Curricula for Using Waste Tires in Civil Engineering Applications

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The United States generates about 300 million waste tires each year. Approximately 40 million of these are generated in California alone. Waste tires stored in stockpiles can pose significant public health and environmental issues. Stockpiled waste tires provide an ideal breeding ground for mosquitoes and rodents, which can transmit diseases. Tires placed in stockpiles can ignite resulting in tire fires that are difficult to extinguish. Although the Environmental Protection Agency does not consider scrap tires as hazardous waste, tire fires release hazardous compounds which pollute the air, soil and water. Nationwide, millions of dollars has been spent to clean up tire fires.

BACKGROUND

The California Integrated Waste Management Board (CIWMB) is tasked with diverting these tires from the waste stream to being recycled into useful products. Tire derived products possess some desirable engineering properties, especially for civil engineering applications, which is the fastest growing market for waste tire products. These applications include roadway construction, landfill applications, septic leach fields, gas and leachate collection systems, retaining walls, lightweight embankment fill, and vibration attenuation for railways.

Not all of the general public understands sustainability and utilizing waste tires as recycled products. Using recycled materials in real applications may face many challenges, especially if the knowledge of how to use the recycled materials such as waste tires has not been well disseminated. These challenges involve many different people, including engineers. Engineers may not have adequate knowledge about the physical properties, long term performance, design guidelines, and construction specifications. They may not want to take the risk of using recycled tires instead of conventional materials.

To promote sustainable and successful waste tire applications in civil engineering, a curriculum development and dissemination project was funded by CIWMB. Undergraduate engineering students are the future engineers; they need to learn how to utilize recycled materials such as waste tires in civil engineering applications as well as traditional materials such as steel, wood, and concrete. The primary purpose of this project was to produce and disseminate teaching materials that could be used in undergraduate civil engineering courses on utilizing waste tires in civil engineering applications.

OBJECTIVES

The objectives of this research are to:

- synthesize the knowledge of utilizing waste tires in civil engineering applications
- develop effective teaching materials to educate university students about utilizing waste tire products in civil engineering
- promote sustainability by using waste tires in civil engineering applications through university education

The goal of this paper is to summarize the curricula of civil engineering applications of waste tire products and to make faculty aware of the existence of the course materials and resources developed on this project.

APPROACH AND PROPOSED CURRICULA

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

1. developing only one new class to include all aspects of waste tire applications
2. add teaching modules to different levels and related civil engineering classes

The second method was chosen because it is more flexible and can reach more students. It also gives students more opportunity to be exposed to waste tire educational materials.

Therefore, it was proposed to develop waste tire application teaching modules for a variety of civil engineering courses from freshman level to senior level. Each module contained one or more lectures. Figure 1 illustrates the courses that training modules were developed for.

