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16. Abstract

Previous laboratory and field research has demonstrated that virgin synthetic and cellulose fibers provide important attributes for hot mix asphalt (HMA): reduced asphalt (mastic) draindown during construction for certain types of mixtures, reinforcement which significantly reduces cracking; and, in some cases, reduced rutting. By-product fibers from grinding of scrap tires offer an excellent, low-cost alternative to virgin and cellulose fibers. Currently, most of these fibers are being disposed of in landfills or incinerated.

Two types of recycled tire fibers were evaluated to determine whether they can be used in different types of HMA mixtures as a replacement of currently used cellulose fibers or mineral fiber. The researchers tested three different types of mixtures: stone mastic asphalt (SMA), permeable friction course (PFC), and coarse mix high binder (CMHB) mixtures with two different types of recycled tire fibers, one cellulose fiber, and no fiber. HMA specimens were prepared using all of these combinations and tested using several common laboratory test procedures. The laboratory tests used to evaluate the mixtures were: draindown test, dynamic modulus test, overlay test, indirect tensile strength test, and Hamburg wheel tracking test.

Mixtures containing tire fibers, in most cases, outperformed the mixtures containing cellulose fiber and mixtures with no fiber. Draindown test results clearly revealed that recycled tire fiber can be used in SMA and PFC mixtures as a replacement for cellulose fiber (or mineral fiber) to prevent asphalt draindown during construction. Researchers examined the availability of by-product tire fibers and found them to be readily obtainable in various parts of the USA. The incorporation of recycled tire fiber into HMA does not require any special technique or equipment beyond that typically used for handling other fiber products. The cost of tire fiber will probably be less than cellulose fiber, particularly when tire fiber is available locally.

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Fibers From Recycled Tire as Reinforcement in Hot Mix Asphalt

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DISCLAIMER

This research was performed in cooperation with the South West University Transportation Center (SWUTC) and Department of Transportation, in the interest of information exchange. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the SWUTC or Department of Transportation. This report does not constitute a standard, specification, or regulation. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This report is not intended for construction, bidding, or permits purposes. The engineer in charge of the project was Joe W. Button, P.E. #40874.

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The authors like to extend their gratitude to Texas Tire Recycle in Texas and CRM of America in Arizona for providing recycled tire fibers. The authors are also thankful to Texas Department of Transportation for providing mixture design and materials at no additional cost to the project.

EXECUTIVE SUMMARY

Thousands of tons of fibers from the tire recycling process are produced each year all over the United States and other industrialized countries. A typical tire contains approximately 60 percent rubber, 20 percent steel, and 20 percent fiber. The potential benefits of a process that fosters the utility of this otherwise unusable product are tremendous.

Previous laboratory and field research has demonstrated that virgin synthetic and cellulose fibers provide important attributes for hot mix asphalt (HMA):

- reduced asphalt (mastic) draindown during construction for certain types of mixtures,
- reinforcement which significantly reduces cracking, and,
- in some cases, reduced rutting.

By-product fibers from grinding of scrap tires offer an excellent, low-cost alternative to virgin fibers. Currently, most of these fibers are being disposed of in landfills or incinerated.

The overall objective of this project was to conduct a laboratory test program to examine the utility of by-product tire fibers in HMA for paving purposes. The test program included (Table 1):

- two different types of by-product tire fibers from two tire recycling plants (long fiber and short fiber), one virgin fiber for comparison, and no fiber in control specimens,
- three different types of HMA mixtures: stone mastic asphalt (SMA), porous asphalt course (PFC), and coarse matrix-high binder(CMHB),
- five test protocols (asphalt draindown, indirect tension, dynamic modulus Hamburg rolling wheel tester, and specialized overlay tester to examine relative cracking resistance).

Laboratory tests were performed following the test matrix shown in Table 1. Specimens were prepared using three different types of mixtures. Each mixture was prepared with no fibers (control mixture) and with fibers. The amount of cellulose fiber used in the SMA and PFC mixtures was designed at 0.3 percent (of total mixture weight) in the TxDOT mixture design. To determine the amount of each of the two tire fibers utilized, researchers decided to go with similar volume basis. All three fibers were placed loosely in three containers with same volume. The weights of the fibers were measured. It was observed that a given volume of loosely filled long tire fiber weighs same as that of neat cellulose fiber. On the other hand, the same volume of loosely compacted short fiber weighs three times more than the neat cellulose fiber. Since this measurement was subjective, three different people followed the same steps and the average was selected. So, the percentage of short and long fiber was 0.3 percent and 1.0 percent of total mixture weight, respectively.

Table 1. Experimental Plan for Evaluating Tire Fibers in HMA

Fiber Type	Mixture Type	Type of Test				
		Asphalt Draindown	Indirect Tension	Dynamic Modulus	Overlay Tester	Hamburg Wheel Tracking
No Fiber or Control	SMA	X	X	X	X	X
	PFC	X	X		X	X
	CMHB	X	X	X	X	X
Tire Fiber 1 (Long Fiber)	SMA	X	X	X	X	X
	PFC	X	X		X	X
	CMHB	X	X	X	X	X
Tire Fiber 2 (Short Fiber)	SMA	X	X	X	X	X
	PFC	X	X		X	X
	CMHB	X	X	X	X	X
Cellulose Fiber	SMA	X	X	X	X	X
	PFC	X	X		X	X
	CMHB	X	X	X	X	X

Findings

The following conclusions are based on findings from the laboratory tests.

- Mixtures containing tire fibers, in most cases, outperformed the mixtures containing cellulose fiber and mixtures with no fiber.
- Draindown test results clearly revealed that recycled tire fiber can be used in SMA and PFC mixtures as a replacement for cellulose fiber (or mineral fiber) to prevent asphalt draindown during construction.
- The use of one percent short fiber appeared to be excessive. In several cases, those mixtures containing short tire fiber demonstrated poorer performance than other mixtures, including control mixture. Since the design asphalt content of the mixture was not modified upon the addition of fibers, the authors believe that one percent short fiber absorbed significant asphalt and yielded a mixture that was stiffer and less resistance to cracking.

- The presence of fiber in HMA mixtures produced mixed results for indirect tensile strength test. Tensile strength was improved for the SMA and PFC mixtures but was reduced for the CMHB mixture.
- Application of long tire fiber significantly improved the overlay test results for the PFC and CMHB mixtures but slightly decreased performance for SMA mixture.
- In most cases, the mixtures containing tire fibers outperformed the mixtures containing cellulose fiber and the control mixtures when they were tested for permanent deformation using Hamburg wheel tracking device.
- The dynamic modulus test did not clearly discriminate the performance of the different SMA mixtures.
- The incorporation of recycled tire fiber into HMA does not require any special technique or equipment beyond that typically used for handling other fiber products. Tire fibers can be mixed using similar procedure used for cellulose or mineral fiber. The cost of tire fiber will probably be less than cellulose fiber, particularly when tire fiber is available locally.

Recommendation

Based on these findings, the researchers offer the following recommendations.

- Fiber percentage should not be arbitrarily determined. It should be determined during the mixture design process (e.g., based on draindown criteria for SMA and PFC mixtures) so that the presence of fiber does not affect the effective asphalt content.
- Promising results of using recycled tire fibers in HMA, based on this laboratory study, warrants some field demonstration projects. These field projects can be implemented by coordination between state DOTs and paving contractors. The field demonstration type project will provide more long-term performance evaluation and identify any unpredicted problems that may occur during construction.

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CHAPTER 1:
INTRODUCTION

BACKGROUND

High-quality long-lasting hot mix asphalt (HMA) pavements are essential to the sustainability of the US economy. Freeman et al. (*1989*) pointed out that the low tensile strength of HMA is a major contributor to its performance problems. HMA pavements are subjected to a variety of loading conditions that result in internal tensile stresses and, consequently, may induce cracking. The capacity to resist cracking is requisite to pavement durability and longevity.

Previous research and construction projects have demonstrated that virgin synthetic fibers can provide excellent reinforcing aids in asphalt paving mixtures (*Button and Hunter, 1984*). Fibers from scrap tires offer an excellent, low-cost alternative or supplement to virgin fibers. As no good use has been found for these by-product fibers from the tire grinding process, they are currently being disposed of in landfills or, in some cases, incinerated.

