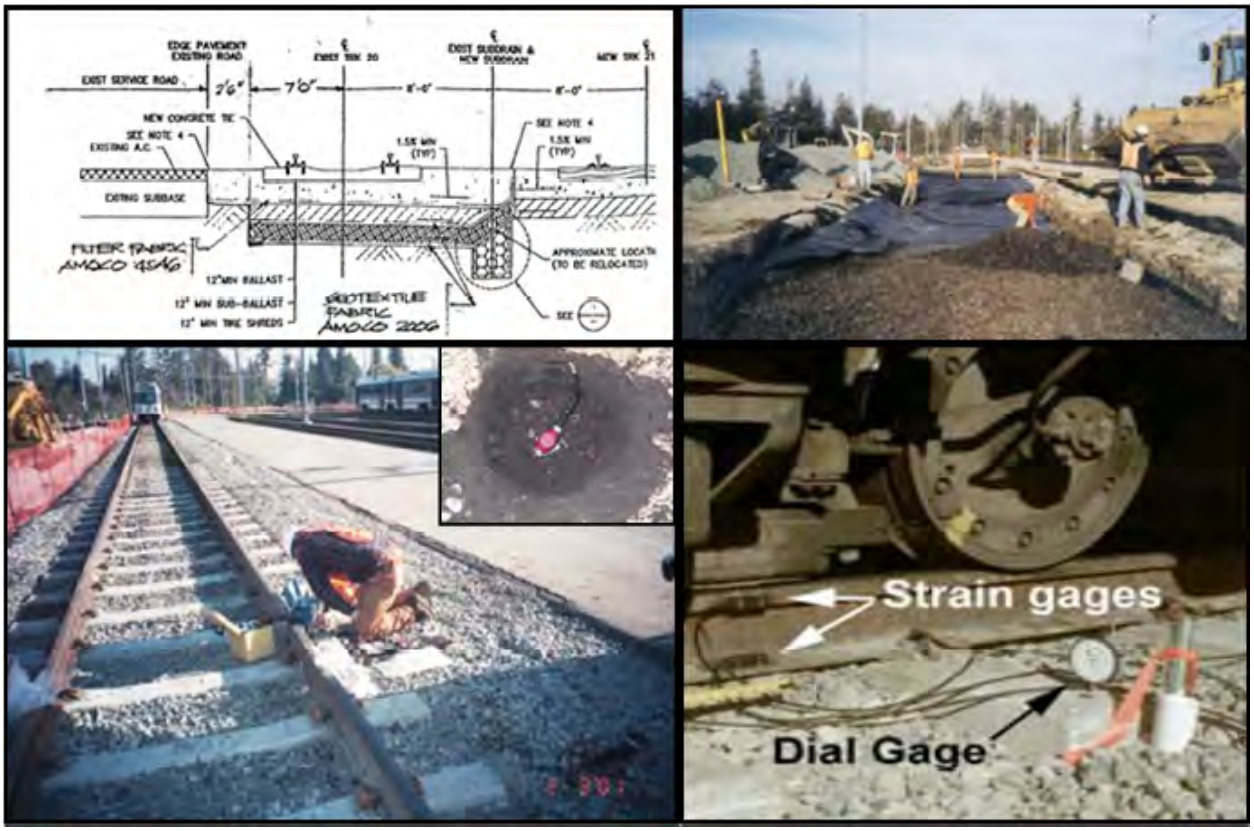

Figure 9. Test track Plans and Construction

Top Left: Test track cross-section **Top Right**: Workers covering TDA subbase with geotextile

Bottom Left: Finished test track and picture of vibration sensor **Bottom Right**: Strain and dial gage setup

3.3 Results

Test results showed that using tire shreds beneath the rail line did reduce vibration levels significantly. The tire shred section was also structurally sufficient. The elastic deformations cased by the light-rail were slightly higher than those of the control section, but still within the tolerable range. There was however, some permanent deflection of the ties, which means that they may need to be re-leveled more frequently. The most significant train vibrations are in the range from 10 to 250 hertz. Vibrations of 10 to 80 hertz are felt whereas 20 to 250 hertz is in the

bottom of the audible range. The graph shows a reduction in ground borne vibrations in this frequency range, and in fact demonstrated an order of magnitude reduction at 63 hertz, with even better performance at higher frequencies. The estimated cost of the track was determined to be about $121 per foot, which was higher than the price of $100 per foot for normal track sections but much lower than cost for sections of track using an alternative method of vibration mitigation, which ranges from $600 to $1000 per foot.

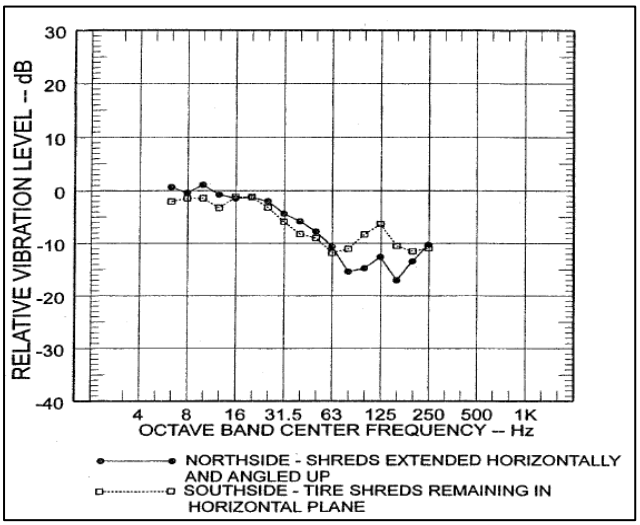

Figure 10. Vibration Mitigation

This is a graph comparing the vibrations of the track with TDA subbase to a typical track section. The zero decibel line represents normal vibrations and the two lines represent vibration form their respective TDA sections relative to the normal vibration. This shows TDA subbase reduces vibration significantly. The Bel scale is logarithmic, so negative ten decibels means one-tenth the normal vibration and negative twenty decibels means one-hundredth the normal vibration, etc.

3.4 Case Study Conclusion

When vibration is of no concern, it is best to use conventional track design. However, when vibration is a concern (near houses or businesses for example), TDA can be used to reduce vibration for a relatively small cost increase without sacrificing track performance. In fact, TDA worked so well that VTA chose to use tire shreds for several sections of the Vasona Light Rail Project where vibration reduction was needed due to close proximity to houses and businesses.

4.0 Summary and Conclusions

Some materials, such as TDA, have very complex behavior that is extremely difficult to analyze. However, material models, which are completely different, can be calibrated to behave very similarly at a macroscopic level. What this means is that, even though many materials such as TDA are not made out of springs and dashpots, their overall behavior can be accurately modeled and predicted using combinations of springs and dashpots. Oftentimes, rather than making an

actual spring and dashpot model, test data for a given material is collected and then used to formulate and calibrate empirical equations and/or graphs to fit the materials behavior. The empirical approach is often simpler and thus more common, but it is important not to get lost in the numbers. Understanding the concepts of how material models work and the types of properties associated with different behaviors will greatly enhance the ability of the engineer to understand conceptually how a material will behave. For example, from looking at the three materials in figure 7, it should be apparent that the one represented by the graph on the far right would work best for a diving board (it restores mechanical energy, which would help a diver to jump high), while the one on the far left would work the best for constructing a wrestling mat (it dissipates a lot of energy). In this example, they may both be required to resist similar forces and impact energy, but performance is based on *how* they handle loads, not just whether or not they can withstand them without failing.

TDA has been discovered as a great subbase under light rails where vibration mitigation is needed (and for many other engineering applications) because, like our example with diving boards and wrestling mats, engineers are trying to find materials that do not just work, but perform well. TDA is a great material for many applications because of its performance, low cost, and positive environmental impact.

5.0 References

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CIVL 312 Structural Testing Lab

1.0 Introduction

The civil engineering market encompasses a wide range of uses for scrap tires. Scrap tire materials typically replace other material currently used in construction such as lightweight fill materials, drainage aggregate, or even soil. A considerable amount of tire shreds for civil engineering applications come from stockpile abatement projects.

Tires that are reclaimed from stockpiles are usually dirtier than other sources of scrap tires and are typically rough shredded for these applications. Many civil engineering applications can accommodate this dirtier material.

California alone generates about 40 million waste tires each year. To reduce the stockpile of waste tires, the CIWMB has increased its efforts to turn these waste tires into useful products. One of the major applications of waste tires is the use of tire derived aggregates (TDAs) in civil engineering applications. There are two types of TDA, shown in Figure 1, commonly used in civil engineering applications, namely, Type A and Type B. Type A TDA, with particle sizes typically less than three inches, is mainly used as a drainage material, in septic leach fields, and for vibration dampening beneath railways, etc. Type B TDA has larger size tire shreds than those of Type A TDA. The particle sizes of Type B TDA are normally up to about 12 inches across. The Type B TDA's are mainly used as lightweight fill material for embankments or as light weight backfill for retaining walls.

Figure 1. Type A TDA (left) and Type B TDA (right)

The civil engineering applications that use TDA include:

- Subgrade fill and embankments
- Backfill for retaining walls and bridge bbutments
- Subgrade insulation for roads
- Lateral edge drains
- Vibration damping layer beneath rail lines
- Landfill applications

- Septic system drain fields

Of particular interest in this module is the use of tire shreds to construct embankments and fills over weak, compressible foundation soils. Tire shreds are viable in this application due to their light weight, typically weighing 1/3 to 1/2 that of the soil it replaces. Using tire shreds as a lightweight fill material may be significantly cheaper than other alternatives, especially if scrap tires are readily available and light weight fill is not. Subgrade fill and embankment applications include: protecting roads from erosion, enhancing the stability of steep slopes along roadways, and reinforcing roadway shoulder areas. The light weight of the tire shreds also reduces horizontal pressures and allows for construction of thinner, less expensive retaining walls. Tire shreds can be used to reduce problems with water and frost build up behind walls because tire shreds are free draining and provide good thermal insulation.

To use scrap tire products in civil engineering applications, several material properties need to be established. Some of the properties that engineers need include:

- Gradation
- Specific Gravity and Absorption capacity
- Compressibility
- Resilient Modulus
- Time Dependent Settlement of TDA Fills
- Lateral Earth Pressure
- Shear Strength
- Hydraulic Conductivity (Permeability)
- Thermal Conductivity

In this chapter the shear strength of scrap tire products will be investigated. Since this material was developed to be introduced in a materials testing lab, which typically deals with solid materials like steel and wood, the student needs to be introduced the fundamental behavior of discrete materials, like TDA. In courses on Strength, or Mechanics of Materials, students cover Continuum Mechanics, which deal with materials with a uniform distribution of matter. These materials are idealized as possessing no voids and are cohesive, i.e. all portions are connected together, and have no breaks, cracks, or separations. The materials dealt with in this chapter, including crumb rubber and TDA are discrete materials, which contain air voids and may or may not possess cohesion. They will display mechanical properties similar to the sands and gravels that they replace.

1.1 Objectives

The objective of this lesson plan is to give students an understanding of the shear strength of scrap tire products. They are introduced to civil engineering applications of TDA and to the mechanical properties required to design these projects. In particular, the factors affecting the shear strength of TDA will be presented. Determining the shear strength of TDA is not possible given the size of the testing equipment available in a normal Materials Testing Lab, so tests will be conducted on crumb rubber samples (also a scrap tire product). A direct shear testing machine is used to determine the relationship between shearing strength and normal stress for a crumb

rubber sample. Values of both c and ϕ in the Mohr-Coulomb failure criteria will be estimated for the crumb rubber sample.

2.0 Factors Affecting the Shear Strength of TDA

In the study of continuum mechanics, deformable bodies develop both normal (tension or compression) and shear stresses when acted on by applied loads. Brittle materials fail in tension *perpendicular* to the maximum tensile stress whereas ductile materials fail in shear *parallel* to the maximum shear stress. The Poisson's ratio, ν, relates the transverse contraction to the longitudinal elongation (or vice versa) and that the range for ν is $0.25 < \nu < 0.34$ for most civil engineering materials.

Scrap tire products (including TDA, crumb rubber, and tire buffings) are a discrete material and can support compression but not tensile stresses and typically fails in shear along a plane of weakness. There are four factors that affect the shear strength of crumb rubber and TDA:

- Size and shape of the rubber pieces.
- The density (packing) of the sample at the beginning of the test.
- Magnitude of the compressive normal loading, and
- The orientation of the particles in the sample.

2.1 Size and Shape of the Scrap Tire Rubber

The crumb rubber sample is "uniformly graded" i.e. all the particles are nearly the same size and are approximately cubical in shape. On the other hand, TDA (Tire shreds) are also fairly uniformly graded but are irregularly shaped, being more plate like. The following plots show typical gradation curves for TDA, crumb rubber, and rubber buffings:

Figure 2. Particle Size and Shape of Tire Buffing (top) and Crumb Rubber (bottom)

Figure 3 shows the gradation for Type A TDA from multiple manufacturers and demonstrate that the samples are generally uniformly graded (same size). However, the maximum size varies according to manufacturer. The gradation tests were conducted according to ASTM D 422 standards. Gradation curves shown in Figure 4 for Type B TDA, are again uniformly graded with particle sizes that would be considered as coarse gravel and boulders.

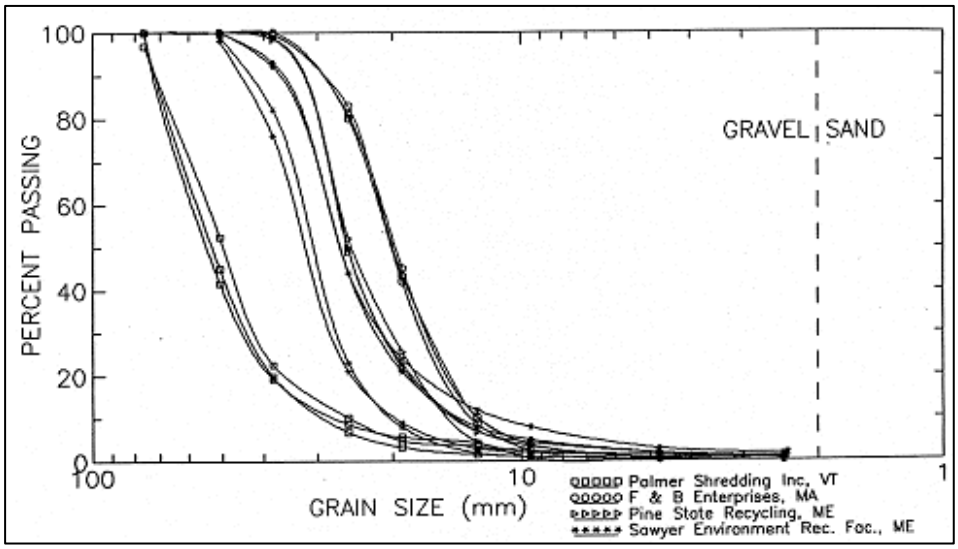


Figure 3. Gradations of Type A TDAs from Different Manufactures

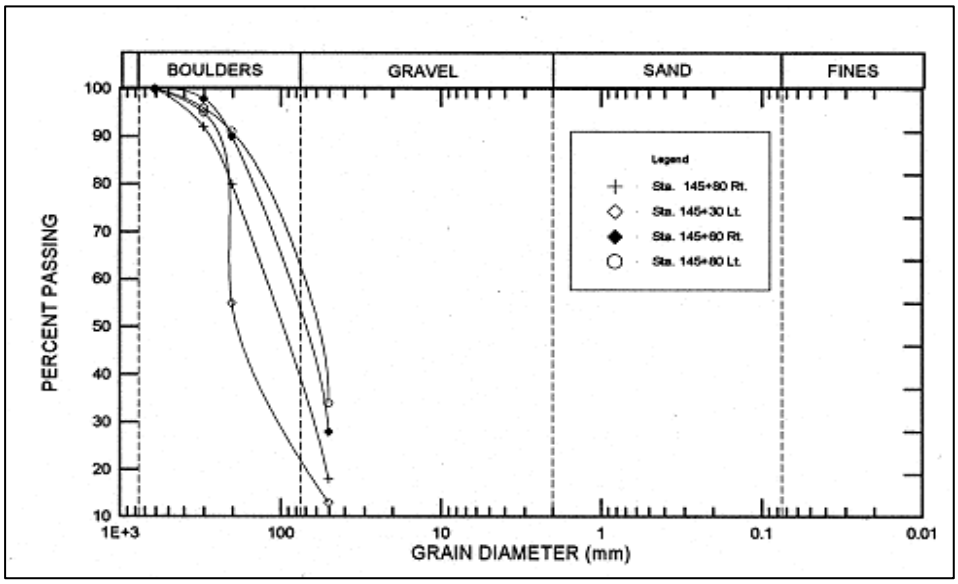


Figure 4. Gradations of Type B TDAs from Different Manufactures

The following figures show the gradations of crumb rubber and tire buffing used as tire rubber in the shear test sample at CSU, Chico.

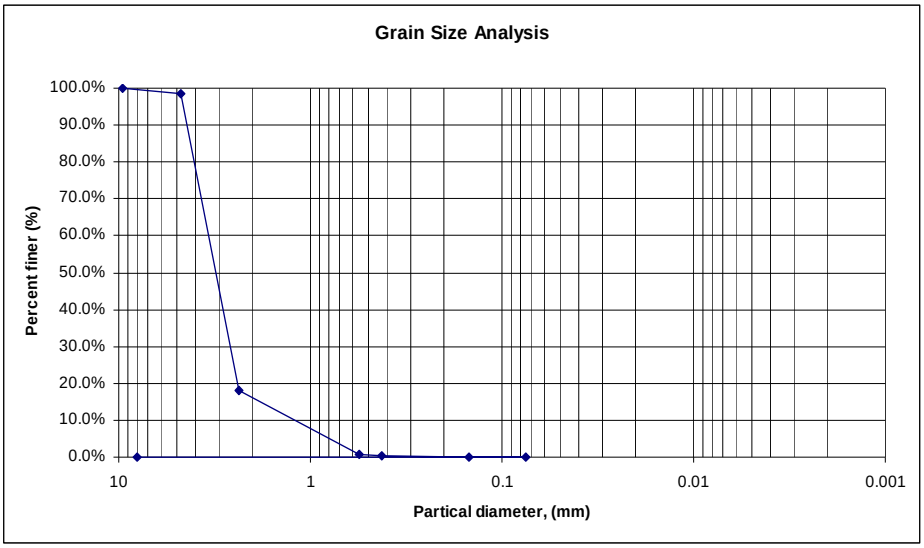


Figure 5. Gradation of Crumb Rubber Particle Sample Used in CSU Chico

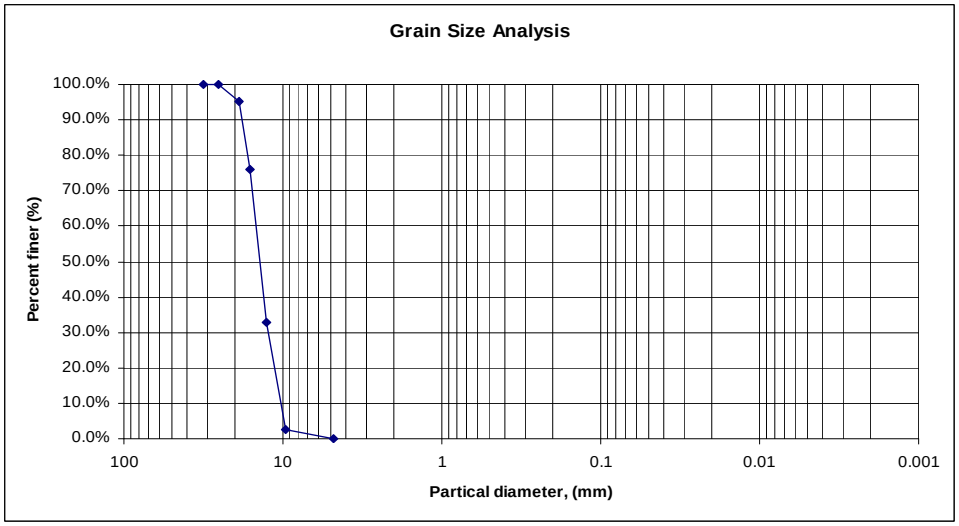


Figure 6. Gradation Curve for Tire Buffings Used in CSU Chico

2.2 Effect of Density of Tire Rubber

The second factor influencing the shear strength of granular materials is the density (packing) of the sample at the beginning of the test. The preparation of the sample may influence the shear stress/strain behavior of the specimen. Initially loose samples will decrease in volume as the sample is sheared whereas initially densely packed samples will “dilate” or expand as the sample is sheared. This phenomena require measuring the displacement perpendicular to the direction of loading to determine which behavior the sample exhibits.

The relative volume change characteristics of the sample are a function of the void initial ratio, e, defined as volume of voids/ volume of solids. Densely packed samples posses a low void ratio and will dilate when sheared whereas loosely packed samples possess a high void ratio and will densify when sheared. For uniform spheres, both loose and densely packed, the following graph shows both the change in shear stress and void ratio as a function of the shear displacement of the sample:

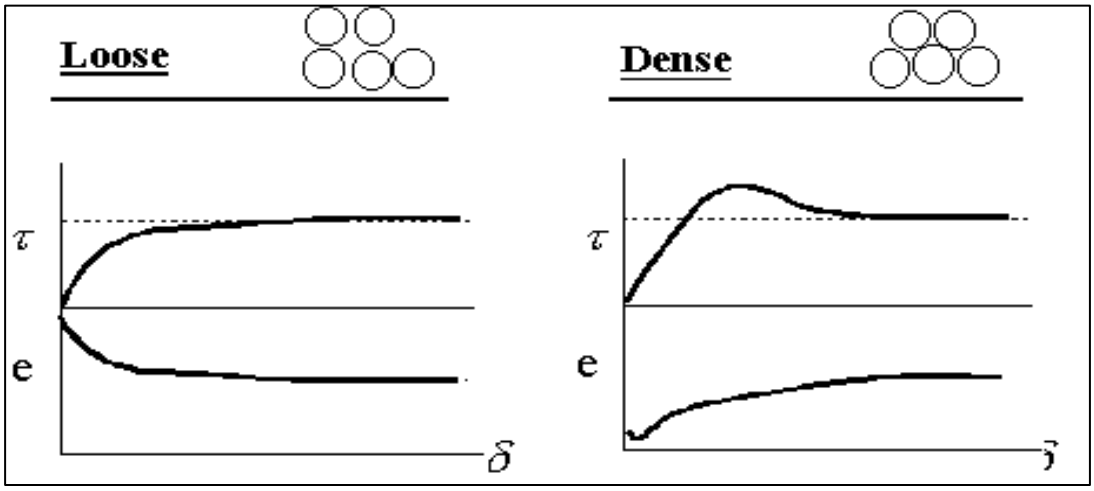


Figure 7. Shear Stress and Void Ratio Changes with Horizontal Shear Displacement

Note that there exists a void ratio, called the critical void ratio, which is the void ratio that either type of sample reaches after being sheared. The critical void ratio is also the transition point between the two types of volume change behavior when sheared. In other words, it is the highest void ratio where dilation will occur when the sample is sheared.

2.3 Normal Force Effect on Shear Strength

The third factor that influences the shear strength of a granular material is the magnitude of the normal force (perpendicular to the applied shear force) loading. As the normal stress on the sample is increased, the shear strength of the sample increases. The relationship between the normal stress and the shear stress for a granular material like crumb rubber and TDA is given by Mohr-Coulomb failure criteria:

$$\tau = c + \sigma \tan\phi$$

τ = shear stress on the failure plane
σ = normal stress on the failure plane
c = the cohesion intercept (= 0 for granular materials)
ϕ = angle of internal friction (slope of the line relating shear stress to normal stress).

Although TDA is a granular material, it possesses apparent cohesion under compressive loading similar to cohesive soils.

The focus here is on determining the shear strength of scrap tire products. There are two commonly available laboratory tests for accomplishing this: Triaxial Test and Direct Shear Test.

The triaxial testing machine shown in Figure allows for the application of a confining stress by pressurizing the sample with air or water pressure, which surrounds the sample. Vertical load can then be applied to the specimen until failure is reached. This vertical load produces stress in the sample above the confining stress, called the deviatory stress. This deviatory stress forms the diameter of Mohr's circle, which increases with increasing confining pressure for TDA drained test.

Figure 8. Typical Triaxial Shear Testing Apparatus

The results of a triaxial test on a cohesionless material in the drained configuration (meaning no pore water pressure can be developed, which is the case for a dry granular material) is shown in

the following figure. Note that the line that is tangent to the failure Mohr's circle passes through the origin (zero cohesion) and has a slope equal to the angle of internal friction for the material. Combinations of shear and normal stress that have Mohr's circles that fall below this envelope, will not result in failure of the specimen, values above would represent failure of the sample.

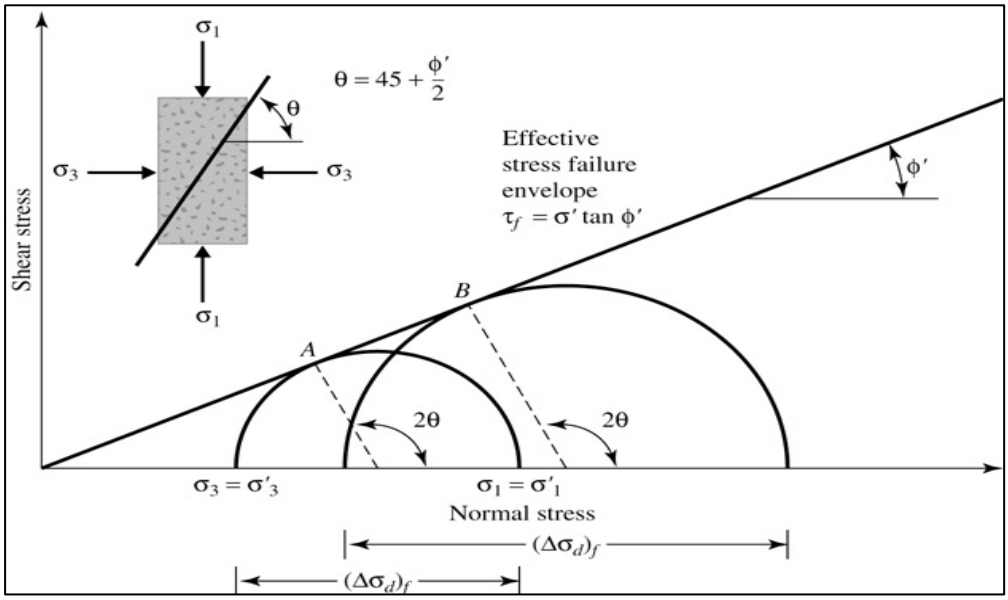


Figure 9. Example Failure Envelope from Triaxial Test

The second test procedure commonly done in the lab is the direct shear test. Figure 10 shows the apparatus for the direct shear test:

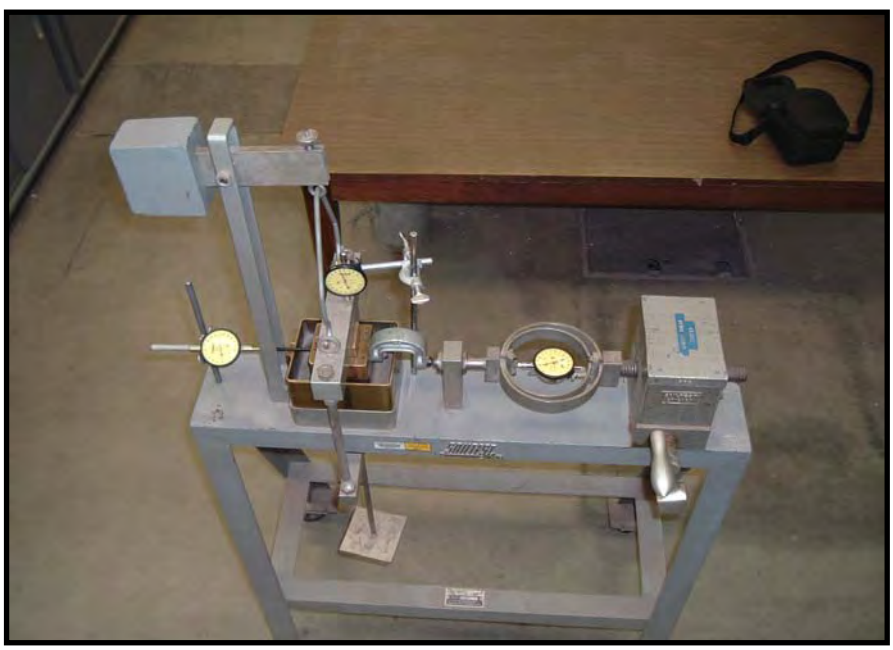


Figure 10. Typical Direct Shear Testing Equipment

The test equipment consists of a metal shear box in which the sample is placed. The box can be square or circular. Square boxes are usually 2"x2" or 4"x4" squared and 1" high.

The box is split horizontally into two halves as shown in Figure 11.

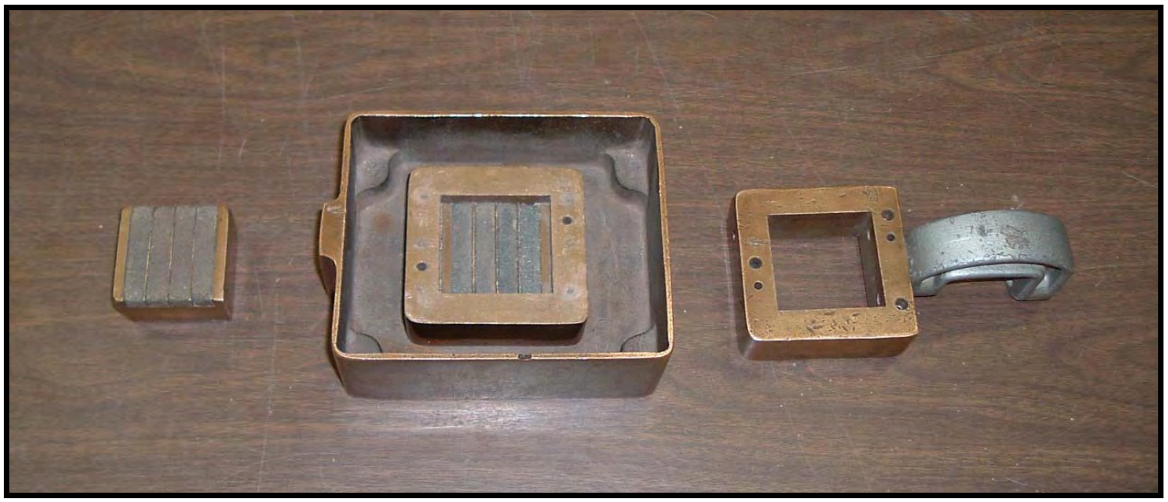


Figure 11. Shear Box Components of a Direct Shear Apparatus

Normal force on the sample is applied from the top of the shear box (on the left above). The shear force is applied by moving the upper halve of the box relative to the lower halve of the box as shown below:

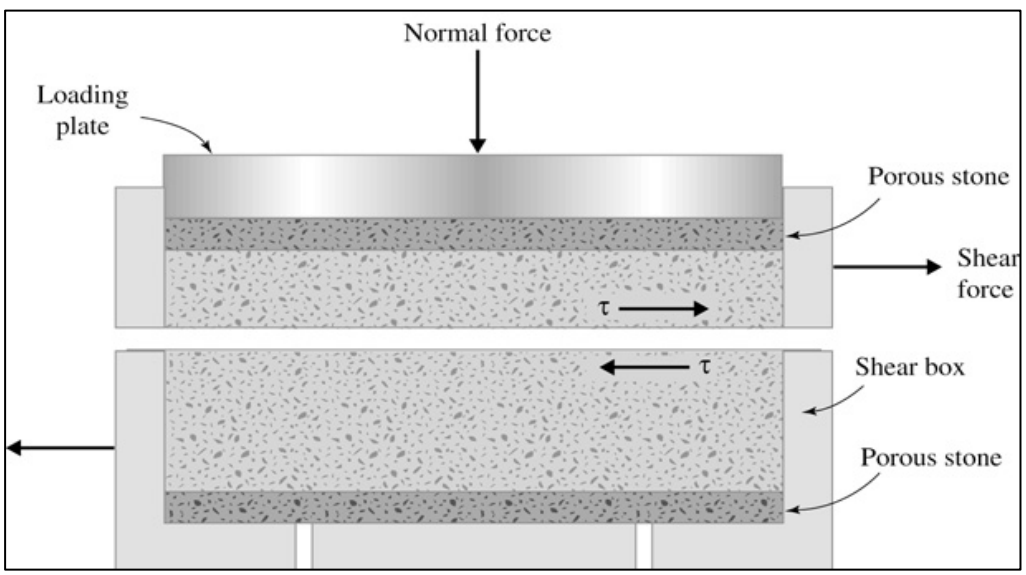


Figure 12. Schematic of Shear Box Set Up and Loading

During the test, the shear displacement along the shear plane is recorded by a horizontal dial gauge, and change in the height of the specimen is measured by a vertical dial gauge (to allow for calculation of change in volume). The normal force is applied as a dead loading weight acting vertically on the specimen shown in Figure 13.

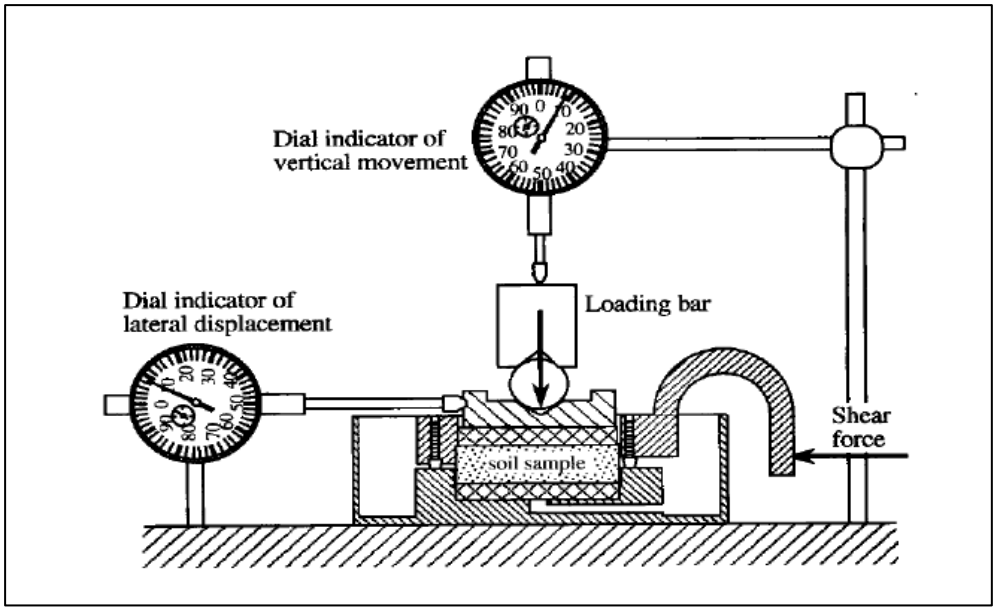


Figure 13. Force and Displacement Measurement of Direct Shear Test

Illustrated in Figure 14, as one half of the specimen is forced to slide relative to the other half of the specimen, a resisting shear force is developed on the shear surface between the boxes. The shear force can be measured by a horizontal proving ring or load cell. The normal stress is calculated from the normal force and the cross sectional area of the shear box. The shear stress is calculated from the shear force and the cross sectional area. At the initial stage of a test, under a given normal stress, shear stress (resistance) will gradually increase with increasing shear displacement. The resistant shear stress will reach a maximum, then it will no long increase or might even decrease, as indicated in the shear stress versus shear displacement curve below. Physically, this means failure has occurred and the sample is no longer able to support additional shear stress.

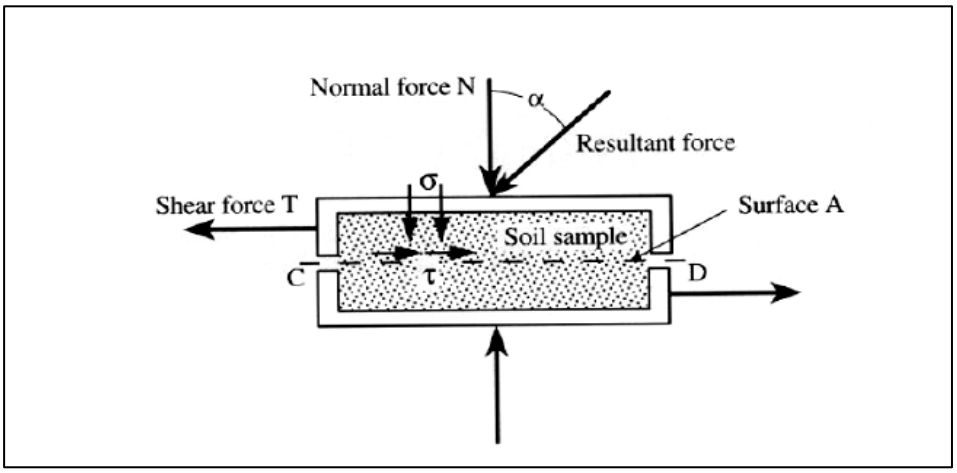


Figure 14. Normal Force and Shear Force for Direct Shear Tests

For each test at a specific normal stress, the maximum shear stress is recorded and the normal stress and the corresponding shearing stress are plotted as a point on the sigma versus tau coordinate system. For a given soil, multiple direct shear tests are performed at different normal stresses. The normal stresses and the corresponding maximum shear stress obtained from a number of tests are plotted on the σ-τ coordinate system as shown in Figure 15:

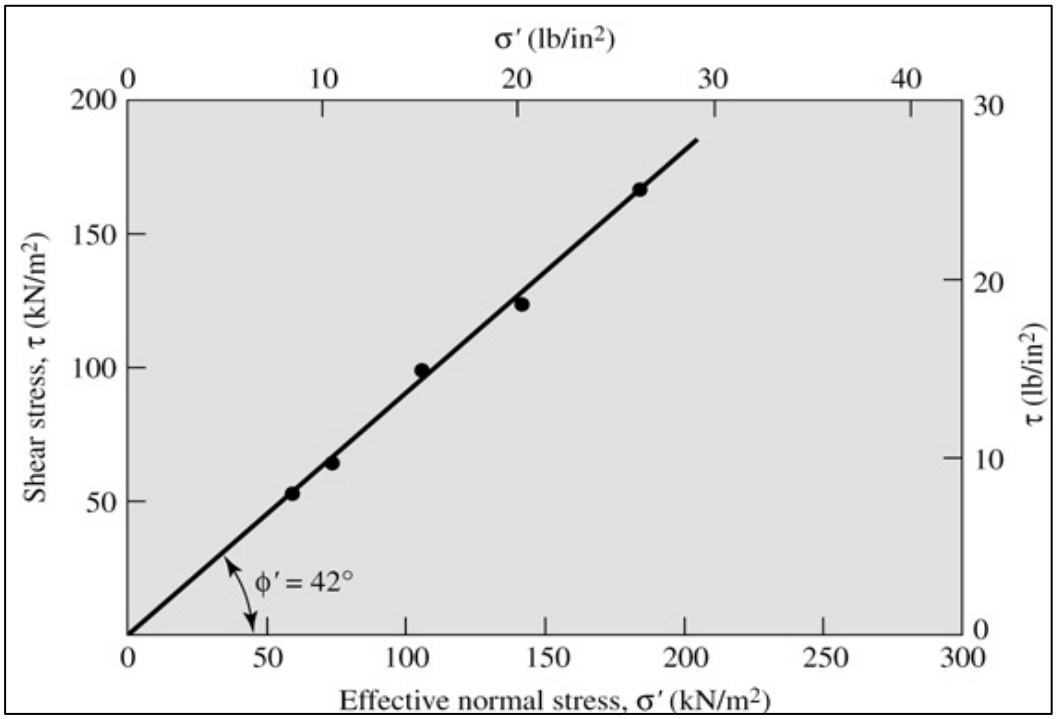


Figure 15. Normal Force versus Shear Strength of a Direct Shear Test

The test data will generally exhibit an approximately linear relationship. Using the least-squares method, a best fit line can be determined. This best fit line is the failure line, having an equation that is defined by the Mohr-Coulomb failure criterion. Therefore, the slope of the line is tan ϕ'(internal angle of friction) and its intersect with the τ axis is c' (cohesion)

The following curves in Figure 16 show the shear stress and sample height change versus shear displacement plots for both loose and dense granular soil samples. For loose sand samples, shear stress develops and increases to resist sliding until a failure shear stress, τ_f is reached. After that, the curve levels off, and the shear resistance remains approximately at τ_f. This failure stress (τ_f) is defined as the ultimate shear strength of the sample. For dense samples, the resisting shear stress increases to a peak value (called the Peak Shear Strength), decreases some, then approaches a constant value which is equal to the ultimate shear strength of the sample.

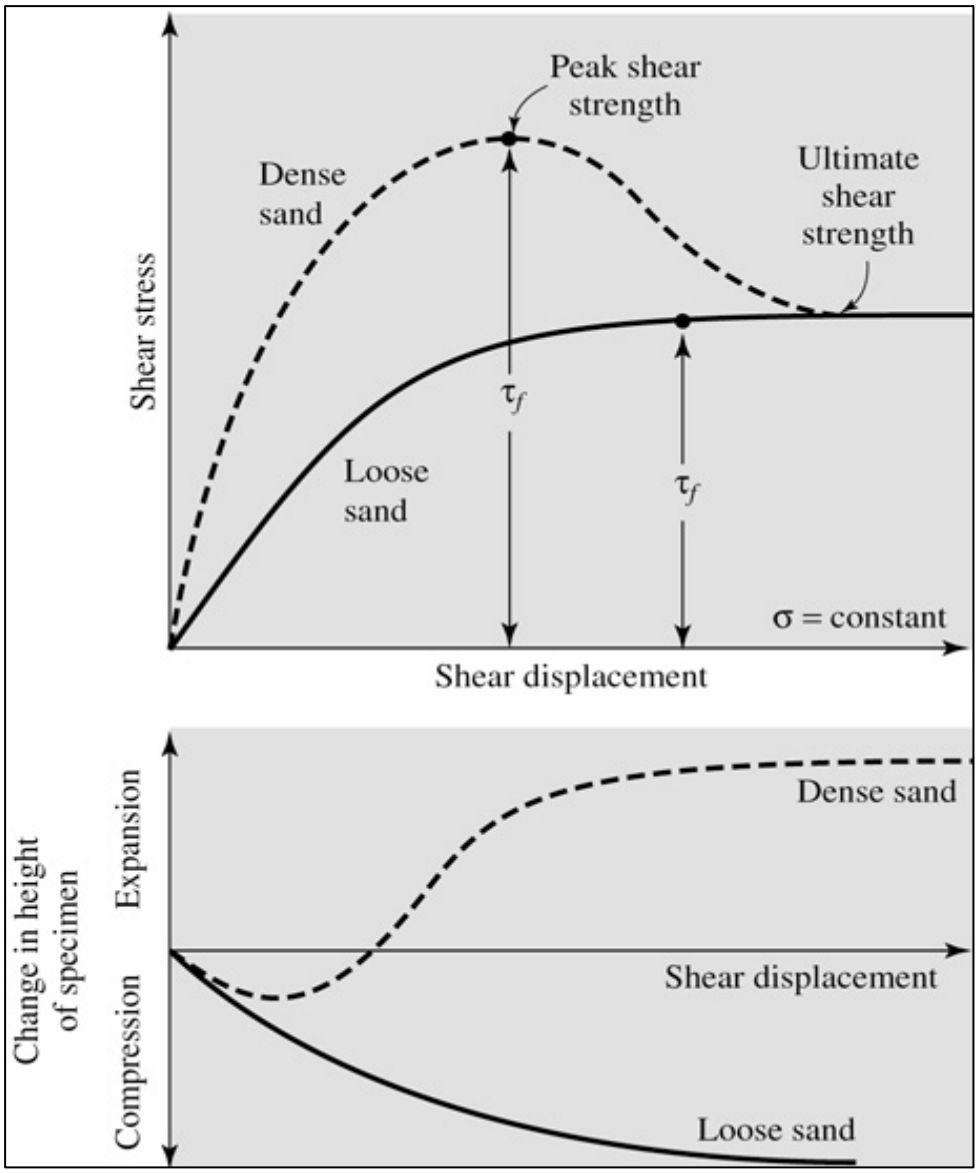


Figure 16. Direct Shear Test Results Comparison between Loose and Dense Sand

The direct shear test method has some distinct advantages and disadvantages. Disadvantages include the fact that the sample is forced to fail along the plane of the split of the shear box, instead of along a plane of natural weakness. Also, the distribution of shear stress is not uniform, but assumed to be uniform across the sample. Advantages include the fact that the tests are simple to perform, and it is a good method for testing the shear strength along contacting surfaces of different materials (e.g., TDA and foundation materials).