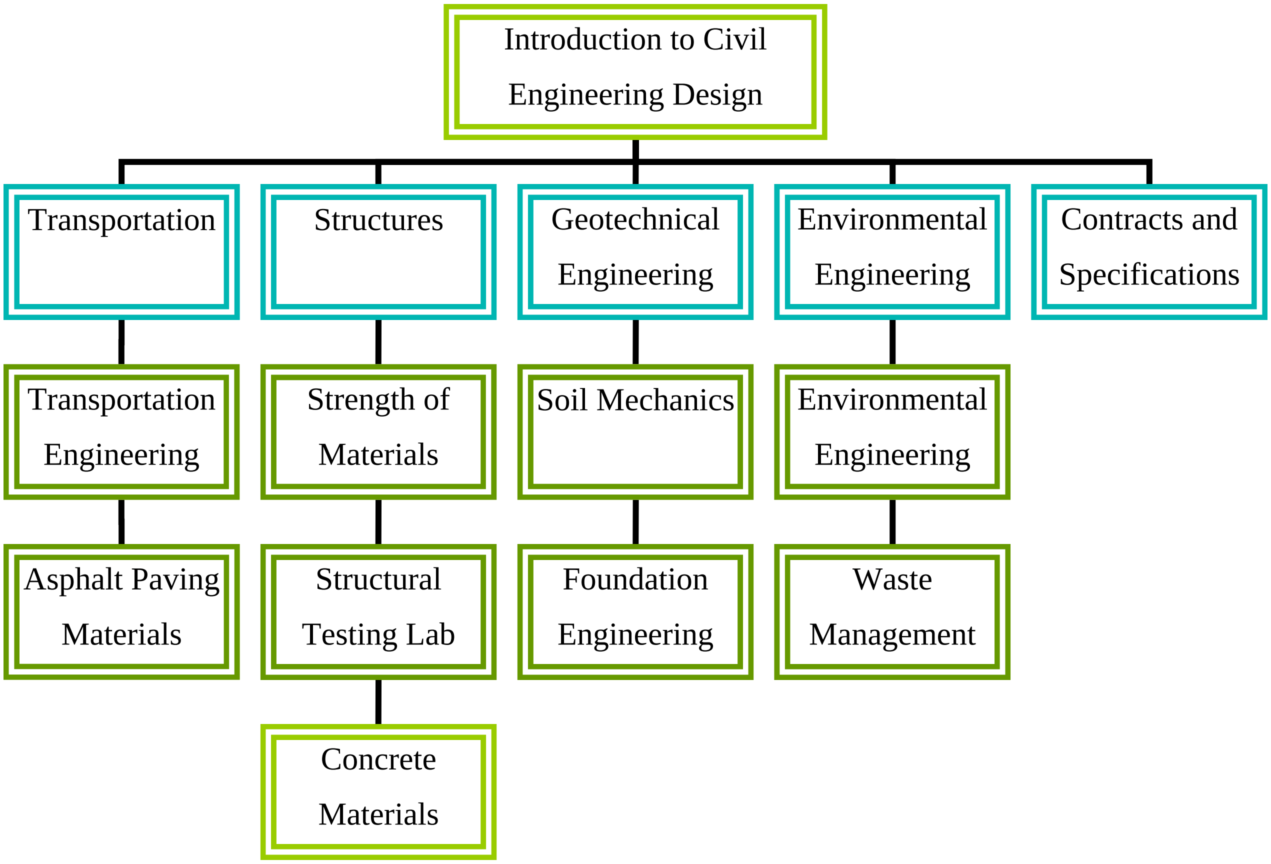

FIGURE 1. Roadmap for Waste Tire Applications in Civil Engineering Curricula

By offering teaching modules for waste tire applications at different class levels, more students are reached than would be by a single elective class. By the end of university education, a student may be exposed to waste tire applications multiple times. It was deemed as a more effective way of teaching students about unconventional materials, such as waste tire derived materials.

CURRICULA DEVELOPMENT

A series of course modules have been developed for a variety of undergraduate Civil Engineering courses, including the following areas:

- Introduction to Civil Engineering Design
- Mechanics of Materials and Materials Testing Laboratory
- Soil Mechanics and Foundation Engineering
- Contracts and Specifications
- Environmental Engineering
- Solid Waste Management
- Reinforced Concrete Design
- Transportation Engineering and Pavement Materials

The following sections describe the objectives, scope, and major components in each teaching module or class. For each module, assignments or evaluation worksheets were also developed.

Teaching modules are independent of each other. Each module emphasizes a different aspect of utilizing waste tire products in civil engineering applications. Some may discuss geotechnical engineering applications, while others may illustrate pavement material modification. In addition, they don't need to be offered all together. The format of the training materials can be flexible so professors or instructors can tailor the teaching module to their teaching needs as they please. Material from different lectures may be combined or edited as the instructor sees fit.

Introduction to Civil Engineering Design

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

The lecture introduces waste tire materials by discussing the potential negative environmental impacts if waste tire materials are not managed properly. 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 town of Westley, California. The fire burned for three months. It took seven years to clean up the site and cost about 20 million dollars.

The lecture covers the benefits and challenges of using waste tire derived products in civil engineering and transportation applications. It discusses physical properties of waste tire derived aggregate (TDA). More importantly, it gives an overview of the major applications in civil engineering and transportation, 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 presents a roadmap of civil engineering classes that cover waste tire applications.

Mechanics 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 (*1*). The common properties of TDA affecting 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 the Bay Area of California. The results show that it is a very cost effective vibration attenuation material. The average vibration level of a light rail line has been reduced by 10 dB for the 30 to 250 Hz range comparing with a standard control section. This is a great noise reduction because dB is in log scale. The project also saved VTA approximately $1 to $2 million compared with a floating slab vibration mitigation technique.

Structural Testing Lab

The lecture portion 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. In the lab portion of the class students test the shear strength of crumb rubber using standard direct shear apparatus.

A literature review and comparison of shear strength parameters from many different sources were conducted. The shear strength of the TDA primarily depends on the: (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.

Contracts 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 of tire rubber, material characterization, usage, construction practices, guideline for fills, and leachate etc (*1*). 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 are illustrated using Caltrans standard specifications on RHMA – O (open graded rubberized hot mix asphalt) and RHMA – G (gap graded rubberized hot mix asphalt) (*2*).