Thousands of tons of fibers from the tire recycling process are produced each year all over the United States and other industrialized countries. A typical tire contains approximately 60 percent rubber, 20 percent steel, and 20 percent fiber (*Putman and Amirkhanian, 2004*). The potential benefits of a process that fosters the utility of this otherwise unusable product are tremendous.

Button and Hunter *(1984*) successfully incorporated virgin synthetic fibers into HMA and demonstrated benefits in the laboratory and, on a limited basis, even in the field. Virgin fibers were shown to improve the resistance of HMA to cracking and rutting.

A few specialized types of HMA (e.g., stone mastic asphalt [SMA] and open-graded friction course [OGFC]) actually require the use of fibers to prevent asphalt draindown during the construction process. It is believed that fibers from tire rubber can be used to benefit not only these specialized mixtures but also conventional HMA paving mixtures.

OBJECTIVES

The overall objective of this project is to conduct a laboratory test program to examine the utility of by-product tire fibers in HMA for paving purposes. In summary, the researchers obtained by-product tire fibers and incorporated them into HMA paving mixtures, prepared and tested HMA specimens in the laboratory, and evaluated the benefits of fibers in different types of HMA. Initially, the availability of by-product tire fibers in the US was examined. Some preliminary work was necessary to determine appropriate fiber contents for the different mix types. The researchers contacted individuals at industrial firms who they believed were willing offer assistance regarding obtaining by-product tire fibers and offer advice and assistance in obtaining relevant information.

SCOPE OF THIS REPORT

This report documents the effort and findings of the research study supported by Southwest University Transportation Center. The report is divided into several chapters. Chapter one describes the background, objective, and scope of this report. Chapter two summarizes the literature review regarding the use of different types of fibers in different types of asphalt mixtures. Chapter 3 presents the experimental design and rationale behind selecting the materials and laboratory test procedures. Laboratory test results are documented in Chapter 4. The findings and recommendations are discussed in Chapter 5. Detailed information regarding the mixture designs and some detail test results are presented in the appendices.

CHAPTER 2:
LITERATURE REVIEW

INTRODUCTION

Asphalt Rubber Technology Service (*http://www.ces.clemson.edu/arts/process.html*) points out that during the tire grinding process, all fibers and metals are discarded. They are interested only in the rubber. The fibers are typically disposed of in landfills. Worldwide, this amounts to thousands of tons of fibers annually. Many believe that these fibers are valuable resources and can be used to advantage as reinforcement in various engineered products such as transportation related materials.

Several studies have shown that incorporation of a small quantity (approximately 0.5 percent by weight of mixture) of fibers in HMA mixtures is feasible during pavement construction and that they reduced cracking in pavement surface mixtures for new construction and overlays (*Button and Hunter, 1984; Freeman et al., 1989; Maurer, 1985; Maurer and Arellano, 1987; Kietzman, 1963*). Serfass and Samonos (*1996*) asserted that the addition of fibers enables the development of mixes with higher than normal asphalt contents (i.e., asphalt film thickness), which therefore display excellent resistance to moisture damage and aging as well as fatigue and other forms of cracking.

In a comprehensive laboratory and field study, Button and Hunter (*1984*) found that neat synthetic fibers (some of which were very similar to those used for reinforcing tires) reduced cracking in HMA paving mixtures. This work was some of the first research to examine the effects of fibers in HMA. They used fibers from 10 different suppliers composed of different materials (e.g., polypropylene, polyester, glass, and Kevlar) in standard dense-graded HMA and observed modest benefits. Their work demonstrated that fibers in HMA provide more flexibility (thus increased fatigue life), less sensitivity to asphalt content, but slightly lower strength and stiffness. Their work suggested that, when fibers are added to HMA, some of the small aggregate particles should be extracted. That is, the volume of the fibers added should probably replace a similar volume of small aggregate particles. This was later proven to be true by other researchers.

In fact, since 1984, researchers have found that fibers provide significantly more benefit in the newer "new-generation" or stone-skeleton HMA mixtures with thick asphalt films such as stone mastic asphalt (SMA) (*Kuennen, 2003*), coarse matrix high binder (CMHB), and open-graded or permeable friction course (PFC) mixtures (*Asphalt Institute, 2004*). During construction, the high surface area and capillary action of fibers prevent excessive draindown of asphalt in these asphalt-rich mixtures. During service, fibers directly or indirectly contribute to mixture toughness and resistance to cracking, moisture, and oxidation. Fibers have been demonstrated to be a key to the comparatively remarkable success of the new generation PFC mixtures by reducing their tendency toward raveling, particularly during cold, wet weather.

Polymeric fibers, cellulose, and synthetic mineral fibers have been successfully used in asphalt mixes (*King, 1999*). The authors summarized the use of different fibers in HMA. They mentioned that the fibers can increase the tensile strength and cohesion of HMA and asphalt emulsion mix. Fibers can maintain higher asphalt contents on open-graded (e.g. PFC) or SMA mixtures without allowing asphalt or mastic draindown during construction. These fibers are sometimes placed in easily melted plastic bags and added to the mix in the pugmill of a HMA batch plant. For some drum mix plants, the fibers are typically blown into the drum using a pneumatic blower. Polypropylene fibers (about 1 cm long) have been successfully used in asphalt mixtures at 0.3 percent by weight of total mixture. But polypropylene fiber melts at higher temperatures and, hence, should not be used at temperatures exceeding 300°F (150°C). Polyester fibers can maintain their mechanical strength up to 482°F (250°C). A typical dosage rate for polyester fiber varies from 0.15 percent to 0.38 percent of total mix and increases the design asphalt content by approximately 0.1 to 0.2 percent. Mineral fibers have been used in Europe and the USA especially for SMA mixtures. This type of fibers is manufactured from diabase or mineral aggregate. They are typically about 6 mm long and used in SMA mixtures at a rate of 0.3 to 0.4 percent by total weight of the mixture. Cellulose fibers are the most popular type of fiber used in HMA due to its low cost. Cellulose fibers do not provide significant increases in mechanical strength like other fibers, but they are very effective in reducing asphalt draindown during construction.

Some states prefer the use of mineral fibers over cellulose fibers in OGFC mixtures, as the cellulose fibers are of organic origin and they can absorb water leading to premature moisture problems in field (*Cooley, 2000*). Cellulose fibers can also absorb asphalt, which is becoming an increasingly expensive loss of active binder. Their laboratory study comparing the performance between mineral fiber and cellulose fibers did not yield any measurable differences.

Li et al. (*2004*) used waste tire chips (1/2 to 3/4 inch diameter) and tire rubber "fibers" (strands of tire rubber approximately 0.2 inches in diameter and 1 to 3 inches long) in portland cement concrete (PCC) to improve toughness and cracking resistance. They reported that toughness of the rubberized PCC was greater than that of the control sample. It will thus absorb dynamic loads and resist crack propagation more than the control PCC. Plastic deformation and impact resistance of the PCC was increased. This makes it potentially good for applications such as sound and crash barriers. Cracking resistance of the PCC was increased. Workability of the modified samples was not adversely affected; however, strength and stiffness of the rubberized samples were reduced. The control PCC disintegrated when peak load was reached, while the rubberized PCC exhibited considerable deformation without disintegration. The stress concentration in the tire fiber modified PCC is smaller than that in the rubber chip modified PCC. This means the rubber fiber-modified PCC can bear a higher load than the rubber chip modified PCC before the concrete matrix breaks. The stress concentration decreases as the rubber fiber stiffness increases. Therefore, using stiffer rubber, for instance truck tires with steel belt wires included is an effective way for improving the tensile strength of rubber fiber-modified PCC. They concluded that waste tire fiber-modified PCC has a higher strength and stiffness than waste tire chip-modified PCC and, further, that tire waste should be used in the form of fibers instead of chips in modifying PCC.