2.4 Orientation of TDA Particles

The fourth factor influencing the shear strength of TDA is the orientation of the particles. A random orientation would have different shear strength characteristics than if the sample were

oriented either horizontally or vertically in the shear box. No data currently exists that compares the effects of orientation on the shear strength of TDA.

3.0 TDA Shear Strength Measurement from Literaure

It is important to know the engineering properties of the TDA, especially the shear strength of the large size Type B TDA, in embankment fill and retaining wall backfill applications. The shear strength of TDA may be determined in the laboratory by conducting direct shear or triaxial tests. Results on smaller tire shreds are available in the literature. However, due to the large size of tire shreds of Type B TDA, which are as big as 12 inches across, the direct shear or triaxial tests are seldom used due to the size limits of the direct shear boxes or triaxial loading cells that are commonly available. The triaxial test shouldn't be used for tire shreds with protruding steel belts as it may puncture the membrane containing the sample.

Estimating the shear strength of 3 inches or larger sized TDA from smaller size tire shred shear test data may not be suitable because large tire shreds have different size, shape, and tire particle contact patterns than small tire shreds. The following graph compares the shear stress versus horizontal deformation for a 2 inch minus TDA with three different normal stresses (250, 500 and 1000 psf). These curves indicate a loose initial state behavior for the TDA sample with no dilation as the rate of shear stress increase decreases with an increase in shear displacement.

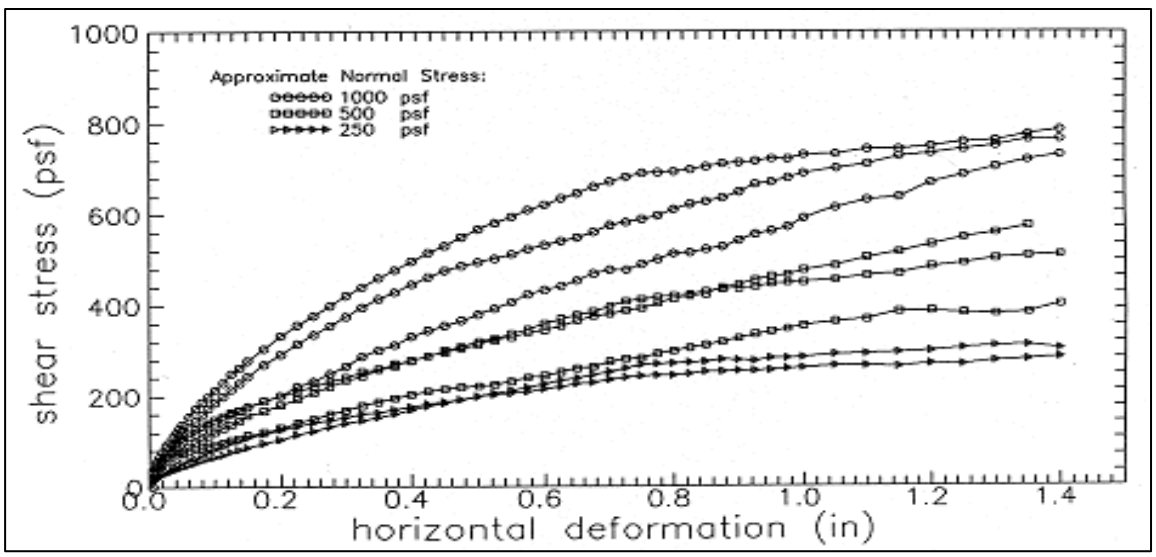


Figure 17. Shear Stress vs. Horizontal Deformation for Pine State Recycling Tire Shreds Tested in Direct Shear Box (Humphrey, 2003) .

The following graph compares the failure envelopes for tests conducted at low stress levels, less than 2000 psf. In all cases, the failure envelopes were non-linear and concave down. Therefore, tests should be conducted at normal stresses close to what would be encountered in the field if a linear failure envelope is to be fit to the data.

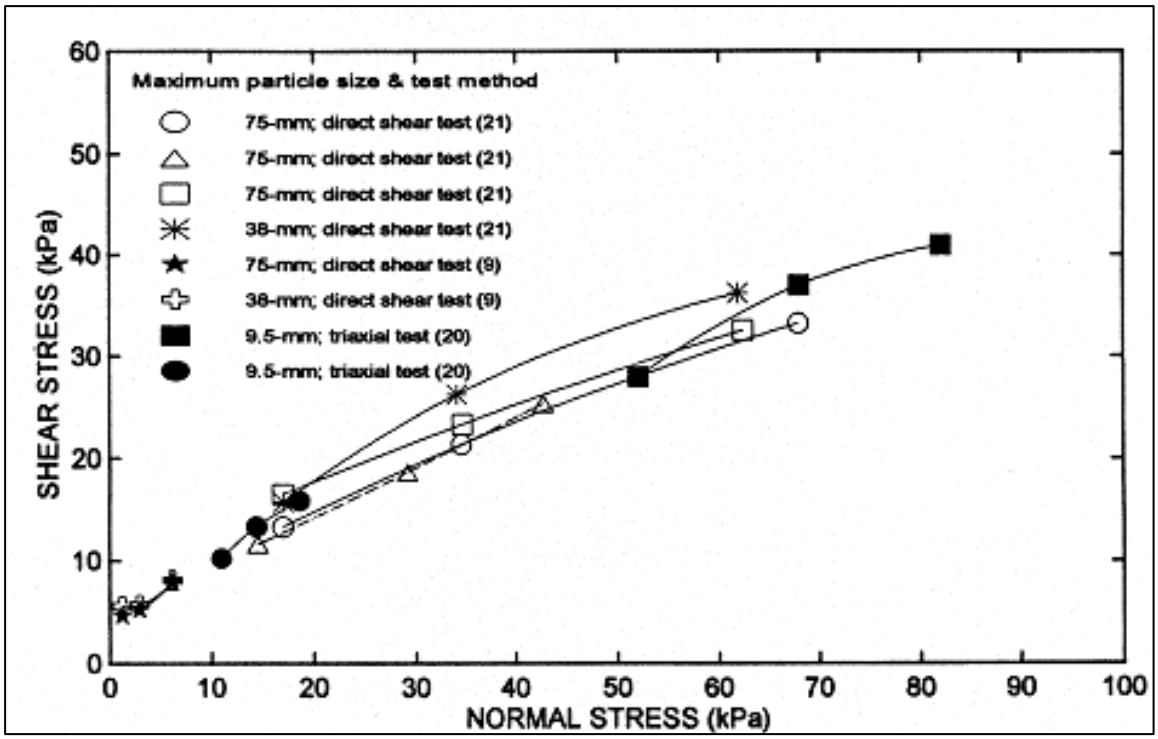


Figure 18. Comparison of Failure Envelopes of TDA at Low Normal Stress Levels (less than about 2000 psf)

Tests on 0.5-in and 1-in tire shreds at higher stress levels produce failure envelopes that were approximately linear. For high stress tests, using a failure criteria of 15% axial strain, Ahmed (1993) obtained cohesion intercepts from 572 to 689 psf and friction angles from 15.9 to 20.3 degrees.

4.0 Student Lab Assignment Example: Direct Shear Testing of Crumb Rubber

The following document is the lab report developed for introducing students to the shear strength of waste tire products. Direct shear testing of crumb rubber is investigated in this lab exercise.

4.1 Objective

To determine the relationship between shearing strength and normal stress for a crumb rubber sample using the direct shear testing machine. Values of both c and ϕ in the Mohr-Coulomb failure criteria will be estimated for a crumb rubber sample.

4.2 Background

In many engineering problems such as design of foundation, retaining walls, slab bridges, pipes, sheet piling, the value of the angle of internal friction and cohesion of the soil involved are required for the design. The direct shear test can be used to predict these parameters quickly. This laboratory activity covers the laboratory procedures for determining these values for granular materials. The Mohr-Coulomb Failure criterion is given as:

$$\boldsymbol{\tau = c + \sigma \tan\phi}$$

where τ = shear stress on the failure plane

σ = normal stress on the failure plane

C = the cohesion intercept (= 0 for granular materials)

ϕ = angle of internal friction (slope of the line relating shear stress to normal stress).

The internal angle of friction, ϕ is a function of the grain size distribution (gradation), particle size and shape, and the method of compaction of the sample. A densely packed sample will dilate when loaded at a higher shear stress than a loosely packed sample, thus increasing the internal friction angle.

4.3 Equipment

Direct Shear Testing Apparatus

1. Shear box
2. Loading frame for vertical and shear loading
3. Dial gauges.
4. Proving ring with dial gage.

4.4 Description of Equipment

Figure 19 shows a direct shear test machine, which shows shear box, normal force tray, gauges for measuring both horizontal and vertical displacements, calibrated proving ring, and shear loading drive assembly. The strain controlled direct shear test machine consists of a shear box, loading units for both applying the shear force, and for applying the vertical normal force , calibrated proving ring for measuring shear force, dial gauges to measure both shear deformation and volume changes. A two piece square shear box is the type that will be used in this lab (see Figure 20).

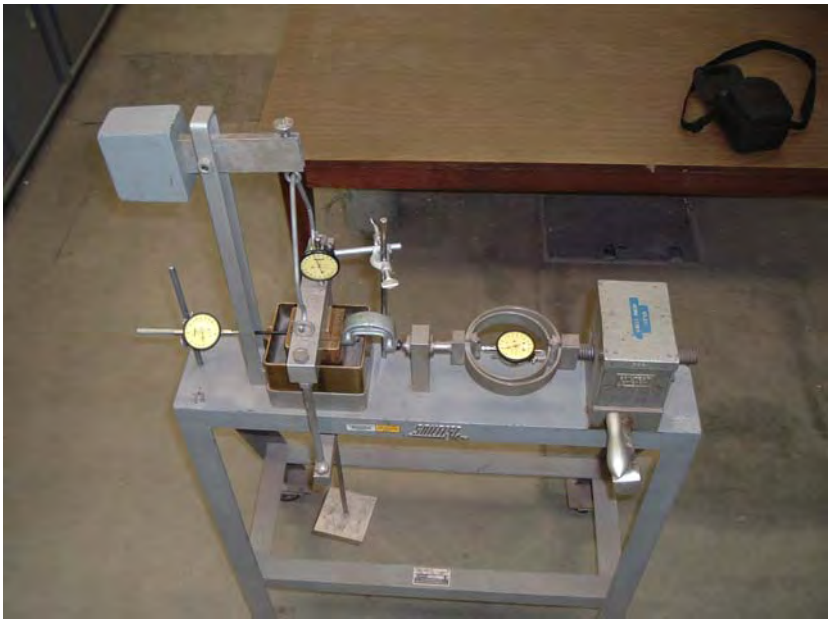


Figure19. Direct Shear Testing Machine Set Up

Figure 20. Disassembled Shear Box Showing (left to right) Normal Force Loading Head, Fixed Base, and Sliding Portion of Shear Box

4.5 Procedure

1. Measure the inner dimensions of the shear box. They will be needed to calculate stresses.

2. Back off the sample box spacing and clamping screws and assemble the box with the temporary pins provided.

3. Place the sample in smooth layers (approximately 10 mm thick). If a dense sample is desired tamp the specimen. Make the surface of the soil plane, a little below the top surface and place the normal load block on top of the sample.

4. Place the assembled shear box in the testing machine and apply the desired normal force to the load tray. Attach the vertical displacement gauge as shown in figure 1. You should include the weight of the normal force block and the upper half of the shear box as part of the sample load.

5. Remove the shear pin.

6. Advance the three vertical screws that are located on the side walls of the upper shear box. The space between the two halves should be about the size of the sample particles.

7. Set the loading head by tightening the two horizontal screws located in the top half of the shear box. Next, back off the three vertical screws so there is no connection between the upper and lower shear boxes.

8. Attach the dial gauge which measures the shear displacement as shown in Figure 19.

9. Record the initial reading of the dial gauges and calibration values.

10. Before proceeding to test check all adjustments to see that there is no connection between two parts except the crumb rubber sample. You are now ready to start the test.

11. Apply the shear force to the specimen at a rate between 0.5 and 2mm per minute (you should practice this first to get the rate correct) while recording the gauge readings from all three dial gages. (use the supplied data sheets) Take readings at 5, 10, 20, 30 etc (increment by 10) horizontal displacement units. Continue loading until proving ring either:

a. proving ring dial gauge reading reaches a maximum value and then falls off, or

b. proving ring dial gauge reading reaches a maximum and then remains constant

12. Repeat the test at least two more times with different normal forces.

4.6 Calculations for Direct Shear Test RESults

1. Calculate the normal stress, $\sigma = \frac{\text{Normal load}}{(L)(B)}$

2. For Table 1, the horizontal, vertical, and proving ring dial gauge readings are obtained from the test (Columns 2, 3 and 4).

3. For any given set of horizontal and vertical dial gauge readings, calculate the shear force (Column 6)

S = (No. of divisions in proving ring dial gauge, i.e., Column 4) x (proving ring calibration factor. i.e., Column 5)

4. Calculate the shear stress, τ, as (Column 7)

$$\tau = \frac{\text{shear force, S}}{\text{area of the specimen}} = \frac{S}{(L)(B)}$$

Note: A separate data sheet has to be used for each test (i.e., for each normal stress, σ).

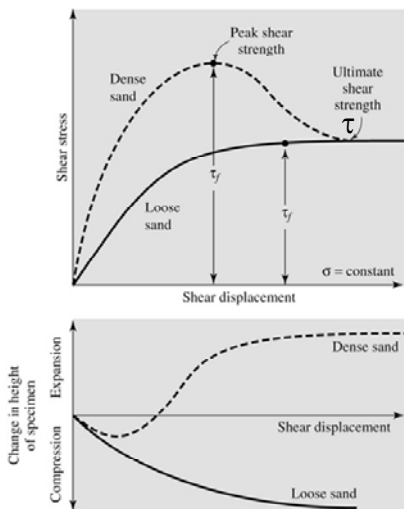
4.7 Graphs for Direct Shear Test Results

1. For each normal stress, plot a graph of τ (Column 7) vs. horizontal displacement (Column 2) (as shown in Figure 21below for the results obtained from Table 1). On the bottom of the same graph paper, using the same horizontal scale, plot a graph of vertical displacement (Column 3) vs. horizontal displacement (Column 2). There will be at least three such plot (one for each value of σ). Determine the shear stresses at failure, s, from each τ vs. horizontal displacement graph (as shown in Fig 21).

2. Plot a graph of shear strength, s, vs. normal stress, σ. This graph should be a straight line passing through the origin. Figure21 shows such a plot for a sample sand. The angle of friction of the soil can e determined from the slope of the straight line plot of s vs. σ as

$$\phi = \tan\text{-}1(s/\sigma)$$

Example direct shear test curves



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Example failure envelope (dry sand, note c is zero)

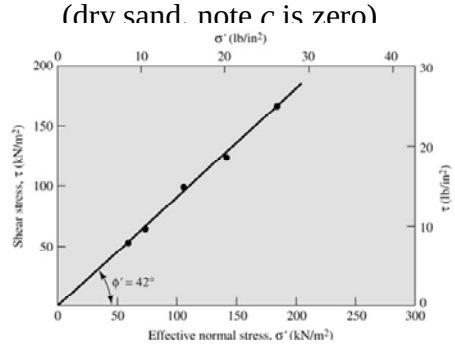

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Figure 21. Sample Direct Shear Testing Results on Sand

DIRECT SHEAR TEST DATA SHEET FOR CRUMB RUBBER

Name _____ Lab Group Number_____

Date of Testing _____

Shear box dimensions, L = _____ B = _____

Normal load = _____ Normal stress = _____

Loading Rate = _____ Loading Ring Constant = _____(low)

= _____ high

Table 1. Direct Shear Test

Normal Stress (1)	Horizontal Displacement (2)	Vertical Displacement (3)	Load Dial Reading (4)	Proving Ring Calibration Factor (5)	Shear Force (6)	Shear Stress (7)

Proving Ring constant..... Least count of the dial.....

Calibration factor.....

Leverage factor.....

Dimensions of shear box 60 x 60 mm

Empty weight of shear box.....

Least count of dial gauge.....

Volume change.....

S.No	Normal load (kg)	Normal stress(kg/cm^2) load x leverage/Area	Normal stress(kg/cm^2) load x leverage/Area	Shear stress proving Ring reading x calibration / Area of container
1 2 3				

5.0 General Remarks

1. In the shear box test, the specimen is not failing along its weakest plane but along a predetermined or induced failure plane i.e. horizontal plane separating the two halves of the shear box. This is the main draw back of this test. Moreover, during loading, the state of stress cannot be evaluated. It can be evaluated only at failure condition i.e. the Mohr's Circle can be drawn at the failure condition only. Also failure is progressive.

2. Direct shear test is simple and faster to operate. As thinner specimens are used in shear box, they facilitate drainage of pore water from a saturated sample in less time. This test is also useful to study friction between two materials with one material in lower half of box and another material in the upper half of box.

3. The angle of shearing resistance of sands depends on state of compaction, coarseness of grains, particle shape and roughness of grain surface and grading. It varies between 28° (uniformly graded sands with round grains in very loose state) to 46^o(well graded sand with angular grains in dense state).

4. The volume change in sandy soil is a complex phenomenon depending on gradation, particle shape, state and type of packing, orientation of principal planes, principal stress ratio, stress history, magnitude of minor principal stress, type of apparatus, test procedure, method of preparing specimen etc. In general loose sands expand and dense sands contract in volume on shearing. There is a void ratio at which either expansion contraction in volume takes place. This void ratio is called critical void ratio. Expansion or contraction can be inferred from the movement of vertical dial gauge during shearing.

5. The friction between sand particles is due to sliding and rolling friction and interlocking action.

The ultimate values of shear parameter for both loose sand and dense sand approximately attain the same value so, if angle of friction value is calculated at ultimate stage, slight disturbance in density during sampling and preparation of test specimens will not have much effect.

6.0 Conclusions and Recommendations

The following conclusions can be drawn for this teaching module:

- In order to determine the strength properties rubber tire particles, lab tests need to be conducted.
- The most appropriate method for TDA is the direct shear test as large scale triaxial test apparatus are not commonly available.
- Like soil, the shear strength of rubber particles increases as normal stress increases.
- Under normal loading, TDA develops an apparent cohesion even though it is an essentially granular type material that can withstand no tension stress.

More studies need to be conducted with large scale shear boxes to establish the shear strength behavior of large sized type B TDA. Also, the interface shear strength between the tire shreds and concrete and other materials needs to be evaluated. The effects of tire shred orientation on shear strength should be studied as well to gain a better understanding of the shear strength of TDA.

7.0 References

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3. Das, B.M. “Principle of Geotechnical Engineering”, 6th edition. Thomson Learning, 2006.
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CIVL 402 Contracts and Specifications on Rubberized Asphalt Concrete

1.0 Introduction

This is one of the two chapters for Contract Specifications and Technical Writing (CIVL 402) course. The main focus of this chapter is on Rubberized Hot Mix Asphalt (RAC) and Rubberized Hot Mix Asphalt Concrete (RHMA). This chapter will cover the standard specifications, and standard special provisions of Rubberized Hot Mix Asphalt. It will also cover asphalt rubber definitions, asphalt rubber binder, asphalt rubber binder design, types of mixes, and cautions for using Rubberized Hot Mix Asphalt.

Plans and specifications describe how to build a project. Plans provide a layout and dimensions for the project. Specifications describe project specific requirements for various things, such as materials, workmanship, and general and special provisions. The different types of specifications include: Proprietary, Method, Quality Control/Quality Assurance, End Result, Performance-Related (PRS), Performance-Based (PBS), Performance (e.g., Warranty/Guarantees), Design/Build, and Design/Build/Operate. For intuitive specifications (Method, End Result), the relationship to performance is unknown. While for the following specifications, relationship to performance is better known: Performance-Related, Performance-Based, and Performance Specifications.

Method, Quality Control/Quality Assurance, End Result, and PRS/PBS specification methods are based on statistical analysis. Brand/Product/Process/Manufacturer Specific is proprietary specifications and is difficult to use in the competitive bidding process. Method Specifications are detailed descriptions of materials and procedures that are used to construct the final product. The method specifications are the procedural and prescriptive specifications, which require continuous on-site inspection, and historically are the most commonly used specifications. Quality Control/Quality Assurance specifications are used in 35 states, and is commonly used as it falls between method and end result specifications. Quality Control/Quality Assurance specifications are made up of the following elements: definitions, materials, construction process, construction equipment, mix design, acceptance (lot and sublot, sampling, and testing), pay factors/method of payment, and training, certification, and accreditation.

End Result specifications specify minimum in-place material properties (e.g., density), they do not specify construction methods – which allows for Contractor freedom and Innovation. They may or may not include material specifications, and are gaining in popularity. Statistically Based End Result Specifications consider both agency or owner and producer or contractor risk, they require both Quality Control and Quality Assurance, thus need a third party for inspection, and are commonly used today.

Performance-Related and Performance-Based Specifications are commonly used in equipment and machinery manufacturing industries. They are being introduced to construction as well as to other industries. The Federal Highways Administration (FHWA) strongly supports the development of performance-related specs such as, HMA – WesTrack and PCC - ERES/Illinois. FHWA requires functional specifications for materials and in-place properties. Tight quality

control/quality assurance are also required, and there must be demonstrated dependable relationships between material properties and actual pavement performance. The elements of "Ideal" performance based specifications are reproducible test methods, well defined construction variability, existence of robust relationships between tests (measured properties) and pavement performance, and definable and measurable pavement performance. Performance specifications specify a minimum level of performance over a specified period, for example: less than 5% fatigue cracking after 10 years of service, and/or rut depths less than 13 mm (1/2 in) after 15 years of service. They also require warranties on all work performed.

2.0 Asphalt Rubber

According to ASTM D8, "Asphalt Rubber is a blend of asphalt cement, reclaimed tire rubber and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles." The ASTM D 6114 Standard specifies that Asphalt Rubber Binder is a High viscosity material (usually field-blended) that typically requires agitation to keep CRM particles dispersed. In California, components that make up asphalt rubber binder are crumb rubber modifier, which is made of scrap tire rubber and high natural rubber content scrap rubber, and extender oil. Figure 1 shows the difference between scrap tire rubber and high natural rubber. In terms of percentages, California Department of Transportation (Caltrans) specifications for High Viscosity (Field Blend) AR Binders, requires extender oil at 1 to 6% by mass of asphalt (For chip seal binders, Caltrans may continue to require minimum 2.5% extender oil), asphalt plus extender oil at 78-82% by total mass of AR binder, total CRM at 18-22% by total mass of AR binder, of which: scrap tire CRM = 73-77% of total CRM, high natural CRM = 23-27% of total CRM. Crumb Rubber Modifier (CRM) is produced from grinding whole scrap tires, tread buffings, and other waste rubber products. CRM comes in a variety of grades and size designations from various suppliers and/or other sources. CRM gradation and content affect not only AR binder properties, but also influence the voids structure of RHMA-G mixes. Gradation limits used by Caltrans and ADOT are broad and allow considerable variation; changes in gradation limits are being considered. Project specific provisions should also check to verify any CRM gradation limits in effect for that project.

Figure 1. Difference between Scrap Tire and High Natural Rubber

High natural rubber CRM is used to improve adhesion and flexibility, chip seal aggregate retention, and to insure compatible asphalt and CRM interactions. It has high natural rubber content (40-48% by mass) and may be made from truck scrap tires or other non-tire sources. Caltrans requires that "high natural rubber" be used in binders for RHMA mixes.

Asphalt cements come in a variety of grades and designations. AR-4000 was used to make traditional asphalt rubber in the past. Caltrans adopted the Performance Graded (PG) system in 2006. Caltrans does not recommend using modified asphalts as the base asphalt cement for CRM modification. For mountainous and high desert areas, use PG 58-22 is recommended as the base asphalt. For other areas (coastal, inland valleys, low and south mountains, and desert) the use of PG 64-16 as base asphalt is suggested. Some additives in the rubberized asphalt include extender oils, which aid in the interaction of the crumb rubber and asphalt by providing aromatics which are absorbed by the rubber, and help with dispersion by chemically suspending the rubber in the asphalt; extender oils are required by Caltrans. Anti-stripping agents are used to improve adhesion of the binder to the aggregate.

The Asphalt Rubber blend design requires the following submittals: supplier and identification (or type) of scrap tire and high natural CRM, typical gradation of each type of CRM material used in the asphalt rubber binder design, and percentage of scrap tire and high natural CRM by total mass of the asphalt-rubber blend. If CRM from more than one supplier is used, info will be required for each CRM supplier used, including laboratory test results for test parameters shown in the special provisions. Other asphalt rubber blend design submittals include:

- base asphalt PG binder grade, supplier, and Certificate of Compliance (COC)
- percentage of the combined blend of asphalt and asphalt modifier by total mass of asphalt rubber binder
- asphalt modifier type, supplier, identification, and test results demonstrating conformance to specs

- percentage of asphalt modifier by mass of asphalt, the design profile, minimum interaction time and temperature, and material safety data sheets for all materials

The asphalt rubber blend design profile shown in Table 1 was developed to evaluate the compatibility between materials used, compliance of component interaction properties, and to check for stability of the AR blend over time. A 24-hour design profile will be required for each project, for both hot mix and spray applications. Previous AR blend designs may be validated for currently available materials and may be submitted for more multiple projects.

There are four different types of rubberized asphalt hot mixed concrete; Dense-graded (limited use by Caltrans), gap-graded, open-graded, and open-graded (high binder, HB). Figure 2 shows the different gradations used in the RHMA mixes.

Table 1: Example of Asphalt Rubber Blend Design Profile

	Reaction Time (Minutes)					**Spec. Limits @ 45 minutes (Caltrans 12/2005)**
TEST	45	90	240	360	1,440	
Viscosity, cP Haake@ 190ºC	2400	2800	2800	2800	2100	1500 - 4000
Resilience@ 25ºC (% Rebound) (ASTM D 5329)	27	--	33	--	23	18 Minimum
R & B Softening Pt., ºC (ASTM D36)	59.0	59.5	59.5	60.0	58.5	52 – 74 (125-165ºF)
Cone Pen @ 25ºC (ASTM D217)	39	--	46	--	50	25 – 70

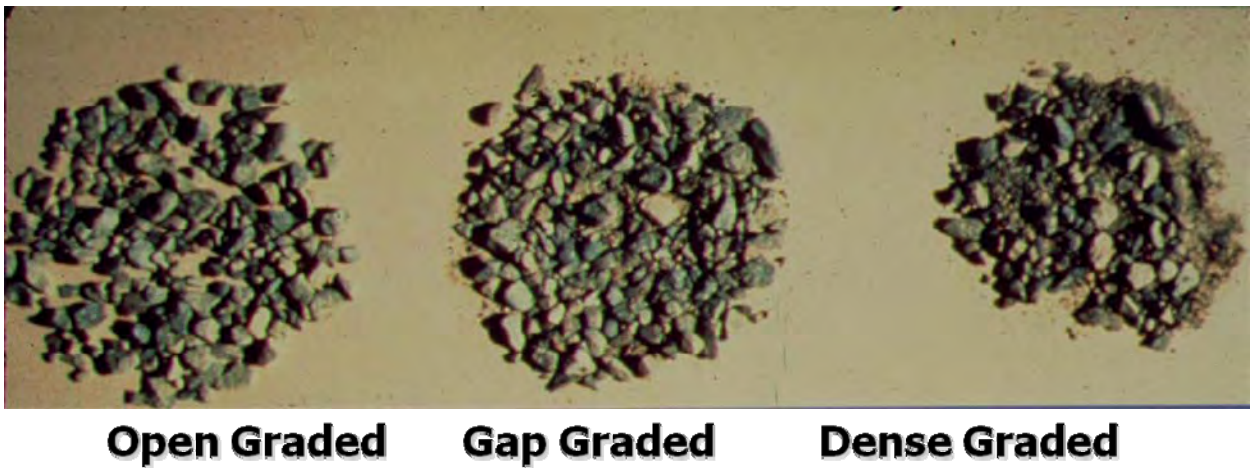

Figure 2: Different aggregates used in RHMA mixes.

3.0 Examples RHMA Types Used by Caltrans

Dense-Graded mixes (RHMA-D) which saw early use by Caltrans showed variable performance improvements vs. cost in large part because it had inadequate void space to accommodate the AR binder. Caltrans discontinued this usage with high viscosity (field blend) binders and but they may be suitable for use with no agitation CRM-modified binders (terminal blend) such as rubber modified binder (MB).

Gap-Graded mix (RHMA-G) is the most commonly used RHMA mix type. The Gap-Graded mix provides increased resistance to rutting, fatigue, reflective cracking, and oxidative aging. Standard special provisions (SSP) for RHMA-G with high viscosity (field blend) AR binder are currently being updated to address PG binder implementation. Some revisions include the removal of test methods from the body of SSP; develop corresponding CT lab procedures for CRM sieve analysis and measuring rotational viscosity of AR binder, and to format SSP for inclusion in section 39 of Caltrans standard specifications. Adjustments to the Hveem Mix Design Method (CT 367) include: modifying (coarsen) aggregate gradation requirements, particularly for the 600 µm sieve size, to facilitate achieving minimum VMA (18%); add maximum VMA limit of 23%; and test three briquettes at each binder contents and use the average values for calculations and plots. Other adjustments to the Hveem Mix Design Method are designing air voids content so they may range from 3 to 5% based on traffic index and climate, and as designated by the engineer in the project special provisions. Also, the Hveem Mix Design Method still requires minimum AR binder content of 7.0% by weight of dry aggregate to provide durability (must have sufficient binder content to provide the expected performance benefits). The Hveem Mix Design Method requires the use of Caltrans Laboratory procedures LP-1 through LP-4 for volumetric calculations, report voids filled with asphalt (VFA) and dust proportion for information only, and to plot average unit weight, stability, percent air voids, VMA, and VFA versus asphalt rubber binder content.

Standard specifications for RHMA-O (open graded) and RHMA-O-HB (open graded high binder) were also updated to incorporate PG binder implementation. Changes are similar to those for

RHMA-G, but with less impact on mix design methods. Effects of CRM gradation and content in the binder have been found to have relatively little effect on the void structure of open-graded mixes. RHMA-O is designed to provide a free-draining surface (reduced splash/spray and hydroplaning) while maintaining good frictional characteristics in wet or dry conditions. Such mixes are not considered to be structural elements and no thickness reduction applies. RHMA-O is typically placed in thin lifts, nominally 24 to 30 mm thick. Open-graded mixes are not to be used where there is a significant amount of stop and go traffic or turning vehicles is required, such as on city streets or in parking lots. These porous low modulus pavements are susceptible to tire scuffs from braking and turning motions, and to damage from leaking vehicle fluids. Caltrans does not use RHMA-O in snow country. RHMA-O mixture design is performed according to California Test 368, with asphalt rubber binder content set at 1.4 times the optimum bitumen content for the designated PG binder grade. A check test is used to verify that binder drain down is not excessive. If long hauls are anticipated, drain down should be checked in the laboratory for the expected haul time. RHMA-O-HB mixes have higher binder contents (1.6 times demand for PG asphalt instead of 1.4). HB provides improved friction course durability and performance due to thicker AR binder films. A drain down check is more important for high binder mixes. RHMA-O-HB does not drain as freely as RHMA-O due to the higher binder content, but still drains more freely than DGAC. Benefits of using RHMA-O and RHMA-O-HB are that they provide a smoother ride with significantly reduced tire noise. Joint Caltrans/ADOT/FHWA studies are in progress to measure and document noise reduction changes over a ten-year period.

The standardized language used with construction contracts to amend, supplement, and incorporate the Caltrans Standard Specifications is the Standard Special Provisions (SSP). Standard Special Provisions are continually being created and updated to reflect new understanding of materials, workmanship, as well as new products or procedures. SSP for RHMA-O is made up of the following sections:

1) General
2) Materials
3) Proportioning and mix design
4) Review of RHMA mix design
5) Contractor quality control, sampling, and testing
6) Equipment for production of asphalt-rubber binder
7) Proportioning of binder, aggregates
8) Spreading and compacting
9) Measurement and payment

Some precautions for using RHMA mixes by the specifications and mix design methods discussed in this presentation should be applied to the use of high viscosity asphalt rubber binders (field blend) in gap and open-graded RHMA mixes. Agitation binders (low viscosity, terminal blend) should never be directly substituted for high viscosity binders in any RHMA mix. The two different types of CRM-modified binders have different ranges and behave very differently in asphalt concrete hot mixes.

4.0 Conclusions

This teaching module introduced the different types of rubberized hot mix asphalt concrete, including RHMA-G, RHMA-O, and RHMA-O-HB. Different specifications including method specification, performance based specification, and QC-QA statistical based specification were introduced. As an example, the Caltrans standard specifications for Rubberized Hot Mix Asphalt were introduced.

5.0 References

1. Caltrans Standard Specification, 2008
2. Caltrans Asphalt Rubber Design Guide, 2003

CIVL 402 Contracts Specifications on ASTM Standards

1.0 Introduction

1.1 Background

This is the first chapter for the Contract Specifications and Technical Report Writing, (CIVL 402) course. The second chapter for the Contract Specifications and Technical Report Writing will be presented later as a separate chapter which is about asphalt rubber and rubberized asphalt concrete. The main focus of this chapter is on ASTM International standards which are useful in developing civil engineering applications for waste tires. This chapter covers the history of ASTM standards, what they are used for, and some specific standards related to scrap tire products, in particular, ASTM D 6270-98 (Reapproved 2004), "Standard Practice for Use of Scrap Tires in Civil Engineering Applications".

Standards provide the means that are necessary to establish uniformity for separate individual products. These voluntary standards are actually Standard Specifications that are developed by various non-profit associations, government agencies, and manufacturers groups. This allows users (e.g. engineers and contractors) to reference published data for each of these products with assurance that manufacturers comply with the established standard. These standards become a part of the construction contract only if called out in the plans and specifications. Plans and specifications describe how to build a project. Plans provide a layout and dimensions for the project. Specifications describe project specific requirements for various things, such as materials, workmanship, and general and special provisions.

1.2 Objectives

The objective of this chapter is to introduce students to ASTM International standards that relate to utilizing scrap tire products in civil engineering applications. Topics covered include who produces standards, what they are used for, how they are organized, and which ASTM standards are pertinent to using scrap tires in civil engineering applications.

1.3 History

A group of scientists and engineers, led by Charles Benjamin Dudley formed the *American Society for Testing and Materials* in 1898 to address the frequent rail breaks plaguing the fast-growing railroad industry. ASTM is a not-for-profit organization that provides a forum for the development and publication of voluntary consensus standards for materials, products, systems, and services. Originally known as the American Society for Testing and Materials, it is now called ASTM International. The organization's headquarters is in West Conshohocken, Pennsylvania, which is about 5 miles northwest of Philadelphia. A complete history of ASTM International is available as a pdf download on their web site (http://www.astm.org/HISTORY/index.html).

ASTM International is currently one of the largest voluntary standards developing organizations in the world. ASTM's members represent producers, users, consumers, government, and academia from over 100 countries, which develop technical documents that are a basis for manufacturing, management, procurement, codes, and regulations. Committees have developed more than 12,000 ASTM standards that can be found in the 77 volume Annual Book of ASTM Standards. ASTM standards are organized into fifteen different sections as follows:

1. Iron and Steel Products
2. Nonferrous Metal Products
3. Metals Test Methods and Analytical Procedures
4. *Construction*
5. Petroleum Products, Lubricants, and Fossil Fuels
6. Paints, Related Coatings, and Aromatics
7. Textiles
8. Plastics
9. *Rubber*
10. Electrical Insulation and Electronics
11. Water and Environmental Technology
12. Nuclear, Solar, and Geothermal Energy
13. Medical Devices and Services
14. General Methods and Instrumentation
15. General Products, Chemical Specialties, and End Use Products

Of interests to this chapter are sections 4, Construction, and 9, Rubber (italicized above) as these sections contain Standards that pertain to using scrap tire products in civil engineering applications. Section 4 on Construction contains the following sub-sections (among others):

- Volume 04.01 - Cement, Lime; Gypsum
- Volume 04.02 - Concrete and Aggregates
- Volume 04.03 - Road and Paving Materials; Vehicle-Pavement Systems
- Volume 04.04 - Roofing and Waterproofing
- Volume 04.05 - Roofing, Waterproofing, and Bituminous Materials
- Volume 04.06 - Thermal Insulation; Environmental Acoustics
- Volume 04.07 - Building Seals and Sealants; Fire Standards; Dimension Stone
- *Volume 04.08 - Soil and Rock (I): D 420 to D 5779*
- *Volume 04.09 - Soil and Rock (II): D 5780 - latest; Geosynthetics*
- Volume 04.10 - Wood
- Volume 04.11 - Building Construction
- Volume 04.12 - Building Constructions (II): E 1672 - latest; Property Management Systems

Volume 04.08 and 04.09 contain construction related standards that are useful in determining the properties of scrap tire products, and their use in civil engineering applications. Volume 9 has the following subsections that relate to this topic:

- Volume 09.01 - Rubber, Natural and Synthetic -- General Test Methods; Carbon Black
- Volume 09.02 - Rubber Products, Industrial - Specifications and Related Test Methods: Gaskets; Tires

2.0 ASTM Standards

Many organizations produce standards for a variety of products. These include various non-profit organizations, government agencies, and manufacturers groups. The most recognized of all American standards is the American Society for Testing and Materials (ASTM) International. ASTM International covers material specifications, testing requirements for materials, and in some cases performance standards. Although ASTM International has no role in requiring or enforcing compliance with its standards, ASTM standards are needed to insure that products meet minimum performance requirements. They may become mandatory when referenced by an external contract, corporation, or government agency. Other governments (local and worldwide)

also reference ASTM standards in their specifications and codes. Corporations doing business internationally may choose to reference an ASTM standard for their products and projects.

Membership in the organization is open to anyone with an interest in its activities. Standards are developed within committees, and new committees are formed as needed, upon request of interested members. Membership in most committees is voluntary and is initiated by the member's own request, not by appointment or invitation. Members are classified as users, producers, consumers and "general interest". The later include academics and consultants. Users include industry users, who may be producers in the context of other technical committees, and end-users such as consumers. To meet the requirements of antitrust laws, producers must constitute less than 50% of every committee or subcommittee, and votes are limited to one per producer company. Because of these restrictions, there is a substantial waiting-list of producers seeking organizational memberships on the more popular committees. Members can, however, participate without a formal vote and their input will be fully considered. As of 2007, there are more than 30,000 members, including over 1100 organizational members, from more than 120 countries.

2.1 Listings

ASTM listings are characterized by designations such as ASTM D 6270-98 (Reapproved 2004), “Standard Practice for Use of Scrap Tires in Civil Engineering Applications”. The letter prefix “D” indicates that the standard refers to material category D, Miscellaneous Materials. The following material categories are currently used by ASTM:

A	Ferrous metals
B	Nonferrous metals
C	Cementitious, ceramic, concrete, and masonry materials
D	Miscellaneous materials
E	Miscellaneous subjects
F	Materials for specific applications
G	Corrosion, deterioration, and degradation of materials
ES	Emergency standards

The “98” refers to the year that the edition of the standard was approved, in this case reapproved in 2004.

2.2 Tire Related Documents

ASTM D 6270-98 is divided into several different parts that are presented in a logical order. Part 1 of this standard covers the “Scope” of the standard:

“1.1 This practice provides guidance for testing the physical properties and gives data for assessment of the leachate generation potential of processed or whole scrap tires in lieu of conventional civil engineering materials, such as stone, gravel, soil, sand, or other fill materials. In addition, typical construction practices are outlined.”

Part 2 covers “Referenced Documents” which lists other ASTM standards that are used in classifying waste tire products, as well as AASHTO and USEPA Standards. Part 3 Lists definitions and terminology pertinent to scrap tire products. Part 4 covers “Significance and Use”. This particular standard covers the use of the following scrap tire products in civil engineering applications:

- tire chips or tire shreds comprised of pieces of scrap tires
- tire chip/soil mixtures
- tire sidewalls
- whole scrap tires

It covers the use of the first two tire derived products listed above that are used in the following CE applications:

- lightweight embankment fill
- lightweight retaining wall backfill
- drainage layers
- thermal insulation layer to limit frost penetration beneath roads
- insulating backfill to limit heat loss from buildings
- replacement for soil or rock in other fill applications

It goes on to state; “Use of whole scrap tires and tire sidewalls includes construction of retaining walls and drainage culverts, as well as use as fill when whole tires have been compressed into bales. It is the responsibility of the design engineer to determine the appropriateness of using scrap tires in a particular application and to select applicable tests and specifications to facilitate construction and environmental protection. This practice is intended to encourage wider utilization of scrap tires in civil engineering applications.” Figures 1 and 2 shows the whole tire applications as a culvert and retaining wall, respectively.

Figure 1 Scrap tire side walls tied together to form a culvert

Figure 2 Retaining wall constructed of whole waste tires supporting a residential exterior deck

2.3 Materials Characterization

Part 5 of ASTM D 6270-98 covers "Material Characterization" of the properties of waste tire products that are of interest in civil engineering applications. These material properties along with the other Standards referenced are listed below:

> 5.1 Specific Gravity and Absorption Capacity, to be determined in accordance with ASTM Test Method C127. However, since the specific gravity of tire shreds is less than

one-half that of common earth materials, they permit using a minimum weight of the test samples that is one-half the specified value.

5.2 Gradation of tire shreds to be determined according to ASTM Test Method D 422 with one half the sample weight requirements as discussed above.

5.3 Laboratory Compacted Dry Density, or Bulk Density of Tire Chips and Tire Chips/Soil Mixtures with less than 30% retained on the 19.0-mm sieve to be determined according Test Method D698 or D 1557. Minimum mold diameters as a function of tire shred size are tabulated, as are other allowable modifications to the standard test procedures.

5.4 Compressibility of Tire Chips and Tire Chips/Soil Mixtures is to be measured in a rigid cylinder with a diameter several times greater than the largest particle size. The cylinder can be instrumented to measure the horizontal stress that the tire shreds exert on the wall to determine the at rest coefficient of lateral earth pressure, K_o. Because of the high compressibility of tire shreds, a ratio of initial specimen thickness to diameter of the sample should be greater than one. Also, the stress at the top and bottom of the sample should be measured with the average of the two used as the vertical stress to account for friction between the tire shreds and the cylinder wall. The cylinder wall should be lubricated to minimize friction. A test apparatus as shown below is designed to determine the compressibility of tire shreds.