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 (*1*). 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 road surfaces (*3*).

In the lecture material, the Dixon landing interchange project at the intersection of I-880 and Dixon Landing Road in the Bay Area is used as a case study to illustrate the design, construction, and cost benefit of the project (*4*). 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 the 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 standard lightweight aggregate for the project. When the purchase price of the TDA is subtracted, the cost savings was still $230,000 (*5*).

Another case study for the soil mechanics class is using TDA as subgrade insulation for Witter Farm Road, Orono, Maine (*3*). Frost in this cold climate region can cause heaving of the road which can crack the asphalt, while the thawing weakens the road subbase leading to rutting of the gravel and cracking of the asphalt. From the test results, the frost depth was reduced from 55 inches in control section to about 30 inches in a TDA fill section (*3*).

The lecture also introduces using TDA for Marina Drive slope repair in Ukiah, CA (*6*). 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 (*7*).

Concrete Materials

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

One of the most important factors to consider in using waste tire products in the production of concrete is the mix design. From the literature review shown in Table 1, 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.

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.

TABLE 1. Summary of Rubberized Concrete Mix Designs from Literature

Author	Rubber Type	Rubber Content	Method of Mix Design
Kaloush et. al. (*8*)	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. (*9*)	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. (*10*)	Buff Rubber	5 and 10%	Replaced 5% and 10% of coarse aggregate with buff rubber by volume
Schimizze et.al. (*11*)	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 (*12*)	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. (*13*)	Ground tire chips, fine crumb rubber	0,25,50,75,100% by volume	Test specimens replacing either coarse or fine aggregate

Foundation Engineering

Lateral earth pressure is defined as 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 a 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 (*3*).

This lecture introduces a full scale retaining wall testing project conducted at the University of Maine (*3*). 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 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 (*14*).

The lecture also introduces a case study of constructing of a real world retaining wall with TDA. Caltrans and the CIWMB have constructed a 300 linear foot retaining wall, called 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 were measured with strain gauges; temperatures of tire shred materials were measured using temperature sensors; and the displacement of the wall was monitored by a tilt meter. The retaining project was very successful and it used 837 tons of TDA. The following picture shows the construction of the Wall 119.

FIGURE 2. TDA as Backfill for Retaining Wall 119 in Riverside, CA (*15*)

Environmental Engineering

This lecture focuses on the environmental aspects of utilizing waste tires in civil engineering and transportation. 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 with the knowledge of what environmental factors that they should pay attention to when they use waste tires in civil engineering applications. Generally, recycled rubber derived from scrap tires is a safe recyclable material (*16*). 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. It may not be safe to use when the pH is too high or too low (*17*).

Solid and Waste Management

The construction of modern mechanized landfills requires large quantities of material which possess the same material properties as TDA. TDA is a free draining material and its permeability is greater than 1 centimeter per second. TDA can be used in many landfill applications such as operational layers, and gas collection systems.

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 an excellent material 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 highly permeable material such as TDA.

Landfills are required 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.

Transportation Engineering

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

The students are first introduced to the history of using asphalt rubber 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 discussed. The second module introduces the structural design of AR pavements. A 2005 Caltrans study is referenced in this module to review the revised practices of using AR in new pavements as well as an overlay (*18*). Students are informed on the recommended design strategies for new pavements and overlays using AR. An overview of the revised practices for using AR in overlays and new pavement is also presented. This module also presents 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 AR binder production, AR mix production, inspection of paving and troubleshooting. Some or all of these modules could be included in transportation and pavement engineering classes.

Asphalt Paving Materials

This lecture consists of asphalt rubber (AR) binder design, the different types of AR mixes and cautions for 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 between 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.

OUTCOMES

Teaching materials for utilizing waste tire products in civil engineering applications have been developed for eleven different civil engineering courses. The teaching materials are available on a website hosted by CSU, Chico. All these lectures have been taught at the undergraduate level at California State University, Chico in a variety of civil engineering courses. Students have greatly improved their knowledge on utilizing waste tire products in civil engineering applications. They were able to demonstrate their knowledge of, and interest in waste tire applications through their term projects, lab reports, presentations, and homework assignments.

A website was created to store the teaching materials, which includes PowerPoint presentations, lecture notes, sample assignments and sample solutions and student work. The link for the website is:

http://www.ecst.csuchico.edu/cp2c/dxcheng/Curricula/CIWMBEducation.php

Professors and instructors can easily access the teaching materials by logging onto the website. If you log in as a professor, you will be able to use all of the teaching materials. The public can also access part of the teaching materials by logging in as a guest. Generally, they can only access the PDF versions of the presentations. A snapshot of the webpage for professors is shown as following figure.