PRODUCTION OF TIRE FIBERS

Recovery of tire fibers differs slightly at different scrap tire processing plants. Basically, in the processing plant, passenger tires and truck tires are separated; tires containing metallic rims are de-rimmed. The tires are re-introduced to the tire conveying system to reduce the whole tires through shredding and granulating down to various particle sizes, classified into three groups (coarse, mid-range, and fine sizes). Mesh sizes of 3/8 inch with 95% metal-free products and 5–30 mesh with 90% fiber and 99.9% metal-free products can be marketed as-is for numerous applications or further reduced to smaller sizes (*Sunthonpagasit and Duffey, 2004*). Metals are usually separated using magnets. Tire fibers are then vacuumed out from the crumb rubber. The appearance, shape, and size of the tire fibers depend on the type of processing.

CHAPTER 3:
EXPERIMENTAL DESIGN

MIXTURE AND MATERIAL SELECTION

During selection of HMA the mixture for this study, the researchers were interested in finding a meaningful variety of mixtures in which they can evaluate the performance of waste tire fibers. Three different types of HMA mixtures were selected for this purpose. They were: Stone Mastic Asphalt (SMA), Coarse Matrix High Binder (CMHB), and Porous Friction Course (PFC). All three mixtures use relatively high asphalt contents and their aggregate gradations are relatively coarse. Current mixture design procedures for SMA and PFC require the use of a certain percentage of cellulose or mineral fiber to prevent draindown of the “excess” asphalt (or rather mastic) in the mixture during transport and construction. So, these two mixtures provided ideal candidates for tire rubber fiber evaluation of national interest. The CMHB mixture is important for the Texas Department of Transportation (TxDOT).

The researchers contacted several TxDOT district offices to obtain realistic mixture designs for these three types of HMA mixtures.

SMA Mixture

An SMA mixture was obtained from TxDOT Waco District office. This mixture was originally designed for use on Interstate Highway 35 in McLennan County. The limestone aggregate used this project came from Hanson, Oklahoma and Hanson, Perch Hill. The asphalt used was PG 76-22 TR from Wright Asphalt and the design asphalt content was 6.1 percent based on 4 percent air voids at 75 gyrations. Additionally, this mixture was designed with 0.3 percent cellulose fibers. More detail of this SMA mixture design can be found in the Appendix.

PFC Mixture

The PFC mixture was obtained from TxDOT Austin District office. This mixture was designed for use on State Loop 360 in Travis County. The limestone aggregate of the PFC mixture came from Delta D-Rock and Hanson, New Braunsfels. The design called for 6.2 percent PG 76-22S asphalt from Marlin Asphalt. The design asphalt content was based on 20 percent air voids. This PFC mixture design also required 0.3 percent cellulose fiber. Details of the mixture design are given in Appendix.

CMHB Mixture

The CMHB mixture used in this research project was obtained from TxDOT Bryan District office. It was a mixture commonly used in Bryan District. The limestone aggregate in this mixture came from Hanson Aggregate's New Braunfels quarry. This CMHB mixture was designed with 4.6 percent PG 64-22 asphalt from Fina. Originally, the CMHB mixture did not require any fiber. Typically, CMHB mixtures do not utilize fibers. More details regarding the mixture design can be found in Appendix.

Tire Rubber Fiber

The researchers identified and obtained three different by-product tire fibers from three different tire grinding processes. Among these three fibers, two fiber types (short and long) were selected for use in the laboratory test program. One of these two fibers was supplied by CRM of America, a recycling company located in Arizona. This product has two types of fibers in it: very thin (about 10 mm long), and relatively thick (about 18 mm long). It is fluffy and has low amount ground rubber particles. This product will be referred as 'long fiber' in rest of this report. Figure 1 depicts a sample of long fiber.

Figure 1. Long Fiber Obtained from CRM of America.

Another tire fiber was obtained from Texas Tire Rubber, a recycling company located in Texas. This product consists of a relatively short fiber (about 6 mm) and a rather large amount of fine granular crumb rubber. For remainder of the report, this product will be referred as 'short fiber.' Figure 2 depicts the short fiber.

A third type of fiber (cellulose), typically used in SMA and PFC, is shown in Figure 3. Cellulose fibers are typically very short, fine fibers. The cellulose fiber will be referred as 'neat' fiber. It was obtained from a company named Interfibe located in Michigan.

Figure 2. Short Tire Fiber from Texas Tire Rubber.

SELECTION OF TEST PROCEDURES

Two different approaches were employed during selection of the laboratory test procedures to evaluate tire rubber fiber in hot mix asphalt paving mixtures. The first approach was to examine whether the tire rubber fiber can perform essentially the same as the cellulose fiber. For this purpose, an asphalt draindown test was selected to compare the relative performance of the different fibers. The second approach was to examine any mixture performance improvement due to the use of tire rubber fiber. The researchers selected several laboratory test procedures: Indirect Tension, Overlay Tester, Dynamic Modulus, and Hamburg Wheel Tracking Device (HWTD). Table 1 presents the test matrix (partial factorial) for evaluating the tire fibers. The following paragraphs briefly describe the laboratory test procedures employed in this project.

Figure 3. Typical Cellulose Fiber.

Table 1. Experimental Plan for Evaluating Tire Fibers in HMA

Fiber Type	Mixture Type	Type of Test				
		Asphalt Draindown	Indirect Tension	Dynamic Modulus	Overlay Tester	Hamburg Wheel Tracking
No Fiber or Control	SMA	X	X	X	X	X
	PFC	X	X		X	X
	CMHB	X	X	X	X	X
Tire Fiber 1 (Long Fiber)	SMA	X	X	X	X	X
	PFC	X	X		X	X
	CMHB	X	X	X	X	X
Tire Fiber 2 (Short Fiber)	SMA	X	X	X	X	X
	PFC	X	X		X	X
	CMHB	X	X	X	X	X
Cellulose Fiber	SMA	X	X	X	X	X
	PFC	X	X		X	X
	CMHB	X	X	X	X	X

Draindown Test

During this project the standard test method used to measure the draindown of asphalt was AASHTO Designation: T 305-97, "Determination of Draindown Characteristics in Uncompacted Asphalt Mixture." Using this test method, one can measure the amount of liquid asphalt draindown from an uncompacted loose HMA mixture sample when the sample is held at elevated temperatures comparable to those encountered during the production, storage, transport, and placement of the mixture (*AASHTO, 2003)*. This test is particularly suitable for mixtures with high concentrations of coarse aggregate and/or high asphalt contents such as PFC and SMA. This test method can be used to determine whether the amount of draindown measured for a given HMA mixture is within predetermined acceptable limits. This test is used to provide an evaluation of draindown potential of a mixture during the mixture design phase as well as during field production.

In this draindown test, an HMA mixture sample is produced in the laboratory or is obtained from the field. The mixture sample is placed in a wire basket with a specific opening (mesh) size. The basket with sample is positioned on a plate or other suitable container (capable of holding liquid asphalt) all with known masses. The sample, basket, and plate/container are placed in a forced draft oven for one hour at a preselected temperature. After one hour of heating, the basket containing the mixture is removed from the oven along with the plate or container. The mass of the plate or container is measured. The mass difference between the empty container and the container with liquid asphalt/mastic (if any) yields the amount of draindown. Mixture draindown is expressed as the weight percentage of original HMA mixture specimen.

Indirect Tension Test

The indirect tensile test has been used extensively in structural design research for rigid pavements since the 1960's and to a lesser extent in HMA mixture design research. However, the indirect tensile test is a popular test for HMA mixture characterization in evaluating pavement structures. The primary reason for its popularity is that cores from thin lifts can be tested directly in the laboratory (W*itzak et al. 2002*).

The indirect tensile method is used to develop tensile stresses along the diametral axis of the test specimen. The test is conducted by applying a compressive load to a cylindrical specimen through two-diametrically opposite arc-shaped rigid platens, as shown in Figure 4. The test specimen is placed with its axis horizontal between the platens of the testing machine.