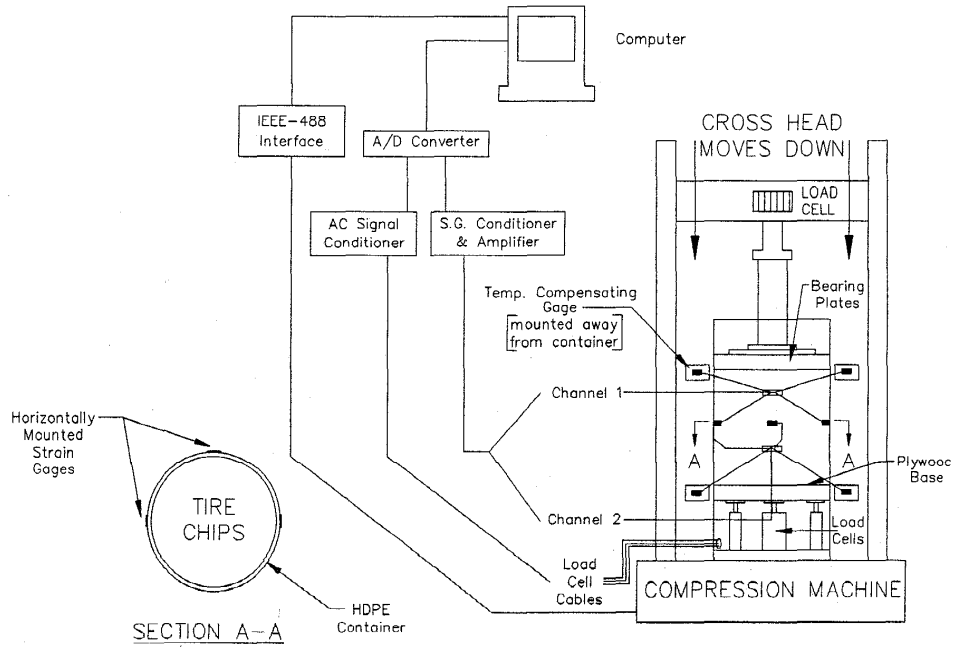

FIG. 1 Compressibility Apparatus for Tire Shreds Designed to Measured Lateral Stress and the Portion of the Vertical Load Transferred by Friction from Tire Shreds to Container (8)

Figure 3. Compressibility Measurement and Stress Monitoring Apparatus

5.5 Resilient Modulus (M_R) to be determined according to AASHTO T 274 on particle sizes less than 19mm.

5.6 Coefficient of Lateral Earth Pressure at Rest (K_o) and Poisson's Ratio, μ with the test apparatus shown in Figure ???? above.

5.7 Shear Strength of tire shreds may be determined with direct shear tests according to ASTM test Method D 3080 or by using triaxial shear tests. The large size of tire shreds precludes triaxial testing due to sample size limitations, and the presence of exposed steel belts that may puncture the membrane that surrounds the sample. It is more practical to construct large scale shear boxes to accommodate the larger particle size.

5.8 Hydraulic Conductivity (Permeability) of Tire Chips and Tire Chips/Soil Mixtures should be measured with a constant head permeameter with a diameter several times the maximum particle size. For maximum particle size of 19mm, ASTM Test Method D 2434 may be used, for larger particle sizes an apparatus as shown in Figure 4 may be employed.

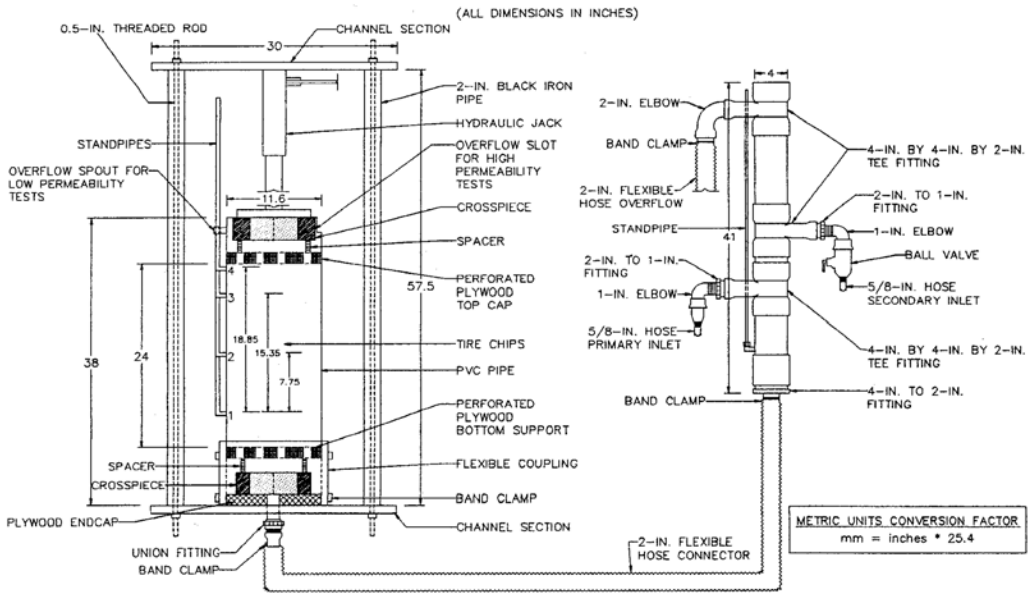

Figure 4. Hydraulic Conductivity Measurement for TDA

5.9 Thermal Conductivity of tire shreds are to be determined by utilizing commercially available or custom designed guarded hot plate apparatus.

2.4 Construction

Part 6 of ASTM D 6270-98 covers “Construction Practices” which can be summarized as follows:

6.1 Tire shreds have 1/3 to 1/2 of the dry density of typical soil. This makes them useful for lightweight embankment fill on weak compressible soils where slope stability and/or excessive settlement are of concern.

6.2 Tire shreds have a thermal resistivity about eight times greater than typical soil. Useful applications include limiting the depth of frost penetration beneath roadways and as backfill around basement walls to reduce heat loss.

6.3 Lateral earth pressures reduced by 50% compared to soil backfill combined with low compacted dry density, high permeability, and low thermal conductivity; make tire shreds an attractive retaining wall backfill material.

6.4 High hydraulic conductivity make tire shreds suitable for drainage applications, including French drains, leach fields for septic systems and in land fill applications as drainage layers and cover systems.

6.5 Covers the two different sizes that are commonly used (Type A: <3in, Type B: <12in) and other shredding requirements such as the largest shred should be quarter circle in shape and should have one side wall severed from the tread.

6.6 Large tire shreds should be compacted by a tracked bulldozer, sheepsfoot roller, or smooth drum vibratory roller with a minimum weight of 10 tons in lifts not to exceed 12 inches for type A TDA and 3 feet for type B TDA. A minimum of six passes of the compaction equipment is needed at each point in the fill for each lift.

6.7 Tire shreds should be covered with a sufficient thickness of soil to limit deflections caused by traffic loading in the overlaying pavement. For light traffic loads this may require only 3 feet of cover whereas heavy traffic loading may require 3 to 7 feet of cover. In unpaved applications, only 1 to 2 feet are required.

6.8 Where pavement will be placed over the tire shreds and in drainage applications, the tire shreds should be wrapped completely by a geotextile material to prevent the infiltration of surrounding soil particles.

6.9 Whole tires and tire sidewalls can be used for retaining walls and for culverts if bound together.

6.10 Lists the known causes of internal heating in TDA fills and recommends several requirements for minimizing this possibility.

To summarize, the following construction practices make use of the listed desirable characteristics of scrap tire products (TDA):

- Lightweight Embankment Fill: Low-Compacted Dry Density
- Insulating Layer: Thermal Resistance
- Retaining Wall Backfill: Low-Compacted Dry Density, High-Hydraulic Conductivity, Low-Thermal Conductivity
- Drainage Applications: High-Hydraulic Conductivity
-

2.5 Environmental Considerations

Part 7 of ASTM D 6270-98 covers “Leachate” which references the Toxicity Characteristics Leaching Procedure (TCLP) of USEPA Method 1311. The results of this test indicate that tire shreds do not have to be classified as a hazardous waste material. Part 7 also concludes that

pending further study, tire shreds should only be used in applications where they are placed above the ground water table.

2.6 Standard Calculations

In general, ASTM D 6270-98 uses standard calculations commonly used in geotechnical and transportation engineering as follows:

Density of tire shred solids $\rho_s = S_a(\rho_w)$ (1)

where:
S_a = apparent specific gravity, and
ρ_w = density of water.

Resilient modulus $M_R = A\Theta^B$ (2)

where:
Θ = first invariant of stress (sum of the three principal stresses),
A = experimentally determined parameter, and
B = experimentally determined parameter.

Coefficient of lateral earth pressure at rest $K_O = \sigma_h / \sigma_v$ (3)

Poisson's ratio $\mu = K_O / (1 + K_O)$ (4)

where:
σ_h = measured horizontal stress, and
σ_v = measured vertical stress.

2.7 Nonmandatory Information

The appendix of ASTM D 6270-98 includes what is termed "Nonmandatory Information" which includes typical material properties, results of field studies on environmental and drinking water studies, and Material Safety Data Sheets for whole tires. Finally, 30 references related to the use of tire shreds in civil engineering applications are cited.

As an example of the information contained in the appendix of ASTM D 6270-98, the following two graphs and one table are cited. Figure 5 presents the results of tests conducted with varying percentages of tire chips mixed with both Crosby Till and Ottawa Sand using different compaction methods.

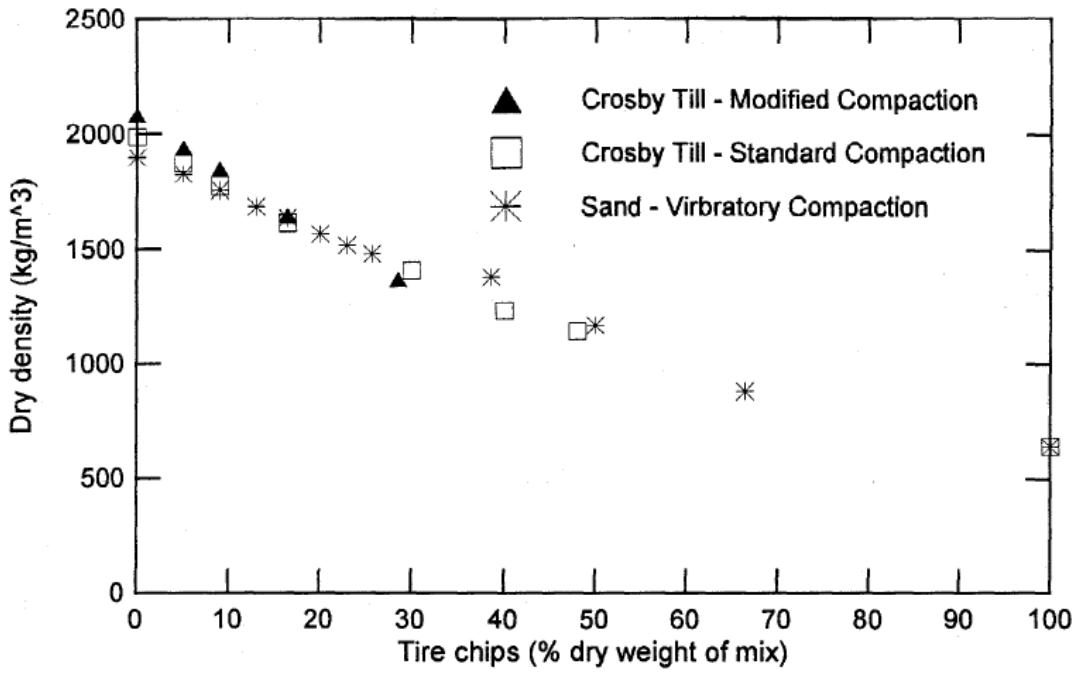

FIG. X1.1 Comparison of Compacted Dry-Density of Mixtures of Tire Shreds with Ottawa Sand and Crosby Till (5)

Figure 5. Compaction Density Comparison of TDA Mixed with Crosby Till and Ottawa Sand

Table 1 summarizes the compressibility of different tire shreds in terms of vertical strains obtained on initial loading for different vertical stresses and varying initial density states. Vertical strains exceeded 50% for loosely compacted materials with higher applied vertical stress values!

Table 1 Compressibility on Under different Initial Loading and Density States

TABLE X1.3 Compressibility on Initial Loading

Particle Size Range (mm)	Tire Shred Type	Tire Shred Source	Initial Dry Density (kg/m³)	Vertical Strain (%) at Indicated Vertical Stress (kPa)				
				10	25	50	100	200
2 to 75	Mixed	Palmer	Compacted	7 to 11	16 to 21	23 to 27	30 to 34	38 to 41
2 to 51	Mixed	Pine State	Compacted	8 to 14	15 to 20	21 to 26	27 to 32	33 to 37
2 to 25	Glass	F and B	Compacted	5 to 10	11 to 16	18 to 22	26 to 28	33 to 35
2 to 51	Mixed	Sawyer	Compacted	5 to 10	13 to 18	17 to 23	22 to 30	29 to 37
	Mixed		Compacted	4 to 5	8 to 11	13 to 16	18 to 23	27
75 max	Mixed	Pine State	510 to 670	12 to 20	18 to 28	- - - -	- - - -	- - - -
2 to 51	Mixed	Pine State	Loose	18	34	41	46	52
2 to 25	Mixed	F and B	Loose	8	18	28	37	45
	- - - -		Loose	9	12 to 17	17 to 24	24 to 31	30 to 38

The hydraulic conductivities of tire shreds with varying percentages of sand at different applied vertical stresses are shown in Figure 6. It is interesting to note the diminishing effect of increased vertical stress on the hydraulic conductivity.

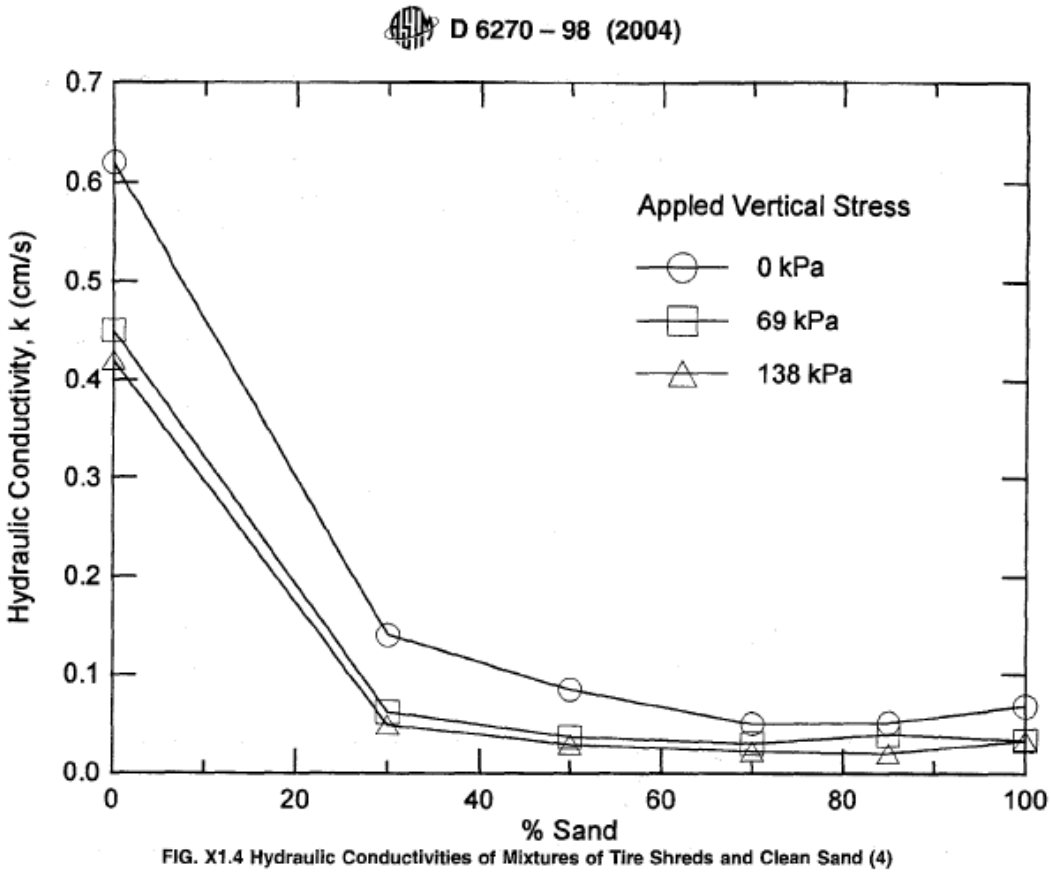

Figure 6. Tire Shreds Hydraulic Conductivity Reduction with Pressure and Sand Percentages

3.0 Example (or Case Study)

The application of ASTM D 6270-98 to the construction of embankment fill will now be discussed. Shredding of scrap tires produces chunks of rubber ranging in size from large shreds to smaller chips. Tire shreds and tire chips have both been used as lightweight fill materials for roadway embankments and backfill behind retaining walls. The shreds or chips can both be used by themselves or blended with soil. Tire shreds normally range in size from 12 in (Type B TDA to 3 in (Type A TDA) as shown in Figure 7:

Figure 7. Tire chips are usually sized from a maximum of 3 in down to a minimum of 1/2 in.

Embankments containing tire shreds or chips are constructed by completely surrounding the shreds or chips with a geotextile fabric and placing at least 3 ft of natural soil between the top of the scrap tires and the roadway as shown in Figure 8.

Figure 8. Placement of Tire Derived Aggregate with Bulldozer

At least 15 states have utilized scrap tire shreds or chips as a lightweight fill material for the construction of embankments or backfills (TFHRC, 2004). Some projects have used tire shreds or chips as embankment material, while other projects have blended tire chips with soil. In 2004, more than 70 successful projects have been constructed on state, local, or private roads.

Aside from problems with puncturing of rubber tires on haul vehicles by the exposed steel in tire chips or shreds, there have been no other construction-related problems on scrap tire embankment projects. Adequate compaction, which is always a prime concern on any embankment project, is of even greater concern on a tire shred or chip embankment project, where it is known that some consolidation will occur after the fill is completed. Some cracking of the roadway above a tire shred or chip embankment is possible because of long-term settlement or differential settlement adjacent to TDA fills. As of 2004, at least 15 states had completed scrap tire embankment projects; only six states (North Carolina, Oregon, Vermont, Virginia, Wisconsin, and Maine) had prepared specifications or some provisions for this use (TFHRC, 2004).

A summary of material characteristics covered in ASTM D 6270-98 include:

- Specific Gravity
- Water Absorption Capacity
- Gradation
- Compacted Dry Density
- Compressibility
- Resilient Modulus
- Coefficient of Lateral Earth Pressure
- Poisson's Ratio
- Shear Strength
- Hydraulic Conductivity
- Thermal Conductivity

The values that can be used from ASTM D 6270-98 for embankment fill include:

- Specific Gravity: 1.1 to 1.3
- Compacted Unit Weight: 20 lb/ft3 to 45 lb/ft3
- Friction Angle: 19° to 25°
- Cohesion value: 160 lb/ft2 to 240 lb/ft2
- Young's Modulus: 112 lb/in2 to 181 lb/in2
- Permeability: 1.5 to 15 cm/sec

Other useful information contained in the Standard related to soil tire chip mix design for embankment fill includes:

- Tire chips can be mixed or blended with soil
- As the percentage of soil is increased, the unit weight of the blend increases
- Mix ratios are usually prepared on a volumetric basis
- A maximum 50:50 tire chip to soil ratio is suggested so that tire chip usage is not reduced too greatly
- If the unit weight of the fill is not a concern, then even small percentages (10 to 25 percent) of tire chips can be blended into the soil. This could improve the compactibility of the fill

The site of the embankment should be prepared in essentially the same manner as though common earth were being used for fill material. However, if there is a high water table or swampy area that will be at the base of the embankment, it may be advisable to construct a drainage blanket. If there is a natural flow of runoff through the area where the embankment is to be constructed, provisions should be made to pipe the runoff beneath the embankment. When tire shreds or chips are to be blended or mixed with soil, the mixing should be performed volumetrically, using bucket loads from a front end loader and blending the materials together as well as possible with the bucket. As another option to the mixing of tire shreds or chips and soil, alternate layers of the tire shreds or chips and the soil can be constructed. A geotextile fabric is required to separate the fill materials so fines do not migrate into the TDA fill.

In terms of placing TDA fill, tire chips should be spread across a geotextile blanket using a tracked bulldozer with a minimum 2 foot layer or lift thickness shown in Figure 9. The recommended maximum 3 foot lift thickness can still be spread and compacted with standard compaction equipment.

Figure 9 Unloading, spreading and compacting TDA fill with a bulldozer.

Compaction may be achieved by at least three passes of the tracked bulldozer over the layer of tire chips. The chip particles align themselves with each other and settle fairly readily. The

weight of the bulldozer passing over the tire chips is enough to readily compact the layer of chips. For larger chips or thicker layers, as many as 15 passes of a bulldozer may be required to achieve compaction. The top layer of a tire chip embankment should be kept at least 3 ft below the base or subbase layer of the pavement that will be on top of the embankment. Each layer of a tire chip embankment must be fully compacted before the next layer is placed. When the top layer of tire chips has been fully compacted, the sides and top of the tire chips should be fully wrapped and enclosed by a geotextile fabric. A minimum of 3 ft of compacted soil should be placed on top of the geotextile and tire chips. The soil should be compacted in thinner layers of between 6 in. to 12 in. in thickness. The tire chip embankment will experience further deflection during placement and compaction of the soil cover, which will require more fill material.

Although several successful projects have been constructed using TDA as embankment fill, there are still some unresolved issues. The first and most pressing unresolved issue is to determine the cause or causes of the exothermic reactions that resulted in three scrap tire embankment fires that occurred during 1995. Other tire shred or tire chip embankment projects, especially the thick fills, including those that have caught on fire, should be more closely monitored, possibly by installing temperature probes and gas sampling wells. The pH of any water leaching from scrap tire fills should be also measured. Laboratory investigations should also be undertaken under varying conditions and temperatures to pinpoint under which conditions exothermic reactions (which lead to ignition of the tire scraps) may be initiated.

There are other ASTM Standards that relate to the use of scrap tires products in civil engineering applications, some of these include:

- ASTM D422: Particle Size Analysis of Soils
- ASTM D575: Test Methods for Rubber Properties in Compression
- ASTM D698: Test Methods for Compaction Characteristics of Soil Using Standard Effort
- ASTM D5084: Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter
- ASTM D3080: Direct Shear Test of Soils Under Consolidated Drained Conditions

The following is the quantitative determination of which test method is to be used to determine the distribution of particle sizes in soils based on ASTM D422, Particle Size Analysis of Soils:

- Distribution of particle sizes larger than 75 μm is determined by sieving
- Distribution of particle sizes smaller than 75 μm is determined by a sedimentation process, using a hydrometer to secure the necessary data.

ASTM D575 covers “Test Methods for Rubber Properties in Compression” covers two test methods that are useful in comparing stiffness of rubber materials in compression. This Standard can be used by rubber technologists to aid in development of materials for compressive applications. The two test methods are:

- Compression Test of Specified Deflection: The force required to cause a specified deflection is determined
- Compression Test of Specified Force: A specified mass or compressive force is placed on the specimen and the resulting deflection is measured

ASTM D698 covers “Test Methods for Compaction Characteristics of Soil Using Standard Effort”. This test method employs the following procedure:

- A soil at a selected water content is placed in three layers into a mold of given dimensions
- Each layer is compacted by blows of a rammer dropped from one foot high
- The resulting dry unit weight is determined
- The procedure is repeated for a sufficient number of water contents to establish a relationship between the dry unit weight and the water content for the soil
- When plotted the data represents a relationship known as the compaction curve
- The values of optimum water content and standard maximum dry unit weight are determined from the curve.

ASTM D5084: covers “Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter”. This Standard applies to one-dimensional, laminar flow of water within porous materials such as soil and rock. The hydraulic conductivity of porous materials generally increases with an increasing amount of air in the pores of the material. The test assumes that Darcy's law is valid and that the hydraulic conductivity is unaffected by hydraulic gradient. The validity of Darcy's law may be evaluated by measuring the hydraulic conductivity of the specimen at three hydraulic gradients; if all measured values are similar (within about 25%), then Darcy's law may be taken as valid. When the hydraulic gradient acting on a test specimen is changed, the state of stress will also change, and, if the specimen is compressible, the volume of the specimen will change as well.

ASTM D3080 covers the “Direct Shear Test of Soils Under Consolidated Drained Conditions.” The test method consists of placing the test specimen in the direct shear device to which a predetermined normal stress is applied. The shearing force and horizontal displacements are measured as the specimen is sheared.

4.0 Summary

The origin, background, and purposes of ASTM standards have been discussed. Some of the ASTM standards that are useful for utilizing waste tires in civil engineering applications have been reviewed, with particular emphasis on ASTM D 6270-98 (Reapproved 2004), "Standard Practice for Use of Scrap Tires in Civil Engineering Applications". The application of TDA in embankment fill according to ASTM D6270 and other sources was presented.

5.0 References

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CIVL 411 Soil Mechanics

Waste Tire Applications in Geotechnical Engineering

1.0 Introduction

1.1 Background

California currently generates approximately 40 million waste tires each year. The California Integrated Waste Management Board (CIWMB) is tasked with coming up with ways to divert these tires from the waste stream to being recycled into useful products. They see the use in Civil Engineering applications as being the largest growing market for waste tire products. There are many benefits of using waste tires as a construction material. Some of these benefits are that it helps get rid of stockpiled waste tires, preventing waste tire fires (which are harmful to the environment), preserves valuable aggregate and users can utilize the unique engineering properties of waste tires.

Tires are a non-biodegradable material, which means that when they are disposed of, they will never really disintegrate. If no uses for waste tires were available in the U.S., the stockpiles would continue to grow, at virtually the same rate that the tires are produced. Being non-biodegradable can be both good and bad. The upside is that tires can be used for a long time, even after they are no longer fit for their primary purpose. The downside is, if they enter the waste stream instead of recycling them, they must be stockpiled. Aside from ugliness of waste tires, and the wasted space, these stockpiles are not good because they present potential hazards to the environment. If they catch on fire, it is very difficult to extinguish them. This is dangerous to people and the environment because tire fires release several heavy metals and hazardous compounds into the environment such as Arsenic, Chromium, Lead, Manganese, Nickel, Mercury, Cadmium, and Pyrolytic Oil. For example, the Westley fire released 250,000 gallons of Pyrolytic Oil and resulted in 4 million gallons of contaminated fire fighting water. Over the years, we have and continue to successfully reduce the amount of stockpiled waste tires in the U.S. by finding creative ways to recycle them. Using Tire Derived Aggregate for Civil Engineering projects is one of these many ways. Figure 1 shows the waste tires in stockpiles reduced from 1 billion in 1992 to about 188 million in 2005. In fact, the volume of waste tires used for Civil Engineering projects is second only to the volume used for Tire derived fuel. The Figure 2 below shows the trends of waste tire reuse in the U.S.

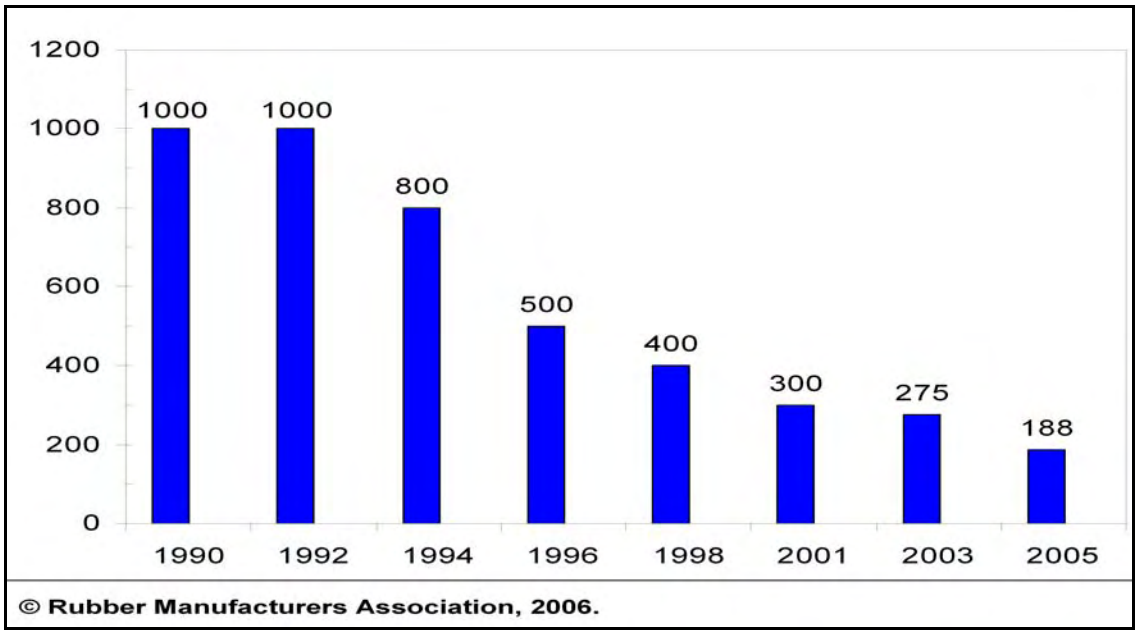

Figure 1. Millions of Scrap Tires remaining in U.S. Stockpiles, 1990-2005

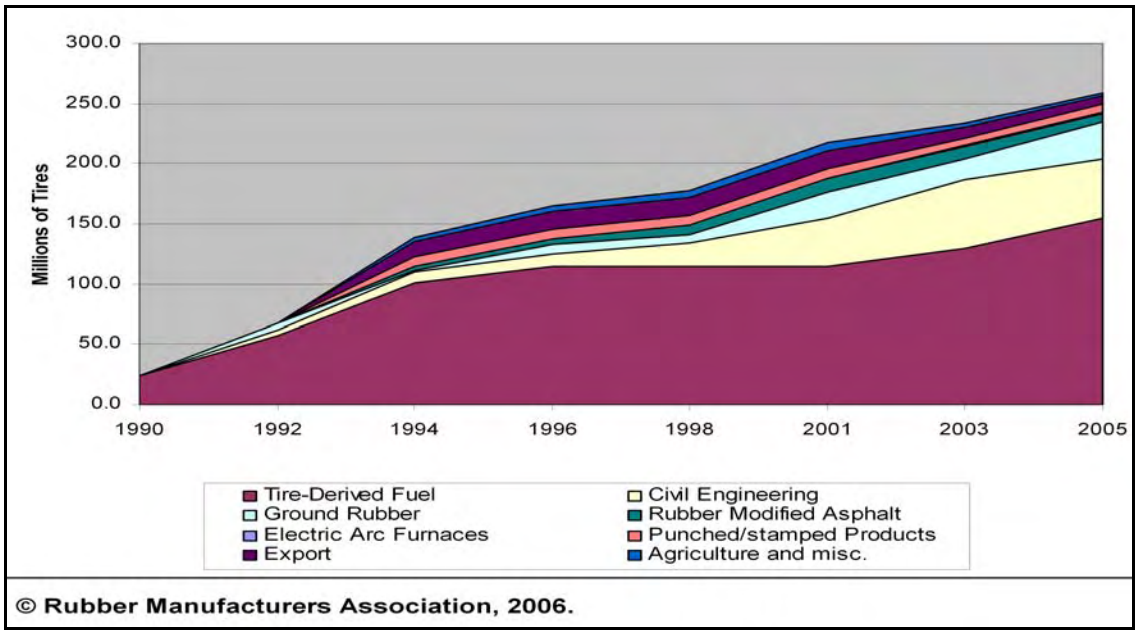

Figure 2. Scrap Tire Recycling and Their Trends in the U.S.

In addition to reducing waste tire stockpiles, using Tire Derived Aggregate (TDA) reduces aggregate use, which can bring economic benefits, especially where aggregate is costly, and also reduces the environmental impact of mining for aggregate. Although TDA may be considered as

a ‘substitute’ for aggregate, this does not mean that it cannot work just as well, or even better, when properly designed for certain applications.

1.2 What is Tire Derived Aggregate (TDA)

Tire Derived Aggregates (TDA) are pieces of processed tires that have a consistent shape and are generally between 25mm (1 in.) and 300mm (12 in.) in size. Tires processed by simply shredding them and then removing a portion of the steel for the tire beads and belts with magnets over a conveyer belt. There are two main classifications of TDA: type A and type B. The following figure shows the two types of TDA. Type A TDA is made of shreds less than 3 inches long and is well-suited for drainage, insulation, and vibration damping. Type B TDA is made of shreds less than 12 inches long is well-suited for use as lightweight fill.

Figure 3: Left- Type A TDA Right- Type B TDA

2.0 Properties and uses for TDA

Some of the useful properties of TDA are that it has a low unit weight (1/3 to 1/2 of soil), has low lateral earth pressure (1/2 of soil). It also has good thermal insulation (8 times better than common soil), and drainage (10 times better than common soil) characteristics. It is compressible, and it is durable. Some of the geotechnical engineering applications for TDA include, backfill for retaining walls and bridge abutments, lightweight embankment fill and subgrade fill, subgrade insulation for roads, and slope repair.

2.1 Retaining Wall Backfill

Tire shreds make excellent backfill material for several important reasons. First of all, the light weight of the tire shreds reduces horizontal pressures on the walls, which allows for construction of thinner, less expensive walls. Additionally, tire shreds can also reduce problems with water and frost build-up behind the walls, because they are free draining and provide good thermal insulation.

2.2 Subgrade Fill and Embankments

TDA's low unit weight and low cost compared with other lightweight fill materials make it a great material for subgrade and embankments fills. Tire shreds, because of their light weight, work well for constructing embankments on weak, compressible soils because they put less pressure on the supporting soil, and because TDA is often cheaper than light weight aggregate (or in some cases, free), which can save the user substantial amounts of money. Example uses include, protecting roads from erosion, enhancing the stability of steep slopes along highways, and reinforcing shoulder areas.

2.3 Subgrade Insulation for Roads

In cold climates, subgrade materials may freeze and cause frost heave, which can damage road surfaces. In addition, there will be a loss of strength after the subgrade soils thaw. Tire shreds are 8 times better than gravel for reducing frost penetration, so, by placing a 6 to12 inch layer of TDA under roads, freezing can be prevented. Additionally, the high permeability of tire shreds allows water to drain freely from beneath roads, preventing damage to road surfaces. Therefore, tire shreds offer protection against frost heave and seasonal strength-loss for roads in cold climates.

2.4 Slope Repair

When landslides occur, it is often necessary to excavate the sliding road material down to more stable soil, and then rebuild the slope and road in shallow, compacted sections called lifts. Additionally, drainage improvements are usually made to increase its stability. Because, tire shreds have great drainage capabilities, they are lightweight and easy to excavate, and are inexpensive, they are desirable for civil engineers, public works directors, and contractors to use for designing and building quality, cost-effective projects in this application.

3.0 Case Studies

3.1 Retaining wall backfill for Wall 119, Riverside, CA

TDA was used as backfill in a project constructed in summer and fall of 2003 to widen the West bound side of Route 91. A 12 ft wall was constructed according to Caltrans standard specifications utilizing TDA as a backfill material. The question to be answered was, 'Is TDA as effective as typical backfill soil in this application?' To answer this question, engineers decided to instrument the wall to measure the wall's performance. Instrumentation included four types of gauges: strain gauge, pressure cell, temperature sensor, and tilt meter. The strain gauge was used to measure strain in the rebar inside the wall. To measure the stress in the wall, the pressure cell was put in place to monitor the amount of pressure the TDA fill exerted on the surface of the wall. The Temperature sensor was used to monitor the temperature of the TDA (if it gets to hot it could combust), and the tilt meter was used to measure the tilt of the wall. An analysis of the measured data helped engineers conclude that the answer to the question is, 'Yes, TDA is just as effective as typical backfill soil'. Figures 4 and 5 shows the construction of the retaining wall 119 including TDA backfill construction.

Figure 4. Retaining Wall 119 Construction on Route 91 in Riverside

Figure 5. Top Left- Strain Gauges, Top Right- Installation of Temperature Sensor
Bottom Left- Installation of Tilt Meter, Bottom Right- TDA Placement

3.2 Embankment Fill- Dixon Landing Interchange

The Dixon Landing interchange required the in situ soft bay mud to support an embankment for a highway I-880 south on ramp. TDA's light weight made it a good candidate for the project, so it was used for the core of the embankment. Not only did tire shreds work well for the project, but using them also saved approximately $230,000. Figure 6 shows a typical cross section of Dixon Landing project. Figure 7 shows the construction of the Dixon Landing interchange. Note that no special construction equipment is needed to construct the TDA embankment.

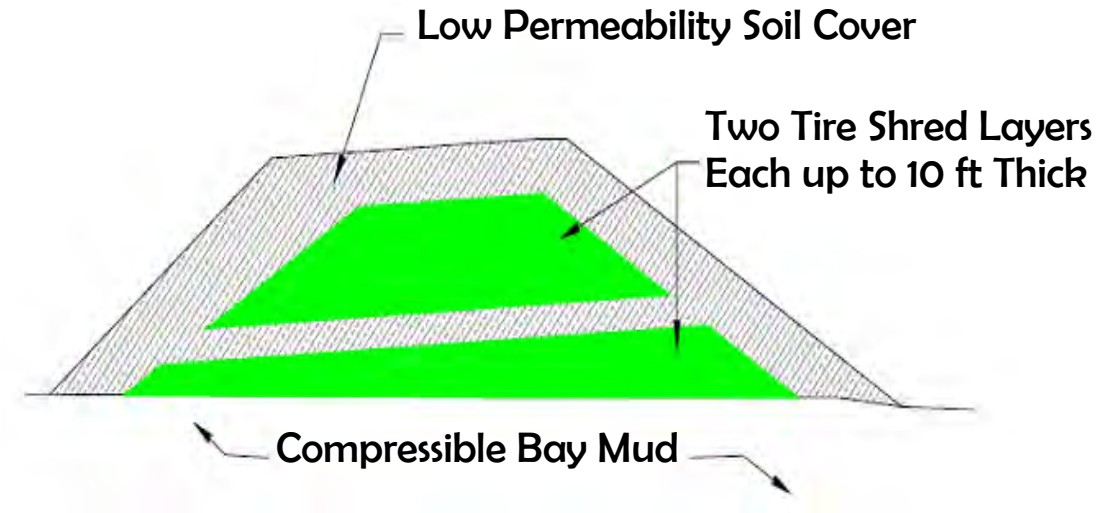

Figure 6. Typical Cross-Section of Dixon Landing TDA Project

Figure 7. Top Left- Unloading TDA, Top Right- Spreading TDA, Bottom- Compacting TDA

3.3 Subgrade Insulation- Witter Farm Road, Orono, Maine

This road was highly susceptible to frost heave due to Maine's cold climate, and a weakening of subbase during the melting season, which leads to cracking and rutting of the asphalt pavement. TDA was used as subbase under the road, which prevented frost heave from occurring. Figure 8 shows a typical cross section of the road. Additionally, the tire shreds proved to be much more permeable than gravel so that water drains away easily. Figure 9 shows the construction of the TDA as a subgrade insulation layer. Figure 10 shows that tire shreds can significantly reduce the frost heave. The frost depth of sections 2, 3, 4, and 5 were less than that of the control section.

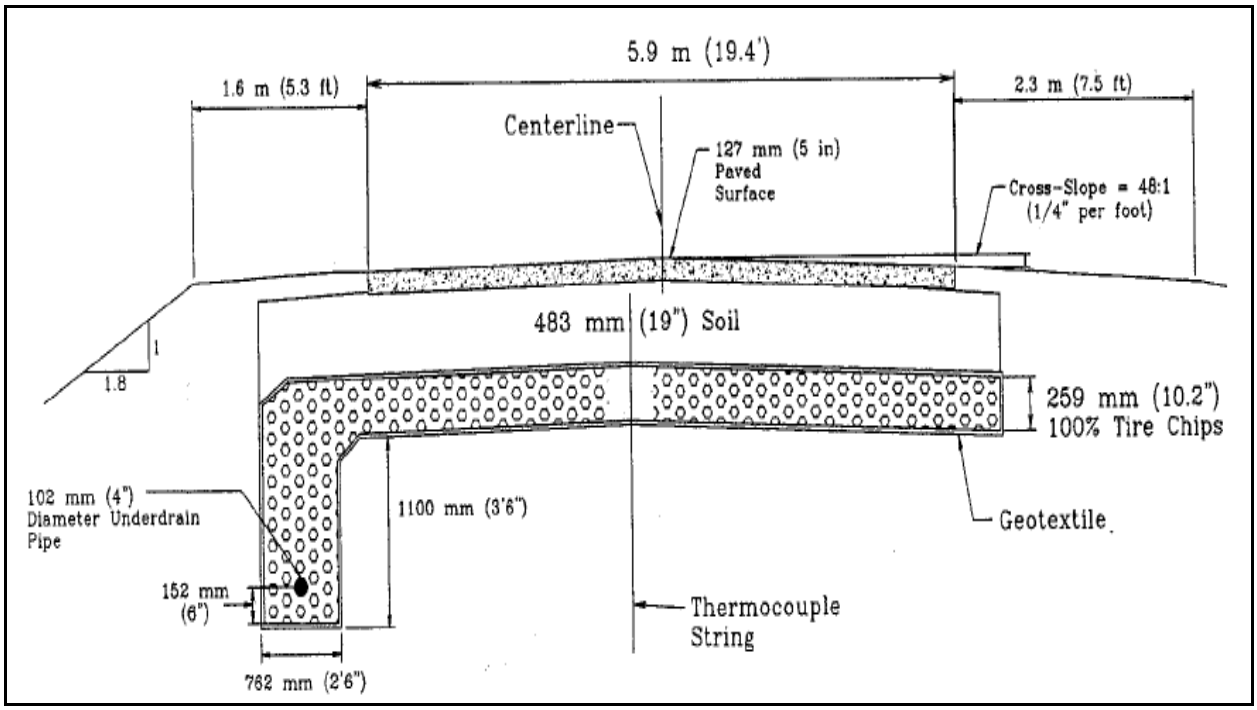

Figure 8. Typical Cross-section of Witter Farm Road

Figure 9. Witter Farm Road, Placing and Compacting of TDA

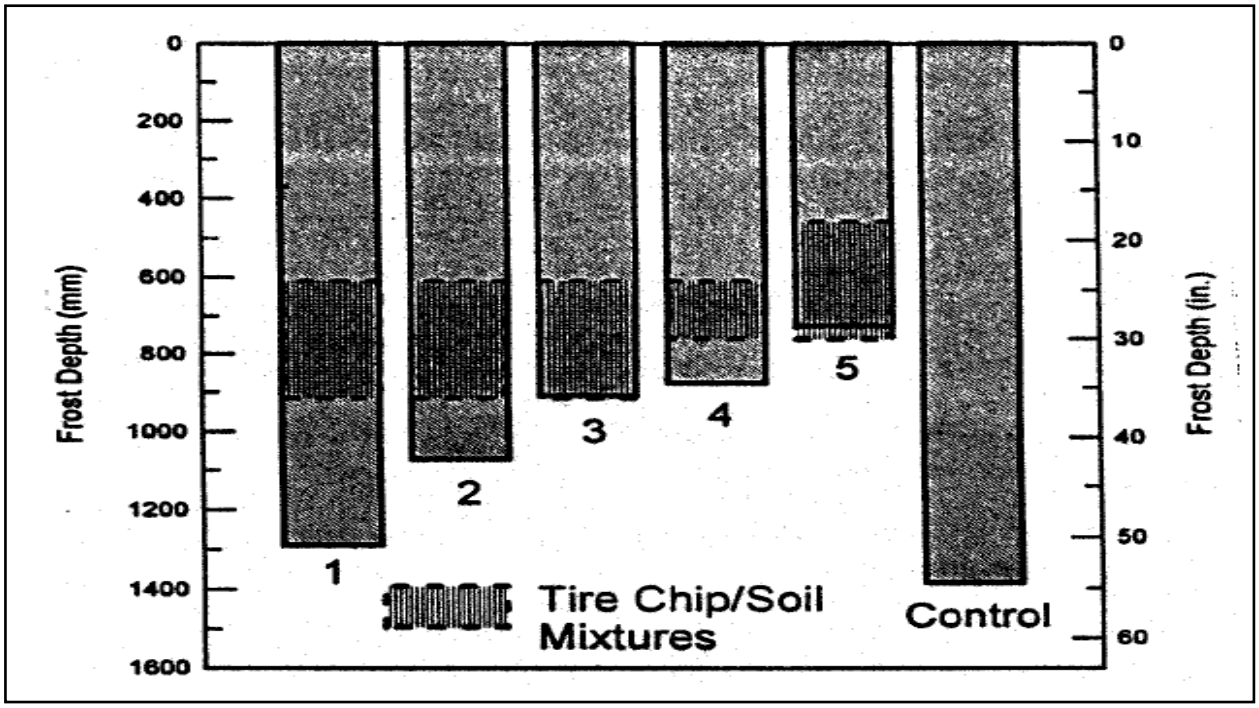

Figure 10. Witter Farm Road, Frost Penetration for Winter of 1996/7

3.4 Slope Repair- Marina Drive, Ukiah, CA

A section of the Marina Drive road washed out and TDA was used as a replacement instead of typical backfill soil. Figure 11 shows the washed out portion of Marina Drive. TDA proved to be an excellent alternative to traditional backfill soil.