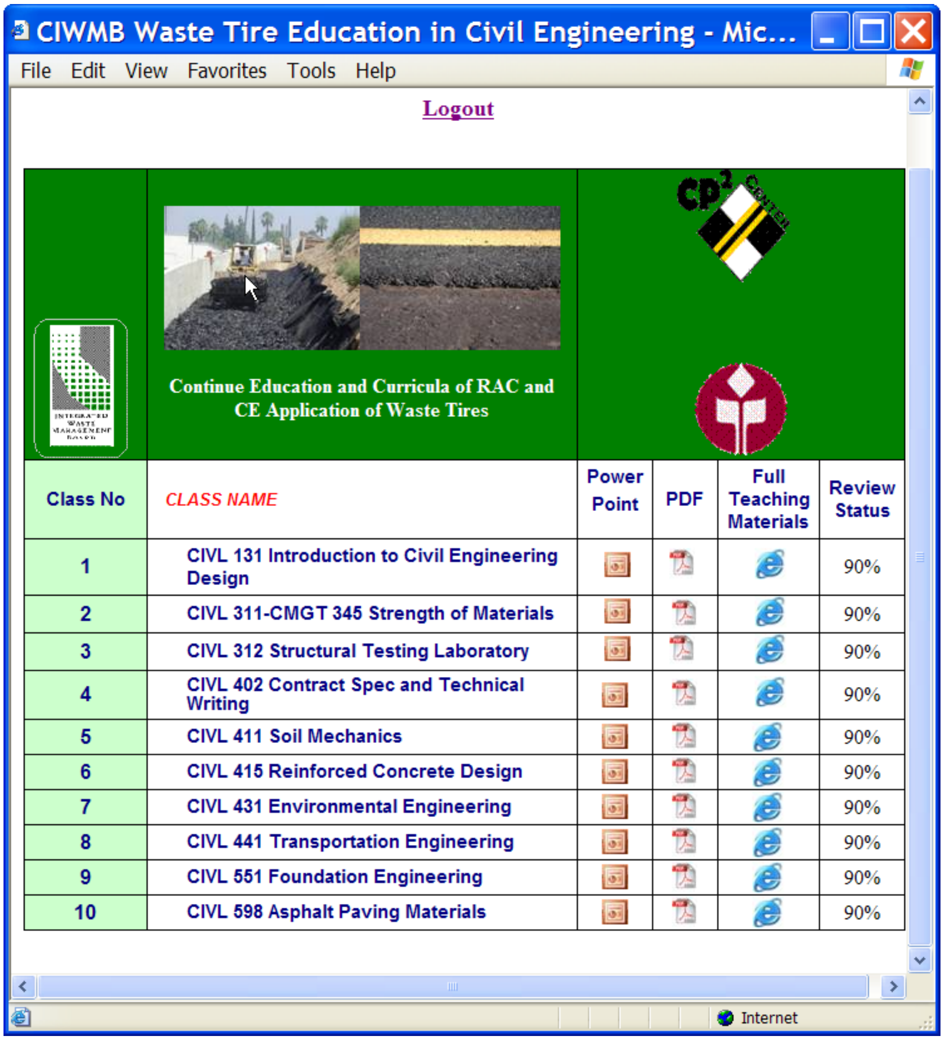

FIGURE 3. Sample Webpage to Access Teaching Materials for Waste Tire Applications

These course materials are available to be integrated into various courses in the undergraduate Civil Engineering curriculum and serve to introduce students to sustainable building practices and “green” construction.

CONCLUSIONS

Each year, civil engineering applications and asphalt rubber combine together to consume more than 60 million waste tires. In order to promote the beneficial usage of waste tires in civil and transportation engineering, educational curricula, including a series of lectures for undergraduate courses were developed. The following conclusions can be drawn from the curricula development project:

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

- 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.

- Outcomes show that introduction of curricula in a variety of courses is an effective way to teach waste tire applications and can reach more students. Students have demonstrated a knowledge of and interest in the sustainable use of waste tire materials through their school work.

Students in civil engineering are the future engineers and their knowledge of waste tire applications will affect the sustainable usage of recycled materials such as waste tires. It was a good experience promoting the education of the sustainable usage of recycled waste tires in civil and transportation engineering by developing teaching materials. The education on the use of other recycled materials can follow a similar approach.

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