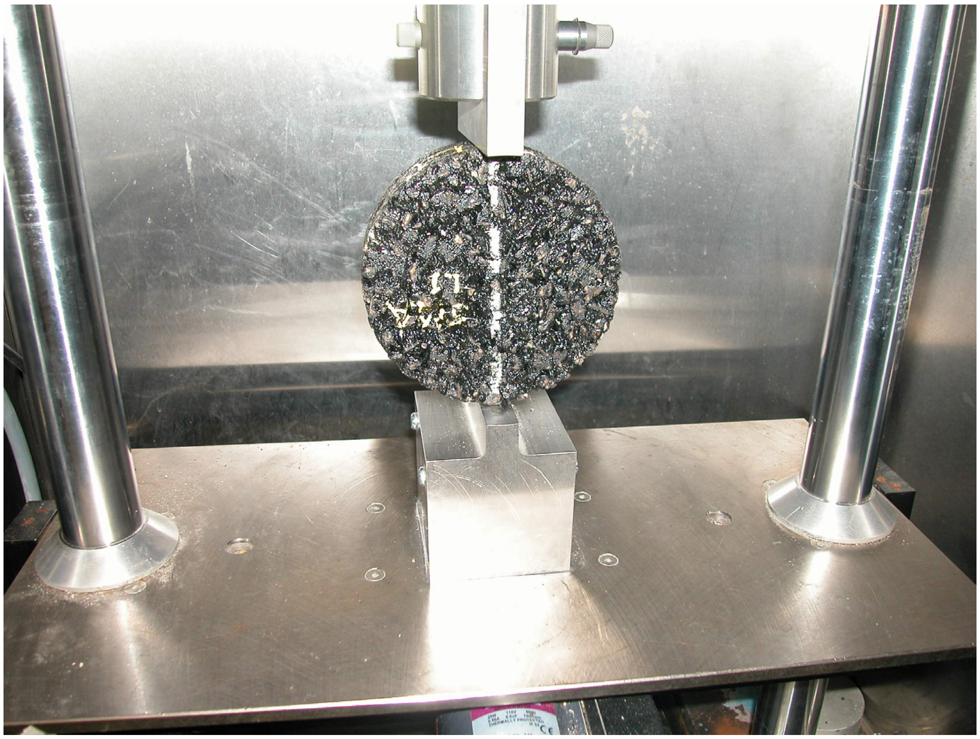

Figure 4. Indirect Tension Test Setup.

The indirect tensile strength is measured by applying the load at a constant strain rate until the specimen fails by splitting along the diametral axis. The horizontal tensile stress at the center of the test specimen is calculated using following equation.

$$\text{Horizontal Tensile Strength,} \quad \sigma_{xy} = \frac{2P}{\pi t d}$$

Where:

d = the diameter of the specimen.

P = the applied load.

t = the thickness of the test specimen or core.

Dynamic Modulus Test

The dynamic modulus test is typically performed over a range of different temperatures by applying sinusoidal loading at different frequencies to an unconfined specimen. A sinusoidal axial compressive load is applied to a cylindrical specimen at a series of temperatures and loading frequencies. The typical parameters derived from this test are complex modulus (E*) and phase angle (ϕ). E* is a function of the storage modulus (E′) and loss modulus (E″). Typically, the magnitude of the complex modulus is represented as:

$$|E^*| = \frac{\sigma_0}{\varepsilon_0}$$

where,

σ_0 = axial stress and
ε_0 = axial strain.

The phase angle can be used to assess the storage and loss moduli.

Figure 5. Dynamic Modulus Test Setup.

In this task, tests were conducted in accordance with the AASHTO Designation: TP 62-03 “Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixture” at 25, 10, 5, 1, 0.5, and 0.1 Hz; and 14, 40, 70, 100 and 130°F (*Witczak et al., 2002*). The stress level for measuring dynamic modulus was chosen to achieve a measured resilient strain within a range of 50 to 150 microstrain. The research team performed each test in order of lowest to highest temperature and highest to lowest frequency of loading at each temperature to minimize specimen damage. Figure 31 shows the test equipment.

The data generated were used to plot a master curve using the sigmoidal curve fitting function as Pellinen (*2002*) demonstrates. The sigmoidal function used is given below:

$$\log(|E^*|) = \delta + \frac{\alpha}{1 + e^{\beta - \gamma \log(\xi)}}$$

where,

|E*| = dynamic modulus,
ξ = reduced frequency,
δ = minimum modulus value,
α = span of modulus values,
β = shape parameter, and
γ = shape parameter.

Dynamic Modulus Test Results

Parameters from the dynamic modulus test used for evaluating the mixtures in this project are:

- E* sin ϕ at 10 Hz and 14°F to compare the cracking potential of the different mixes, which is based on previous work by Witczak et al. (*2002*);
- E*/sin ϕ at 1 Hz and 130°F to compare the rutting potential. The researchers selected these test parameters based on previous research (*Witczak et al., 2002; Bhasin et al., 2003*); and
- dynamic modulus master curve.

Overlay Testing

Germann and Lytton, et al. (*1979*) designed the TTI overlay testers to simulate the opening and closing of joints or cracks, which are the main driving force inducing reflection crack initiation and propagation. Later, this overlay tester was further modified and developed. Two types of overlay testers have been successfully used at TTI to evaluate the effectiveness of geosynthetic materials and modified binders on retarding reflection cracking. These applications indicate that the overlay tester has the potential to characterize the reflection cracking resistance of hotmix asphalt concrete mixtures.

The overlay tester data include the time, displacement, and load corresponding to a certain number of loading cycles. In addition, the crack length can be manually measured. Two types of information can be gained from the overlay tester: one is the reflection cracking life of a hotmix asphalt concrete mixture under certain test conditions; the other is fracture parameters of a hotmix asphalt concrete mixture.

Figure 6 depicts the key parts of the apparatus. This overlay tester consists of two steel plates; one is fixed, and the other moves horizontally to simulate the opening and closing of joints or cracks in the old pavements beneath an overlay. The load is applied in a cyclic, triangular waveform with constant magnitude. The overlay test is run at room temperature (77 ºF) in a controlled displacement mode at a loading rate of one cycle per 10 seconds with a maximum displacement of 0.025 inch until failure occurs. This amount of horizontal movement is approximately equal to the displacement experienced by Portland Cement Concrete (PCC) pavements undergoing 30 °F (16.7 ºC) temperature changes in pavement temperature with a15-feet joint or crack spacing (*Zhou and Scullion, 2003*).

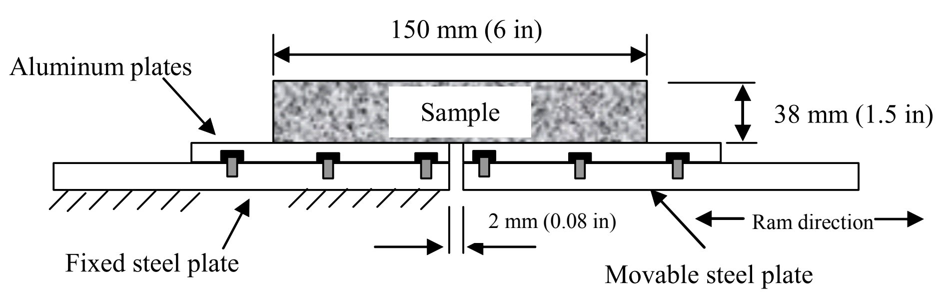

Figure 6. Schematic Diagram of TTI Overlay Tester System.

Three prismatic specimens (6 inch × 3 inch × 1.5 inch) sawed from 6-inch diameter cylinders prepared using the Superpave gyratory compactor (SGC) were tested using the TTI overlay tester at 77°F (25°C). Tests were performed following the protocol suggested by Zhou and Scullion (*2003*). All compacted specimens were contained 7±1 percent air voids.