Figure 11. Marina Drive, damaged road sections

Figure 12 shows the schematic cross section design of using TDA as fill material to reduce the weight and increase the stability of the slope. Figure 13 shows the construction of the project. And Figure 14 illustrate the finished project with green grass cover.

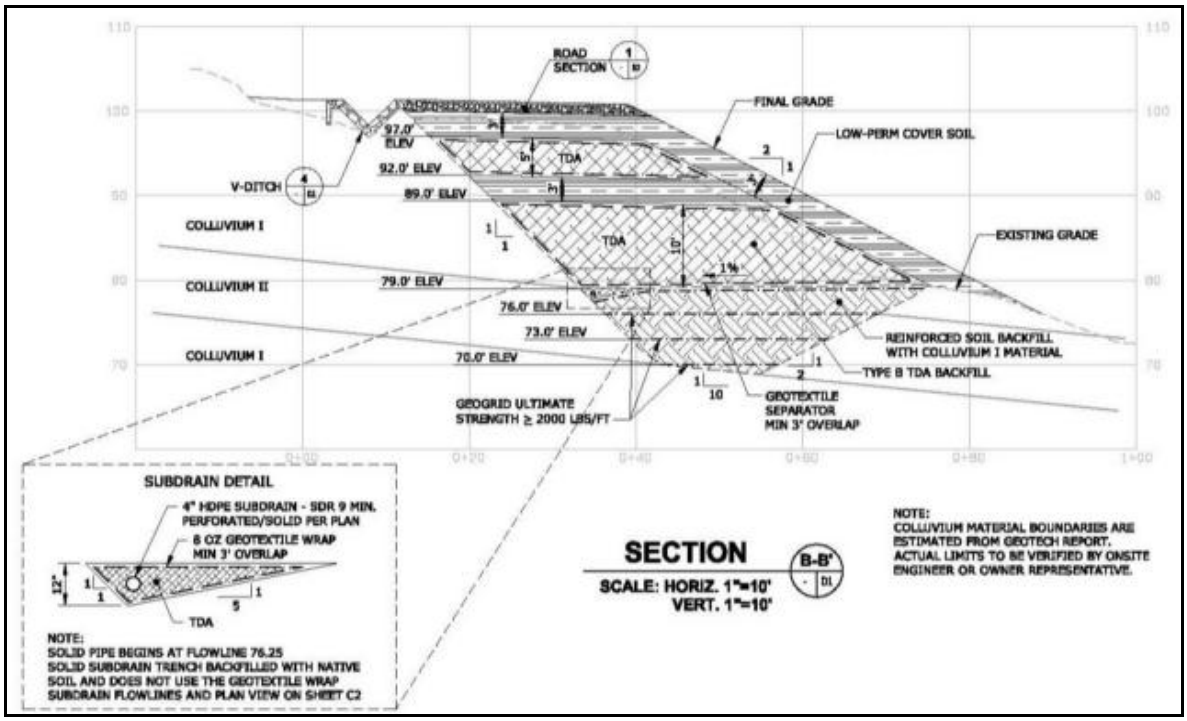

Figure 12 Marina Drive, Proposed Cross-section Drawing

Figure 13. TDA construction at the Marina Drive Slope Repair

Figure14. Finished Project at the Marina Drive Slope Repair

4.0 Summary and Recommendations

Tire Derived Aggregate (TDA) has many unique physical properties that can be used in Geotechnical engineering. The in-place density of TDA ranges from 45 lb/ft^3 to 58 lb/ft^3, which is about 1/3 to 1/2 the unit weight of soil. TDA can be used as a lightweight material to construct embankments on weak, compressible foundation soils. TDA has high permeability, more than 1 cm/sec, which can replace conventional aggregate to be used as gas collection media or leachate collection material. TDA is a good thermal insulation material, which has a thermal insulation 8 times greater than that of gravel. In cold climates, placing a 6 to 12 inch tire shred layer under the road can prevent subgrade soils from freezing. In addition, excess water may be released when subgrade soils thaw in the spring. The high permeability of tire shreds allows water to drain freely from beneath the roads, preventing damage to the road surfaces. Due to its lightweight, TDA is also a great fill material for slope repairs to increase the factor of safety over conventional fill materials.

5.0 References

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CIVL 415 Reinforced Concrete

Rubber Included Concrete (RIC)

1.0 Introduction

A substantial amount of research has been conducted on using recycled tire products in the manufacture of rubber included portland cement concrete (RIC). To date, however, no widely accepted commercial applications exist for rubber included concrete (RIC). Teaching materials were prepared to look at applications of adding scrap waste tire products to concrete mixes to alter the resulting concrete's mechanical properties. A lab project was developed to determine the effects of adding different percentages of crumb rubber and tire buffings in place of both fine and coarse aggregate in the mix. Proper methods of achieving a proper substitution in the mix are discussed. A discussion of the effects of adding waste tire products to concrete properties is presented.

1.1 Objectives

The objectives of this chapter are to introduce students to use a non-traditional recycled material in concrete mix design, and to evaluate the effects of these materials on the resulting concretes engineering properties.

1.2 History

The literature contains a substantial body of research on the impacts of using waste tire products in the manufacture of portland cement concrete. Different types of waste tire products from finely ground rubber to tire chips have been evaluated for a variety of mechanical properties of the resulting rubber included concrete. In spite of this, no commercial application of RIC is in common use today.

1.3 Theory

Several researchers have evaluated the effects of adding waste tire products to modify the engineering properties of the resulting concrete mix. These researchers have adopted several different names to describe their newly formulated mix design e.g.:

- Crumb Rubber Concrete (CRC)
- **Rubber Included Concrete (RIC)**
- Rubberized Concrete
- Rubcrete
- Tire Rubber-Filled Concrete

Rubber included concrete (RIC) was chosen as the best possible name to use in this module. Major problems are encountered in comparing the results of this research. Not only do different researchers use different waste tire products, but they formulate their mix designs in many different ways. This is further complicated by different pre-treatment and mixing methodologies

employed by the different researchers. This makes direct comparison of results from the literature challenging at best, but general conclusions about the effects of adding waste tires to portland cement concrete mixes can be drawn.

1.4 Benefits and Limitations of RIC

The potential benefits of adding waste tire products to portland cement concrete include:

1. Reduces compressive strength. Reducing the compressive strength is not generally a benefit, except when you consider that concrete properties are usually correlated to the compressive strength. For instance, the lower the compressive strength, the lower the modulus of elasticity of the concrete. If a more flexible mix is desired, reducing the compressive strength will may help achieve this.
2. Increases ductility. The ability of the concrete to deform without failure, especially for concrete subjected to tensile stresses is increase by the inclusion of rubber..
3. Increases toughness. T he ability to absorb energy without fracturing, which is represented by the total area under the stress strain curve, occurs with the inclusion of rubber..
4. May reduce cracking. An increase in the ductility and toughness of the RIC combined with the increased flexibility (reduced stiffness) may result in a decrease in the tendency of the concrete to crack.
5. Reduces the unit weight of the concrete. Because the specific gravity of the rubber is nearly unity compared to the specific gravity of the mineral aggregate which is in the range of 2.6 to 2.7. Also, adding scrap tire products to the concrete mix tends to increase the air content of the concrete, further reducing the unit weight.
6. Reduces the thermal expansion/contraction coefficient. Interestingly, even though rubber has a coefficient of thermal expansion an order of magnitude greater than concrete (70 to 110 x $10^{-6}/^{o}F$ for rubber versus 4 to 8 x $10^{-6}/^{o}F$ for concrete), RIC had a lower value than for the control mix without rubber. This may be due to the much lower stiffness of the rubber than the mineral aggregate, which allows the expansion/contraction to take place by expanding/compressing the rubber in the mix, and not causing a change in size of the specimen with temperature changes.
7. May replace air entraining agent in cold environments. The rubber in the concrete, if well dispersed, can compress to allow volume to accommodate the increase in volume of the water as it undergoes the phase change expansion upon freezing. In addition, adding rubber to the mix increases the amount of air entrained due to the air bubbles that are attached to the rubber particles. This may allow the mix designer to replace expensive air entraining chemicals with a much cheaper recycled product. One has to question the validity of using pressure pots to measure air content as they are calibrated for mineral aggregates which are much more rigid (nearly incompressible) compared to rubber (ratio of modulus of elasticity of stone to rubber is on the order of 10,000). So the question is how much of the air content is measured as compressing of the rubber in the concrete mix. This could be evaluated by calibrating your pressure pot with water according to the

directions in the user manual, then replacing some of the water with the expected amount of rubber in the same volume of concrete as the pressure pot. The resulting air content (if no air bubbles are present on the surface or inside of the rubber particles) then the pressure pot can be recalibrated to include the compressibility of the rubber.

8. Improves insulation (but decreases thermal mass). Rubber is a much better insulator than concrete, so adding rubber to concrete will make the concrete a better insulator. However, rubber stores much less heat than concrete, so adding rubber to concrete will decrease its thermal mass.
9. Reduces sound transmission. Rubber is an excellent vibration mitigation material, and when added to concrete mixes will reduce the sound transmitted through the concrete.

The primary disadvantage of using scrap tire rubber in portland cement concrete is the reduction in compressive (and tensile) strength. The compressive strength has been reported to decrease dramatically with increases in rubber content. This is caused by several factors including:

1. The rubber is weaker and less stiff than mineral aggregate.
2. Adding rubber to concrete generally increases the air content, further reducing the compressive strength
3. Some researchers added rubber to the mix by weight not volume which increased the absolute volume of the coarse and/or fine aggregates in mix which also decreases compressive strength.
4. Portland cement is manufactured to bond to mineral aggregates, not rubber. There may be a decrease in strength caused by the poorer bond between the cement paste and the rubber particles.

Other disadvantages include the reduced fire resistance of RIC and the toxic fumes that it would release when subjected to elevated temperature. Also, RIC may not be as recyclable as ordinary concrete.

Potential applications for RIC include:

1. Tire rubber may replace air entraining in cold weather applications.
2. RIC may be more flexible and crack resistant for light weight paving.
3. RIC may be useful where vibration damping and sound transmission mitigation is desired.

2.0 Synthesis of Research Results

Table 1 summarizes a few of the mix designs found in the literature buy rubber type, content and method of mix design. Several difficulties exist when trying to interpret the results of the literature:

1. Different types of tire particles were utilized
2. Different methods of mix design were employed

3. Different pretreatment methods were used for the tire particles
4. Different testing procedures were used to evaluate the resulting concrete

Table 1. Literature Review of Mix Designs for Rubber Included Concrete

Author	Rubber Type	Rubber Content	Method of Mix Design
Kaloush et. al. (include dates for all references)	1mm Crumb Rubber	0, 50, 100, 150, 200, and 300 #/yd^3	Replaced fine aggregate with crumb rubber by weight, increased w/c ratio
Fedroff et. al.	Super fine powder	0, 10, 20, and 30%	By weight of cement in mix adjusted w/c ratio to get 3 to 5 inches of slump
Tantala et.al.	Buff Rubber	5 and 10%	Replaced 5% and 10% of coarse aggregate with buff rubber by volume
Li et. al.	Cyrogenic Ground Rubber<2mm	33%	Replaced 33% of fine aggregate by volume
Schimizze et.al.	Fine/Coarse Reclaimed Rubber	5% of mix design by weight	Lowered both 1. fine aggregate and 2. fine and coarse aggregate to get 5% rubber by weight
Biel and Lee	3/8" minus rubber droppings	0 to 90% in 15% increments	Replaced fine aggregate with crumb rubber by volume gave 0 to 25% rubber by volume in mix
Eldin et.al.	Ground tire chips, fine crumb rubber	0,25,50,75,100% by volume	Test specimens replacing either coarse or fine aggregate

Particle sizes ranging from super fine powder to 1-1/2" tire shreds are used. Some tire particles include only rubber and others have belts included. Many different mix strategies were used, some volumetric, some based on weight and some just adding tire particles to the mix. Different pretreatments of the tire particles are reported, including presoaking, and coating with Portland cement and other chemicals. Therefore, only general conclusions can be drawn from the results published in the literature.

3.0 Case Studies

What follows is a summary of some of the engineering properties of rubberized concrete from the literature. These properties generally include:

- Compressive Strength
- Tensile (Split Cylinder) Strength

- Flexural (Modulus of Rupture) Strength
- Unit Weight
- Air Content
- Stiffness
- Ductility
- Toughness
- Coefficient of Thermal Expansion
- Durability
- Damping characteristics

The most important characteristic of concrete and what all other mechanical properties are generally correlated to is the compressive strength (, f_c). Therefore a lot of research has been done on evaluating the effects of adding scrap tire rubber to concrete on its compressive strength. Rubber is weaker and less rigid than the mineral aggregate that they replace, which reduces the compressive strength. Increasing rubber content has been found to increase the air content, which also reduces the compressive strength. The bond characteristics between the cement paste and the rubber may also reduce the compressive strength. As always, w/c ratio, unit weight, workmanship, and curing affect compressive strength.

As an example of the effects of adding scrap tire rubber to concrete, the work of Kaloush, et.al.(date) is presented as a case study for compressive strength. First, it is important to understand the type of rubber used and the mix design parameters. A summary of the mix design is given in the following table:

Table 2. Various Rubber Included Concrete with Different Parameters

Project / Mix ID #	*Unit Weight lbs/cu ft*	*W/C ratio*	*Dry weight of materials, (lbs/Cyd)*		
			Cement	*FA*	*CA*
0 lbs per Cyd *(Trial)*	147.8	0.42	525	1417	1731
50 lbs per Cyd *(Trial)*	140.1	0.44	525	1367	1731
100 lbs per Cyd *(Trial)*	135.7	0.45	525	1317	1731
150 lbs per Cyd *(Trial)*	125.7	0.46	525	1267	1731
200 lbs per Cyd *(Trial)*	126.5	0.47	525	1217	1731
300 lbs per Cyd *(Trial)*	109.2	0.48	525	1117	1731

They utilized 1mm particle size crumb rubber and replaced different weights of the fine aggregate (50,100,150,200, and 300 lbs/cbyd). This resulted in more absolute volume of fine aggregate in the mix design which would be expected to lower the compressive (and tensile) strength. The

unit weight of the concrete declines with increasing crumb rubber content which can be correlated with the decrease in compressive strength. Also, the water cement ratio was increased with increasing crumb rubber content, which also lowers compressive strength. Later, you will see that the slump of the concrete decreased while the air content increased with increasing weights of crumb rubber added to the mix. Decreased slump leads to decreased workability (ask any Contractor!), and workability influences the quality of the final product, which may account for some of the reduction in compressive strength. Finally, an increase in air content causes a dramatic reduction in compressive strength as well. Figure 1 shows a look of the resulting concrete for different crumb rubber contents both in cross section, and close up Figure 2 shows the visual effects of adding crumb to the mix and the distribution of crumb rubber in the concrete.

Figure 1, Cross Section of Concrete Sample with Different Amount of Scrap Tire Rubber (references should be included in all figures)

Figure 2. Close Up of a Rubber Included Concrete Sample

The effects of rubber content on compressive strength were reported as shown in Figure 3.

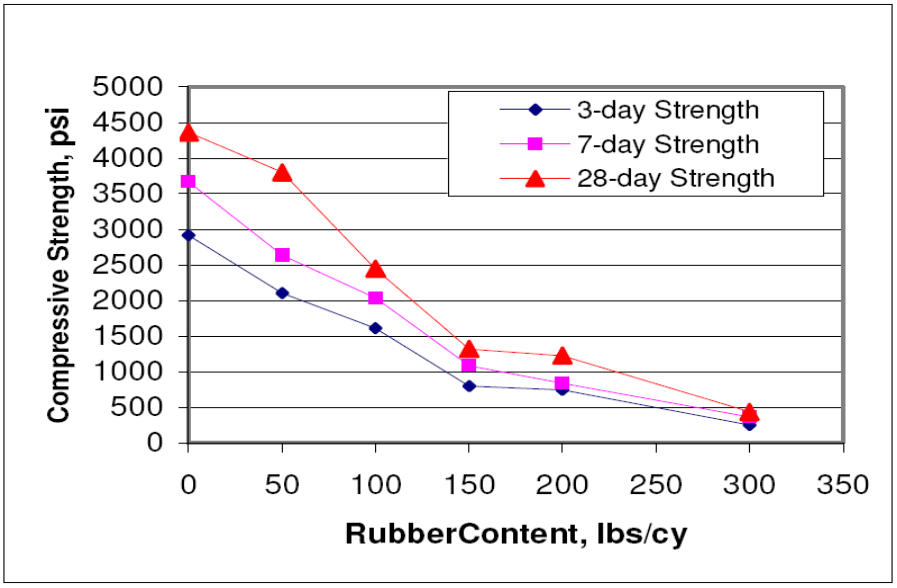

Figure 3. Compressive Strength versus Rubber Content

The dramatic decrease in compressive strength is evident, with 300lb/cuyd concrete having roughly 10% the strength of the control mix. The author also reported the following data associated with these mix designs:

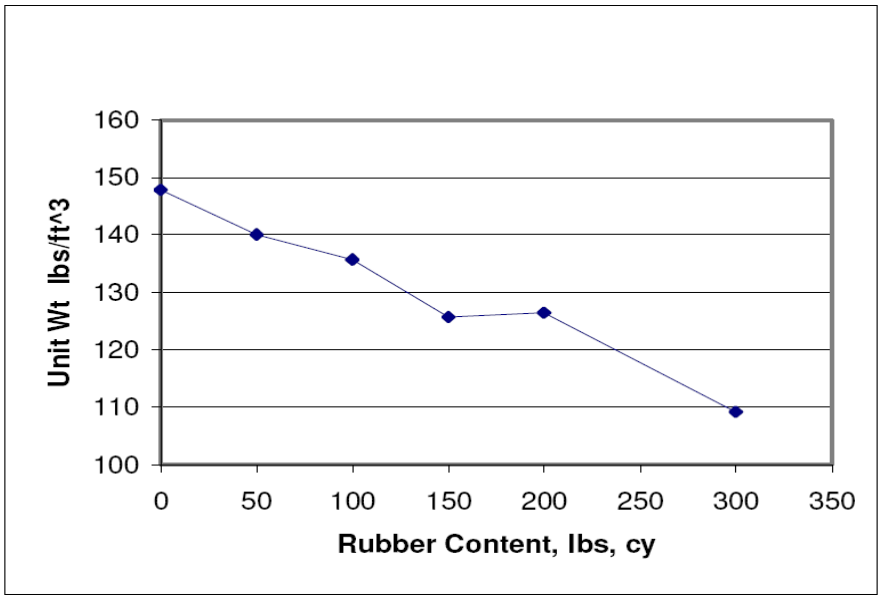

Figure 4. Unit Weight of Concrete Versus Rubber Content

The Author states that the unit weight decreases about 6.2pcf for every 50 pounds of crumb rubber added to the mix. Part of this decrease is due to the increase in air content of about 5% for each 50 pounds of crumb rubber added to the mix as shown below:

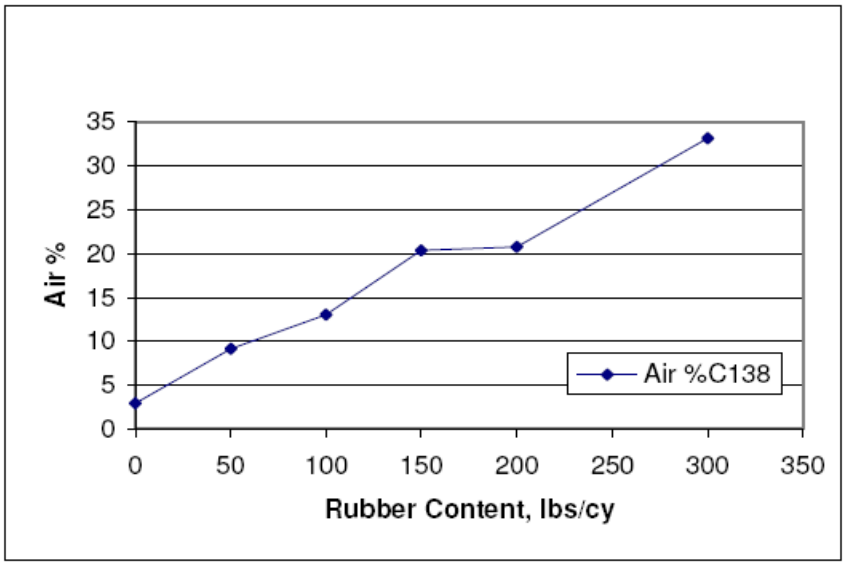

Figure 5. Air Content versus Rubber Content

Again, adding crumb rubber to the concrete mix added about 5% air for each 50 pounds of crumb rubber added to the mix. Air bubbles attach themselves to the relatively rugged particles and are

hard to dislodge. This has prompted several researchers to look at pre-treating the rubber to not only remove air, but to increase the bond strength between the rubber and the cement.

Even though the w/c ratio was increased slightly from 0.42 at 0 pounds to 0.44 at 50 pounds, and then by about 0.01 for each additional 50 pounds of crumb rubber added to the mix, the slump and hence the workability decreased with increasing Rubber Content shown in Figure 6. This may be due to the increased volume of fine aggregate in the mix.

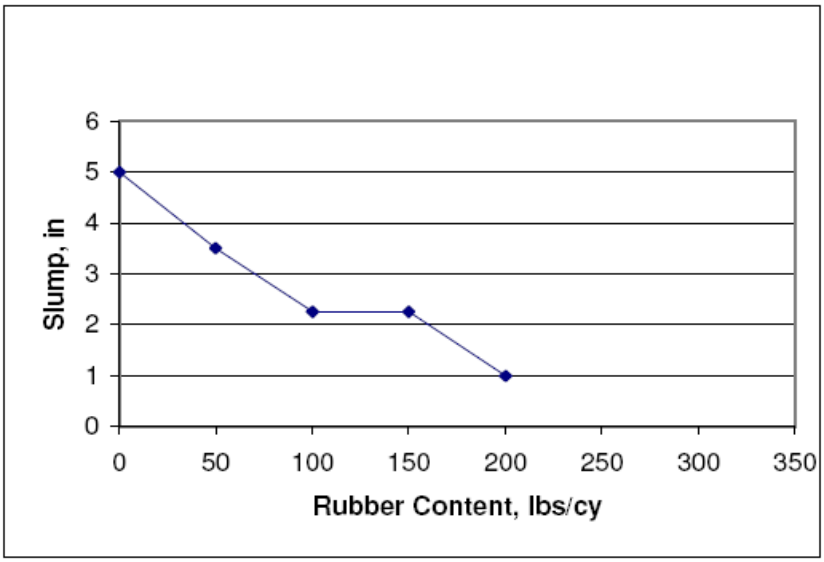

Figure 6. Slump versus Rubber Content

Li et.al. (1998) evaluated the effects of replacing fine aggregate with 33% cyrogenic ground crumb rubber < 2.5mm in size by volume, with a w/c ratio of 0.5. They evaluated both the compressive and flexural strength and stiffness of the resulting concrete for different pretreatment methods shown in Figure 7; RBC-0 is plain concrete, RBC-1 plain rubber without coating, RBC-2 is saturated surface dry (SSD) rubber coated with Portland cement and additional water, and RBC-3 is soaked in METHOCELL cellulose ether (Dow Chemical Co.).

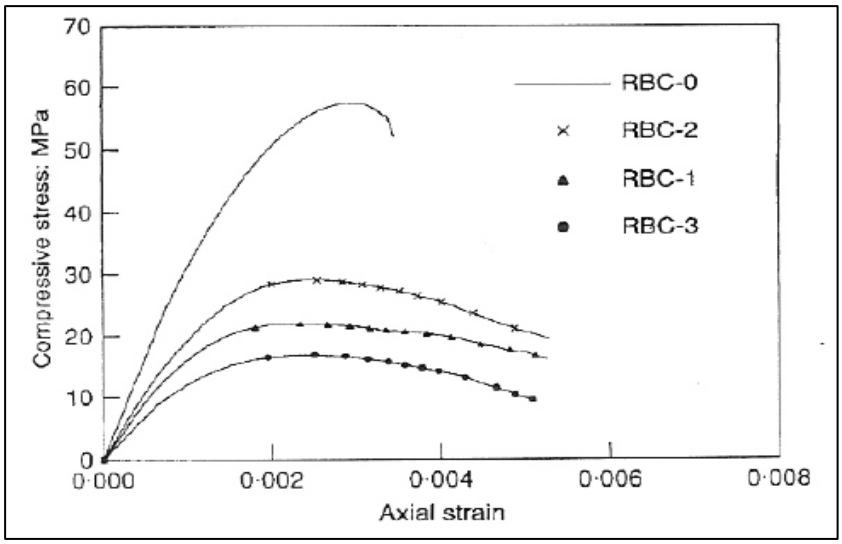

Figure 7. Compressive Stress versus Axial Strain for Different Types of Mixes

Both compressive strength and stiffness (modulus of elasticity) is reduced with the addition of crumb rubber. However, some increase in compressive strength and rigidity can be achieved by pre-coating the particles relative to non-pretreated. Also note the increase in the ultimate failure strain- a measure of ductility. The following bar chart presents the data in a different way:

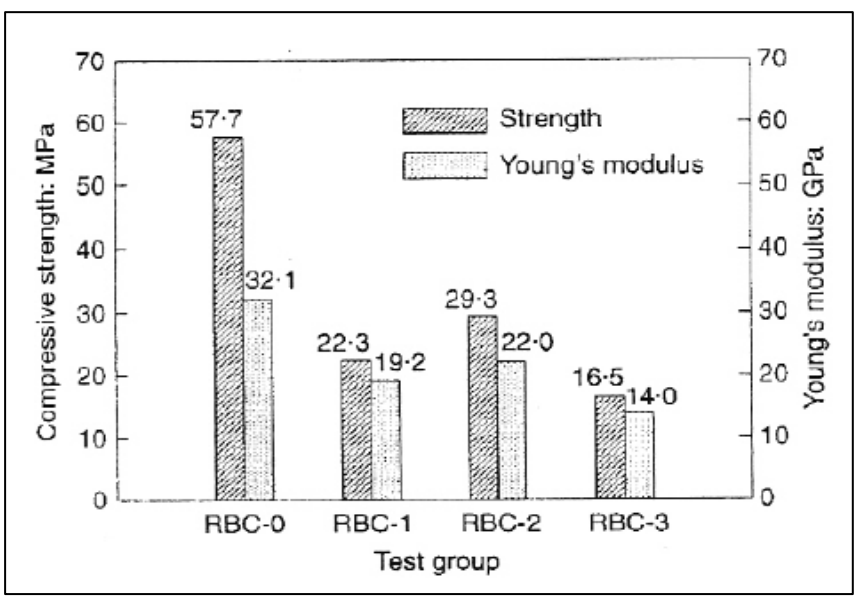

Figure 8. Compressive Strength of Different Types of Concrete Mixes

The results show about a 60% decrease in compressive strength and 40% decrease in stiffness without pre-coating, and about a 50% decrease in compressive strength and 30% decrease in stiffness with pre-coating, i.e. pre-coating the rubber particles with Portland cement increases compressive strength about 30% and stiffness by about 15% versus not pre-coating.

The results of Li's study indicated a smaller reduction in flexural strength compared to compression tests (about 33%) shown in Figure 9, but large increases in ductility as measured by the failure strain. Thus, RIC is capable of absorbing much more energy in tension as evidenced by the larger area under the stress strain curve.

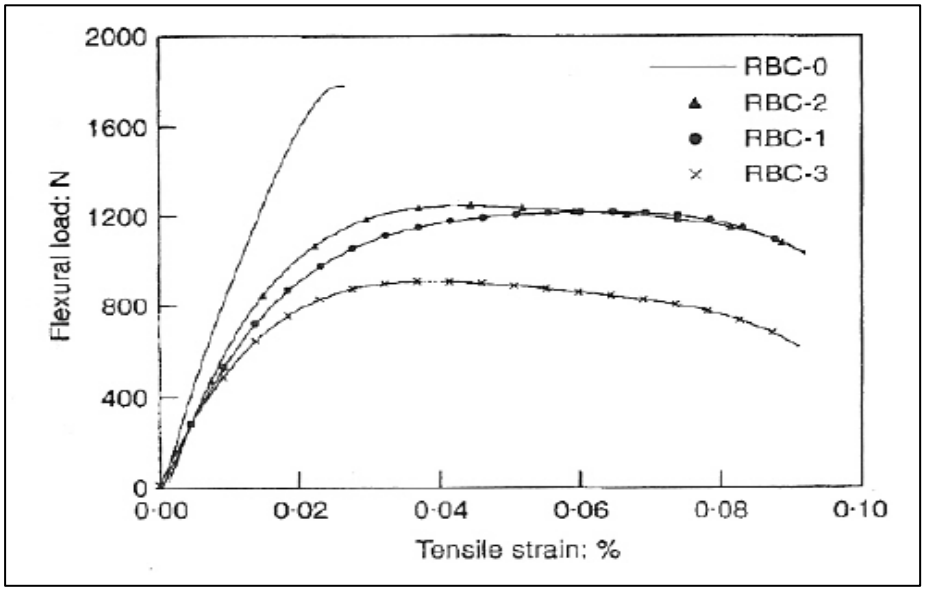

Figure 9 Flexural Load versus Tensile Strain

Tantala et.al. (2002) evaluated the compressive stress strain curves for ordinary concrete, and replacing a percentage (5 and 10%) of the coarse aggregate with buff rubber by volume. They also, considered two pre-treatment methods, water cleaning and acid washing. Only water cleaned aggregate results are considered here. For each of the following graphs note the data reported in the legend as it will be summarized later. Figure 10 shows the stress strain curve for ordinary concrete. Figures 11 and 12 shows the stress-strain curves for 5% and 10% rubber included concretes, respectively. Note that the total area under the stress strain curve represents the toughness of the material.

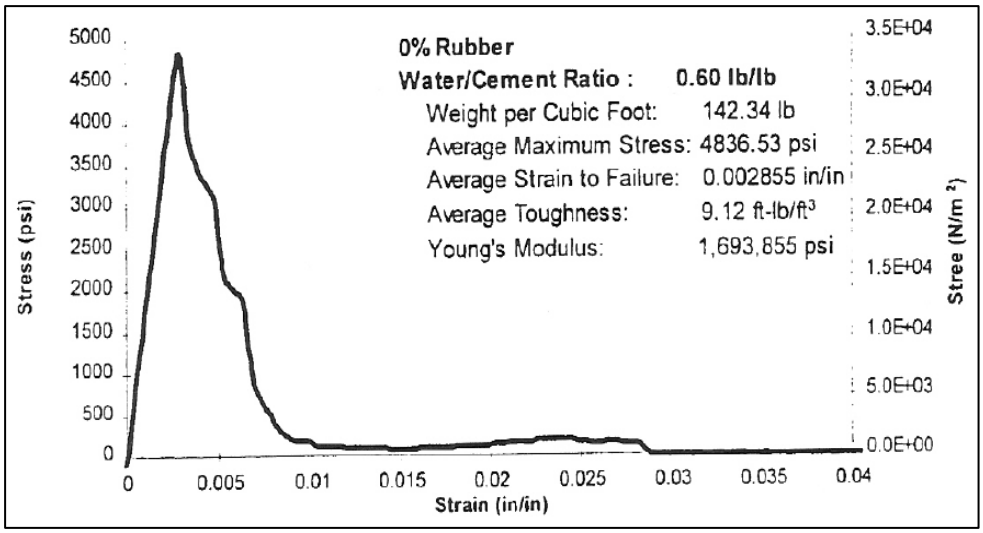

Figure 10.Stress Strain Curve for 0% Rubber

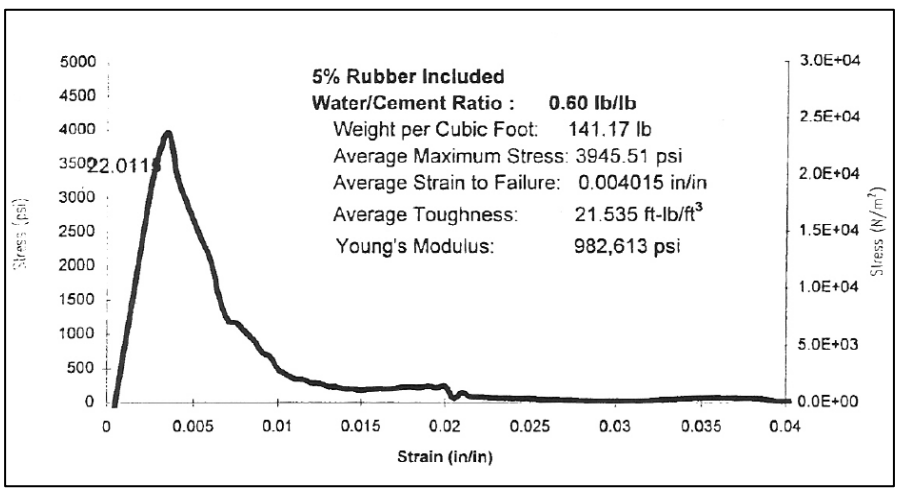

Figure 11. Stress Strain Curve For 5% Rubber Tire Buffings in the Mix

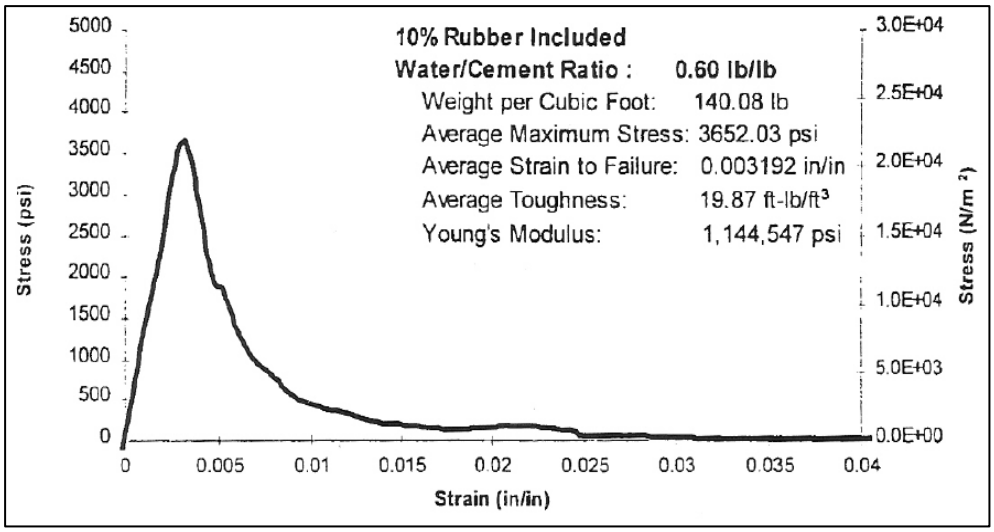

Figure 12. Stress Strain Curve For 10% Rubber Buffings in the Mix.

The following two figures display data taken from the legends of the previous three graphs. The failure stress decreases with increase of rubber content as expected. However, a dramatic increase in toughness with five percent crumb rubber compared to ordinary concrete was reported. Then, there is a decrease in toughness going to ten percent rubber because of the lower compressive strength of the sample.

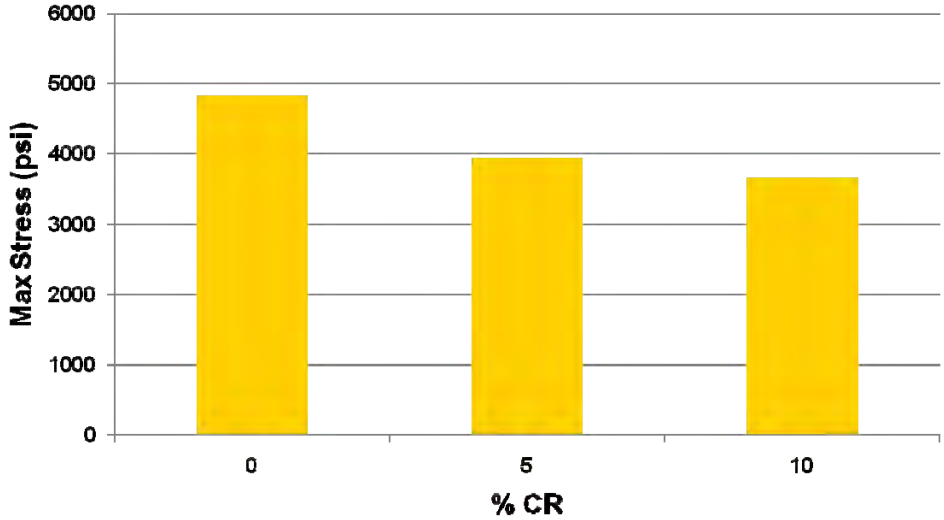

Figure 13, Maximum Compressive Stress versus Percent of Crumb Rubber

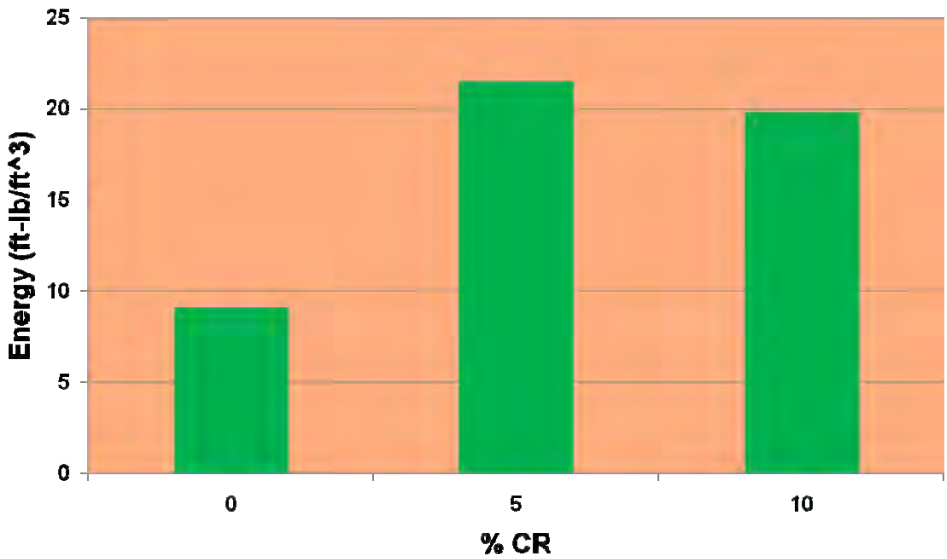

Figure 14. Dissipated Energy or Toughness versus Percent of Crumb Rubber

Biel et.al. (1996) evaluated portland cement (PCC) and magnesium oxychloride cement (MOC) as binders. 3/8" minus scrap tire rubber including steel and fibers from the tire grinding operation was used. They replaced 0 to 90% of fine aggregate with tire particles by volume, giving 0 to 25% tire particles in the concrete mix. The w/c of 0.46 was used to get a slump of 1 to 2 inches. The following graphs show their results for both compressive strength and split cylinder tensile strength.

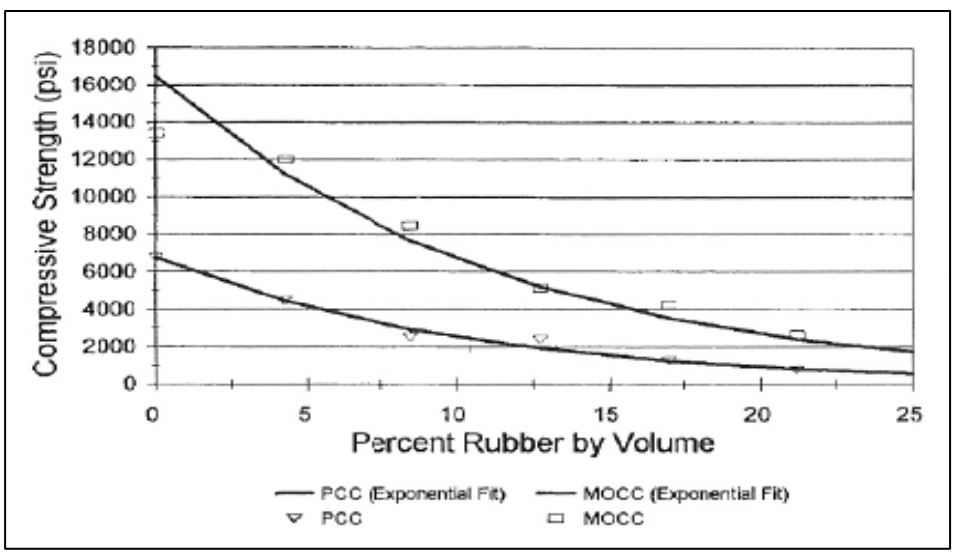

Figure 15. Compressive Strength versus Percent Rubber by Volume

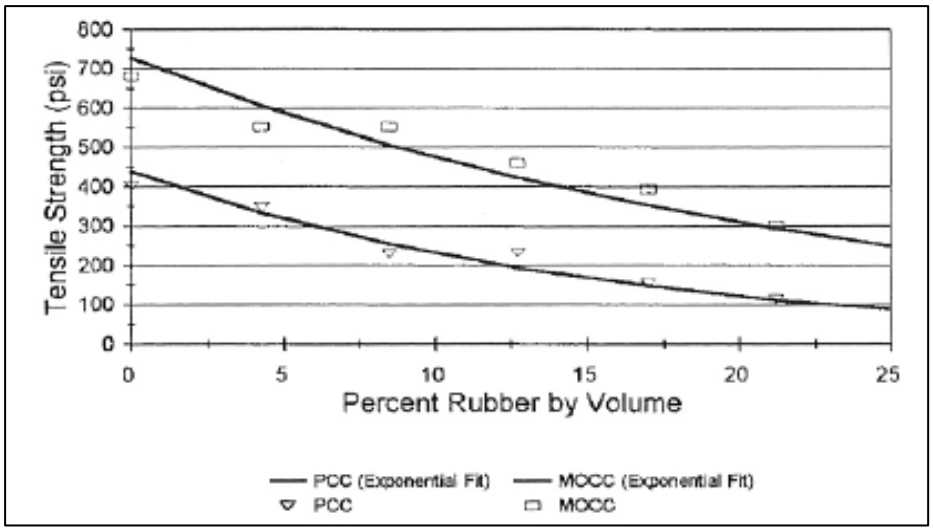

Figure 16. Tensile Strength versus Percent Rubber by Volume

As expected, both compressive and tensile strength declines with increasing rubber content. Kaloush et.al. (2004) reported a less catastrophic failure for the split cylinder test with the inclusion of rubber in the mix. The following photos show this effect:

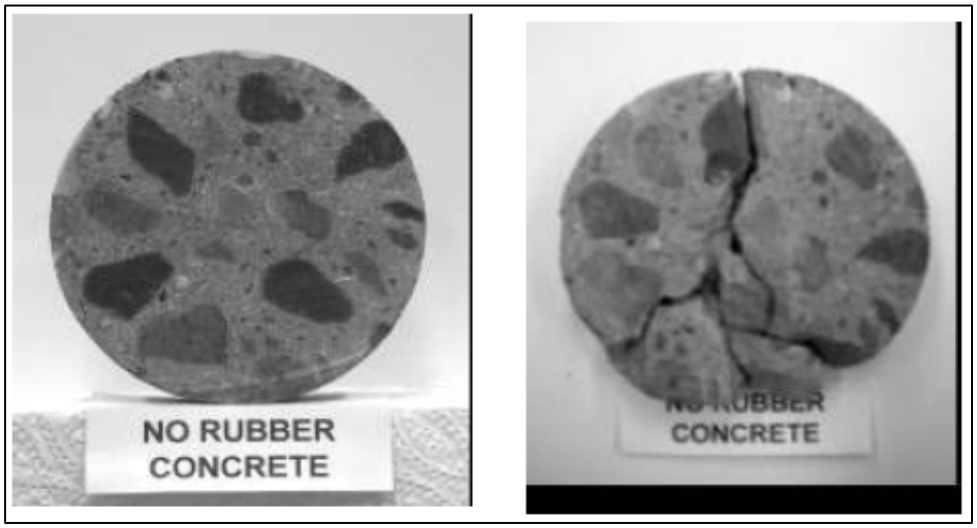

Figure 17. Split Cylinder Test on Ordinary Concrete

Figure 18. Split Cylinder Test on 400 lbs Rubber per Cubic Yard Concrete

Note the "shattering" of the ordinary concrete specimen compared to the more gentle failure of the 400lb/cuyd. concrete.

In order for RIC to work with steel reinforcing, it must have a coefficient of thermal expansion of near that of steel reinforcing which is 6.5×10^{-6} in./in. per ^{o}F. Normal weight ordinary concrete ranges from 4 to 7 with an accepted value of 5.5×10^{-6} in./in. per ^{o}F. Kaloush reports the following coefficient of thermal expansion data (in metric units) for both heating and cooling of the concrete specimens with different rubber contents in Figure 19:

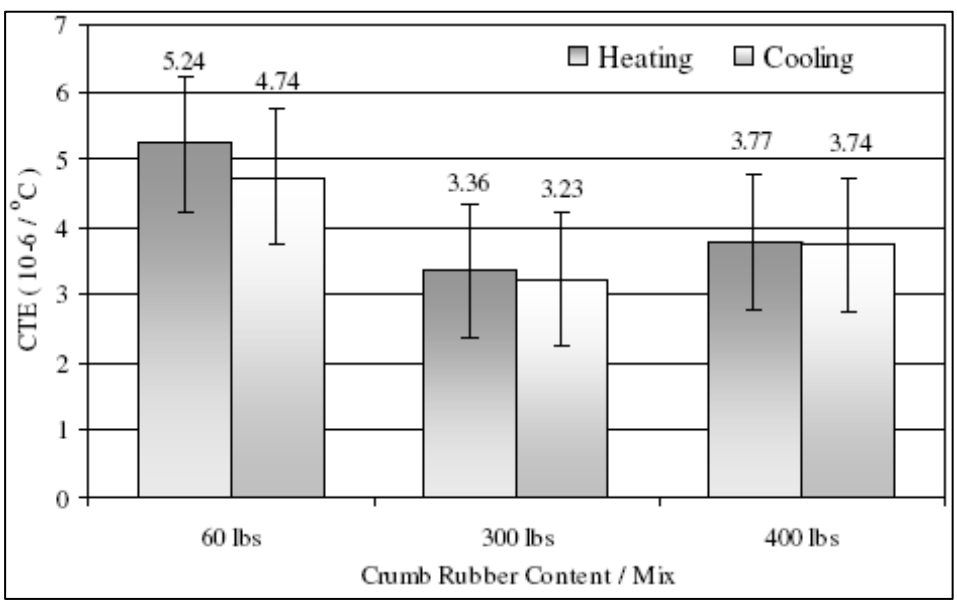

Figure 19. Coefficient of Thermal Expansion for Rubber Included Concrete

Although the literature contains much more research on these and other properties of rubber included concrete, the discussion will now focus on the RIC lab that the students will be performing.

4.0 Lab Exercise

The primary purpose of this lab exercise is to introduce students to using a non-traditional material (scrap tire products) in the manufacture of portland cement concrete. They should gain an understanding on how and why the mechanical properties of the resulting concrete are altered. Finally, they are introduced to how different researchers approached the problem, in terms of scrap tire materials used, mix design philosophy, and treatment methods. They should gain an understanding of how difficult it is to compare and utilize the results of this research for their specific application. First, a discussion of mix design issues is presented, followed by a discussion of the effects of adding scrap tire rubber on the plastic concrete mix (before hardening) and the mechanical properties of hardened concrete.

The mix design should be based on the absolute volume method, replacing mineral aggregate with tire particles of similar size characteristics (gradation). This is accomplished by utilizing the specific gravity of the aggregates. The specific gravity of normal weight mineral aggregates is on the order of 2.6 to 2.7, where as for waste tire particles the range is 1 to 1.2. This results in much less weight of the aggregates and a corresponding drop in the unit weight of the concrete with increasing rubber content in the mix. If this procedure is not followed (i.e. rubber is added by weight) the resulting concrete will have more fine and coarse aggregate by volume in the mix which will have a deleterious effect on the quality of the concrete mix and its resulting mechanical properties.

The parameters needed to complete a mix design when replacing aggregate with like size scrap tire particles include:

- Type of rubber particles, different researchers used different types of scrap tire products ranging from finely ground crumb rubber to tire chunks containing steel and polyester belts.
- Size of rubber particles and aggregate, generally want to replace coarse and/or fine aggregate with tire particles of similar size characteristics.
- Gradation of rubber particles, rubber particles like crumb rubber and tire buffings used in this lab are often uniformly graded, which means that they have roughly the same particle size. Economical concrete requires well graded aggregate to get the densest packing of inexpensive mineral particles in the concrete mix.
- Specific Gravity of Rubber Particles, are on the order of 1 to 1.2 for scrap tire products whereas mineral aggregates have a typical range of 2.6 to 2.7.
- Fineness modulus for the fine aggregate has certain limits as set forth by ASTM. The fineness modulus generally influences the workability of the concrete mix.
- Absorption capacity of the rubber particles influences the amount of mix water added to the concrete during production. If the aggregates are not in a “saturated-surface-

dry" (SSD) condition, they may wick or bleed mix water to the concrete altering the water-cement ratio.

- Rubber content for the mix has to be determined depending on the characteristics the designer is studying or trying to attain.
- Water-cement ratio, as always has a strong influence not only on the workability of the concrete mix, but the resulting mechanical properties.

Note the many different types of rubber used and the different ways the mix proportions were determined. The mix design should be proportioned by volume, and that is the approach that is taken in the mix design lab. It involves replacing both coarse and fine aggregate with coarse and fine crumb rubber by volume, i.e. in proportion to the specific gravity of the crumb rubber to that of the mineral aggregate. This should keep the volumes of the aggregates in relatively equal proportions, resulting in similar workabilty for a given w/c ratio. However, the air content is expected to rise with increasing crumb rubber content.

In order to complete a mix design with a non-traditional material, several material properties must be established, including:

- Gradation (Generally Uniformly Graded)
- Specific Gravity
- Absorption Capacity
- Unit Weights

For this lab, crumb rubber will be used to replace a percentage (10, 20, and 30% by volume) of the mineral fine aggregate and tire buffings will be used for the same percentages of the coarse aggregate.

Figure 20. A Picture of Crumb Rubber Sample Used by CSUC Students

The crumb rubber, which was nearly all black rubber, had a particle size of about 2 to 4 mm, and was uniformly graded as shown in the grain size distribution chart below:

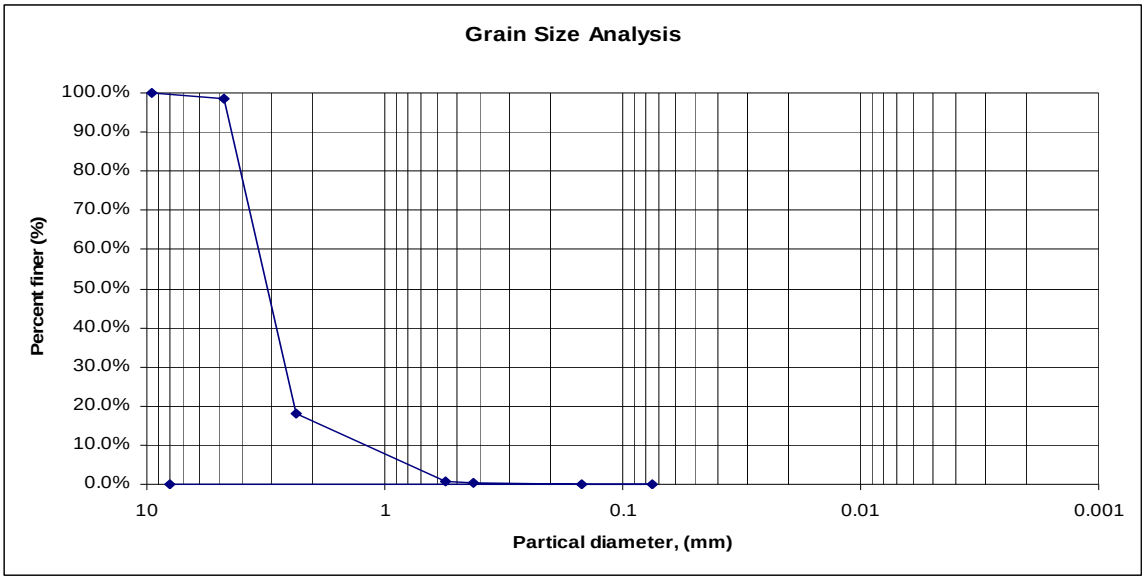

Figure 21. Particle Size Distribution Curve of Crumb Rubber used in CSUC Student Lab

Figure 22. Photos of Tire Buffings Used in Student Lab

The tire buffings, which contained some polyester belting, had particle sizes ranging from 10 to 20 mm showing in the following figure.

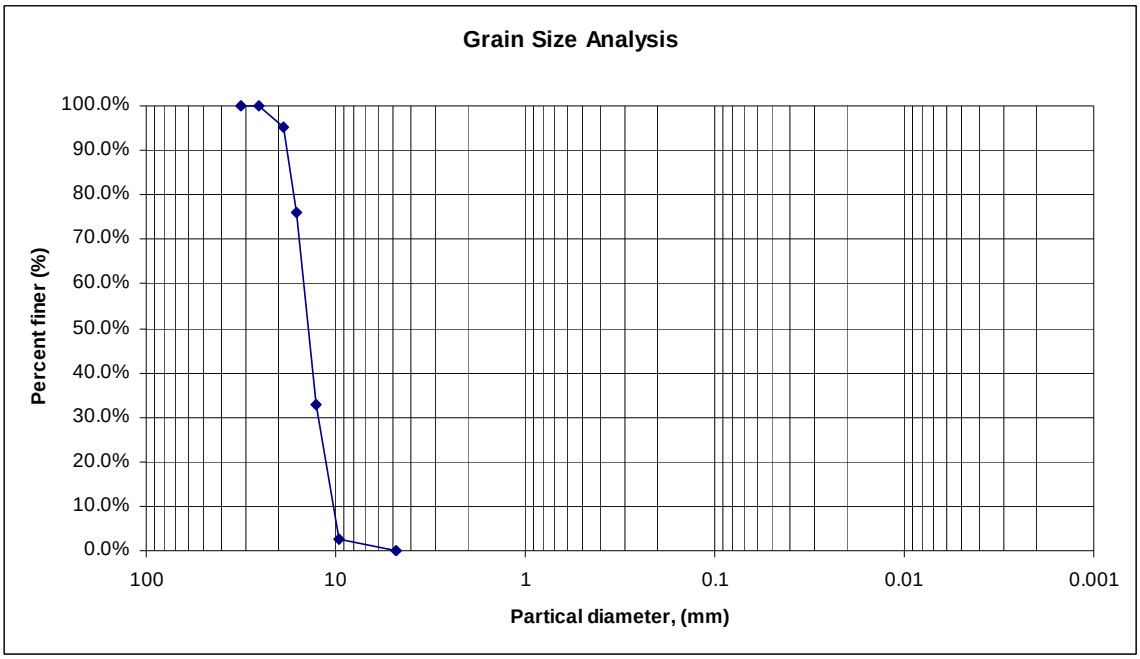

Figure 23. Particle Size Distribution Curve of Rubber Buffings Used in CSUC Student Lab

The specific gravities and absorption capacities for the scrap tire rubber are needed to complete a volumetric mix design. These values could have been obtained in a previous lab activity where these values are typically determined for mineral aggregate. The specific gravities reported in the literature (following table after Humphrey, 2003) ranges from 1.02 to 1.27, with the higher values associated with tire shreds with a higher percentage of steel belts in the particles. In absence of lab data, a specific gravity of one was chosen for both types of rubber particles. The absorption capacity reported in the literature typically ranged from 2 to 4.3%, and a value can be assumed or the student could presoak the aggregate and prepare it in the saturated surface dry condition according to standard lab procedures.

As an example of a concrete mix design, the following mix design was patented for using waste tire products in the manufacture of Portland cement concrete:

- 100 parts by weight of cement
- 100-200 parts by weight of sand
- 200-400 parts by weight of coarse aggregates
- 15-30 parts by weight of shredded particulates comprising rubber, fibers and steel obtained from whole waste tires
- 20-70 parts by weight of water
- Fly ash
- Super-plasticizer

Table 2. Specific Gravities of Various Waste Tire Products

Tire shred	Specific gravity			Water	Reference
type	Bulk	Saturated surface dry	Apparent	Absorption capacity (%)	
Glass belted	----	----	1.14	3.8	Humphrey et al. (1992)
Glass belted	0.98	1.02	1.02	4	Manion & Humphrey (1992)
Steel belted	1.06	1.01	1.10	4	Manion & Humphrey (1992)
Mixture	1.06	1.16	1.18	9.5	Bressette (1984)
Mixture (Pine State)	----	----	1.24	2	Humphrey et al. (1992)
Mixture (Palmer)	----	----	1.27	2	Humphrey et al. (1992)
Mixture (Sawyer)	----	----	1.23	4.3	Humphrey et al. (1992)
Mixture	1.01	1.05	1.05	4	Manion & Humphrey (1992)
Mixture	----	0.88 to 1.13	----	----	Ahmed (1993)

This is a pretty generic mix design specification, but it is interesting that someone obtained a patent for it.

This lab activity is required of all civil engineering majors as part of a four unit (three hours of lecture, three hours of lab each week) capstone design class in reinforced concrete design at CSU, Chico. Students in each of the lab sections were assigned varying water-cement ratios of 0.4, 0.55, and 0.7 (one value for each lab group). Each of three labs were assigned at a different rubber percentage: 10, 20 and 30% by volume. This resulted in nine different data sets varying both the water cement ratio and the tire rubber contents. All lab groups replaced fine aggregate with crumb rubber, and coarse aggregate with rubber buffings by volume for their assigned percentage assuming a specific gravity of 1 for the tire rubber.

The objectives for the lab were to have students study the effects of adding tire particles to their assigned mix. They were asked to determine the effects of adding scrap tire particles on the following:

- Compressive Strength
- Modulus of Elasticity
- Poisson's Ratio
- Air Content
- Comment on workability/segregation

The results of the lab activity are summarized in the Concrete PowerPoint presentation, and only general observations are made here. The lab data results were generally consistent with the findings in the literature; however, the data sets were incomplete as they were assigned the same mix design that was given in class for their ordinary concrete lab, and some results were not recorded by some lab groups. Also, the compressometer used employed analog dial gages to measure the axial and transverse strain, which did not give useful data for many lab groups. To capture meaningful data, it is recommended that digital dial gages be employed with a computer based data acquisition system to record axial and transverse strains and the load data be collected with a load cell.

Figure 24. Compressometer Set Up for Rubber Included Concrete Sample

5.0 Summary and Recommendations

A substantial amount of research has been done in utilizing waste tire particles in portland cement concrete. It has been demonstrated that concrete compressive strength and stiffness decrease dramatically with increasing rubber content. However, tensile strain, ductility, and toughness have been shown to increase with small amounts of rubber particles in the mix. A laboratory exercise was prepared to introduce the students to the issues relating to utilizing a non-traditional recycled material, scrap tire products in this case, in the manufacture of portland cement concrete. Students were required to evaluate the proper mix design procedure and the effects of adding tire particles on some of the mechanical properties of the resulting concrete.

Not much commercial applications currently exist for using scrap tire products in concrete. Possible applications include light duty paving (sidewalks, etc.) where a weaker more flexible concrete may be desired. Using crumb rubber or finely ground rubber may be a good replacement for air entraining agents in applications where concrete is subjected to repeated freeze thaw cycles to increase the durability of the concrete. Rubber included concrete in one form or another may have some interesting applications where energy absorption is required. Potential applications include vibration mitigation from moving loads (vibrating machinery and moving loads (vehicular traffic)), and earthquake and sound energy absorption. There may be other emerging applications that can make use of the unique characteristics of rubber included concrete.

Further research is needed to establish commercial applications for rubber included concrete. More pilot scale projects need to be constructed and evaluated that utilize the unique properties of rubber included concrete. Some incentive or legal requirement may be necessary to promote the development of these applications. Enough waste tires will have to potentially be recycled to make concrete applications a viable option.

6.0 References

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CIVL 431 Environmental Engineering

Environmental Issues of Waste Tires in Civil Engineering

1.0 Introduction

This chapter was prepared for CIVL 402, Environmental Engineering. It is about how waste tires can have negative impact on environment, specifically stockpiles and tire fires. It also covers some civil engineering applications of waste tires and how its use affects the environment. And it includes some environmental assessment research using both lab evaluations and field studies. Finally it concludes with some recommendations for using waste tires in civil engineering applications.

Nationwide, there is an average of one waste tire per person in the United State and there are about 300 million waste tires generated each year. Figure 1 shows the market trend of waste tires. As you can see, more and more waste tires were utilized over the past 20 years (RMA, 2006). The two main concerns of this problem are the stockpiles of waste tire and tire fires. Figure 2 shows the amount of scrap tires in stockpiles were reducing over the years.

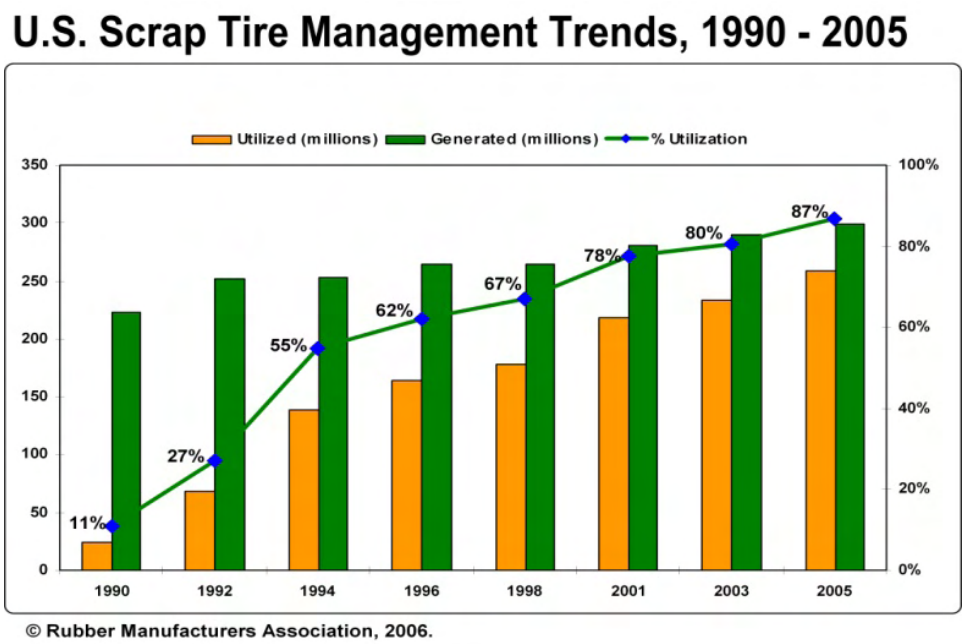

Figure 1. Scrap Tire and Scrap Tire Usage Trends

Figure 2. Amount of Waste Tires Remaining in US Stockpiles

Tire fires can be an environmental nightmare, because of the toxins they release into the air and also into the ground and ultimately into the ground water. The energy content of an average passenger car tire is the equivalent of over two gallons of oil, so just think of a tire fire being an oil fire where millions of gallons are burning. Tire fires release heavy metals and other hazardous compounds that run into streams and seep into shallow wells such as Arsenic, Chromium, Lead, Manganese, Nickel, Mercury, Cadmium, and Pyrolytic Oil. Figure 3 shows a picture of tire fires in Westley, CA in 1999. It burned for three months, it took seven years to clean up, and it cost about 20 millions dollars.

Figure 3: Tire Fire in Westley, CA

Tire Derived Aggregates (TDA) from the shredded waste tires has some useful engineering properties that civil engineers like. In general, civil engineering applications that utilize waste tires include lightweight fill, retaining wall backfill, embankment fill and slope repairs, subgrade insulation layer, landfill applications, septic system drain field, and vibration dampening. Scrap tires used in civil engineering applications come anywhere from two to twelve inches, weigh ⅓ to ½ the unit weight of soil, and one cubic yard of compacted TDA contains approximately 75 passenger car equivalent tires. Scrap tires drain 10 times faster than well graded soil, its insulation is eight time better than gravel, and the lateral pressure on a foundation wall is ½ that of soil. But with the applications in civil engineering, there are some environmental concerns about using waste tires such as groundwater contamination, fire hazard, and long term performance People need to know the lab test results as well as field test results.

2.0 Lab Test of TDA Environmental Impact

Lab tests that have been performed on tire leachates include the Toxicity Characterization Leaching Procedure (TCLP), and the Extraction Procedure Toxicity (EP Tox). Scrap tires are usually pre-cut into a designated dimension and submerged into different solutions, and then the leachate is analyzed. Lab tests can be used as an indicator of the types of contaminants that a scrap tire may produce.

Results from the Minnesota Pollution Control Agency find that none of the laboratory leachate samples exceed the EPA toxicity criteria or the TCLP criteria. For some samples and some leaching conditions, arsenic, cadmium, chromium, selenium, and zinc exceeded the Recommended Allowable Limits (RALs) set by the Minnesota Department of Health for drinking water. As shown in Figure 4, some trace metals were found for acidic solution (low pH value) and hydrocarbon oils were detected for basic solution (high pH value). The study recommended that use of scrap tires in roadway construction be limited to the unsaturated zone. The roadway design should limit infiltration of water through the scrap tires and should promote surface water drainage away from the scrap tire subgrade.

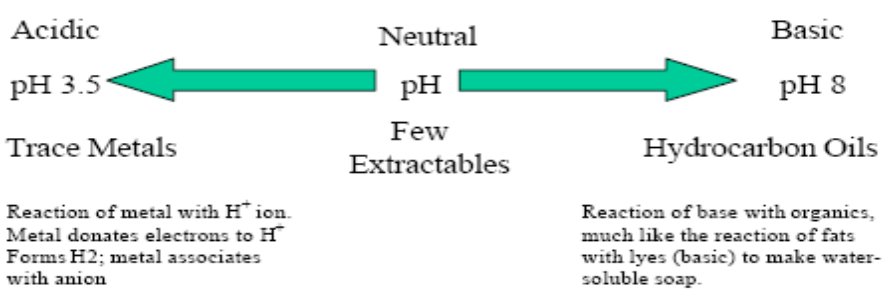

Figure 4: Minnesota Pollution Control Agency findings about what scrap tires release into the ground after being exposed to various acids and bases.

The Virginia Department of Transportation final report on leachable metals in scrap tires consisted of two parts: one-year leaching and TCLP tests. Leaching for two weeks resulted in a leachate that is approximately seven times more concentrated than usual TCLP extracts. However, the stronger leach may be wholly or partially offset by the use of larger particles than the method calls for. The concentrations of metals in the leachate were well below the TCLP regulatory limits.

The Illinois Department of Energy and Natural Resources study was on shredded tires that were subjected to EP toxicity testing by DTC Laboratories Inc. In their results, levels of the organic compounds analyzed were below the detection limits in all cases. None of the metal was above the EP toxicity limits for the EP Tox test. All lab results with various leaching conditions showed that higher concentrations of metals tend to appear at lower pH (acidic) conditions. Higher levels of organics appear under high pH (basic) conditions. Both the metallic components and the organics were well below the TCLP standards and the EP standards. In total, these laboratory tests indicate scrap tires are not a hazardous waste.

3.0 Field Tests of TDA Environmental Impact

In field studies, scrap tires were cut into various sizes, and were used in designated positions in the road. The soil and water were sampled at various times. The impact of scrap tires on the environment was studied. Field studies for scrap tire applications showed the impacts on the air by releasing volatile and semi-volatile organic compounds (VOC and SVOC) when hot. However, that is similar or less than that of asphalt. The release of toxins into the air slows down once the asphalt-rubber cools to the service temperature. Latex allergens may also be released from tire chips, but it should be a manageable amount. The Minnesota Pollution Control Agency field studies did not identify significant differences between waste tire areas and control areas from soil samples and from a biological survey. No evidence was reported of the extractables found in previous laboratory tests under extreme pH conditions. The Department of Geology, Kent State University field studies showed that soil-tire mixtures can be safely used as a light-weight fill material and in situations where improvement in drainage characteristics is required.

Field studies were also conducted to detect the impact of scrap tires on water. Field studies show that when considering the impact of scrap tires on water, three locations for the tire chips are traditionally considered.

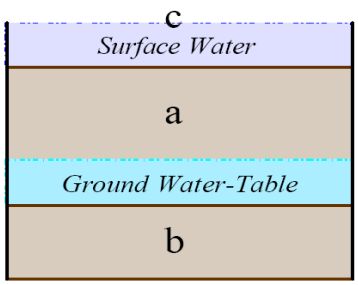

Figure 5: a: above ground water table, b: below ground water table, c: surface water

The Wisconsin Department of Transportation field study showed there is little or no likelihood of significant leaching of tire chips for substances that are of specific public health concern, such as lead or barium. The lead, zinc, and manganese levels were elevated. Chenette Engineering Inc. installed shredded tires that were used in place of crushed stone in a replacement on-site disposal system. This system was installed in December 1991 and a two-year follow-up was reported on in 1993. As anticipated, iron and lead started out at elevated levels; both metal concentrations quickly dropped below Vermont groundwater standards. In a study done by the University of Maine, they improved the monitoring system because of the use of some control wells. There was no evidence that tire chips increased the level of substances above the primary drinking water standard. There was no evidence that tire chips increased the levels of aluminum, zinc, chloride or sulfate, which are included in the secondary (aesthetic) drinking water standards. Iron and magnesium may exceed their secondary standards under some cases. Results were below the detection limit for all compounds.

Below the groundwater table there were increased levels of iron concentration at three test sites. Within the tire chip trench, iron content was up to two orders of magnitude higher than the secondary drinking water standard. The iron did not appear to have migrated downward at any of the sites. Manganese content was also increased by the tire chips. Manganese levels consistently exceeded the secondary drinking water standard in the test well within the tire chip trench. Unlike iron, manganese was observed to migrate downwards with ground water flow. Zinc content was also increased by the tire chip installations; however the concentration was well below the drinking water standard. Chromium concentrations were increased by the tire chips, but only at the peat site. The chromium levels were all below the primary drinking water standard. Iron levels exceeded the Recommended Allowable Level (RAL). However, considering that iron is a secondary allowable drinking water element, it does not pose severe problems to the environment. Among other metallic and organic compounds, there seems to be some disagreement; it may depend on the local soil pH conditions, the water infiltration conditions, and other pedological factors. A maximum allowable steel content for recycled tire rubber should be established.

4.0 Other Studies

4.1 Biological Impact Study of TDA

In a biological survey done by the Minnesota Pollution Control Agency, it was found that no observable difference in either of the study areas when compared to the control areas. Toxicity Characteristics Tests (TCT) concluded that future biological surveys would likely indicate no observable differences at tire sites when compared to background sites.

4.2 Toxicity Study of TDA

In a toxicity survey in 1994 Aberneth found that Zinc levels were found to be 0.023~0.025 mg/L, which is consistent with chemical makeup of tires. Also in 1994 Nelson found that Zinc was found to be present at potentially toxic levels. Cadmium, copper and lead were also present at levels significantly above background sites.

5.0 Conclusions

From the above studies, some conclusions can be drawn:

- Generally, recycled rubber derived from scrap tires is a safe recyclable material.
- A common concern is that the Fe and Mn levels are often elevated. These elements are specified in the secondary drinking water standard based on aesthetic reasons, for example taste.
- Levels of metallic contaminants tend to increase under low pH values, while the level of organic compounds increases under high pH value.
- Generally, it is reasonable to recommend use of recycled scrap tires in civil engineering applications.
- It is important to recognize that the impact of scrap tires on the environment varies according to the local water and soil conditions, especially pH values.

In conclusion some benefits of using waste tires in civil engineering applications include it prevents pollution and waste generation, saves money through prevention of waste tire disposal, creates new recycling industries, and it reduces landfill disposal and expansion.

6.0 References

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3. Humphrey, D.N. and Swett, M. Literature Review of Water Quality Effects of Tire Derived Aggregates and Rubberized Asphalt Concrete. November, 2006.
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CIVL 441 Transportation Engineering

Rubberized Asphalt Concrete in Transportation Engineering

1.0 Introduction

As civilizations grow and evolve the problems which societies face change as well. We have entered an era where much more time and consideration has been placed into understanding how our actions affect not just people but the environment and entire world. The profession of civil engineering has diverted from using strictly traditional materials in design to incorporating green materials into the design and construction of projects.

This class includes four modules about using waste tires as crumb rubber modifier, namely asphalt rubber to improve the performance of asphalt paving materials. In the first module, students will be introduced to the concept of asphalt rubber and its history of use beginning in the 1960's to the present. Caltrans experience with asphalt rubber will be discussed as well as the benefits of using asphalt rubber in transportation applications. The second module will introduce students to the terminology and practices used by Caltrans with regards to asphalt rubber. Here students will be briefed on Caltrans' methods and practices for performing rehabilitative structural asphalt rubber overlays on existing distressed pavements. The third module discusses the construction aspects of asphalt rubber. An overview of the construction process is presented to the students beginning with surface preparation to placement and compaction. The success of using asphalt rubber is highly dependent on proper construction methods and techniques, the important factors are highlighted. Students will also be introduced to the manufacturing process of asphalt rubber from the plant to the job site.

Due to the necessity of using proper practices and techniques to achieve successful placement of asphalt rubber, and inspection module is presented to the student. The fourth module begins by describing the process of modifying the binder to create asphalt rubber. Students are taught how to monitor the binder production and test the results for verification and acceptance. Successful placement is temperature dependent, and temperature guidelines are established for students. Guidelines for construction inspection of the paving site for the entire paving process are introduced.

1.1 Objectives

The objectives of this lesson plan are to introduce students how to utilizing asphalt rubber (AR) in transportation pavements.

1.2 History

Beginning in the early 1950's, the Bureau of Public Roads began laboratory experiments to study the effect of rubber on the properties of various petroleum asphalt products. In the 1960's and 1970's Charles McDonald of the City of Phoenix preformed extensive work in the development of the wet process, a method to combined CRM with asphalt cement before the addition of a aggregate. Asphalt rubber chip seals were used as the primary pavement preservation technique in the City of Phoenix for arterial roadways for nearly 20 years.

In 1975, Caltrans began testing asphalt rubber chip seals on small sections of highway throughout the state. The results of these tests were favorable. In 1978, the first dry process using asphalt rubber was used by Caltrans to construct a portion of pavement; the results were described as good. In 1980, Caltrans employed the wet process to perform emergency roadway repairs on highway 50 located in the "snow country", where the pavement would be subjected to wear and abrasions from snow chains. The rubber asphalt was placed on top of asphalt concrete; it is reported that the rubber asphalt preformed well against resisting chain abrasions and distresses.

In 1983, Caltrans decided against using the costly dense grade asphalt concrete (DGAC) to overlay a section of distresses pavement. The less costly alternative was selected which was using a thin overlay of rubber asphalt. 13 test sections of various depths and forms of asphalt rubber overlays were constructed. These test sections long outlasted any expectation, some lasting over 19 years. After these tests, Caltrans decided thin asphalt rubber pavements were performing much better than thicker conventional pavements, and cost less.

In March of 1992 Caltrans published "Design Guide for Asphalt Rubber Hot Mix Gap Graded". This report was based on studies and reviews of past rubber asphalt projects. By 1995, Caltrans, counties, and cities had constructed over 500 projects which included the use of rubber asphalt.

From 1997 to 2007, the percentage of Caltran's AC pavement using rubberized asphalt concrete was increased dramatically, almost 7 times as shown in Figure 1.

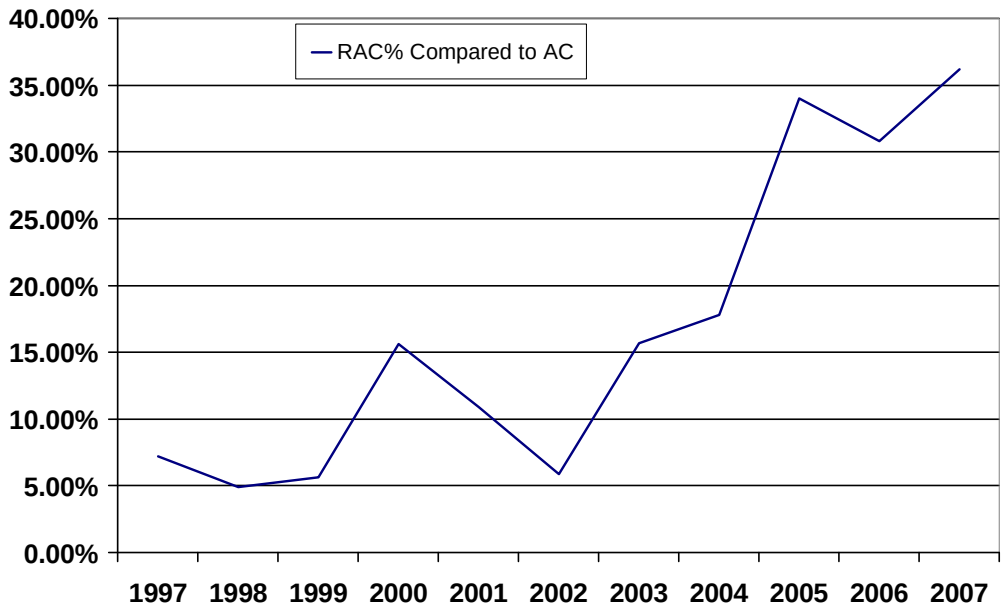

Figure 1. Percentage of Rubberized Asphalt Concrete versus AC over the Years by Caltrans

1.3 Theory

Asphalt rubber is defined by ASTM D8 as: "a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles."

The addition of the crumb rubber, or crumb rubber modifier (CRM), improves the engineering properties of the asphalt which can perform much better than conventional asphalt pavements. Conventional asphalt is a viscoelastic material; at elevated temperatures the elasticity of the asphalt decreases, causing permanent deformation in the pavement, or rutting. The addition of the CRM increases the elasticity of the pavement at high temperatures; stiffens the asphalt binder; decreases the susceptibility of temperature, and decreases permanent deformation. Asphalt rubber has better resistance against reflective cracking and fatigue cracking compared to conventional asphalt.

Asphalt rubber can be used wherever conventional asphalt is used. It is used most effectively in overlay applications and a thin rehabilitative overlay, atop both distressed flexible and rigid pavements. Due to asphalt rubber's improved engineering properties, its overlay thickness can be as much as half that of conventional dense grade asphalt concrete based on Caltrans' past experiences.

The use of asphalt rubber as an alternative to conventional asphalt pavements has numerous advantages. The asphalt rubber can improve durability and resistance to cracking, both surface initiated and reflection. The asphalt rubber is less temperature susceptible resulting in higher elasticity, and less permanent deformation. The addition of the CRM decreases the aging of the rubber asphalt due to higher binder contents, thicker binders, and increased anti oxidants from the rubber. The construction times of the asphalt rubber are less than those of conventional asphalt due to the thinner lifts of asphalt. There is a savings in energy and conservation of natural resources.

2.0 Sample Case Studies

Caltrans constructed five test sections using rubber asphalt between 2002 and 2004. The purpose of these projects was to evaluate the constructability and performance of the rubber asphalt pavements. Two of the projects are highlighted below.

2.1 Firebaugh

In 2004 Caltrans, with funding provided by the California Integrated Waste Management Board (CIWMB), launched a full scale experimental design and construction project using rubberized asphalts as an overlay on existing distressed pavement sections**.** The main focus of this project was to observe the field performance of various mixes of RHMA with different thicknesses, and to evaluate the constructability of the RHMA mixes. Paving began in April 2004 and was concluded in June of 2004. Figure 2 shows the location of the project.

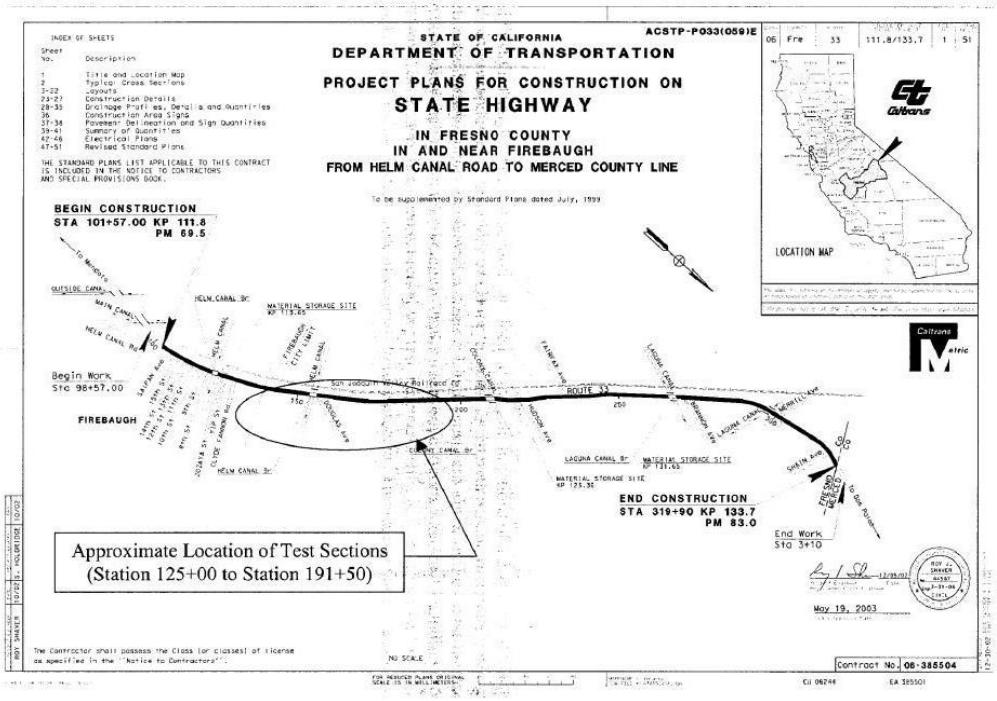

Figure 2. Firebaugh Project Location Map

Three rounds of post-construction performance monitoring were conducted on the project. Falling Weight Deflectometer (FWD) testing was performed during all three rounds. Within each project, four to nine 152-meter performance evaluation sections (PESs) were established for long-term performance monitoring. Detailed locations of different types of experienmental test sections are shown in Figure 3.

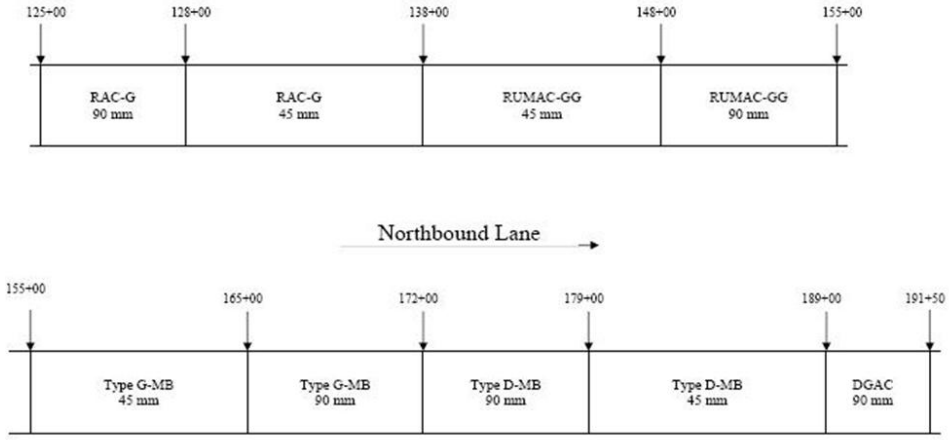

Figure 3. Test Sections Pavement Type Set Up at the Firebaugh Project

A condition survey took place during the last round of the three round evaluations. Distress surveys were conducted according to standard Caltrans definitions for distress type, severity, and extent. The surveys involved measurements of rutting, cracking, raveling, flushing, and other distresses as well as digital photographs. The tests and surveys serve as key components of the

performance monitoring program. The bar graph shown in Figure 4 compares the 80th percentile deflections with the tolerable value. Those that have an 80th percentile deflection greater than the tolerable value are considered structurally inadequate and less likely to survive the 10-year design period.

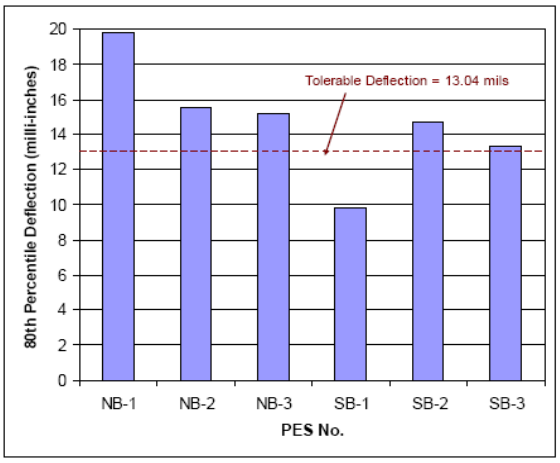

Figure 4. The Deflection Testing Results at the Firebaugh Testing Sections

2.2 San Diego, Highway 75

The San Diego RAC Warranty project shown in Figure 5 is located along the two southbound lanes and shoulders of State Highway 75, District 11, San Diego County, between Coronado and Imperial Beach, CA. The project extends 6.4 miles. The project area is located within the Caltrans "South Coast" climatic area. Precipitation, temperature, and traffic volume data were the key factors used to develop a mix design and pavement thickness. Caltrans engineers determined a 60 mm gap-graded rubberized asphalt concrete (RAC-G) overlay was necessary to achieve desired results.

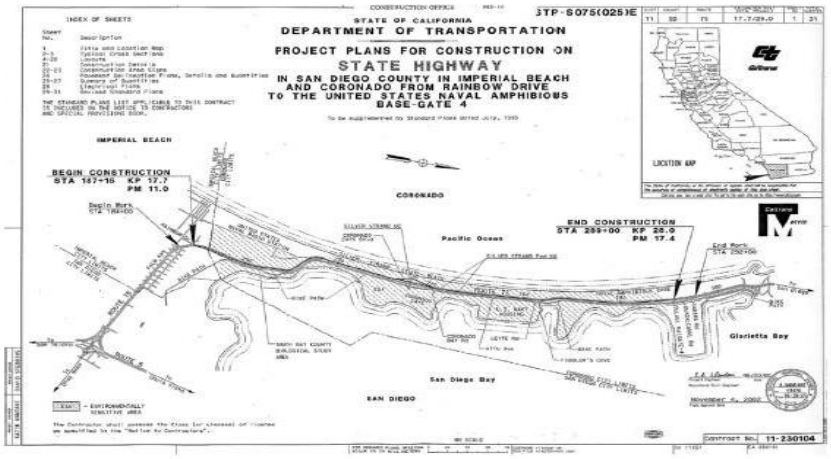

Figure 5. The Location Map of the San Diego HW 75 RAC Pilot Project

The asphalt rubber binder used was an AR-4000 with 20% CRM (75% scrap tire and 25% high natural) and 3% extender oil. Paving took place between April 25 2003 and May 15 2003. Figure 6 indicates that three of the four PESs have 80th percentile deflections that clearly satisfy the tolerable deflection criteria. The pavement is expected to provide good structural performance over the 10-year design period.