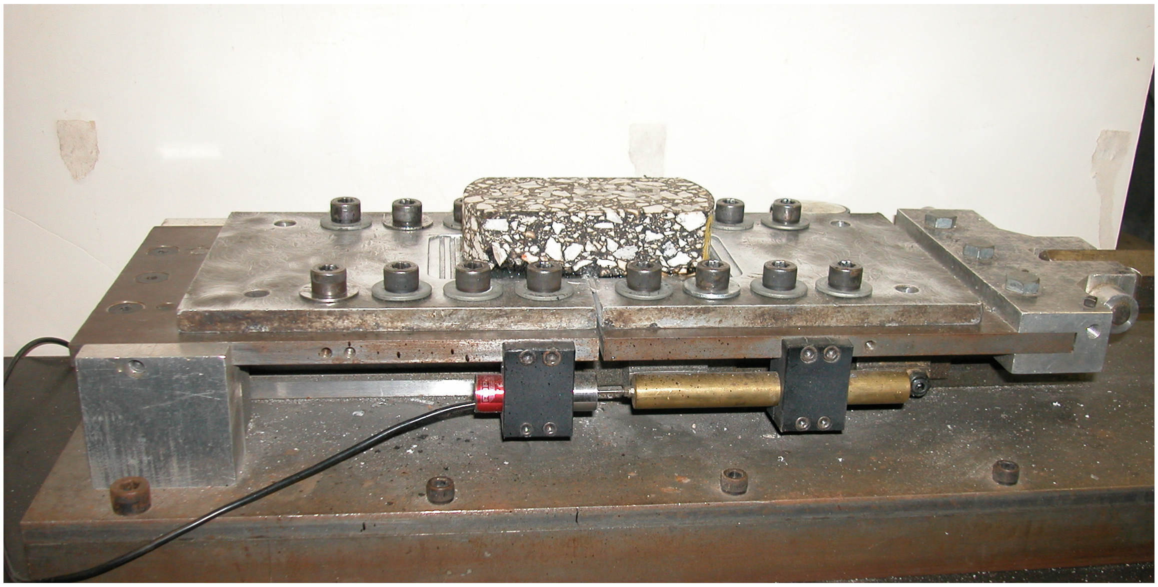

Figure 7. TTI Small Overlay Test Setup.

Hamburg Wheel Tracking Test

The Hamburg wheel tracking device (HWTD) is an accelerated loaded wheel tester. Helmut-Wind, Inc., in Hamburg, Germany, originally developed this device (*Aschenbrener, 1995*). It has been used as a specification requirement for some of the most traveled roadways in Germany to evaluate rutting and stripping (*Cooley et al., 2000*). Use of this device in the United States began during the 1990s. Several agencies undertook research efforts to evaluate the performance of the HWTD. Colorado Department of Transportation, Federal Highway Administration (FHWA), National Center for Asphalt Technology, and TxDOT are among them.

Since the adoption of the original HWTD, significant changes have been made to this equipment. The basic idea is to operate a steel wheel on a submerged, compacted HMA slab or cylindrical specimen. The slab is usually compacted at 7 ± 1 percent air voids using a linear kneading compactor. The test is conducted under water at a constant temperature ranging from 77 to 158°F (25 to 70°C). Testing at 122°F (50°C) is the most common practice. The sample is loaded with a 1.85-inch (47-mm) wide steel wheel using a 158-lb force (705-N) and travels in a reciprocating motion. Usually, the test is conducted at 20,000 cycles or to a specified amount of rut depth. Rut depth is measured at several locations including the center of the wheel travel path, where it usually reaches the maximum value. One forward and backward motion comprises two cycles.

The HWTD measures rut depth, creep slope, stripping inflection point, and stripping slope (*Cooley et al., 2000*). Creep slope is the inverse of deformation rate within the linear range of the deformation curve after densification and prior to stripping (if stripping occurs). Stripping slope is the inverse of deformation rate within the linear region of the deformation curve after the stripping takes place. Creep slope relates primarily to rutting from plastic flow, and the stripping slope indicates accumulation of rutting primarily from moisture damage (*Izzo and Tahmoressi, 1998*). The stripping inflection point is the number of wheel passes corresponding to the intersection of creep slope and stripping slope.

Tim Aschenbrener found an excellent correlation between the HWTD and pavements with known field performance. He mentioned that this device is sensitive to the quality of aggregate, asphalt cement stiffness, length of short-term aging, refining process or crude oil source of the hotmix asphalt cement, liquid and hydrated lime anti-stripping agent, and compaction temperature.

Izzo and Tahmoressi (*1998*) conducted a repeatability study of the HWTD.   Seven different agencies took part in that study. They experimented with several different versions of the HWTD. They used both slab and Superpave gyratory compacted specimens. Some of their conclusions were that the device yielded repeatable results for mixtures produced with different aggregates and with test specimens fabricated using different compacting devices.

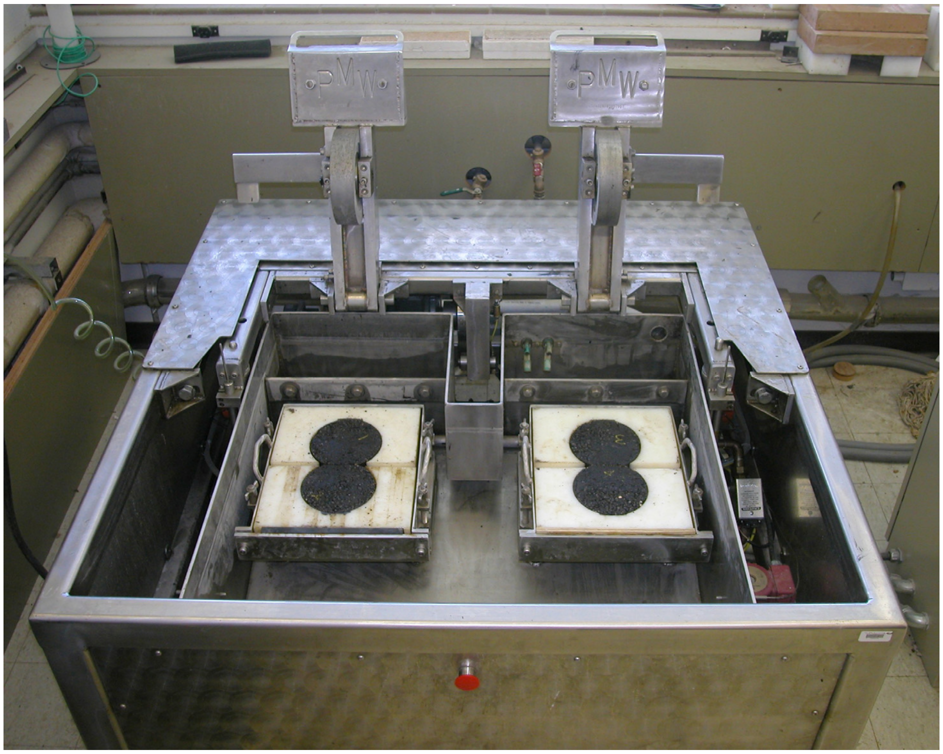

Figure 8. Hamburg Wheel Tracking Test Setup.

CHAPTER 4:
RESULTS AND DISCUSSIONS

INTRODUCTION

Laboratory tests were performed following the test matrix shown in Table 1. Specimens were prepared using three different types of mixtures. Each mixture was prepared with no fibers (control mixture) and with fibers.

The amount of cellulose fiber used in the SMA and PFC mixtures was designed at 0.3 percent (of total mixture weight) in the TxDOT mixture design. To determine the amount of each of the two tire fibers utilized, researchers decided to go with similar volume basis. All three fibers were placed loosely in three containers with same volume. The weights of the fibers were measured. It was observed that a given volume of loosely filled long tire fiber weighs same as that of neat cellulose fiber. On the other hand, the same volume of loosely compacted short fiber weighs three times more than the neat cellulose fiber. Since this measurement was subjective, three different people followed the same steps and the average was selected. So, the percentage of short and long fiber was 0.3 percent and 1.0 percent of total mixture weight, respectively. Results obtained from the different laboratory tests are discussed below.

Draindown Test Results

SMA and PFC mixture used PG 76-22 asphalt; whereas, CMHB used relatively soft PG 64-22 asphalt. Depending on the asphalt grade, their mixing temperatures were different. AASHTO T-305 recommends determining draindown test at mixing temperature and 18°F (10°C) higher than mixing temperature. Researchers decided to conduct the tests only at 18°F higher than mixing temperature with an assumption that higher temperature will cause higher draindown. If a mixture's draindown characteristics are satisfactory at a higher temperature, it should certainly be satisfactory at lower temperature. Table 2 presents the test data obtained for the different mixtures with no fiber and three different fibers.

At the end of the study, researchers conducted the same draindown test with 0.3 percent (by weight of total mixture) short fibers used in both SMA and PFC mixtures at 342°F (172°C). Interestingly, the draindown value measured was zero percent for both mixtures. This result indicates that, even for short tire fibers, 0.3 percent is sufficient to prevent draindown. The use of 1.0 percent short fiber (determined by similar volume process) was not necessary to address the draindown issue.

Table 2. Draindown Test Results.

Mix Type	Fiber Type	Asphalt Type	Test Temp, °C	Draindown, percent		
				Sample 1	Sample 2	Average
SMA	Long	PG 76-22TR	172	0.00	0.00	0.00
	Short	PG 76-22TR	172	0.00	0.00	0.00
	Neat	PG 76-22TR	172	0.00	0.02	0.01
	Control (No Fiber)	PG 76-22TR	172	3.97	3.64	3.81
PFC	Long	PG 76-22S	172	0.00	0.00	0.00
	Short	PG 76-22S	172	0.00	0.00	0.00
	Neat	PG 76-22S	172	0.07	0.06	0.06
	Control (No Fiber)	PG 76-22S	172	2.22	1.11	1.67
CMHB	Long	PG 64-22	135	0.00	--	0.00
	Short	PG 64-22	135	0.00	--	0.00
	Neat	PG 64-22	135	0.00	--	0.00
	Control (No Fiber)	PG 64-22	135	0.00	--	0.00

Indirect Tensile Strength Test Results

Indirect tensile strength tests were conducted at 68°F (20°C) using a universal testing machine. The test description is mentioned in previous chapter. Three replicate specimens, each with six-inch diameter and two-inch height, were tested for all twelve mixtures. Indirect tensile strength of the individual specimens and their averages are recorded in Table 3. Figures 9 through 11 show the results graphically.

Figure 9 reveals that, for the CMHB specimens, the control mixture yielded the highest tensile strength, and the short fiber mixture yielded the lowest tensile strength. It should be noted that the CMHB mixture was originally designed without any fiber and the design asphalt content was not adjusted when fibers were added. This may help explain the highest tensile strength of control CMHB mixture.

Table 3. IDT Strength Test Results Summary.

Mix Type	Fiber Type	Test Temp, °F	IDT Strength, psi				Comment
			Sample 1	Sample 2	Sample 3	Average	
SMA	Long	68	95.36	94.50	95.52	95.1	
	Short	68	101.44	99.73	99.06	100.1	
	Neat	68	100.50	0.00	100.74	100.6	
	No Fiber	68	91.64	93.84	0.00	92.7	
PFC	Long	68	66.36	60.95	58.78	62.0	
	Short	68	57.06	74.77	68.54	66.8	
	Neat	68	73.83	77.23	74.77	75.3	
	No Fiber	68	47.49	51.95	49.70	49.7	
CMHB	Long	68	88.53	90.92	81.08	86.84	
	Short	68	85.96	78.20	81.94	82.0	
	Neat	68	91.56	91.40	89.91	91.0	
	No Fiber	68	92.38	96.04	91.58	93.3	

Figure 10 shows that the addition fiber increased the IDT strength for all three PFC mixtures. PFC with neat fiber produced the highest tensile strength followed by PFC with short fiber. Figure 11 exhibits the results of IDT test with different SMA mixtures. Inclusion of fiber increased the IDT strength in all three cases. Strength of the SMA mixture containing neat fiber and short fiber were similar, but the mixture containing long fiber was slightly lower.

Although not proven herein, it is surmised that the cellulose fibers will absorb more asphalt than the synthetic tire fibers. This may explain the how the neat fibers typically maintained higher tensile strengths than the tire fibers.

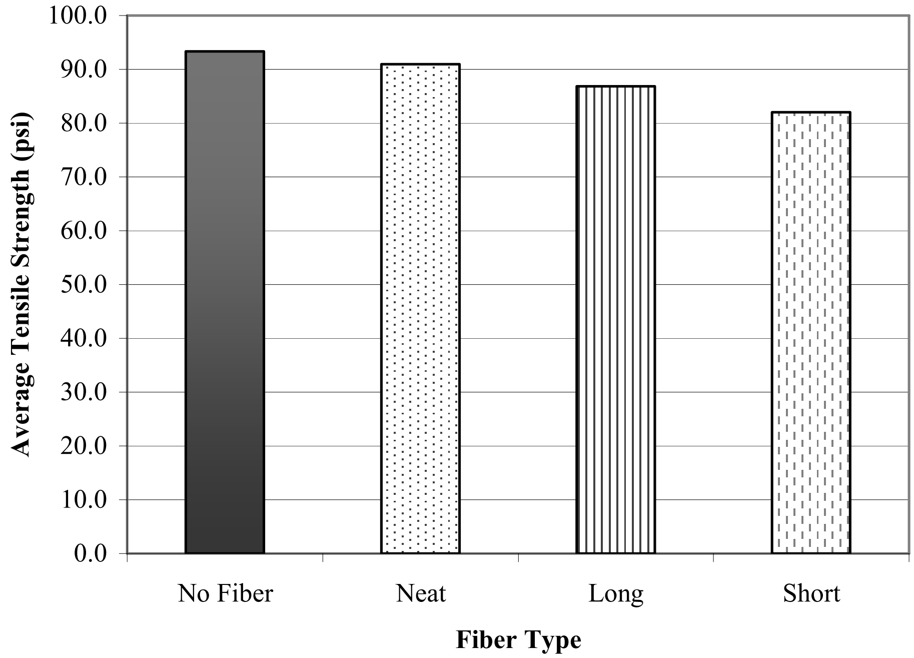

Figure 9. CMHB Mixtures IDT Strength Measured with Different Fibers.

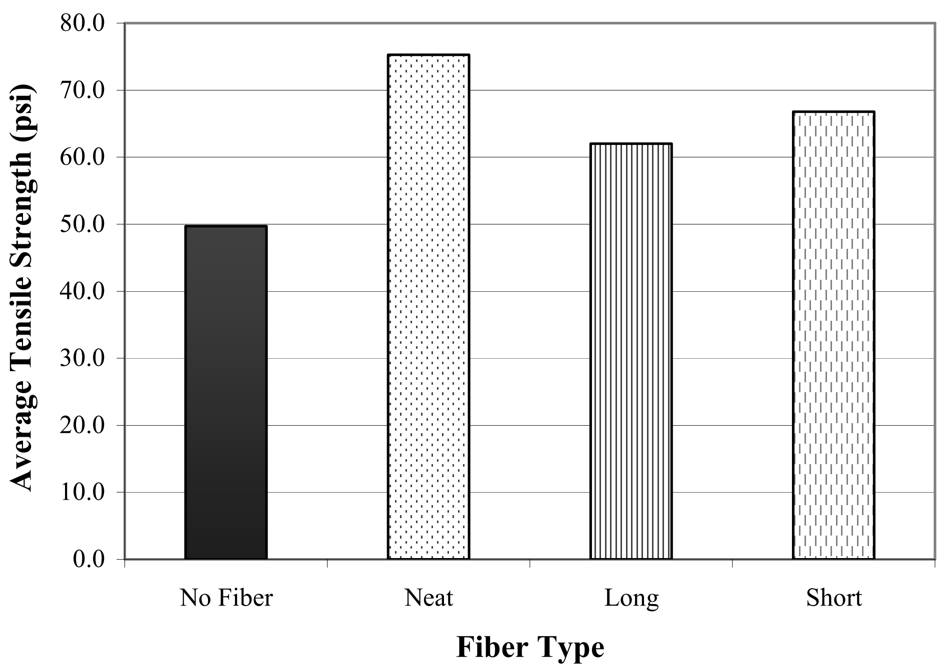

Figure 10. PFC Mixtures IDT Strength Measured with Different Fibers.