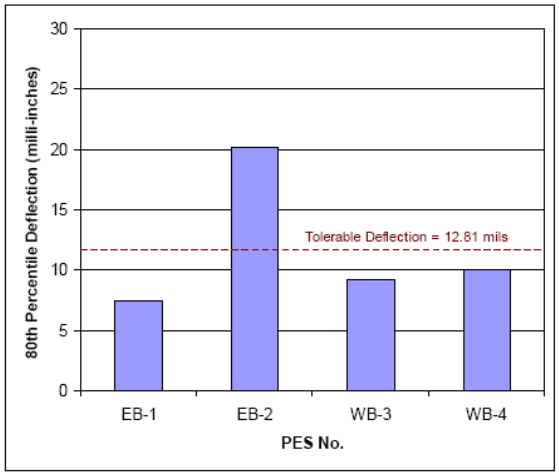

Figure 6. Pavement Deflection Testing Results at the San Diego HW 75 Testing Sections

3.0 Summary

In this teaching module, the course objectives and contents were established. We reviewed history of rubberized hot mix asphalt pavement. The Caltrans' experience and testing projects on the rubberized asphalt pavement were introduced, and the performance advantages of asphalt rubber were also mentioned.

Design and construction of rubberized hot mix asphalt require careful engineering process. The mix design needs to follow Caltrans standard specifications. To ensure a good quality project, one needs to monitor all aspects of the project including manufacturing, mix delivery and hauling, weather condition, surface preparation, placement, compaction, and inspection. Viscosity of asphalt rubber binder is a key monitoring item. One should obtain asphalt rubber samples and other individual component materials for verification and acceptance. In the field, one needs to observe rubberized hot mix asphalt temperature and compaction operations. The compaction acceptance should be based on core samples as well as nuclear density gauges.

Warm mix asphalt with asphalt rubber is in the pilot stage. Caltrans D3 recently built a warm-mix with asphalt rubber on I-5 in Orland, CA. It has a very good potential to reduce various weather and long haul constrains of current rubberized hot mix asphalt constrains. It can also reduce odor, energy consumption and green house gas production at the construction site. In the future, the teaching module for asphalt rubber with warm mix technology should be developed.

Terminal blends, in which finer crumb rubber modifier is mixed with asphalt binder at the refinery terminals, has advantage of no agitation and no special field blending equipment required. A module about terminal blends should also be developed for future teaching.

4.0 References

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2. Caltrans Report, Use of Scrap Tire Rubber – State of the Technology and Best Practices
3. Caltrans Report, Synthesis of Caltrans Rubberized Asphalt Concrete Projects
4. Caltrans. 2002. Flexible Pavement Rehabilitation Manual
5. Asphalt Rubber Design and Construction Guidelines
6. Caltrans. 2007. Caltrans Highway Design Manual.

CIVL 551 Foundation Engineering

Foundation Engineering using Tire Derived Aggregate

1.0 Introduction

1.1 Background

According to the Rubber Manufacturers Association, the U.S. generated approximately 300 million scrap tires in 2005 (RMA, 2006). Historically, these scrap tires took up space in landfills or provided breeding grounds for mosquitoes and rodents when stockpiled or illegally dumped. Fortunately, markets now exist for 87% of scrap tires generated annually-up from about 17% in 1990. These markets-both recycling and beneficial use-continue to grow, and the California Integrated Waste Management Board (CIWMB) believes that the largest growing market for scrap tire products is in civil engineering applications. The remaining scrap tires, however, are still stockpiled or landfilled.

Nation wide, of the 300 million waste tires produced, most were used as follows (RMA, 2006):

- 155 million (52%) were used as fuel (TDF).
- 49 million (16%) were recycled or used in civil engineering projects.
- 30 million (10%) were converted into ground rubber and recycled into products.
- 7.4 million (2.5%) were converted into ground rubber and used in rubber-modified asphalt.
- million (2.3%) were exported.
- million (2.0 %) were recycled into cut/stamped/punched products.
- 3 million (1%) were used in agricultural and miscellaneous uses.

About 2% of the scrap tires may be recycled by cutting, punching, or stamping them into various rubber products after removal of the steel bead. Recycled products include: floor mats, belts, gaskets, shoe soles, dock bumpers, seals, muffler hangers, shims, and washers. Whole tires may be recycled or reused as highway crash barriers, for boat bumpers at marine docks, and for a variety of agricultural purposes.

As can be seen, the three largest scrap tire markets, using about 78%, include:

- Tire derived fuel
- Civil engineering applications
- Ground rubber applications/ rubberized asphalt concrete (RAC)

Both recycling and beneficial use of scrap tires have expanded greatly in the last decade through increased emphasis on recycling and beneficial use by state, local and Federal governments, industry, and other associations. Unfortunately, even with all of the reuse and recycling efforts underway, not all scrap tires are being used beneficially.

The largest single use of scrap tires is as fuel either in shredded form - known as tire derived fuel (TDF) - or whole, depending on the type of combustion device. Each tire contains the energy equivalent of two gallons of oil. Scrap tires are typically used as a supplement to traditional fuels such as coal or wood. In 2006, 155 million scrap tires were used nationwide as fuel (about 52% of all generated) - up from 25.9 million (10.7% of all generated) in 1991 (CIWMB, 2006). There are several advantages to using tires as fuel. Tires produce the same amount of energy as oil and 25% more energy than coal and ash residues from TDF may contain lower heavy metal content than some coal. This results in lower NOx emissions when compared to many U.S. coals, particularly the high-sulfur coals.

The civil engineering market encompasses a wide range of uses for scrap tires. Scrap tire materials typically replace other material currently used in construction such as lightweight fill materials, drainage aggregate, or even soil fill. A considerable amount of tire shreds for civil engineering applications come from stockpile abatement projects. Tires that are reclaimed from stockpiles are usually dirtier than other sources of scrap tires and are typically roughly shredded for these applications. Many civil engineering applications can accommodate this dirtier material.

California alone generates about 40 million waste tires each year. To reduce the stockpile of waste tires, the CIWMB has increased its efforts to turn these waste tires into useful products. One of the major applications of waste tires is the use of tire derived aggregates (TDAs) in civil engineering applications. There are two types of TDA commonly used in civil engineering applications, namely, Type A and Type B shown in Figure 1. Type A, with particle sizes typically less than three inches, is mainly used as a drainage material, in septic leach fields, and for vibration dampening beneath railways, etc. Type B has larger size tire shreds than those of Type A. The particle sizes of Type B are normally up to about 12 inches across. The Type B are mainly used as lightweight fill material for embankments or as light weight backfill for retaining walls.

Type A Tire Derived Aggregate Type B Tire Derived Aggregate

Figure 1. Type A and Type B Tire Derived Aggregates

1.2 Civil Engineering Applications

The civil engineering applications that use TDA include:

- Subgrade fill and embankments
- Backfill for retaining walls and bridge abutments
- Subgrade insulation for roads
- Lateral edge drains
- Vibration damping layer beneath rail lines
- Landfill applications
- Septic system drain fields

Of particular interest in this module is the use of tire shreds to construct embankments and fills over weak, compressible foundation soils. Tire shreds are viable in this application due to their light weight, typically weighing 1/3 to ½ that of the soil it replaces. Using tire shreds as a lightweight fill material may be significantly cheaper than other alternatives, especially if scrap tires are readily available and light weight fill is not. Subgrade fill and embankment applications include: protecting roads from erosion, enhancing the stability of steep slopes along roadways, and reinforcing roadway shoulder areas. The light weight of the tire shreds also reduces horizontal pressures and allows for construction of thinner, less expensive retaining walls. Tire shreds can be used to reduce problems with water and frost build up behind walls because tire shreds are free draining and provide good thermal insulation. In cold climates, excess water is released when subgrade soils thaw in the spring. Placing a 6 to 12-inch thick tire shred layer under the road can prevent the subgrade soils from freezing. In addition, the high permeability of tire shreds allows water to drain from beneath the roads, preventing damage to the road surface.

Landfill construction and operation is a growing market application for tire shreds. Scrap tire shreds can replace other construction materials that would have to be purchased. For Instance, scrap tires may be used as a lightweight backfill in gas venting/collection systems, in leachate collection systems, and in operational liners. They may also be used in landfill capping and closures, and as a material for daily cover.

Some states—Alabama, Florida, Georgia, South Carolina, and Virginia—allow tire shreds to be used in construction of drain fields for septic systems (EPA Web 2009). Tire-derived material replaces traditional stone backfill material, but reduces the expense and labor to build the drain fields. Tire chips can also hold more water than stone and can be transported more easily due to their light weight. This necessitates fewer trucks to deliver a given volume of material, which will save money especially when haul distances are long.

Other civil engineering applications of scrap tire products include:

- Playground surface material
- Gravel substitute

- Drainage around building foundations and building foundation insulation
- Erosion control/rainwater runoff barriers (whole tires)
- Wetlands/marsh establishment (whole tires)
- Crash barriers around race tracks (whole tires)
- Boat bumpers at marinas (whole tires)

1.3 Objectives

In this module the use of Tire Derived Aggregate (TDA) as a retaining wall backfill will be investigated. This module focuses on the material properties of TDA that are needed to evaluate the use of TDA as a retaining wall backfill material. The results of pilot scale testing of a retaining wall with TDA backfill conducted at the University of Maine are presented (Humphrey 2003). A case study of using TDA for backfill on Wall 119 in Riverside California is also discussed (Kennec, Inc, 2008). This module was developed to introduce senior engineering students to the use of TDA in civil engineering projects. It was developed for a course that is offered at most colleges and universities with civil engineering programs, often the course is called "Foundation Engineering".

2.0 Important properties

Of the properties that engineers need to design projects, the following are the most important for using TDA as a back fill material for retaining walls:

- Gradation
- Specific Gravity and Unit Weights
- Compressibility
- Lateral Earth Pressure
- Shear Strength
- Hydraulic Conductivity (Permeability)
- Thermal Conductivity

2.1 Gradation

TDA (Tire shreds) are fairly uniformly graded but are irregularly shaped, being more plate like. Figures 2 and 3 show typical gradation curves for TDAs. Figure 2 shows the gradation for type A TDA from multiple manufacturers. It demonstrates that the samples are generally uniformly graded (same size). However, the maximum size varies according to manufacturer. The gradation tests were conducted according to ASTM D 422 standards. Gradation curve for Type B TDA shown in Figure 3, again uniformly graded with particle sizes that would be considered as coarse gravel and boulders.

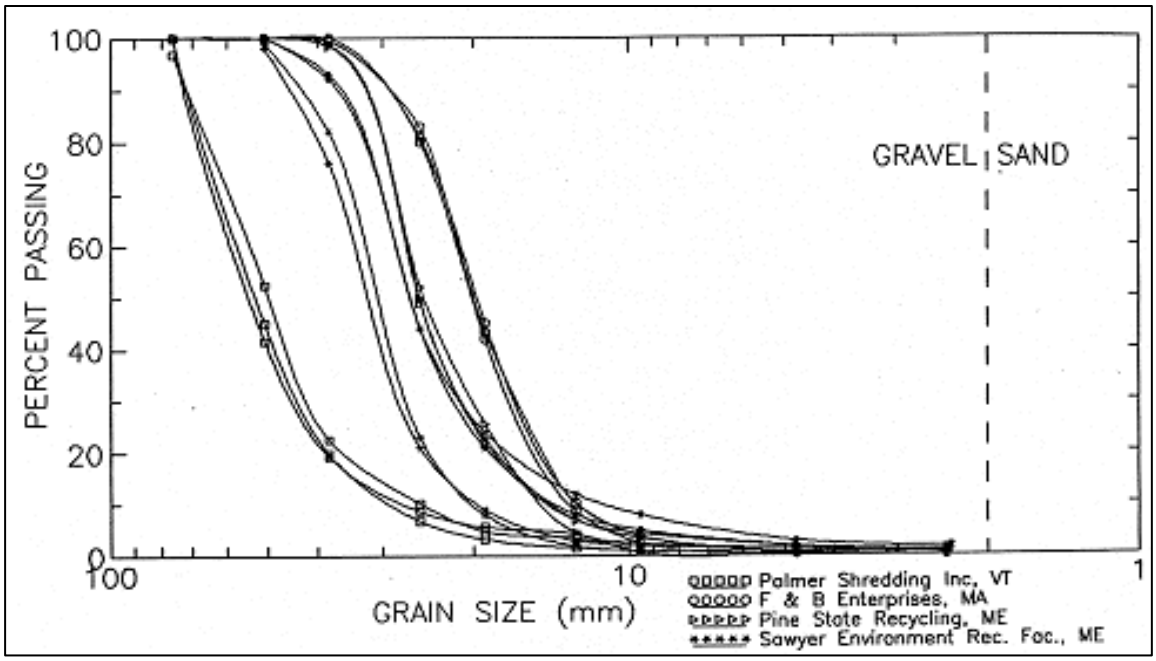

Figure 2 Typical TDA Type A Gradation of Several Tire Shreds Producers

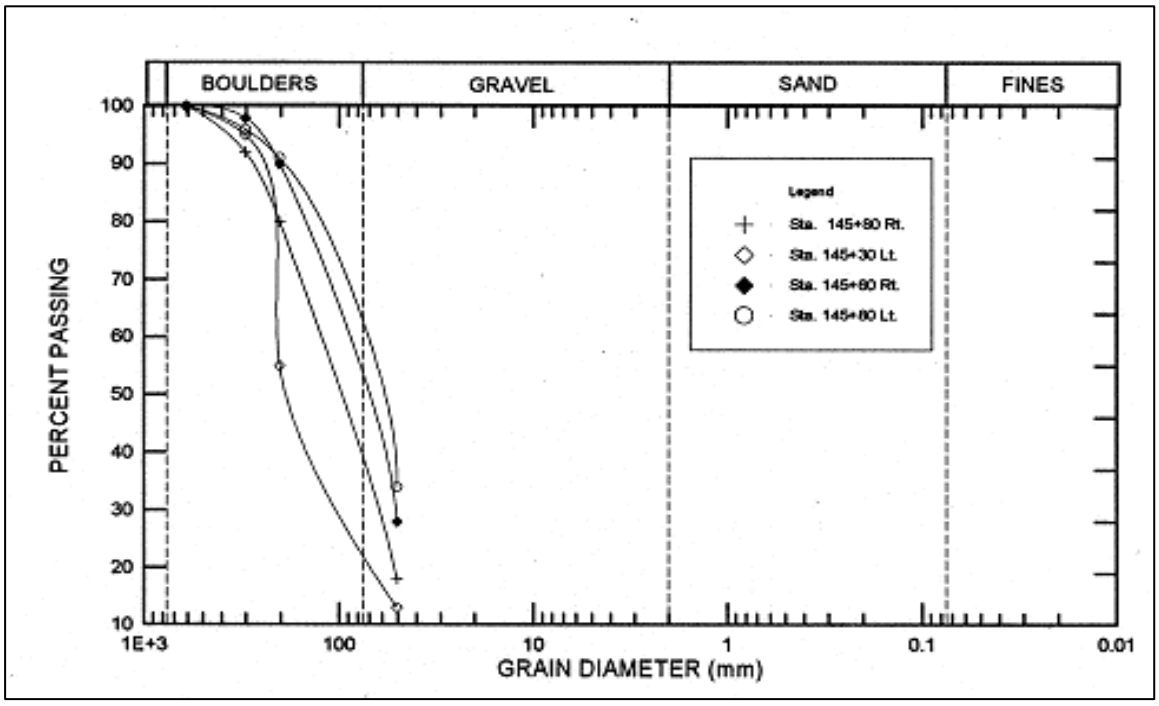

Figure 3. Typical TDA Type B Gradation of Several Tire Shreds Producers

2.2 Specific gravity

The second factor needed in designing projects using TDA as retaining wall back fill is the specific gravity of the material. The specific gravities for the scrap tire rubber are needed to complete a retaining wall design. The specific gravities reported in the literature (Humphrey, 2003) ranges from 1.02 to 1.27, with the higher values associated with tire shreds with a higher percentage of steel belts in the particles. Specific gravities of common soil typically range from 2.6 to 2.7. The lower specific gravity of TDA results in lower unit weights for TDA back fill. The loose density of TDA is between 21.3 to 30.9 pounds per cubic foot (pcf) with no compaction, however, the compacted unit weight increases with increased compactive effort. At 50 to 60% of Standard Proctor compaction 38.3 to 40.1 pcf are reported, at standard compaction energy input, 39.5 to 40.7 pcf is achieved, and at modified compaction the range is 41.2 to 42.7 pcf. So the range of dry compacted unit weights is between 38 to 43 pcf, whereas soil typically has a compacted unit weight on the order of125 pcf. Data is also available in the literature (references) for compacted unit weights of TDA/Soil mixtures.

Table 1. Specific Gravity and Water Absorption Capability of Different Tire Shreds

Tire shred	Specific gravity			Water	Reference
type	Bulk	Sat. surf. dry	Apparent	Absorption capacity (%)	
Glass belted	----	----	1.14	3.8	(1)
Glass belted	0.98	1.02	1.02	4	(2)
Steel belted	1.06	1.01	1.10	4	(2)
Mixture	1.06	1.16	1.18	9.5	(3)
Mixture (Pine State)	----	----	1.24	2	(1)
Mixture (Palmer)	----	----	1.27	2	(1)
Mixture (Sawyer)	----	----	1.23	4.3	(1)
Mixture	1.01	1.05	1.05	4	(2)
Mixture	----	0.88 to 1.13	----	----	(4)

Humphrey et al. (1992), (2) Manion & Humphrey (1992), (3) Bressette (1984), (4) Ahmed (1993)

2.3 Compressibility of TDA

Compressibility is defined as the susceptibility of a material to undergo volume change due to changes in stress. Compressibility is of concern in using TDA as a retaining wall backfill material because of the settlement that will occur during and in the first month or two after placement of fill. Also, in-place unit weight of fill has been shown to vary with compaction effort and deflections caused by temporary loading (e.g. wheel loads) may need to be considered. Due to its porosity and high rubber content, TDA is highly compressible under loaded conditions. TDA can compress by as much as 50% under high normal loads!

2.4 Lateral earth pressure coefficents at rest and Poisson's ratio

Lateral earth pressure is the pressure exerted by a fill material on the wall of a structure like a retaining wall. It can be determined by coefficients of lateral earth pressure, which are calculated by dividing horizontal stress by vertical stress. In the study of mechanics of materials, Poisson's ratio, μ, relates transverse (horizontal in this case) deformation to axial (vertical) deformation. Table 2 lists values for the coefficient of lateral earth pressure and Poisson's ratio (after Humphrey, 2003).

Table 2 Coefficient of Lateral Earth Pressure and Poisson's Ratio

Particle size range (in.)	Tire shred type	Source of tire shreds	Ko	μ	Reference
2	Mixed	Sawyer Environmental	0.44	0.30	(1)
3	Mixed	Palmer Shredding	0.26	0.20	(2)
2	Mixed	Pine State Recycling	0.41	0.28	(2)
1	Glass	F & B Enterprises	0.47	0.32	(2)
----	----	----	----	0.3 to 0.17	(3)
2	Mixed	Maust Tire Recycles	0.4a	0.3	(4)

Notes: a. For vertical stress less than 25 psi.

References:

(1) Manion and Humphrey (1992); Humphrey and Manion (1992)
(2) Humphrey, et al. (1992, 1993); Humphrey and Sandford (1993)
(3) Edil and Bosscher (1992, 1994)
(4) Drescher and Newcomb (1994)

Scrap tire products (including TDA) are a discrete material and can support compression but not tension stresses and typically fails in shear along a plane of weakness. There are four factors that affect the shear strength of crumb rubber and TDA:

1. Size and shape of the rubber pieces
2. The density (packing) of the sample at the beginning of the test
3. Magnitude of the compressive normal loading
4. The orientation of the particles in the sample

2.5 Shear Strength

The shear strength of TDA is an important parameter in retaining wall design. This topic is covered in detail in the Shear Strength Module (CIVL 312 Structure Testing Lab). A direct shear apparatus (ASTM D 3080) or a triaxial shear apparatus (ASTM D4767) can be used to measure the shear strength of tire shreds. When testing tire shreds, larger sample sizes have to be used than are necessary for other soils. This is due to the larger particle size of tire shreds. Large triaxial shear apparatuses only have limited availability, so tests are generally completed on 1-in or smaller tire shreds. The triaxial shear apparatus also shouldn't be used for tire shreds with protruding steel belts as the steel may puncture the membrane that contains the TDA sample.

Estimating the shear strength of 3 inches or larger sized TDA from smaller size tire shred shear test data may not be suitable because large tire shreds have different size, shape, and tire particle contact patterns than small tire shreds. Figure 3 compares the shear stress versus horizontal deformation for a 2 inch minus TDA with three different normal stresses (250, 500 and 1000 psf). These curves indicate a loose initial state behavior for the TDA sample with no dilation as the rate of shear stress increase decreases with an increase in shear displacement.

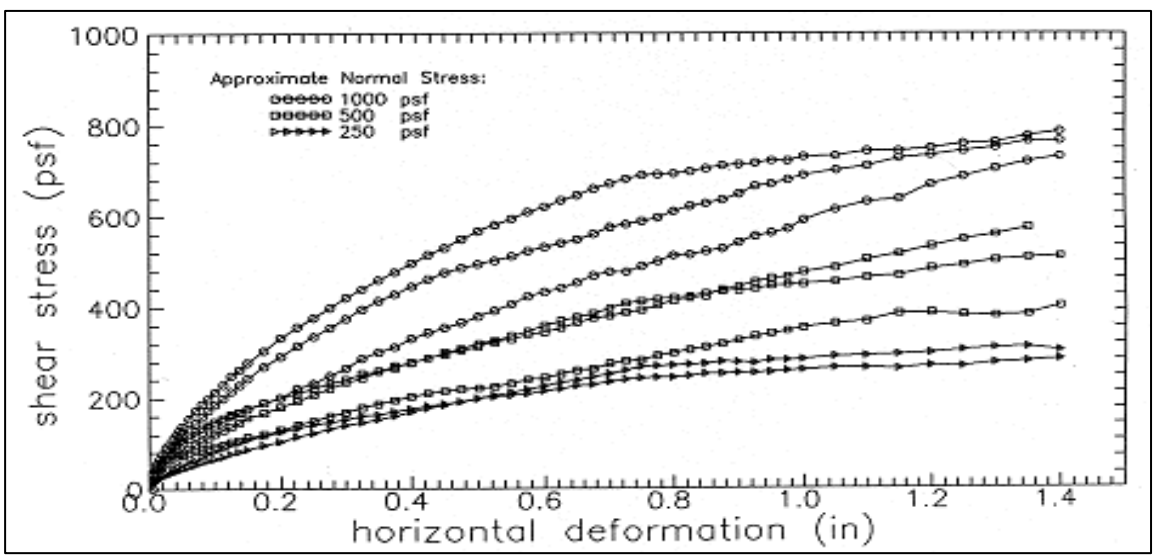

Figure 3 Shear stress vs. horizontal deformation for Pine State Recycling tire shreds tested in direct shear box (Humphrey, 2003) .

Figure 4 compares the failure envelopes for tests conducted at low stress levels, less than 2000 psf. In all cases, the failure envelopes were non-linear and concave down. Therefore, tests should be conducted at normal stresses close to what would be encountered in the field if a linear failure envelope is to be fit to the data.

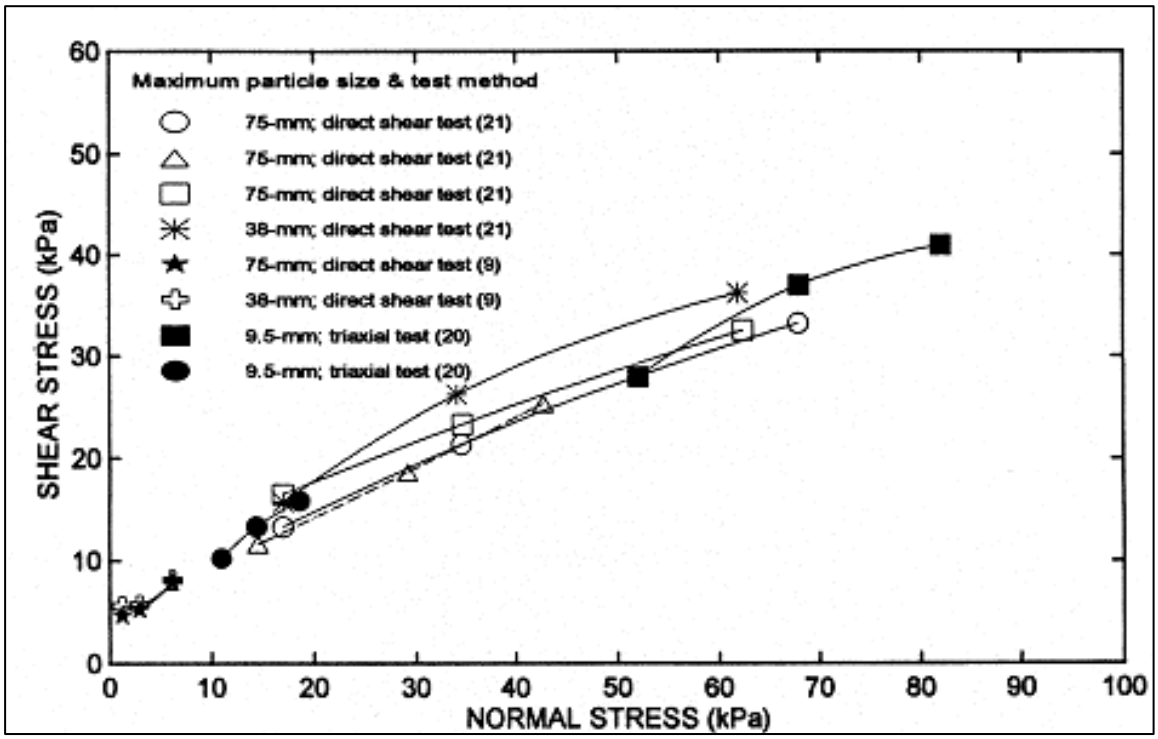

Figure 4 Comparison of failure envelopes of TDA at low normal stress levels (less than about 2000 psf) (Humphrey 2003)

Tests on 0.5-in and 1-in tire shreds at higher stress levels produce failure envelopes that were approximately linear. For high stress tests, using failure criteria of 15% axial strain, Ahmed (1993) obtained cohesion intercepts from 572 to 689 psf and friction angles from 15.9 to 20.3 degrees.

In many engineering problems such as design of foundations, retaining walls, buried pipes, and sheet piling, the value of the angle of internal friction and cohesion of the soil involved are required for the design. The direct shear test is used to predict these parameters quickly. This laboratory activity covers the laboratory procedures for determining these values for cohesionless materials. The Mohr-Coulomb Failure criterion is given as:

$\tau = c + \sigma \tan\phi$

Where

τ = shear stress on the failure plane

σ = normal stress on the failure plane

C = the cohesion intercept (= 0 for granular materials)

ϕ = angle of internal friction (slope of the line relating shear strees to normal stress.

The internal angle of friction, ϕ is a function of the grain size distribution (gradation), particle size and shape, and the method of compaction of the sample. A densely packed sample will dilate when loaded at a higher shear stress than a loosely packed sample, thus increasing the internal friction angle.

2.6 Permeability

The permeability of tire shreds is much greater than most granular soils, with experimental values ranging from 0.58 cm/s to 23.5 cm/s. Often times the permeability of TDA exceeds the flow capacity of the test equipment! Table z lists hydraulic conductivity (permeability) values for tire shreds.

Table 3 The Void Ratio, Dry Density, Hydraulic conductivity of TDAs

Particle size (in.)	Void ratio	Dry density (pcf)	Hydraulic conductivity (cm/sec)	Reference
2.5		29.0	5.3 to 23.5	**Bressette (1984)**
2.5		37.9	2.9 to 10.9	
2		29.3	4.9 to 59.3	
2		38.1	3.8 to 22.0	
1.5	----	----	1.4 to 2.6	**Hall (1990)**
0.75	----	----	0.8 to 2.6	
2	0.925	40.2	7.7	Humphrey, et al.
2	0.488	52.0	2.1	(**1992**, **1993**)
3	1.114	37.5	15.4	
3	0.583	50.1	4.8	
1.5	0.833	38.8	6.9	
1.5	0.414	50.4	1.5	
1.5		0.653	0.58	**Ahmed (1993)**
1.5	0.693	42.0	7.6	**Lawrence, et al.**
1.5	0.328	53.6	1.5	**(1998)**
3	0.857	41.7	16.3	
3	0.546	50.1	5.6	

2.7 Thermal Conductivity

The thermal conductivity of tire shreds is lower than typical soils and varies depending on the sizes of the tire shreds. As particle size increases, and more air can circulate in the voids, thermal conductivity increases, and the tire shreds become less effective as insulators. Thus, for insulation projects, tire shreds with a maximum size of 3 inches should be used. Table 3 gives thermal conductivity as a function of density and void ratio.

Table 3 Void Ratio and Thermal Conductivity of Different Materials including TDA

Sample	Density		Void Ratio	Apparent thermal conductivity		Surcharge
	(pcf)	(Mg/m3)		(Btu/hr-ft-°F)	(W/m-°C)	
gravel	117.6	1.88	0.41	0.295	0.510	none
	121.6	1.95	0.36	0.326	0.563	half
	123.0	1.97	0.34	0.345	0.596	full
F&B-g	38.5	0.62	0.85	0.120	0.207	none
	43.3	0.69	0.64	0.113	0.195	half
	45.4	0.73	0.56	0.114	0.197	full
F&B-s	39.1	0.63	0.85	0.145	0.251	none
	42.8	0.69	0.69	0.130	0.225	half
	45.3	0.73	0.60	0.134	0.232	full
Palmer	39.7	0.64	0.998	0.159	0.275	none
	45.1	0.72	0.76	0.119	0.206	half
	48.5	0.78	0.63	0.125	0.216	full
Pine State	39.2	0.63	0.97	0.158	0.273	none
	45.4	0.73	0.7	0.139	0.240	half
	49.6	0.79	0.56	0.114	0.197	full
Sawyer	36.0	0.58	1.13	0.184	0.318	none
	41.0	0.66	0.87	0.148	0.256	half
	43.7	0.70	0.76	0.156	0.270	full

Thermal conductivities of various materials After Humphrey, 2003

3.0 Benefits of TDA

Tire Derived Aggregate (TDA) has properties that civil engineers, public works directors and contractors need. It is a material that possesses the following desirable characteristics:

- Light weight
- High permeability
- Low earth pressure
- Good thermal insulation
- Durable
- Compressible
- May be cost effective

The use of TDA can help solve a significant environmental problem associated with removing scrap tires from either the waste stream or being stockpiled. It also can help conserve natural aggregate resources by replacing mined aggregates. There are two types of TDA commonly used in civil engineering applications, Type A and Type B (see pictures above). Type A TDA – which typically has a three inch minus particle size, weighs about 1 Ton for 1.4 cubic yards, with 1 Ton using about 100 tires (Passenger Tire Equivalents, PTE). The in-place density of Type A TDA is between 45-58 lb/ft^3 and it has a permeability greater than 1 cm/sec. Common uses of Type A TDA include use as; a drainage material, in septic leach fields, vibrations dampening layers under light rail tracks, gas collection media, leachate collection material. Type B TDA – which typically has a twelve inch minus particle size, weighs about 1 Ton for 1.5 cubic yards, with 1 Ton using about 100 tires (Passenger Tire Equivalents, PTE). The in place density of Type B TDA is between 45-50 lb/ft^3 and it has a permeability greater than 1 cm/sec. Common uses of Type B TDA include use as lightweight fill for embankments, lightweight fill behind retaining walls.

The module on ASTM Standards discusses in detail ASTM D 6270 -98 “Standard Practice for Use of Scrap Tires in Civil Engineering Applications”. This Standard covers the use of TDA as a fill material. It breaks the use of TDA as a fill into two classes. Class I fills have TDA placed in layers less than 1m (~3’) thick. The TDA must have a maximum of 50% (by weight) passing the 38 mm (~1.5”) sieve, and a maximum of 5% (by weight) passing the 4.75 mm (~.19”) sieve. Class I Fills are typically utilized in landfill leachate and gas control applications, and as subbase material beneath roadways and rail lines (ASTM D6270). Class II fills on the other hand have TDA placed in layers ranging from 1 to 3 meters (3 to 10 feet) thick. The TDA must have a maximum of 25% (by weight) passing the 38 mm (1.5”) sieve, and a maximum of 1% (by weight) passing the 4.75 mm (~.19”) sieve. Sample applications of Class II Fills are retaining wall back fill, embankment fills, and slope repairs.

4.0 Case Histories

4.1 University of Maine

The University of Maine constructed world's 2nd largest retaining wall test facility for determining the lateral pressure on the wall with TDA as a fill material. The structure was 16 ft high, and was 15 by 15 ft square in plan area. It could be loaded to a surcharge of up to 750 psf with cast concrete blocks. Tire shreds from three different producers were tested. Two of the shred types were 3-in. max in size and no attempt was made to remove the steel belts, the other type had a 1.5-in. max size and had most of the steel belts had been removed. The tire shreds were placed in 8-in. lifts and compacted with 2300-lb walk behind roller. All tests were conducted with a 750 psf surcharge load applied.

Lateral earth pressures were measured with pressure cells at three locations along the height of the wall. Load cells were used to measure horizontal wall reactions at the top and bottom of the wall, and the vertical reaction was measured at the bottom of the as shown below:

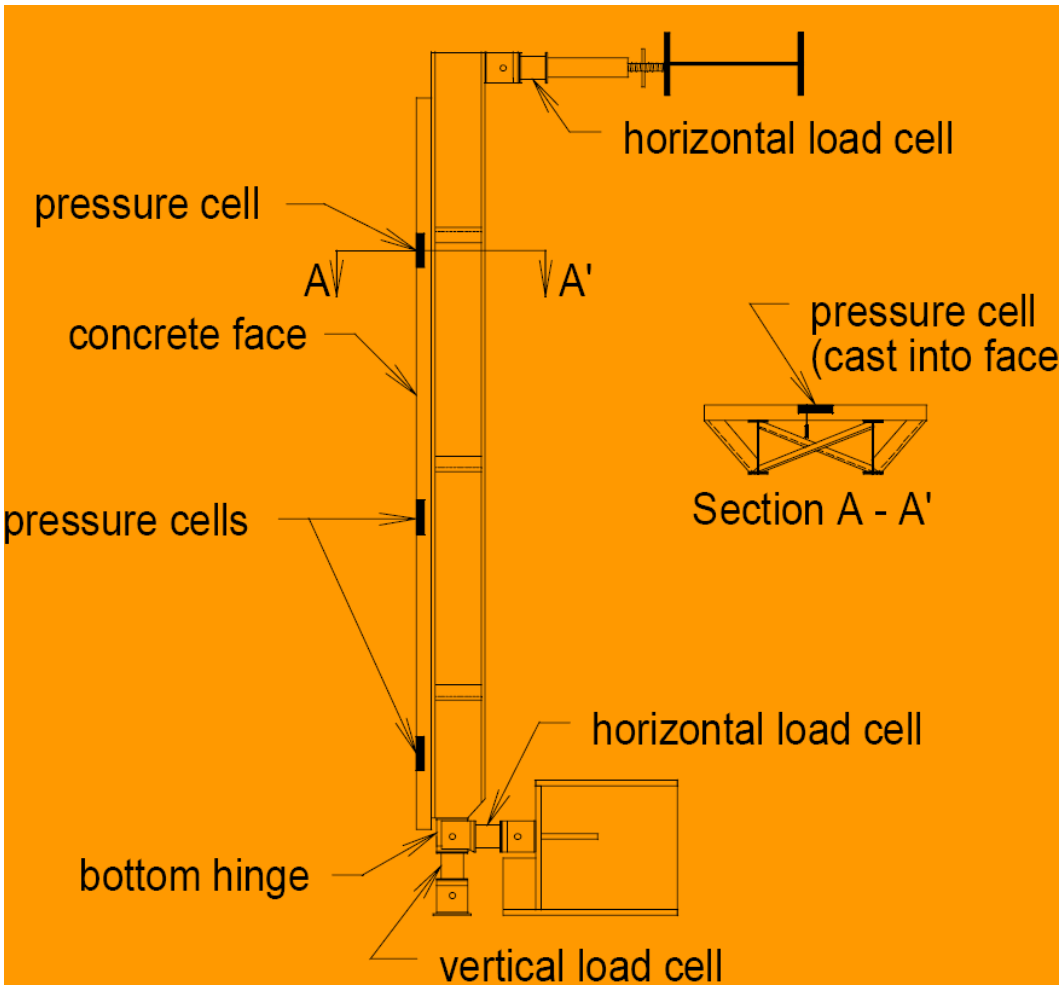

Figure 5. Measurement setup for wall reactions and pressures for UMaine test wall

Figures 6 through 11 document construction of the wall and the testing of TDA as a fill material.

Figure 6. Construction of the University of Maine test wall

Figure 7. The Interior of the Completed Test Wall

Figure 8. Loading the Structure with TDA Fill

Figure 9. Compacting the Fill with the 2300 lb Walk behind Compactor

Figure 10. Precast Concrete Surcharge Blocks

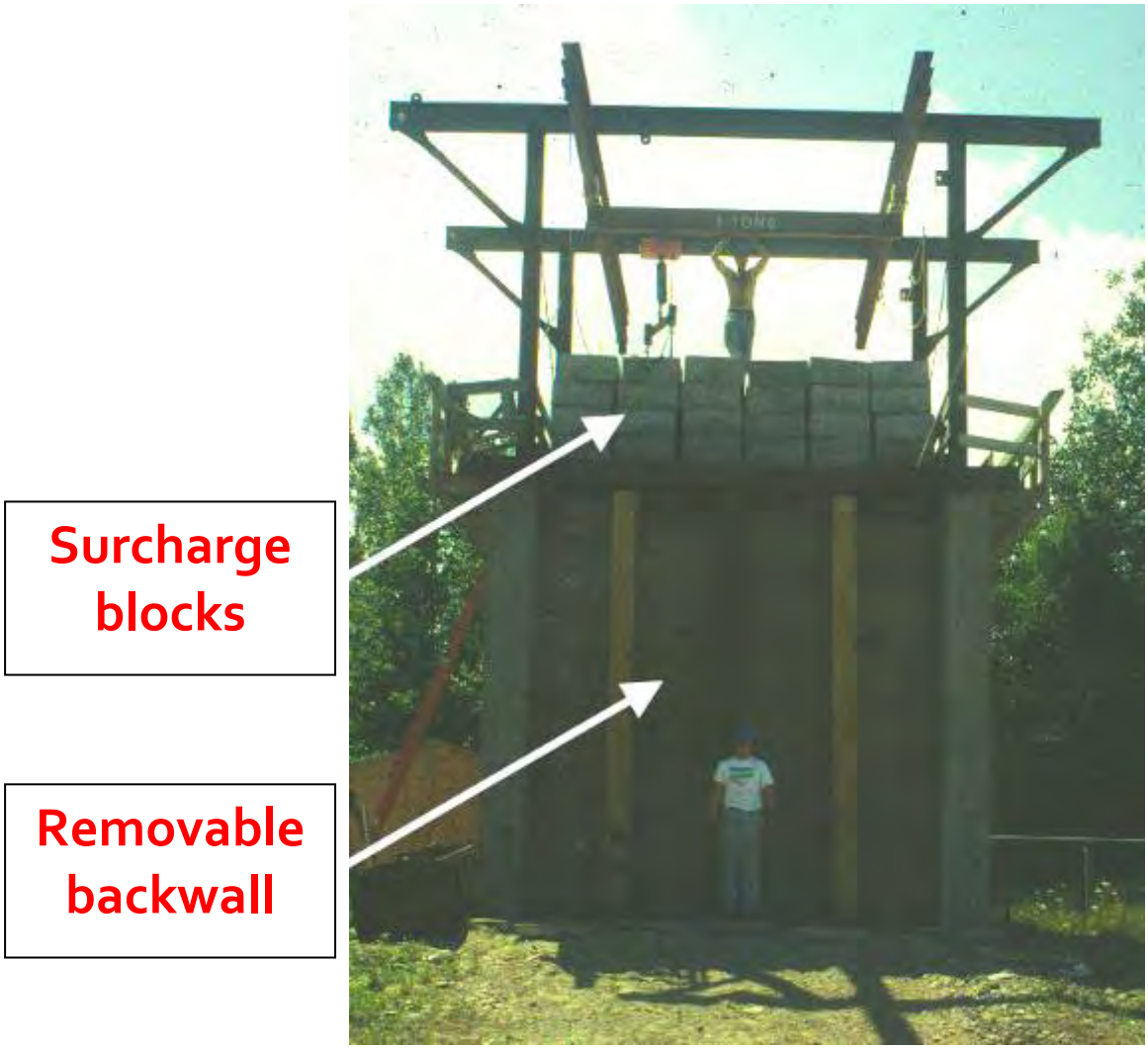

Figure 11. Structure Fully Filled with Compacted TDA and Loaded with 750 psf Surcharge Loading

Measurements were taken for both the at rest condition and for the active case (i.e. the wall rotating away from the fill). The at rest pressure distribution on the wall is shown in Figure 12 for the three TDA tests and for gravel as a fill material.

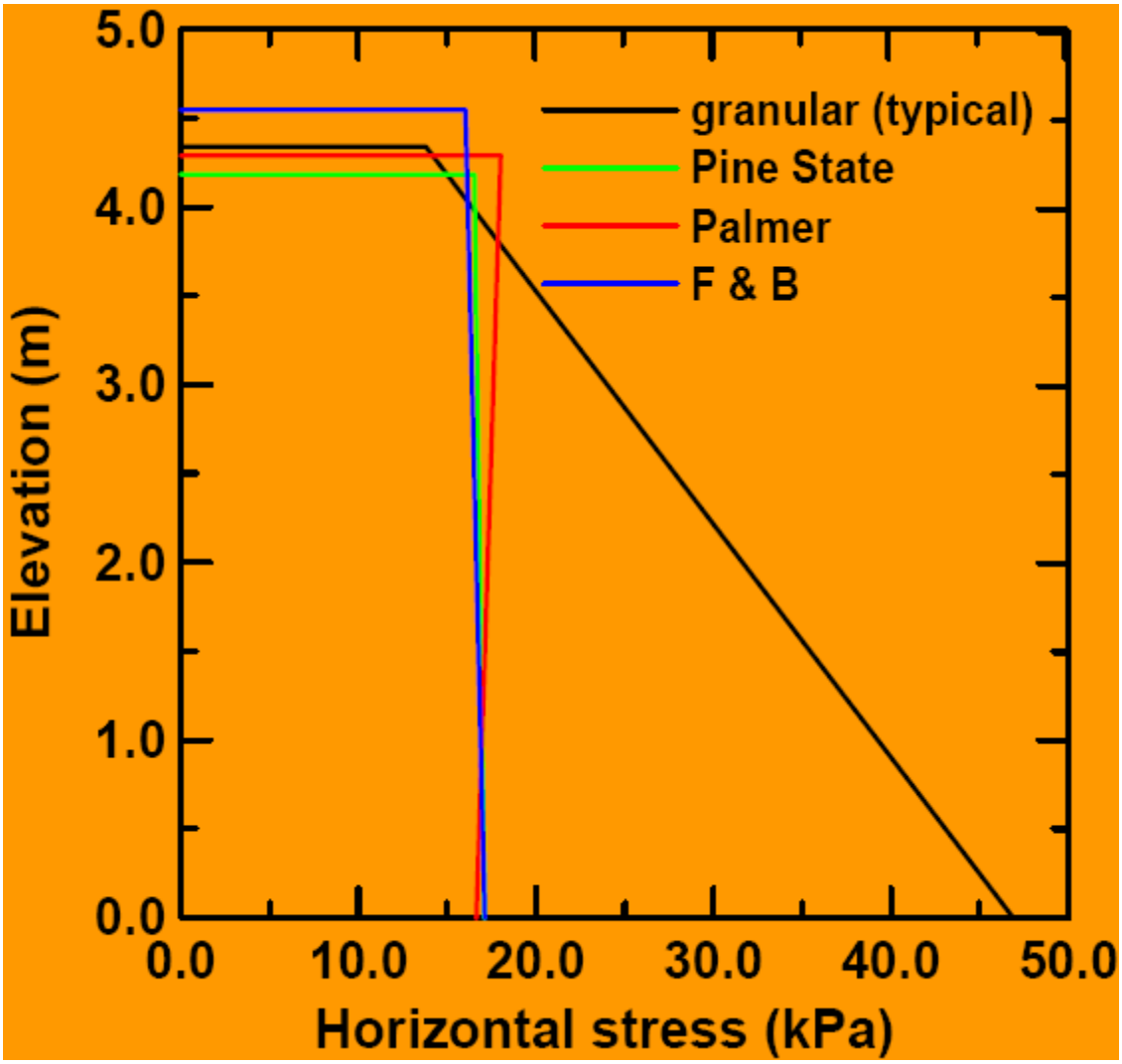

Figure 12 At-rest Stress Distribution at 35.9 KPa (750 psf) Surcharge

It is interesting to note that lateral pressure was nearly constant along the height for the TDA fill, whereas for the gravel fill, the pressure increased with depth as expected.

For the active condition, the wall was rotated outward an amount up to 0.04 times the height of the wall. Pressures near the top of the wall decreased as expected from the at rest case as indicated in Figure 13.

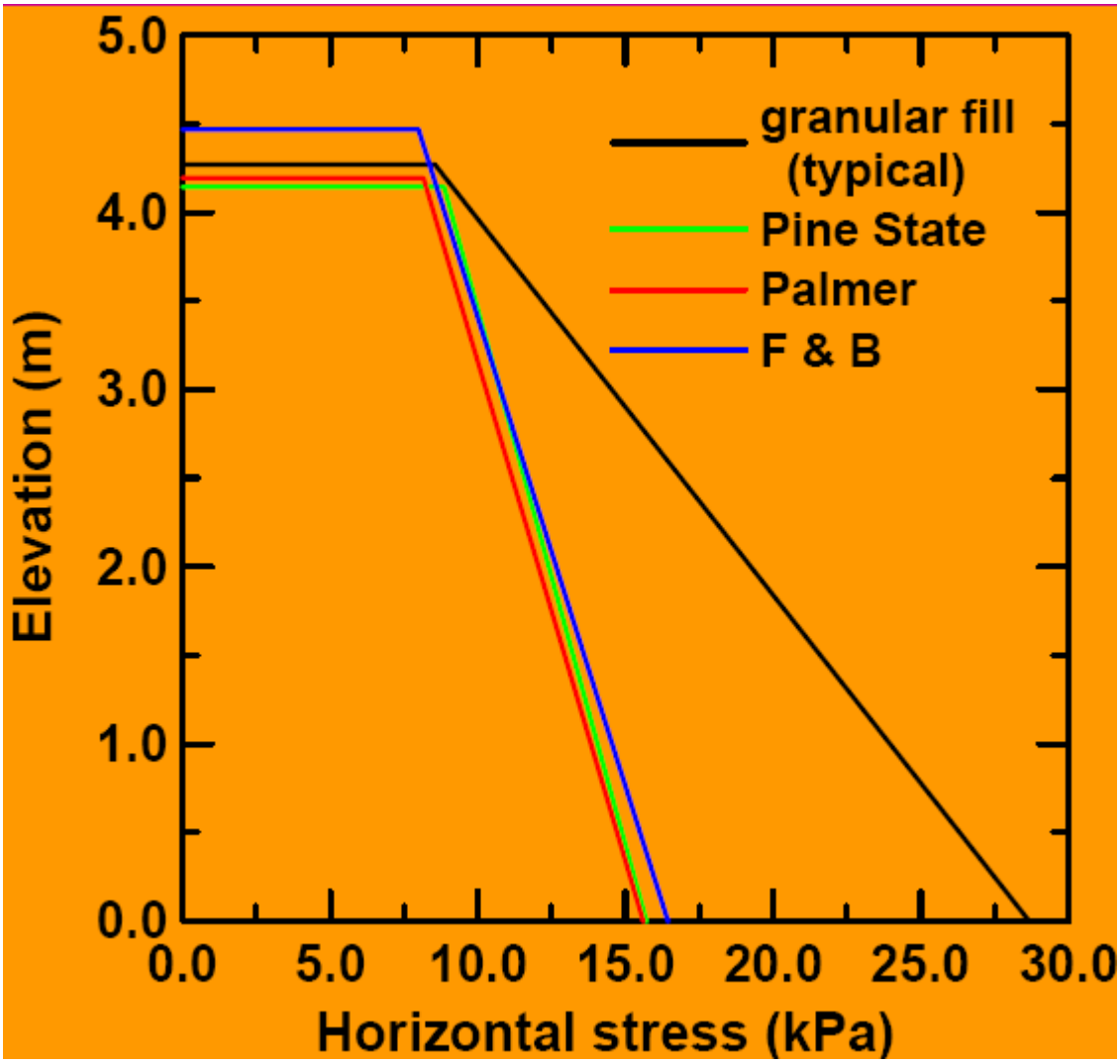

Figure 13. Pressure Distribution on the Wall at a 35.9 KPa (750 psf) Surcharge and 0.01H Wall Rotation

Figure 14 shows that the TDA retained a vertical face with the wall (and surcharge) removed and a tractor mounted back hoe was required to remove the TDA fill.

Figure 14 Surcharge and Wall removed. A Close Up of the TDA and Use of a Tractor Mounted Back Hoe to Remove the TDA from the Test Structure

Some of the benefits of using TDA as a backfill material can be summarized as follows:

- Lower pressure on wall
- Lateral earth pressure coefficient is not constant, but varies with depth
- Results in nearly constant at rest lateral earth pressure as seen in previous graph
- Less rebar and/or thinner retaining wall because of lower pressures
- Gets rid of waste tires

4.2 Wall 119 Riverside CA

TDA was used as a back fill material for a retaining wall constructed along Route 91 in Riverside, California. 9.8' of TDA was placed behind the 12' tall retaining wall, and was enclosed in a geotextile membrane to prevent soil intrusion (Kennec, Inc 2008). Performance of the wall was measured by installing four types of gauges, strain gauges, pressure cells, temperature sensors, and a tilt meter. The following pictures document the wall construction, gauge installation, and placement of the TDA backfill.

Figure 15. Wall 119, Retaining Wall Construction

Figure 16. Wall 119, Strain Gauge Installation

Figure 17. Wall 119, Pressure Cell Installation

Figure 18. Wall 119, Temperature Sensor Installation

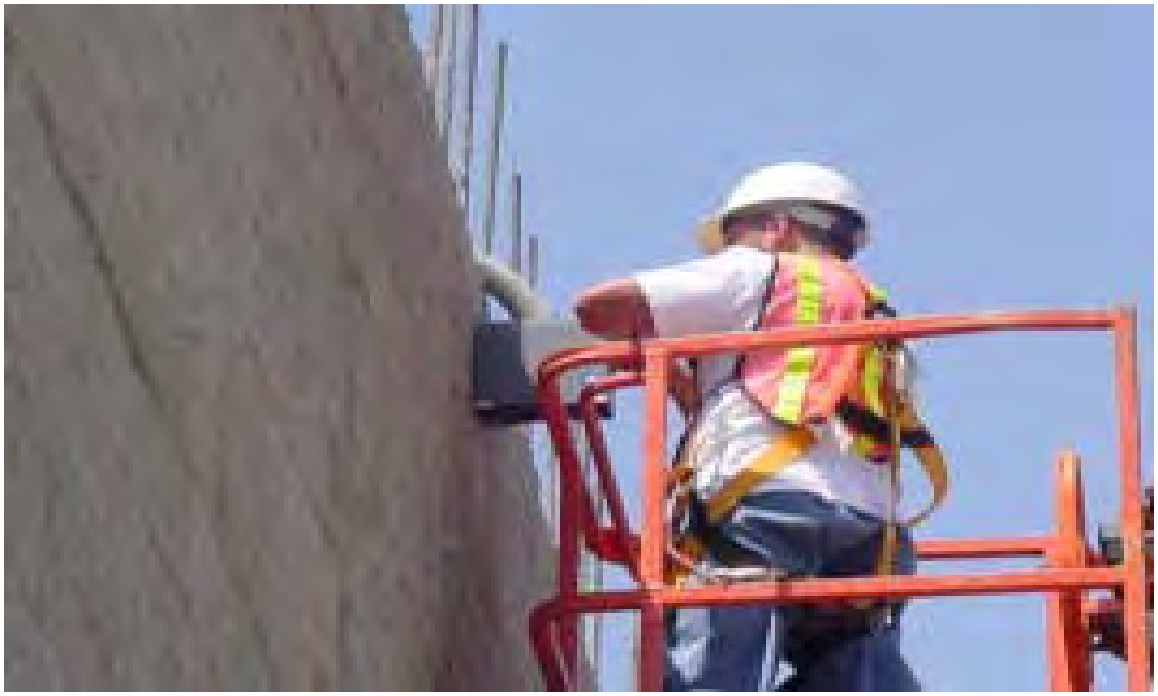

Figure 19. Wall 119, Tilt Meter Installation

Figure 20. Wall 119, TDA Placement from Truck

Figure 21. Wall 119, TDA Compaction

Figure 22. Wall 119, Completed

This project successfully used 1130 cubic yards of type B tire shreds for 262 foot long fill. This equates to 76,500 PTE (passenger tire equivalents). More data can be found at www.usetda.com.

5.0 Summary and Recommendations

Background material for utilizing TDA as retaining wall backfill material was presented. It was demonstrated that TDA has properties that engineers need in this application. The results of full scale testing on a retaining wall with TDA as backfill material were discussed. Finally, Wall 119 constructed by CalTrans in Riverside California utilizing TDA backfill was presented as a case study. A large number of waste tires can be used in this type of application.

This chapter should be expanded to cover in more detail the results of the UMaine test wall program with TDA, as well as the results of the Wall 119 project in Riverside, CA.

6.0 References

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CIVL 575 Solid Waste Management

Applications of Tire Derived Aggregates in Landfills

1.0 Introduction

1.1 Background

In California alone, nearly 40 million waste tires are generated each year. The CAL EPA estimates that 1.5 million of these tires are illegally stockpiled or disposed of. These tires can pose severe problems to public health and the environment. Figure 1 shows a tire fire which is very difficult to distinguish.

Figure 1. Tire Fire Are Difficult to Put Out (CIWMB 2008)

1.2 Objectives

It is necessary to properly dispose of waste tires in a manner which eliminates the possible threats to human health and the environment. Utilizing waste tires in civil engineering applications will eliminate the potential threats of stockpiling waste tires while conserving natural resources. This chapter will introduce the Tire Derived Aggregate (TDA) applications in Landfill including leachate collection, gas collection, operational layer, pipe protection, and daily cover.

1.3 Tire Derived Aggregates

Waste tires are processed into shreds 2 to 12 inches long as TDA shown in Figure 2. These shreds are known as tire derived aggregates, or TDA. TDA has been used in: lightweight fill for highway embankments, retaining wall backfill, vibration damping layers for rail way systems, insulation layers to limit frost penetration, drainage layers for landfills.

Figure 2. A Photo of Tire Derived Aggregates

2.0 Material Properties of TDA

Tire derived aggregates posses properties which make them ideal candidates for the use in civil engineering applications. TDA is a lightweight material; its specific weight is 40 to 60 pounds per cubic foot. TDA is a free draining material; its permeability is greater than 10 centimeters per second. Because of its low weight TDA has a low earth pressure, nearly half that of soil. TDA is an excellent thermal insulator, providing eight times better insulation than gravel. TDA is also a very durable and compressible material.

3.0 TDA Applications in Landfill

The construction of modern mechanized landfills requires large quantities of material which possess the same material properties as TDA. TDA can be used in many landfill applications. Federal guidelines require landfills to employ a layer of material with a high void content to sit in between the waste and the impermeable layer of a landfill in order to contain leachate until removal. This layer is known as the operations or drainage layer. Figure 3 shows TDA as an operation layer. TDA is a good material for this application due to its high permeability. It is necessary that leachate produced in a landfill is collected due to its toxic nature. Landfills have leachate collection systems which require a highly permeable material such as TDA. Many landfills have low points or sumps where leachate is allowed to drain and collect for removal. TDA has been used for a collection media for the leachate.

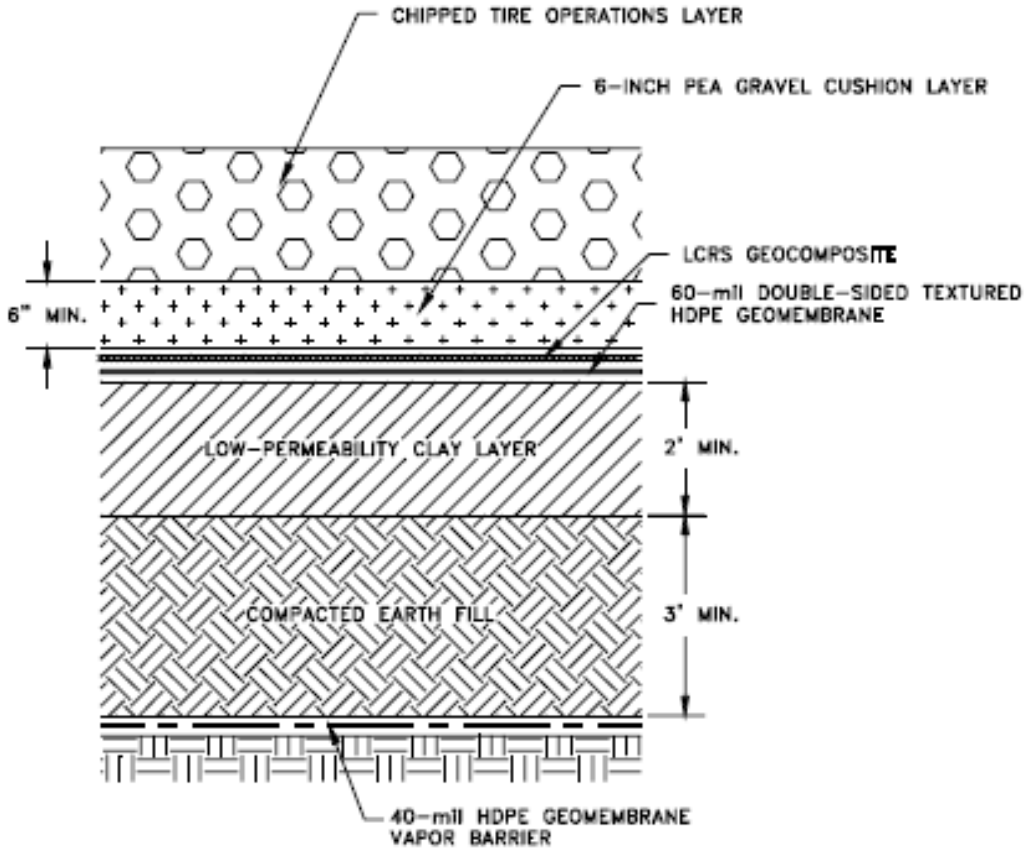


Figure 3. TDA as Operational Layer Material

TDA has also been utilized in leachate recirculation systems. In these applications, TDA is used to insulate perforated pipes which deliver the leachate back into the fill area of a landfill. Landfills use toe drains to collect leachate from the base of landfills. In this application TDA is used as a collection media, where leachate is allowed to drain into a trench with a perforated pipe on the bottom and filled with TDA. The TDA allows the leachate to freely drain into the trench and insulates the perforated pipe to prevent blockage and damage while the leachate flows into the pipe.

Federal and state guidelines require landfills to control and collect methane gas produced during the anaerobic digestion of organic wastes. The methane generated within the landfill tends to follow the path of least resistance. TDA is an excellent material for gas control systems due to its high permeability. Landfills use gas collection trenches to extract and capture the methane gas. Vertical trenches passing through the impermeable landfill cap allows methane gas to vent out of the landfill into a collection system. The vertical trench is composed of perforated pipe surrounded by TDA. This system allows the methane to vent out of the landfill into a collection system. Landfills also use trenchless gas collection systems. In these systems, methane is allowed to vent through the non permeable cap at the toe, located at the bottom of the lift. TDA is placed atop the toe to allow the methane to enter a perforated collection pipe. Due to TDA's high

permeability and durability it is routinely used to protect and insulate parts of the collection systems. TDA is used to insulate horizontal collection pipes as well as protect gas well heads shown in Figure 5.

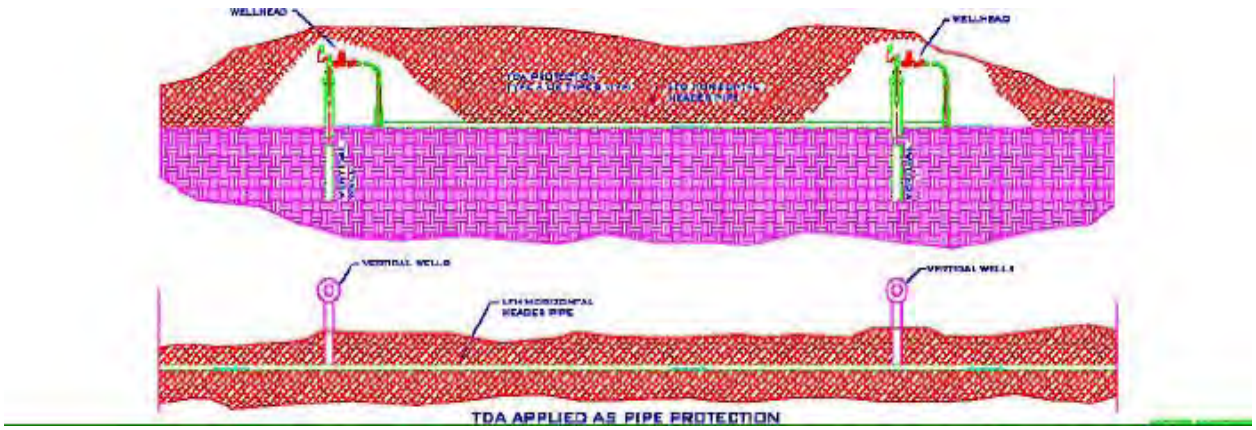


Figure 5. Using TDA as Gas Pipe Protection

Advantages of using the material

In comparison to natural aggregates TDA, in most cases, is a cheaper alternative. The use of TDA utilizes a waste product while conserving natural resources.

Disadvantages of using the material

TDA should not be used bellow the water table. Also TDA should not be used in layers greater than 10 feet in depth.

4.0 Case Studies

4.1 Yolo County Landfill

In Yolo County California, a full scale bio reactor landfill was built. This landfill uses TDA in an operations/drainage layer. The TDA is placed in a two foot layer above six inches of a pea gravel cushion layer atop the geomembrane. TDA should not be placed directly above the geomembrane because steel wires in the TDA can damage the geomembrane. The waste was placed above the TDA. The TDA allows leachate to drain through it into a collection system. Nearly 1.5 million waste tires were used in this project. Figure 6 shows the finished product in Yolo County.

Figure 6. A Full Scale Bioreactor Landfill Was Constructed in Yolo County

4.2 Iowa Landfills

In 2002, the Audubon County Sanitary Landfill, in Audubon, IA, constructed a leachate recirculation trench. The system is used as an as-needed recirculation of leachate back into the landfill's fill area through the recirculation trench, when the head levels of the leachate storage lagoon are elevated to critical levels during the wet months. TDA was utilized to backfill and insulate a perforated pipe located inside an excavated trench. The trench was excavated in the existing waste to allow the overflow leachate to drain back into the landfill. TDA with a nominal size of 3 to 4 inches was backfilled in 3 to 5 foot layers. The TDA insulated the pipe from damage as well as insuring the leachate drained freely through the pipe back into the landfill.

In 2002, the Des Moines County Regional Sanitary Landfill, in Burlington IA, constructed a leachate toe drain. This structure utilized TDA as drainage media to collect leachate from the toe of the landfill. A collection trench was excavated at the bottom of the landfill lift and a four inch HDPE perforated pipe was placed in the base of the trench. The trench was backfilled with 1,004 tons of four to six inch nominal sized TDA. 24 inches of uncompacted soil was placed above the TDA for vegetative growth to control erosion. A geotextile was placed on top of the TDA to serve as a filter. Two feet of uncompacted soil will be placed on top of the liner to allow vegetative growth.

The Metro Park East Landfill in Mitchellville, IA constructed a leachate recirculation trench system in 2003 similar to the Audubon County Sanitary Landfill. The system is an as-needed recirculation of leachate back into the landfill's waste fill area when the head levels of the leachate storage lagoon are elevated to peak levels during the wet months. A 4 inch diameter perforated pipe was insulated with 2 feet of 3 to 4 inch nominal size TDA and backfilled with

uncompacted clay. The pipe extended through the landfill fill area allowing the leachate to drain back into the landfill.

5.0 Summary

When using TDA as a construction material certain precautions and recommendations are advised. ASTM Standard D 6270 states: “It is the responsibility of the design engineer to determine the appropriateness of using scrap tires in any particular application and to select applicable tests and specifications to facilitate construction and environmental protection.” ASTM does not recommend using TDA below the water table. Also, due to internal heating, TDA should not be placed in layers greater than 10 feet. TDA should not be placed directly on top of a geosynthetic layer due to the possibility of wires in the TDA damaging the layer. TDA should be free of dirt, loose wires, oils, and kept as clean a possible. TDA subjected to fires should not be used because the heat may have liberated petroleum from the tire.

TDA is an excellent material for the use in landfill applications. In some cases it is cheaper than using natural aggregates. Using TDA utilizes a waste product while conserving natural resources.

6.0 References

1. Humphrey, D.N., Civil Engineering Applications of Tire Derived Aggregates, 2003.
2. Barker Lemar. Scrap Tire Workshop – Construction Applications for Landfills. 2005.
3. Yazdani, R., Jeff Kieffer, Heather Akau, Full Scale Landfill Bioreactor Project at the Yolo County Central Landfill. Final Report, April 2002.

CIVL 598 Asphalt Paving Materials

Asphalt Rubber

1.0 Introduction

1.1 Objectives

The purposes of this lecture are to introduce students to the technical definitions of asphalt rubber and rubberized hot mix asphalt concrete, as well as discuss the design process and present the different mixes available for rubberized hot mix asphalt (RHMA).

1.2 Definitions

Asphalt rubber, as defined in ASTM D8, is a blend of asphalt cement, reclaimed tire rubber and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles. ASTM D 6114 is the standard specification for an asphalt rubber binder.

The Wet and Dry processes are methods in which the asphalt binders are modified, in this case with a crumb rubber modifier (CRM).

2.0 Types of Asphalt Rubber

2.1 The Wet Process

The Wet Process can produce a wide variety of CRM modified binders from high viscosity (field blend) to no agitation (terminal blend) types shown in Figure 1. The Wet Process is the most widely used approach in Arizona, California, Florida, and Texas. CRM and other components are thoroughly mixed with hot asphalt cement at 400 to 425 ºF. The mixture is allowed to interact at 350 to 375ºF for 45 to 60 minutes where the CRM particles swell and exchange oils with the asphalt binder.

Figure 1. High Viscosity (Field Blend) vs. No Agitation (Terminal Blend)

2.2 Dry Process

The Dry Process substitutes CRM for 1 to 3% of aggregate in hot mix. This process is not considered to modify the binder, although some asphalt- CRM interaction may occur in place over time. The CRM which replaces the aggregate have gradations ranged from coarse (1/4") to fine (#80). The performance history of the Dry Process asphalt rubber has been mixed, and there is limited current use of this modification method. The Dry process is not widely used in California.

3.0 Asphalt Rubber Binder

Asphalt rubber binders consist of crumb rubber modifiers, which include scrap tire rubber and high natural rubber content scrap rubber, asphalt cement and extender oil based on California standards.

3.1 Crumb Rubber Modifier

CRM is produced from grinding whole scrap tires, tread buffing, and other waste rubber products. CRM is available in a variety of grades and size designations from various suppliers or sources. CRM gradation and content affects not only AR binder properties, but also influences the voids structure of various mixes. Gradation limits used by Caltrans and ADOT are broad and allow considerable variation; changes are being considered.

High natural rubber CRM is used to improve adhesion and flexibility, chip seal aggregate retention, and to compatibilize asphalt and CRM interactions. It has high natural rubber content (40-48% by mass) and may be made from scrap tires or other non-tire sources. Figure 2 shows a picture of high natural rubber and synthetic scrap tire rubber. Caltrans also requires that "high natural" be used in binders for RHMA mixes.

Figure 2. Crumb Rubber Modifier (CRM)

3.2 Asphalt Cements

Asphalt cements come in a variety of grades and designations. AR-4000 was used to make asphalt rubber in the past. Caltrans adopted the Performance Graded (PG) system in 2006. Do not use modified asphalts as the base asphalt cement for CRM modification. For high mountain and high desert areas, use PG 58-22 as the base asphalt. For other areas (coastal, inland valleys, low and south mountain, and desert) use PG 64-16 as base asphalt.

3.3 Additives

The addition of extender oils aid in the interaction of the crumb rubber and asphalt by providing aromatics which are absorbed by the rubber. They also help with dispersion by chemically suspending the rubber in the asphalt, which is required by Caltrans.

4.0 Asphalt Rubber Binder Design

The interaction of asphalt and rubber is dependent upon many factors such as: the source and grade of the asphalt cement, the amount, gradation source and type of rubber, and the interaction temperature and time. A design profile is developed to: evaluate the compatibility between materials, check compliance of component interaction properties and check for stability of the AR blend over time. For hot mix and spray applications, a 24-hour design profile will be required.

5.0 Types of RHMA

There are various types of rubberized hot mix asphalts utilized. Dense-graded (limited usage by Caltrans), Gap-graded, Open-graded and Open-graded (High Binder, HB) are the most common types of mixes used. Figure 3 shows the different gradations of aggregates.

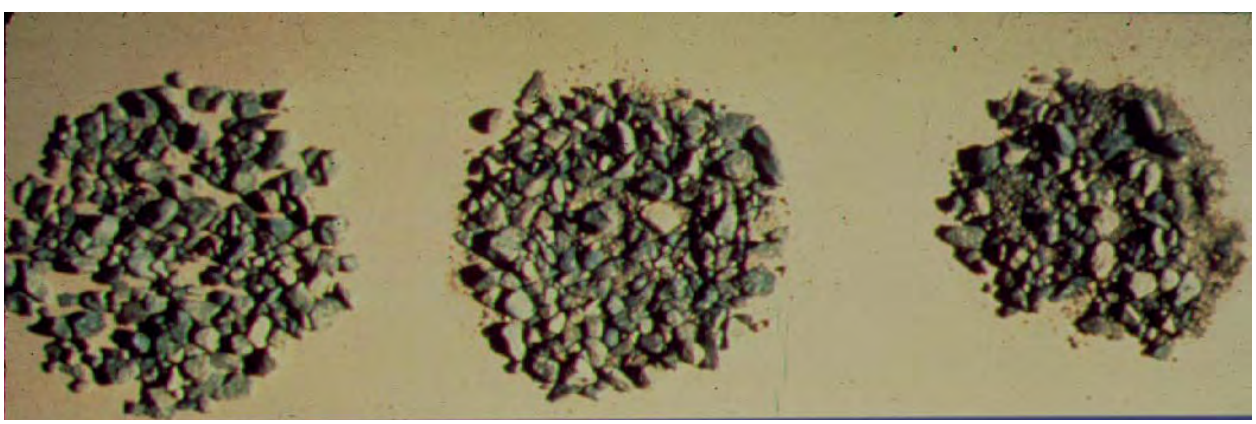


Figure 3. Aggregate Gradation comparison for Open-graded, Gap-graded, and Dense-graded aggregates.

5.1 Dense-Graded Mixes (RHMA-D)

The early use of Dense-graded RHMA showed limited performance improvements for the increased costs. The reason for this was inadequate void space to accommodate sufficient AR binder to modify mix behavior. The use of high viscosity binders has been discontinued.

5.2 Gap-Graded Mixes (RHMA-G)

RHMA-G is the most commonly used RHMA mix type. It is a structural mix that provided increased resistance to: rutting, fatigue, reflective cracking and oxidative aging. The use of RHMA-G is most effective in relatively thin surface lifts (max 60 mm) as overlay of aged or distressed flexible or rigid pavements that are structurally sound. It may be used as surface course for new construction. RHMA-G is also suitable for wide range of traffic volumes and loadings. Based on Caltrans experience, RAC-G can reduce the thickness of overlay as much as half of that of conventional overlay. Figure 4 shows a picture of it.

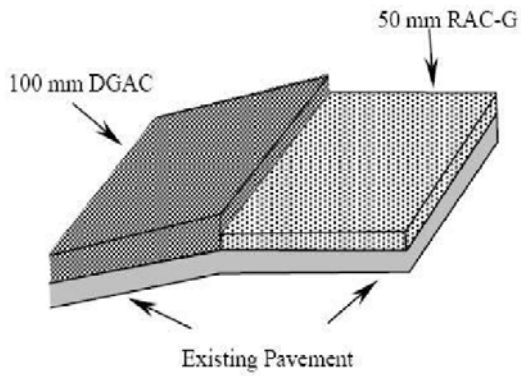


Figure 4. RHMA-G used as an overlay atop distressed conventional dense grade asphalt concrete

5.3 Open-Graded Mixes (RHMA-O)

RHMA-O is designed to provide a free-draining surface (reduced splash, spray, and hydroplaning) that maintains good frictional characteristics in wet or dry conditions. Such mixes are not considered to be structural elements and no thickness reduction applies. RHMA-O is typically placed in thin lifts, nominally 24 to 30 mm thick. RHMA-O may be used as an overlay or as a surface for new construction where traffic flow is essentially uninterrupted by signalization, such as freeways, and some rural and secondary highways.

Do not use open-graded mixes where there is a significant amount of stop and go traffic or turning vehicles, such as city streets or in parking lots. These porous low modulus pavements are susceptible to tire scuffs from simultaneous braking and turning motions, and to damage from leaking vehicle fluids. Caltrans does not use RHMA-O in snow country.

5.4 Open-Graded Mixes (RHMA-O-HB)

RHMA-O-HB mixes have higher binder contents (1.6 times demand for PG asphalt instead of 1.2). HB provides improved friction course durability and performance due to thicker AR binder

films. RHMA-O-HB does not drain as freely as RHMA-O due to higher binder content, but still drains more freely than DGAC.

6.0 Cautions

The specifications and mix design methods discussed in this presentation apply to use of high viscosity asphalt rubber binders (field blend) in gap- and open-graded RHMA mixes. No agitation binders (low viscosity, terminal blend) should never be directly substituted for high viscosity binders in any RHMA mix. The two different types of CRM-modified binders have very different viscosity ranges and behave very differently from each other in asphalt concrete hot mixes.

7.0 Summary

In this Chapter, we introduced the material definitions related to asphalt rubber including wet process, dry process, field blend, terminal blend, base asphalt. We emphasize the important to temperature requirements, viscosity, and mix design profile of asphalt rubber. Finally, the chapter covered the different types of rubberized hot mix asphalt concretes:

- RHMA-D. It is not used very often because it doesn't have enough voids to accommodate high viscosity asphalt rubber.
- RHMA-G. The mix can be used as a structural layer. It can be used reduced thickness because it has high crack resistance capability comparing with conventional asphalt binder.
- RHMA-O. The mix can be used as reduce splashing and improve safety during rainy days. It can be used reduce the highway noise, and
- RHMA-O-HB. The high binder content makes this mix very durable. It can reduce fatigue cracking. It can also reduce aging and oxidization of binder.

8.0 References

1. ASTM D8. Standard Terminology Relating to Materials for Road and Pavements. 2002.
2. ASTM D6114. Standard Specifications for Asphalt-Rubber Binder. 1997.
3. Caltrans. 2003. Asphalt Rubber Usage Guide.
4. Caltrans Report, Use of Scrap Tire Rubber – State of the Technology and Best Practices.
5. Caltrans Report, Synthesis of Caltrans Rubberized Asphalt Concrete Projects.
6. Caltrans. 2002. Flexible Pavement Rehabilitation Manual.
7. Asphalt Rubber Design and Construction Guidelines.
8. Caltrans. 2007. Caltrans Highway Design Manual.

Appendix D

Presentation at the 4th Rubber Modified Asphalt Conference

Life Cycle Costs for Asphalt Rubber Paving Materials

by
R. Gary Hicks and Ding Cheng
CP2 Center
prepared for
4th Rubberized Modified Asphalt Conference, Akron OH
May 7-8, 2009

Presentation Outline

- Work done for RPA on LCCA
- Preliminary work done for the Center by Sousa and Way, 2009
- Conclusions

2

Background

- Asphalt rubber used since 1960s
- Primary uses include:
  - Chip seals
  - Interlayers
  - Hot mix applications
- Other uses
  - Crack sealants
  - Membranes

3

Chip Seals

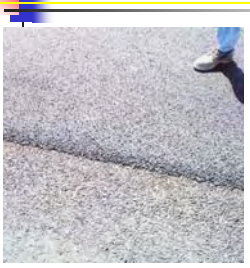
- Use began in 1960s
- Used for preventive maintenance
- Now used by many agencies

4

Chip Seals

5

Interlayers



- Used to prevent reflection cracking
- Used in two or three layer systems
- Used by several agencies

6

Hot Mix Asphalt

- Used in gap-, open-, and dense-graded mixes
- Used primarily in Arizona, California, Florida, and Texas
- Reduced thickness is allowed by some agencies (Caltrans)

7

LCCA Process

- Establish strategies for analysis period
- Establish M&R activity timing
- Estimate agency costs
- Estimate user and non-user costs
- Develop expenditure streams
- Compute net-present value
- Analyze results

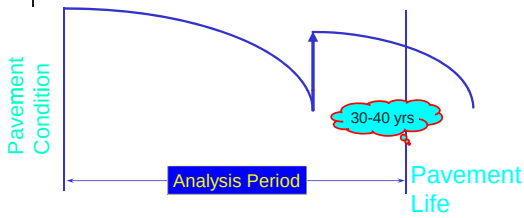
8

Establish Strategies & Timing

- What?
- When?
- How long?

9

Analysis Period



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Agency Costs

- Design & engineering
- Initial construction
- Rehabilitation and maintenance

11

User and Non-User Costs

- Vehicle operating
- User delay
- Accident
- Impacts to adjacent businesses
- Disruptions to local residents

12

Develop Expenditure Streams

- Agency costs
- User and non-user costs
- Salvage value

13

Calculate Net Present Value (NPV)

$$NPV = \text{Initial Cost} + \sum_{K=1}^{N} \text{Future Cost} \left[\frac{1}{(1+i)^n}\right]$$

where

i = discount rate

n = year of expenditure

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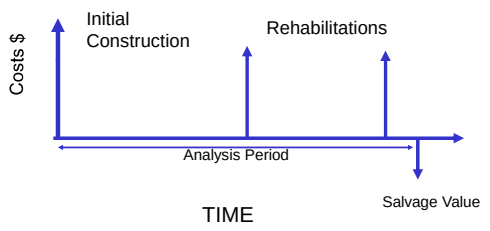
Typical Expenditure Stream



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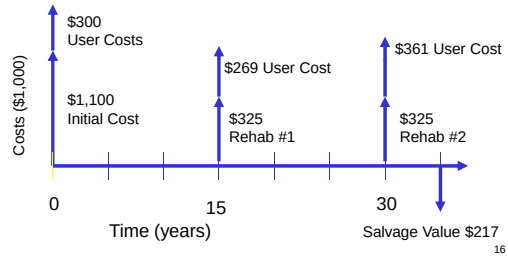
Net Present Value



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Analyze Results

- Deterministic approach (w/o variability)
- Probabilistic approach (w/ variability)

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LCCA Example Calculations

- System preservation - chip seal
- System preservation - thin hot overlay
- Structural overlay - reduced thickness

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Inputs

- Discount rate, % 2.5, 4.0, 5.5
- Analysis period, yrs 40
- Average expected life Conv. AR
  - Chip seals 5 10
  - Thin HMA overlay 3 7
  - Thick HMA overlay 10 15

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Agency Costs - Average

Treatment	Conv.	AR
Chip Seals ($/yd^2)	1.00	2.00
HMA overlays ($/ton)	35	50
Routine maintenance ($/yd^2 per year)	0.15	0.15

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Ranges in Costs and Lives

- High- is exceeded 10 % of the time
- Low- is exceeded 90 % of the time
- Average- is exceeded 50 % of the time

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Scenarios Investigated

System Preservation	Alternates
- Chip Seals	Conventional chip seal followed by 100mm HMA-DG.
	AR chip seal followed by 50mm RHMA-GG over 50mm HMA-DG.
- Thin Hot Overlays	25mm HMA-DG followed by 100mm HMA-DG.
	25mm RHMA-GG followed by 50 mm RHMA-GG over 50mm HMA-DG.

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Scenarios Investigated *(cont.)*

System Preservation	Alternates
Structural Overlays	100mm HMA-DG followed by 100mm RHMA-DG.
	100mm HMA-GG followed by 50mm RHMA-GG.

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Results - Deterministic Approach

Scenario	Present Worth ($/yd)	
Preservation – Chip Seal		
▪ Conventional	18.39	
▪ AR	15.87	2.25
Preservation – Thin HMA		
▪ Conventional	20.69	
▪ AR	17.33	3.36
Structural Overlay		
▪ Conventional	21.97	
▪ AR	14.63	7.34

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Results - Probabilistic Model

Scenario	Percentage of times savings result using AR
Preservation - chip seal	86
Preservation - thin HMA	82
Structural Overlay	86

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Conclusions-LCCA

- Asphalt rubber is cost effective for the scenarios evaluated.
- When variability in the inputs is considered, the AR alternate would be the best choice over 80% of the time
- Study results need to be updated to include both asphalt rubber and terminal blends.

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Part 2- Study for the Center & Caltrans

- Work done by Sousa and Way
- Draft completed in early 2009
- Analytical approach to estimate the life extension benefits of asphalt rubber
- Results are preliminary

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Study Purpose

- Estimate in a rational (objective) manner the treatment life and pavement life extension.

Subjective ≈ Objective

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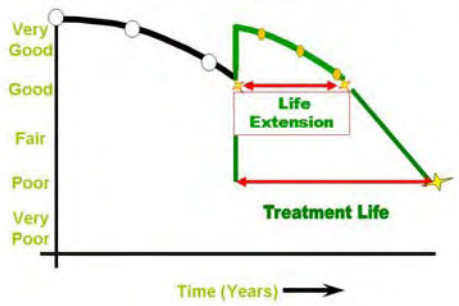
Definition of Treatment Life and Life Extension



Goal of the study

- Develop an analytical model to estimate treatment life and life extension
- Complication-lack of treatment data in the California PMS data base
  - Cracking
  - Structural

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Objective model needed

- Variables included
  - Traffic
  - Climate
  - Existing pavement condition

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Traffic (TI)

- Low Traffic Index (TI) < 6
- Intermediate 6< TI>12
- High TI>12

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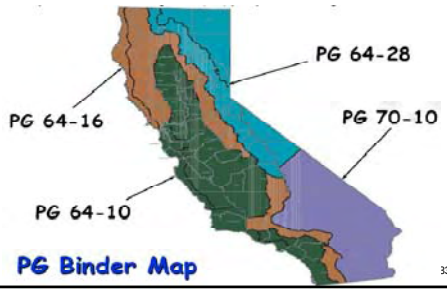
Climate Regions



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Existing Pavement Conditions

- Good- minor distress (< 5% cracking)
- Fair-minor to moderate distress (5-20% cracking)
- Poor- moderate to server distress (>20% cracking)

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Treatments should perform better if they have

- More binder (to some limit)
- Modified binder
- Thicker layers (more waterproofing)

35

Proposed objective measure (TPC)

- Treatment performance capacity (TPC) is a function of
  - Total binder content per area
  - Strain energy at failure
  - Thickness of the treatment
- Field measure is the "true life extension"

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Other factors to consider

- Treatment performance data
- Binder aging
- Treatment cost
- Life extension

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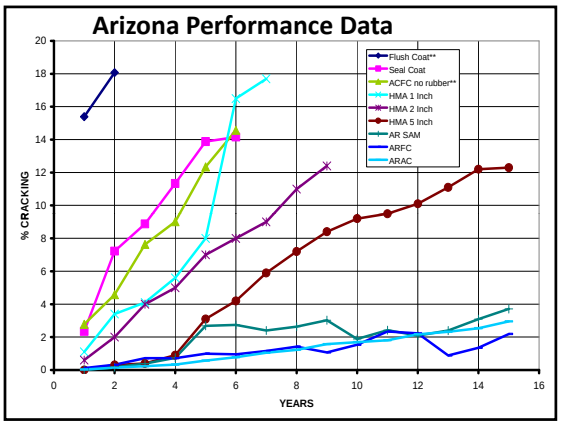
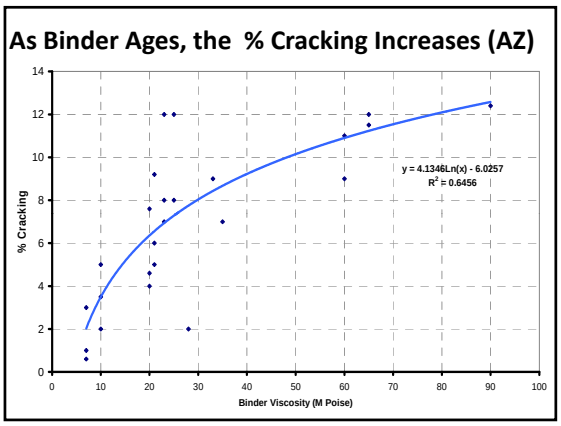
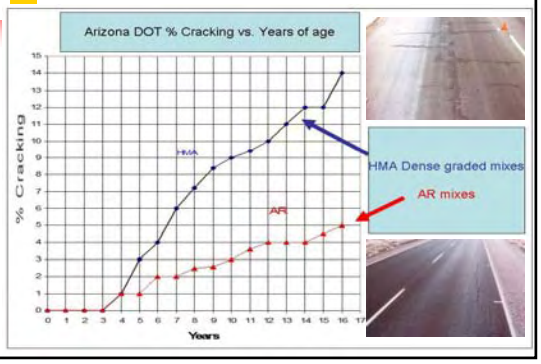
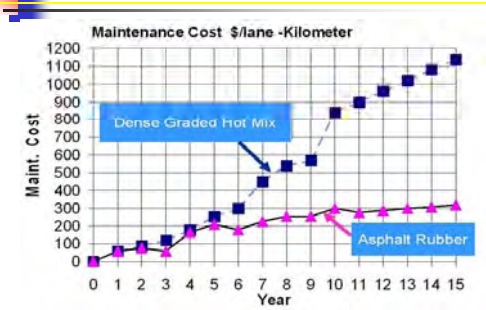




HMA versus RHMA



Maintenance Cost Comparison



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Predicted Life Extension for CA Valley

Treatment	Pavement Life Extension for Coastal and Valley Regions					
	Low Traffic		Moderate Traffic		High Traffic	
	Pavement Condition					
	Good	Fair	Good	Fair	Good	Fair
AR Chip Seals	3.8	2.8	3.3	2.2	3.2	1.9
RAC-G, 1 in	2.8	1.6	2.8	1.6	2.8	1.6
RAC-O, 1in	2.8	1.8	2.8	1.8	2.8	1.8
RAC-O-HB, 1in	3.3	2.6	3.3	2.6	3.3	2.6

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Study is Currently under Review

- By Caltrans, Division of Pavement Management, and the CP2 Center
- We hope to have the draft reports posted to the website in the near future at www.cp2info.org/center

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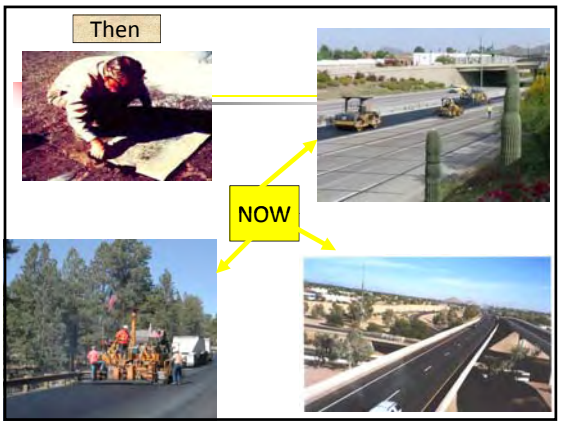

The End

Any questions?