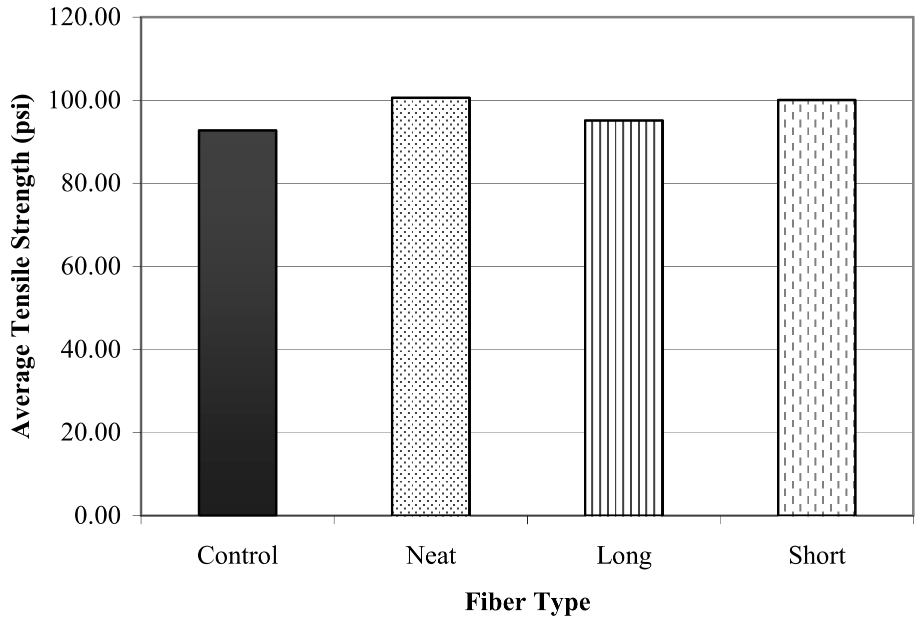

Figure 11. SMA Mixtures IDT Strength Measured with Different Fibers.

Dynamic Modulus Test Results

Dynamic modulus tests were conducted on SMA and CMHB mixtures following AASHTO Standard TP 62-03. The PFC mixture is usually not considered as a structural layer; it provides friction and drainage to the pavement surface. That is why the PFC mixtures were not tested using the dynamic modulus test. Moreover, it is impossible to produce PFC specimens with 7 percent air voids without significantly crushing the coarse aggregates. Dynamic modulus values of each mixture were measured at five different temperature and six frequencies. These values were converted into a master curve by using the time-temperature superposition method described earlier. Figures 12 and 13 present the master curves for the SMA and CMHB mixtures, respectively.

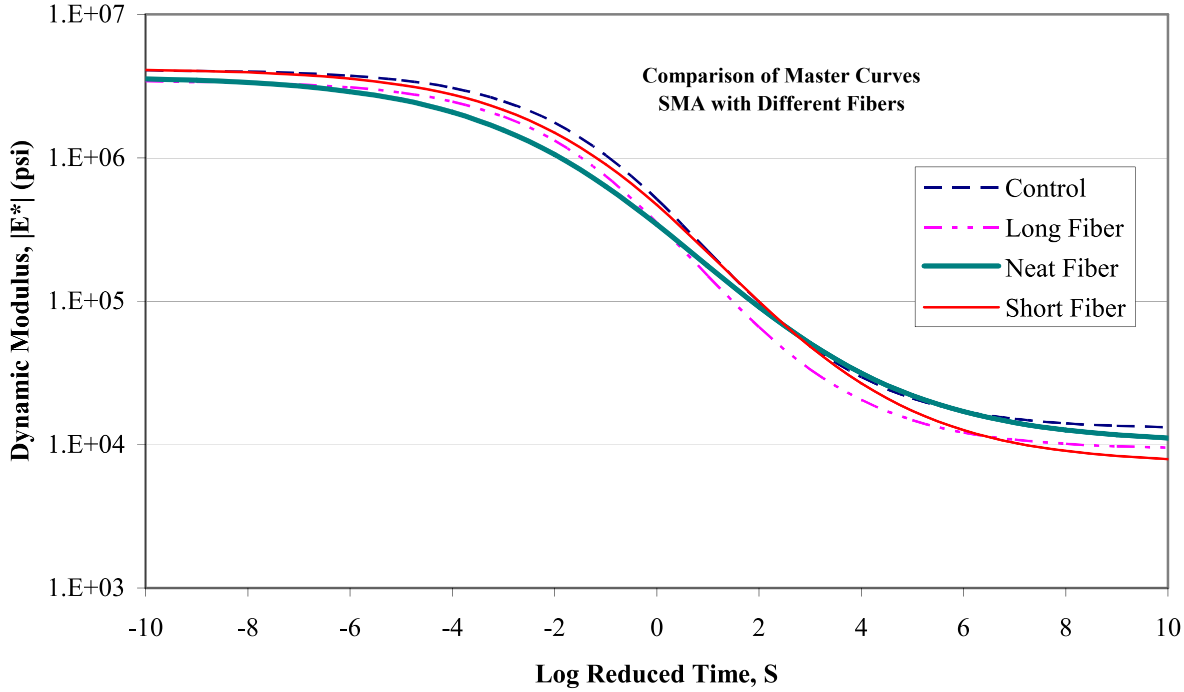

Figure 12. Master Curves of SMA Mixtures with Different Fibers.

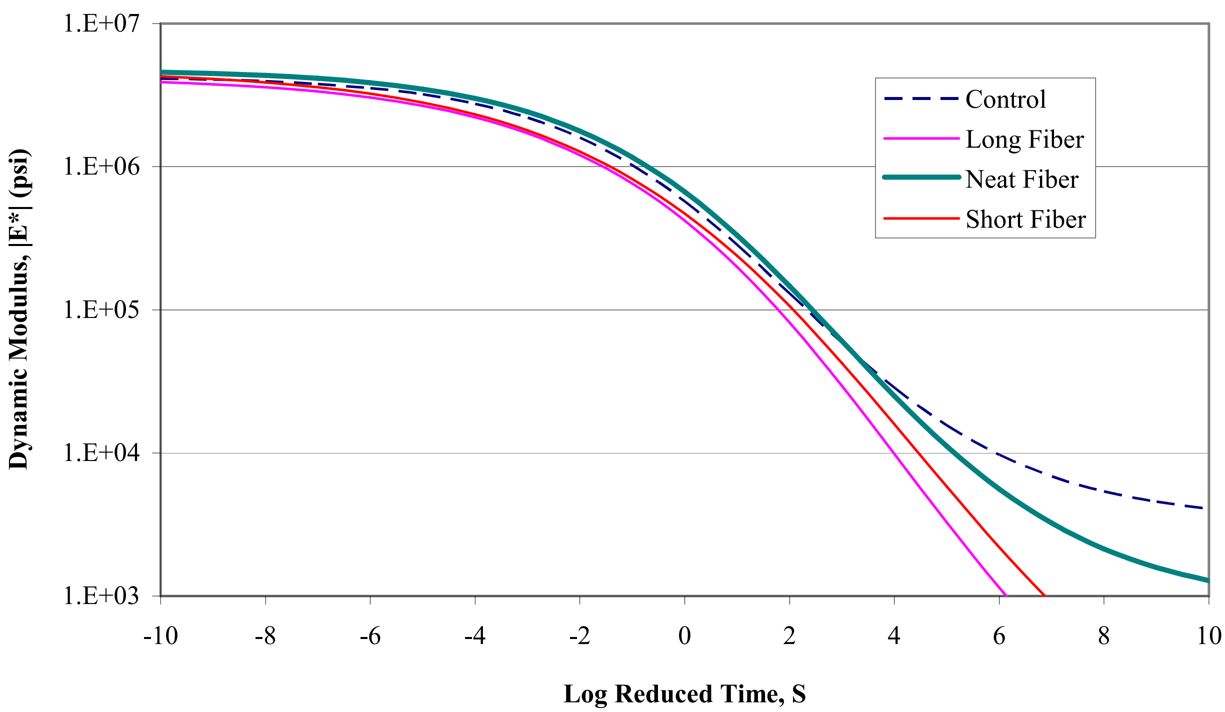

Figure 13. Master Curves of CMHB Mixtures with Different Fibers.