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Appendix E

Sample Workshop Evaluation Form

Professor Training Workshop Evaluation

Teaching Waste Tire Derived Aggregate Applications and Rubberized Hot Mix Asphalt Paving in Civil Engineering Curricula

April 17, 2009

Please take some time to complete this evaluation form. Your feedback is important in helping us to increase the quality of our Workshop and to continual program improvements.

Your Name (optional): _____

Part One. Provide your evaluation to the Workshop by checking the cell that matches your assessment.

Training Quality	Poor (1)	Fair (2)	Good (3)	Very Good (4)	Excellent (5)
1. What is your overall rating of this Workshop?					
2. This training will be beneficial to you in teaching waste tire applications?					
3. Overall speakers' knowledge of the subject					
4. Overall speakers' presentation style					
5. The topics were presented in logical order					
6. Usefulness of the Seminar Material					

Part Two. Please describe your opinions about the Workshop's strengths and weakness.

1. What do you think were the strengths of the Workshop?

_____
_____
_____

2. What do you think were the weaknesses of this Workshop?

_____
_____
_____

3. How would you suggest this Workshop be improved? Do you think an online course or web-based seminar helpful?

_____
_____
_____

4. I would like to have additional information on the following subjects:

_____
_____
_____

5. How did you hear about this seminar?

_____
_____

6. Will you use some of the teaching materials here into your teaching? If not, why not?

_____
_____
_____

7. Do you have any other comments or suggestions? _

1. The staff working for the Board should come to the workshop. Albert will call Professors.
2. Scholarship,
   materials_____
   3. Combine real applications with lecture.

3. Set up teaching seminars for some universities. Professors call will be more effective.
4. multiple lectures in multiple classes._____
_____

Part Three. Please describe your opinions about the presentations and speakers:

Training Quality	Poor (1)	Fair (2)	Good (3)	Very Good (4)	Excellent (5)
Presentation: Introduction to Civil Engineering Design – Ding Cheng					
1. The presentation increased your subject knowledge					
2. The presentation was professional and relevant					
3. I would recommend this presenter for future events					
Presentation: Rubberized Hot Mix Asphalt 101 – Gary Hicks					
1. The presentation increased your subject knowledge					
2. The presentation was professional and relevant					
3. I would recommend this presenter for future events					
Presentation: TDA in Strength of Materials and Concrete – Joel Arthur					
1. The presentation increased your subject knowledge					
2. The presentation was professional and relevant					
3. I would recommend this presenter for future events					
Presentation: Engineering Case Studies of TDA Applications in CA – Joaquin Wright					
1. The presentation increased your subject knowledge					
2. The presentation was professional and relevant					
3. I would recommend this presenter for future events					

Thank you very much for participation of the Workshop. Best Wishes!

Applications of Waste Tire Products in Civil Engineering

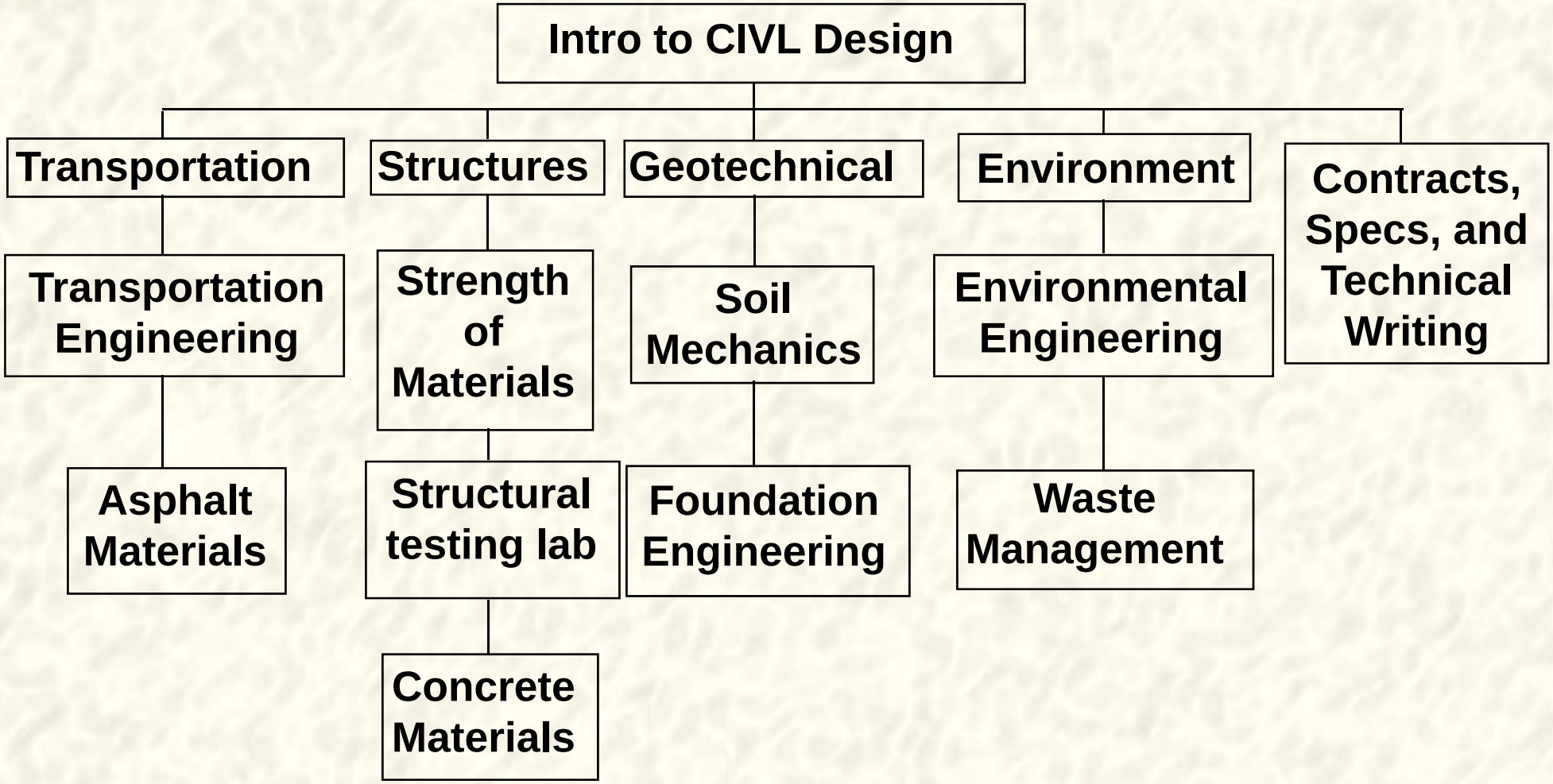
Introduction to Civil Engineering Design

CSU, Chico

Introduction

- Background
- Benefits of Using TDA
- Civil Engineering Applications
  - Lightweight Fill
  - Retaining Wall Backfill
  - Drainage Filter Material
  - Rubberized Asphalt Paving Materials
  - Others
- Challenges and Barriers
- Other Courses Related to Waste Tire Applications

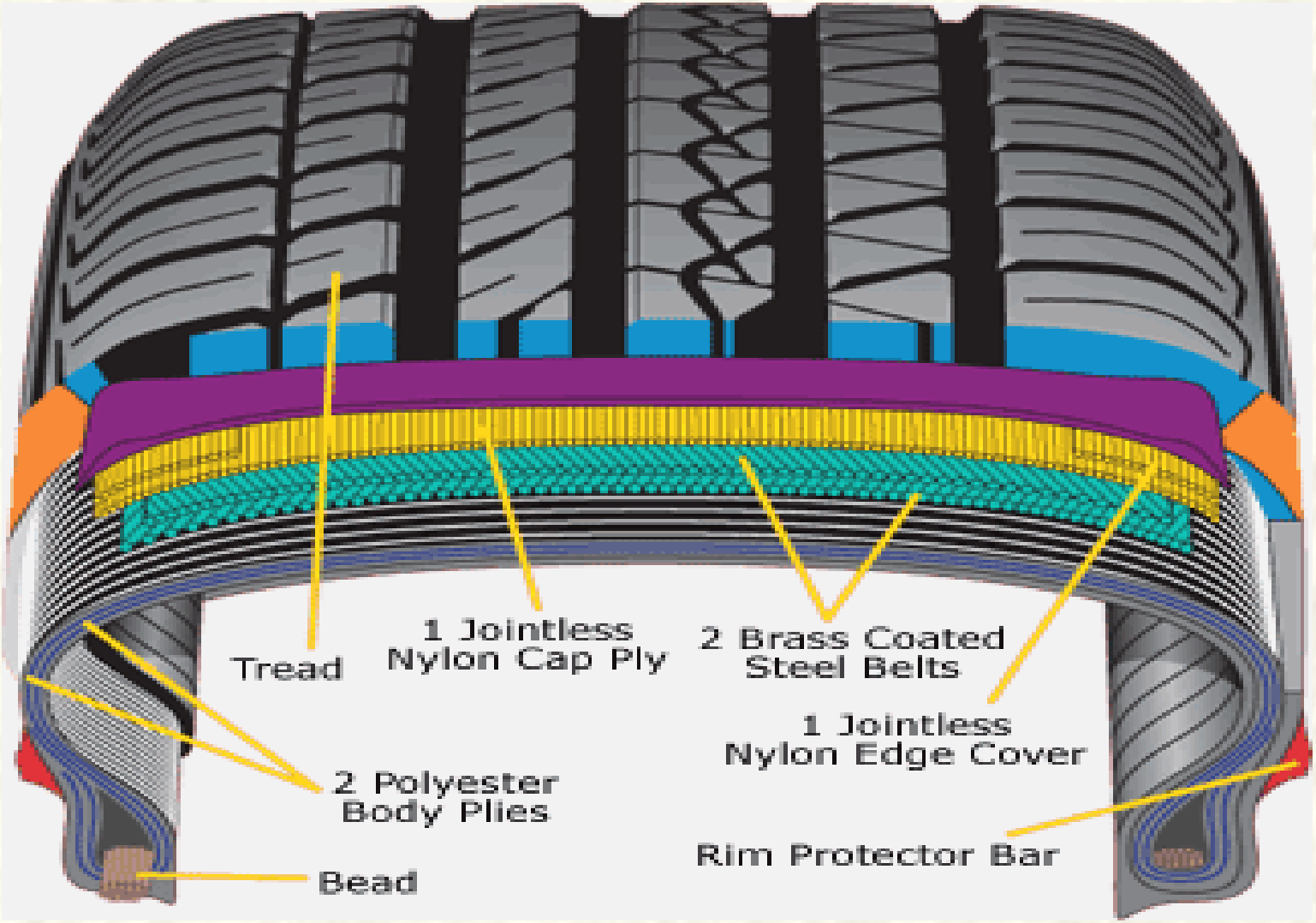
Roadmap for CIVL Curricula Related to Waste Tire Applications



To comply with accessibility requirements, this slide has been added to the original presentation to describe the graphic on the preceding slide.

The “Intro to CIVIL Design” curriculum features five primary categories, most with sub-categories: Transportation (Transportation Engineering and Asphalt Materials); Structures (Strength of Materials, Structural Testing Lab, and Concrete Materials); Geotechnical (Soil Mechanics and Foundation Engineering); Environment (Environmental Engineering and Waste Management); and Contracts, Specs, and Technical Writing.

Tire Composition



Problems

Millions of used tires are already piled up in huge stockpiles: both legally …

Problems

… and illegally

Environmental Issues

Environmental Issues

Tire fires release heavy metals and other hazardous compounds that run into streams and seep into shallow wells

- Arsenic
- Chromium
- Lead
- Manganese
- Nickel
- Mercury
- Cadmium
- Oil

Environmental Issues

Use of Waste Tires in California

- 40.2 million reusable and waste tires are generated each year and an estimated 1.5 million waste tires have been illegally dumped or stockpiled
- CE applications of waste tires in California include:
  - Tire Derived Aggregate (TDA)
  - Rubberized Hot Mix Asphalt (RHMA)

Tire Shredding Process

ECOTIRE scrap tire recycling

Tire Derived Aggregate (TDA)

Benefits of TDA

- TDA has properties that civil engineers need:
  - Lightweight
  - Low lateral earth pressure
  - Good thermal insulation
  - Good drainage/hydraulic conductivity
  - Compressible

Benefits of TDA

- Can use lots of tires!!!
  - 75 tires per C.Y. of TDA fill
  - 100 tires per ton
  - 2000 tires per lane mile of rubberized asphalt pavement
  - 662,700 tires for Dixon Landing Embankment, Milpitas, CA
  - 83,700 tires for 300 ft Retaining Wall 119, Route 91, CA

Range of Civil Engineering Applications

- Rubberized Asphalt Paving Materials
- Lightweight fill for highway embankments
- Retaining wall backfill
- Vibration damping layers beneath rail lines
- Insulation layer to limit frost penetration in roadways
- Landfill and environmental application

Benefits of Rubberized Asphalt Concrete

- Improves traction
- Improves durability
- Reduces noise
- Reduces vibration
- Lowers maintenance needs
- Reduces the spray/splash when raining
- Uses waste tire chips (2000 waste tires per lane mile)

Reduced Noise and Vibration

Reduced Splash/Spray effect

Civil engineering Applications in the United States

- The fastest growing use for scrap tires
- Approximately 60 million tires per year are used in CE applications

Lightweight fill for highway embankments

- Tire shreds are viable in this application due to their light weight.
- For most projects, using tire shreds as a lightweight fill material is significantly cheaper than other alternatives
- Highway embankment in Virginia used 1.7 million tires!

Retaining wall backfill

- The weight of the tire shreds allows construction of thinner, less expensive walls
- TDA can reduce problems with water and frost build up behind the wall, because TDA is free draining and is a good thermal insulator.

Vibration damping layers beneath rail lines

TDA is a good way to dampen the annoying vibrations caused by passing trains

Insulation layer to limit frost penetration in roadways

- Placing a tire shred layer under the road can prevent the subgrade soils from freezing
- In addition, the high permeability of tire shreds allows water to drain from beneath the roads, preventing damage to road surfaces.

Landfill and environmental application

- Daily and Intermediate Alternative Cover
- Landfill Gas Pipe Protection
- Drainage Layers in Landfill Covers
- Leachate Collection and Removal System
- Landfill Gas Extraction Trenches

Barriers to Using Recycled Materials: Civil Engineering Aspects

- Engineering properties not well established
- Lack of long term performance data
- Lack of design standards or manual
- Civil engineers are risk-adverse

Barriers in Using Recycled Materials: Environmental Concerns

- Chemical composition is complex
- Long-term environmental effects unknown
- Public perception – it is a waste, so it must be bad!
- Convoluted regulatory approval process
- Environmental regulators are risk-adverse

Barriers to Using Recycled Materials: Construction Issues

- New procedures and equipment may be required
- Difficult to estimate “in-place” cost
- Supply is uncertain – both quantity & quality
- Sometimes more expensive than conventional construction
- Contractors are risk-adverse

Overcoming Barriers

- Lab studies to determine engineering properties
- Lab studies to determine environmental impacts
- Pilot construction projects (full or nearly full scale)
- Monitor long-term engineering and environmental performance
- Modify specifications, etc. as needed
- Develop national and/or regional standards
- Education – address concerns head-on and focus on the benefits

TDA Sizing and Applications

Type A (Less than 3 inches) - drainage, insulation, vibration damping

Type B (Less than 12 inches) - lightweight fill

Types of Rubberized Hot Mix Asphalt

RHMA-O – Open Graded Asphalt Concrete

RHMA-G – Gap Graded Asphalt Concrete

RHMA-D – Dense Graded Asphalt Concrete

RHMA-O **RHMA-G** **RHMA-D**

Guidelines Available

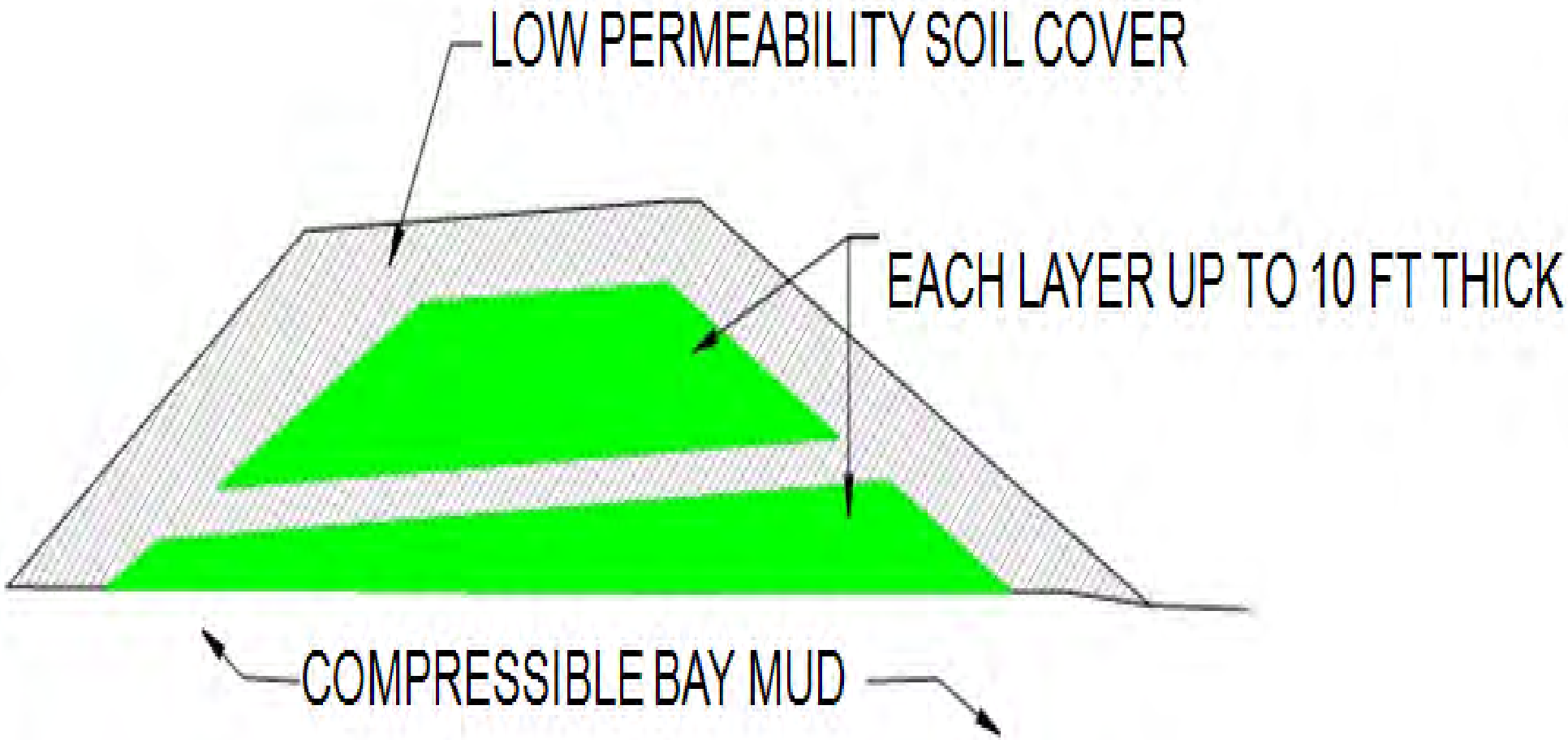
- ASTM D6270 “Civil Engineering Applications of Scrap Tires”
- FHWA guidelines to limit heating in fills
- EPA studies on environmental impacts

Successful TDA Embankment Project

Dixon Landing Interchange

- PROBLEM: Embankment Constructed on Bay Mud
- SOLUTION: Use TDA for the core of the embankment
- CHEAPEST SOLUTION: saved $230,000

Typical Cross Section



Preventing Embankment Heating

- No TDA contaminated with gasoline, oil, grease, etc.
- Limit fine sized TDA
- Max TDA layer thickness is 3 meters (10 ft)
- Minimize access of fill to water & air

Unloading TDA

Spreading with Bulldozer

Compacting with 10-ton Roller

Unit Costs

- Placement costs of TDA (including geotextile) = $3.74/yd^3
- Purchase & delivery costs of TDA = $23.66/yd^3
- In-place cost for TDA = $27/yd3
- In-place cost for lightweight aggregate = $50/yd^3

Cost Savings

- Cost savings to CALTRANS with TDA provided at no cost by CIWMB = $477,000
- Cost savings to state less purchase price of TDA = $230,000

Sample Problems

- **If we need 5000 yd^3 of the Compacted Fill, what is the TDA volume that is needed from the borrowing pit? The expansion factor is 1.5 for this problem.**

Conclusions

- Barriers to using recycled materials can be overcome
- TDA has properties that engineers need
- Civil engineering applications are the fastest growing use for scrap tires in U.S.
- Certain specifications and guidelines are available
- Manageable Environmental effects

THANK YOU

QUESTIONS?

University Curricula Chapter Lectures

Module 1 CIVL 131 Introduction to Civil Engineering Design

DISCLAIMER

The contents of these chapters are draft. They are intended for information only. The purpose of these chapters is to support the teaching modules in Appendix B. Please do not cite or reference this material in other publications. They reflect the views of the authors only. The content does not necessarily reflect the official views or polices of the California Integrated Waste Management Board or the State of California.

CIVL 131 Introduction to Civil Engineering Design

1.0 Introduction

According to the Rubber Manufacturers Association, the U.S. generated approximately 300 million scrap tires in 2005. Historically, these scrap tires took up space in landfills or provided breeding grounds for mosquitoes and rodents when stockpiled or illegally dumped. Fortunately, markets now exist for 87% of these scrap tires-up from about 17% in 1990. These markets-both recycling and beneficial use-continue to grow, and the California Integrated Waste Management Board (CIWMB) believes that the largest growing market for scrap tire products is in civil engineering applications. The remaining scrap tires, however, are still stockpiled or land-filled.

Nation wide, of the 300 million waste tires produced, most were used as follows:

- 155 million (52%) were used as fuel (TDF).
- 49 million (16%) were recycled or used in civil engineering projects.
- 30 million (10%) were converted into ground rubber and recycled into products.
- 7.4 million (2.5%) were converted into ground rubber and used in rubber-modified asphalt.
- 6.9 million (2.3%) were exported.
- 6.1 million (2.0 %) were recycled into cut/stamped/punched products.
- 3 million (1%) were used in agricultural and miscellaneous uses.

As can be seen, the three largest scrap tire markets, using about 78%, are:

- Tire derived fuel
- Civil engineering applications
- Ground rubber applications/ rubberized asphalt concrete

Both recycling and beneficial use of scrap tires has expanded greatly in the last decade through increased emphasis on recycling and beneficial use by state, local and Federal governments, industry, and other associations. Unfortunately, even with all of the reuse and recycling efforts underway, not all scrap tires are being used beneficially

California was the single largest contributing state, producing about 40 million of those tires. It is estimated on average each California resident produces about 1.1 tires each year. The California Integrated Waste Management Board (CIWMB) is tasked with diverting these scrap waste tires from the waste stream to be used in other beneficial applications. Civil engineering applications are the largest growing potential market for scrap tires.

1.1 Objectives

This chapter focuses on the materials that were developed to introduce first year engineering students to potential applications of scrap tires in civil engineering projects. It was developed for a course that is offered at most colleges and universities with engineering programs, often the course is called "Introduction to Engineering".

1.2 History

CIWMB has spent nearly two decades dealing with scrap tire issues in the State of California. They have not only been tasked with diverting scrap tires from the waste stream, but have been involved with reducing the number of scrap tires that have been stockpiled both legally and illegally, and in remediation efforts following devastating tire fires. CIWMB's Waste Tire Recycling Management Program has increased the annual diversion rate of waste tires from 34 percent in 1990 to about 75 percent in 2008 (CIWMB 2008). In addition, the program has cleaned up the majority of large tire piles in the state.

Abandoned waste tires pose potential threats to public health and safety, and to the environment. This is particularly true with respect to fire hazards and mosquito-borne diseases such as West Nile Virus. CIWMB has also completed remediation efforts at California's largest tire fire sites and worked on expanding the markets for tire-derived products.

1.3 Waste Tire Civil Engineering Applications

This module provides a general introduction to the problems related to the generation of waste tires in California and gives an overview of their applications in civil engineering projects. Benefits and problems encountered in using scrap tires as tire derived aggregate (TDA) and rubberized asphalt paving materials are discussed.

Tires are an engineered product with a complex composition. They contain steel belts and beads, polyester belts and both synthetic and natural rubber. They are engineered for toughness and durability, and are not easily recycled. Civil engineering projects can use waste tires in a variety of ways, from crumb rubber particles, to tire shreds, and to whole tires.

The use of scrap tire products in civil engineering applications can be broken down into three broad categories; tire derived aggregate, rubberized asphalt concrete (RAC) paving materials, and the use of whole scrap tires. TDA has many beneficial properties for certain civil engineering applications:

1. Lightweight, tire shreds weigh 1/3 to ½ as much as compacted soil and gravel.
2. Lower lateral earth pressure, about ½ or less than traditional backfill material.
3. Good thermal insulation characteristics, 8 times greater than gravel.
4. High permeability, greater than granular soils (sands).
5. Compressibility, useful for vibration mitigation.

RAC also has many desirable properties including the following:

1. Improves traction compared to traditional asphalt paving.

2. Improves durability of pavement section especially in overlays. Can typically use thinner overlays and get superior performance. Reduces reflection and surface tension cracking.
3. Reduces noise caused by vehicle traffic (noise pollution). Listen to the video on the PowerPoint presentation.
4. Reduces vibration felt in the vehicles.
5. Lowers maintenance costs because of longer service life typical of RAC.
6. Reduces spray/splash when raining. The video in the PowerPoint presentation dramatically demonstrates this effect.

RAC paving materials can improve the performance of the paving system while lowering material requirements due to thinner pavement overlay thicknesses. RAC paving systems have been proven to have lower life-cycle costs.

There are several beneficial applications of TDA in civil engineering projects. TDA can be utilized in several types of civil engineering applications:

1. Lightweight fill for embankments
2. Retaining wall backfill
3. Vibration damping layers under rail lines
4. Insulation layer to limit frost penetration in roadways
5. Landfill applications including daily cover, gas pipe protection, drainage layers, and leachate and gas collection and recovery systems.
6. Solving slope stability problems by replacing heavier soils, reducing the driving force behind slope stability failures.

Utilizing waste tire products in civil engineering applications makes use of the desirable characteristics of these products while helping to solve the environmental problems associated with their improper disposal. These civil engineering applications have the potential to utilize large quantities of waste tire products. For instance, about 75 tires are recycled for each cubic yard of TDA fill, and 2,000 tires are used per lane mile of RAC pavement. CIWMB believes that civil engineering applications represent the largest potential growth market for utilizing waste tires in California.

Several barriers exist to the mainstream use of scrap tires in civil engineering applications. These barriers have civil engineering aspects as well as environmental, regulatory, public perception, and construction issues. Civil engineers are risk adverse and are used to designing with conventional construction materials (soil, concrete, asphalt, timber and steel) that have standards and applicable code acceptance. The engineering properties of TDA are not as well established, and there is a lack of both long term performance data and design standards or manuals. In addition, the chemical composition of scrap tire products is complex as tires are engineered for

toughness, durability and consumer safety. The resulting long term environmental effects are unknown, and the engineer must overcome public perception – it is a waste, so it must be bad!

During design, the engineer is faced with a convoluted regulatory approval process, with many competing objectives (e.g. the EPA and water quality control regulatory groups). Environmental regulators are risk adverse and need reassurance about the impacts of using recycled products in civil engineering applications.

There are several construction issues to overcome as well. New procedures and equipment may be required as is the case for RAC paving systems, which require more controlled manufacturing, transporting and construction procedures. For TDA, it is often difficult to estimate "in-place" cost because of the variations in in-place density achieved and compaction effort to achieve it. Also, supply is uncertain – both in quantity & quality as the resulting TDA varies with the producer. Sometimes, the use of scrap tires may be more expensive than construction with conventional materials. Finally, like engineers, contractors are risk adverse.

However, many of the barriers can be overcome using the following strategies:

- Conducting lab studies to determine engineering properties, and environmental impacts.
- Undertake additional pilot construction projects (full or nearly full scale) utilizing waste tire products in civil engineering applications.
- Monitor long term engineering and environmental performance of these projects.
- Modify specifications, and develop national and/or regional standards, etc. as needed to mainstream the use of recycled products in civil engineering applications.
- Education by addressing concerns head on and focus on the benefits of utilizing these materials.

2.0 Case Studies

2.1 Stockpile fires

Two major tire fires have occurred recently in California, one at Tracy and another in Westley:

- Tracy - On August 7, 1998, a grass fire ignited an estimated 7 million tires at the unlicensed S.F. Royster Tire Disposal Facility in Tracy, California. It was extinguished, after 26 months, with water and foam in December, 2000. It was just recently cleaned up at a cost of 40 million dollars over the last 10 years.
- Westley - On September 22, 1999, lightning ignited stockpiled tires which burned until the fire was extinguished on October 26, 1999. An estimated 2 to 3 million tires burned and it cost an estimated $20 million to clean up.

Tire fires emit clouds of noxious black smoke, carbon black, volatile organics, semi-volatile organics, polynuclear aromatic hydrocarbons, oil, sulfur oxides, nitrogen oxides, carbonoxides, and airborne particulates, such as arsenic, cadmium, chromium, lead, zinc, and iron, which pose serious environmental problems to air, water and soil. Spraying water on tire fires often increases

the production of pyrolytic oil, provides a mode of transportation to carry oils off site, and aggravates contamination of soils and water.

The shape of a tire allows for easy entrance and containment of rainwater. This creates an ideal breeding habitat for mosquitoes and other pests. Tires are non-biodegradable and bulky, and not environmentally friendly looking when stored outside in piles.

2.2 Dixon Landing South 880 Onramp

CIWMB worked with Caltrans to utilize shredded tires (TDA) as lightweight fill on the Dixon Landing/I-880 interchange project in Santa Clara County. Light weight fill was identified as the cheapest option for this on ramp because it was to be built on bay mud, which was too weak to support the weight of traditional fill materials. Also, slope stability and settlement is a major concern when construction embankments on weak soils. TDA was chosen because it weighs one-third to one-half as much as traditional fill material, and TDA had a much lower delivered cost than competing light weight fill materials. The cross-sections of the fill, both perpendicular and parallel to the direction of vehicular travel are shown below:

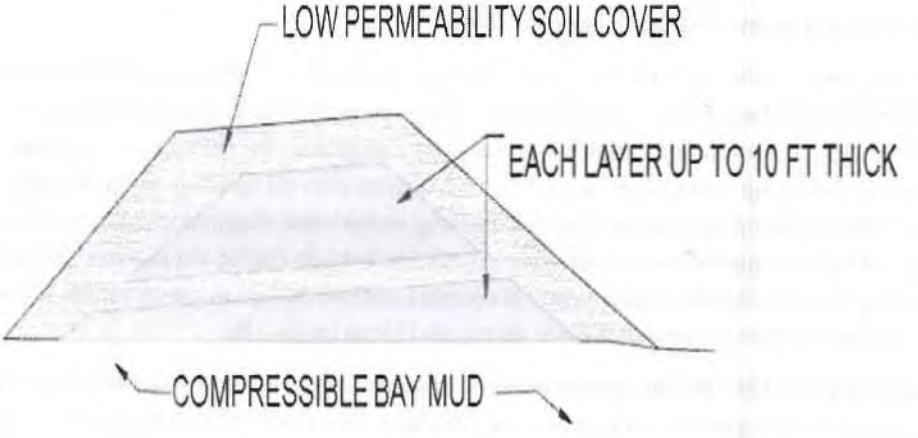


Figure 1. Cross Section View of Dixon Landing Embankment Fill Project with Two Layers of TDA

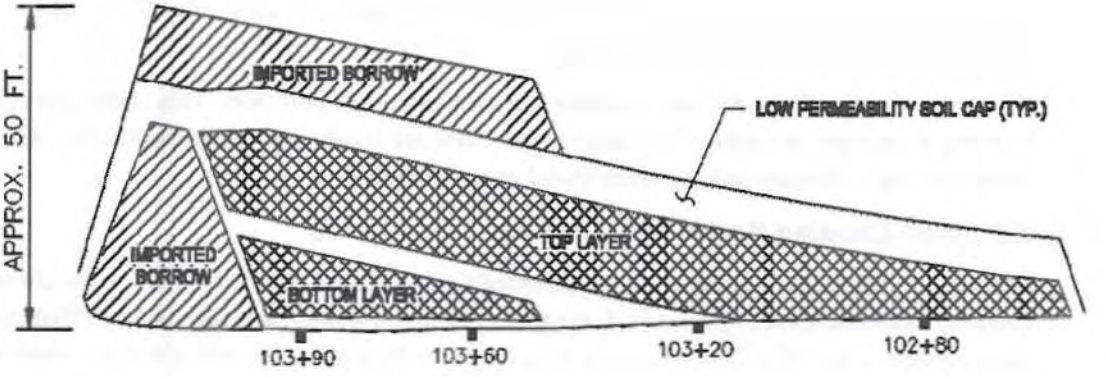


Figure 2. Dixon Landing TDA Embankment Project Profile

Tire shreds were placed in two layers, up to 10 feet thick, and were wrapped in geotextile fabric and separated by a three foot layer of low permeability soil. The 10 foot maximum TDA fill height was used to minimize internal heating that had lead to spontaneous combustion on earlier projects with a greater fill depth back in 1990s.

One such fire involved a TDA tire fill on Fall Springs Road in Garfield County, Washington in October, 1996. The engineers chose to fill a steep ravine with tire shreds instead of building a costly bridge. A few months after the project was completed, the fill began to smolder, followed by flames flaring up through cracks in the road surface with oil running out at the bottom of the ravine. Heavy equipment along with fire fighting crews were required to excavate the fill to full depth. When the ignited tire shreds were exposed to oxygen during excavation, flames erupted engulfing the construction equipment. It cost one million dollars to construct the fill and about three million dollars to remove the tire shreds and clean up the site.

According to ASTM D6270, embankment heating can be prevented by not allowing TDA contaminated with gasoline, oil, grease, etc., limiting fine sized TDA, limiting the max TDA layer thickness is 3 meters (10 ft), and minimizing access of fill to water & air.

On TDA construction projects, it is important to note that other than the haul units used to deliver TDA shown in Figure 3, no special construction equipment is required to spread and compact TDA fills. TDA has a much lower density than traditional fill materials. This means that haul trucks will be volume, not weight limited. This reduces the total number of trucks required to complete a fill project, which maybe an important issue where traffic congestion or limited site access is a concern.

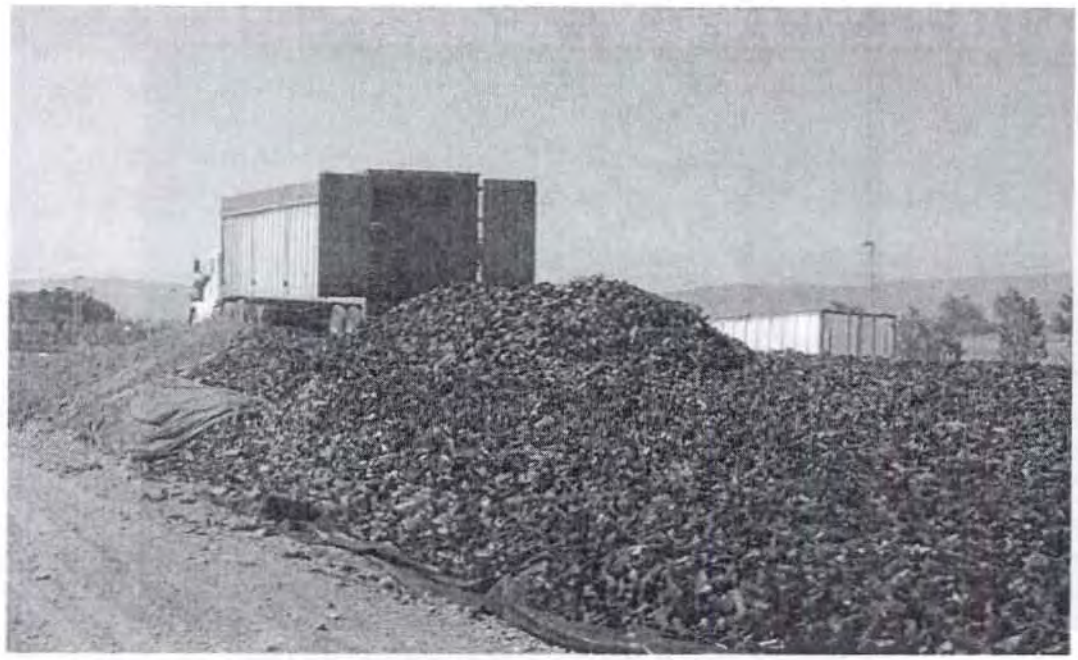


Figure 3 Unloading TDA from Long Haul Truck

The material can be spread with bulldozers and compacted with standard (10 ton) rollers as shown in the Figures 4 and 5. ASTM D6270 specifies that TDA be placed in one foot lifts and be compacted by passing over each point in the fill a minimum of six times per lift. Note that traditional methods of determining in-place density like the sand cone and nuclear gages do no work with TDA. Estimates of in-place density may be obtained by surveying the volume of the fill and knowing the total weight of TDA placed.

Figure 4. Using Bulldozer to Spread TDA

Figure 5. Steel Roller was used to compact the TDA

Unit costs for the Dixon Landing project were as follows:

Placement costs of TDA (including geotextile)	= $3.74/yd3
Purchase & delivery costs of TDA	= $23.66/yd3
In-place cost for TDA	= $27/yd3
In-place cost for lightweight aggregate	= $50/yd3

Note that light weight aggregate was used for fill against the abutment as no data was available on the seismic response of TDA in that application. Cost savings to CALTRANS with TDA provided at no cost by CIWMB was $477,000. The cost savings to the State less the purchase price of TDA was $230,000. This is the amount that using TDA saved tax payers. This project was completed in August 2001, and has been monitored since with no performance problems to date. Figure 6 shows the completed embankment project using TDA.

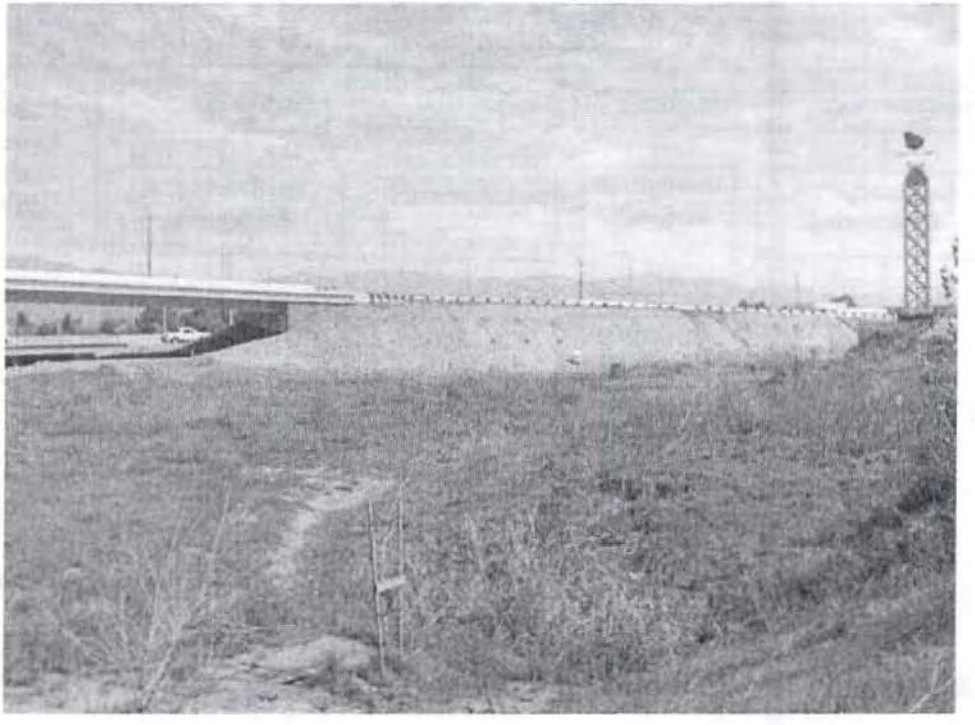


Figure 6. Completed Dixon Landing TDA Light Weight Embankment Fill Project

3.0 Civil Engineering Waste Tire Education Curricula Roadmap

This module also covers an introduction to using scrap tires in civil engineering applications. The following chart shows a roadmap of how information on utilizing scrap tires was spread out through the undergraduate curriculum at CSU, Chico. Course teaching materials are available for each of the topics listed.

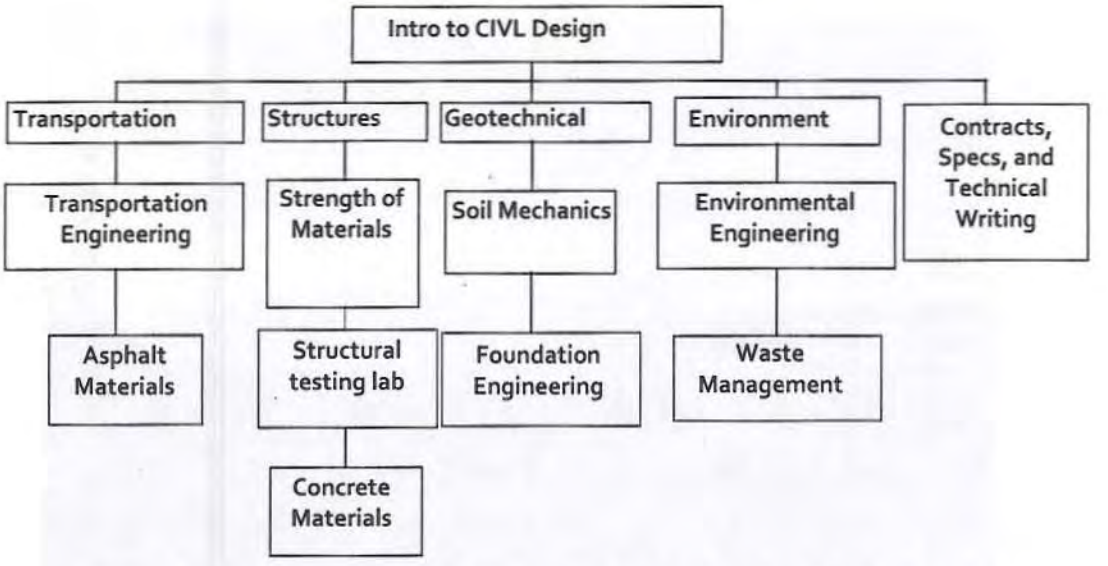


Figure 7. Roadmap of Teaching Waste Tire Applications in Civil Engineering

4.0 Summary and Recommendations

Although, there still remain barriers, Civil engineering applications are the fastest growing use for scrap tires in U.S. TDA has many desirable properties that make it an ideal material for use in a variety of civil engineering applications, while helping to divert waste tires from the waste stream. Although certain specifications and guidelines are available, more research and pilot projects are needed to gain confidence in the use of this recycled material. Long term studies are needed to monitor long term performance, and to determine the environmental impacts.

More work is needed both in terms of getting this material into the hands of educators and to incorporate new pilot project and research results that have been recently completed.

5.0 References

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