Overlay Test Results

As mentioned earlier, the overlay testing system developed at TTI can evaluate the reflection cracking potential of HMA mix. Specimens of all twelve mixtures were tested using the small TTI overlay tester following the test procedure described in Chapter 3. Since this test has relatively large variability, three replicates were tested for each mixture type. They were tested at room temperature (77°F). During all testing, a technician was always present to visually monitor the propagation of cracks. The number of load cycles to failure was determined when one continuous crack was visible completely through the specimen, i.e., cracks visible through two vertical sides and one horizontal (top) surface. Table 4 documents the number of load cycles to failure for each specimen and the average for each mixture type. Figure 14 presents the average number of cycles to failure for each mix type.

Apparently, the addition of tire fiber did not improve the cracking resistance of the SMA mixtures; in fact, for short fiber the numbers of cycles to failure were consistently lower than control SMA mixture. One possible reason could be stiffening of the mixture and asphalt absorption due to use of excess fiber (1 percent). Both the mix with neat fiber and mix without any fiber outperformed mixture with long tire fiber. It should be mentioned here that during the specimen preparation at laboratory for mixture without fiber did not experience any noticeable draindown.

The cracking resistance for PFC mixtures with neat fiber, short tire fiber, and no fiber (control) were similar. But the addition of long tire fiber clearly improved cracking resistance of PFC mixture.

Addition of long fiber in CMHB mixture significantly increased the cracking resistance. Neat fiber also improved the cracking resistance when compared with the control mixture. Like PFC, the CMHB mixture with short tire fiber did not improve cracking resistance. Apparently, the absorption of asphalt by excess amount of short fiber may have offset the positive effect of fiber as a whole.

Table 4. Summary of Overlay Test Results

Mix Type	Fiber Type	Test Temp, °F	Number of Cycles to Failure				Comment
			Sample 1	Sample 2	Sample 3	Average	
SMA	Long	77	23	18	206	82	
	Short	77	5	7	30	14	Adverse effect
	Neat	77	150	220	11	127	
	No Fiber	77	130	150	85	122	
PFC	Long	77	85	25	44	51	Positive effect
	Short	77	7	6	11	8	
	Neat	77	10	16	--	13	
	No Fiber	77	15	9	5	10	
CMHB	Long	77	62	91	230	128	
	Short	77	24	18	21	21	
	Neat	77	55	30	70	52	
	No Fiber	77	9	18	14	17	

-- data not available

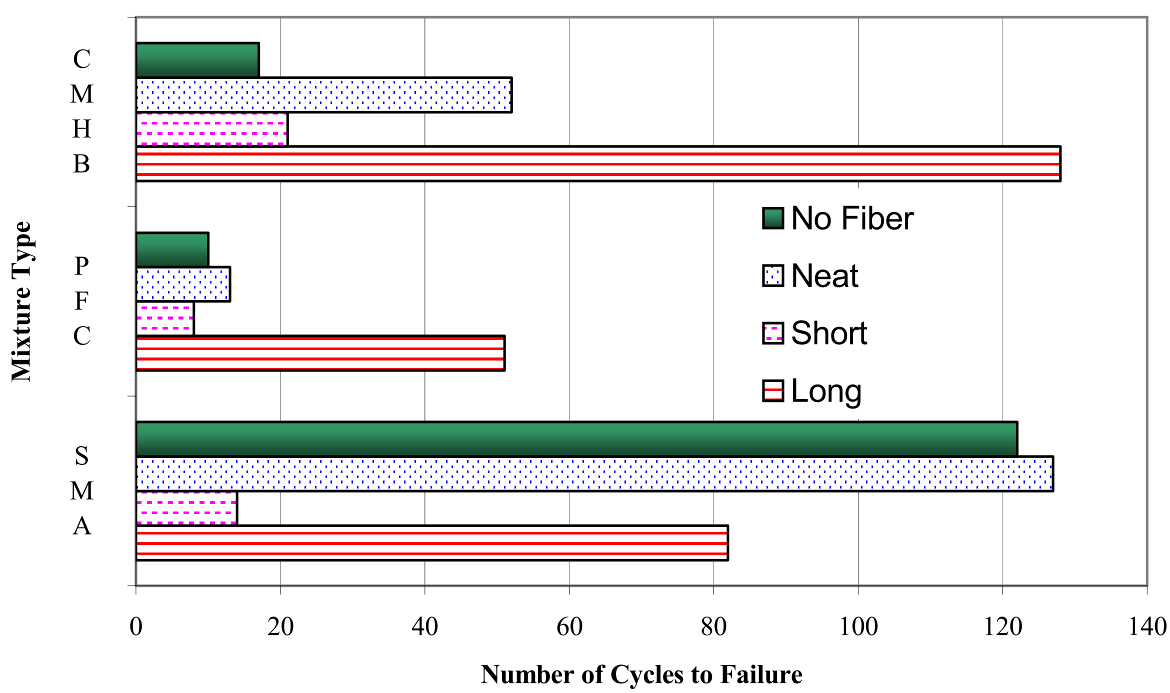

Figure 14. Overlay Test Result Summary.

Hamburg Wheel Tracking Test Result

The Hamburg wheel tracking test was conducted with all twelve mixtures following TxDOT Standard Tex-242-F. According to TxDOT, standard mixture containing asphalt PG 76-XX and PG 64-XX should not experience more than 0.50 inch (12.5 mm) rutting at 20,000 and 10,000 loading cycles, respectively. Table 5 summarizes the test results for all the mixtures.

All SMA mixtures with and without fiber (control) passed the TxDOT rutting criteria, and none of them showed the sign of moisture susceptibility or stripping. Rut depths for SMA mixtures with the two tire fibers and one neat fiber did not show any statistically significant differences. The mixtures containing fibers performed better than control mixture. Repeatability of test results was very good.

PFC mixtures containing the two tire fiber and one neat fiber passed the TxDOT criteria. The PFC mixture with long tire fiber and that with neat fibers showed comparable rutting performance although the former proved to be little better. The mixture containing short fiber demonstrated distinctively better performance. Probably, one percent short fiber was too much to make the mix very stiff. The control PFC mixture (mixture without any fiber) did not pass the criteria. This mixture failed at 15,000 load cycles. Since machine loading stops as soon as the specimen fails, the results for control PFC mixture were extrapolated to determine the rutting depth at 20,000 load cycles. The extrapolation was done to provide a comparison with other mixtures.

All CMHB mixtures passed the TxDOT criteria. Their rutting depth was normalized at 15,000 cycles. The mixtures containing short fiber and neat fiber showed comparable results, which were much better than the control mix. Rutting of the CMHB mixture with long tire fiber was greater than that of the control mixture. Most probably, the long fiber mix should have used slightly more asphalt.

Figure 15 depicts the rut depth for all twelve mixtures. In most instances, the addition of fibers proved to be effective for improving rutting resistance. The relative performance between tire fiber and neat fibers was similar for the SMA mixture; whereas, for PFC mixture, tire fibers demonstrated better performance than neat (cellulose) fiber.

Table 5. Hamburg Test Results Summary

Mix Type	Fiber Type	Asphalt Type	Measured Rut Depth (mm)/ Number of Cycles			Comment
			Left Wheel	Right Wheel	Average	
SMA	Long	PG 76-22TR	4.63/20000	4.06/20000	4.4/20000	No Stripping
	Short	PG 76-22TR	3.95/20000	3.22/20000	3.6/20000	
	Neat	PG 76-22TR	4.15/20000	3.55/20000	3.9/20000	
	No Fiber	PG 76-22TR	5.80/20000	5.89/20000	5.9/2000	
PFC	Long	PG 76-22S	11.13/20000	7.59/20000	9.4/20000	
	Short	PG 76-22S	5.70/20000	5.34/20000	5.5/20000	
	Neat	PG 76-22S	10.19/20000	11.05/20000	10.6/20000	
	No Fiber	PG 76-22S	12.57/13201	12.50/16950	12.5/15000	
			17.3/20000	13.9/20000	15.6/20000	Extra-polated
CMHB	Long	PG 64-22	11.35/15000	13.45*/15000	12.4/15000	
	Short	PG 64-22	6.14/15000	5.86/15000	6.0/15000	
	Neat	PG 64-22	4.83/15000	5.86/15000	5.4/15000	
	No Fiber	PG 64-22	12.05/15000	7.32/15000	9.7/15000	

* Extrapolated value

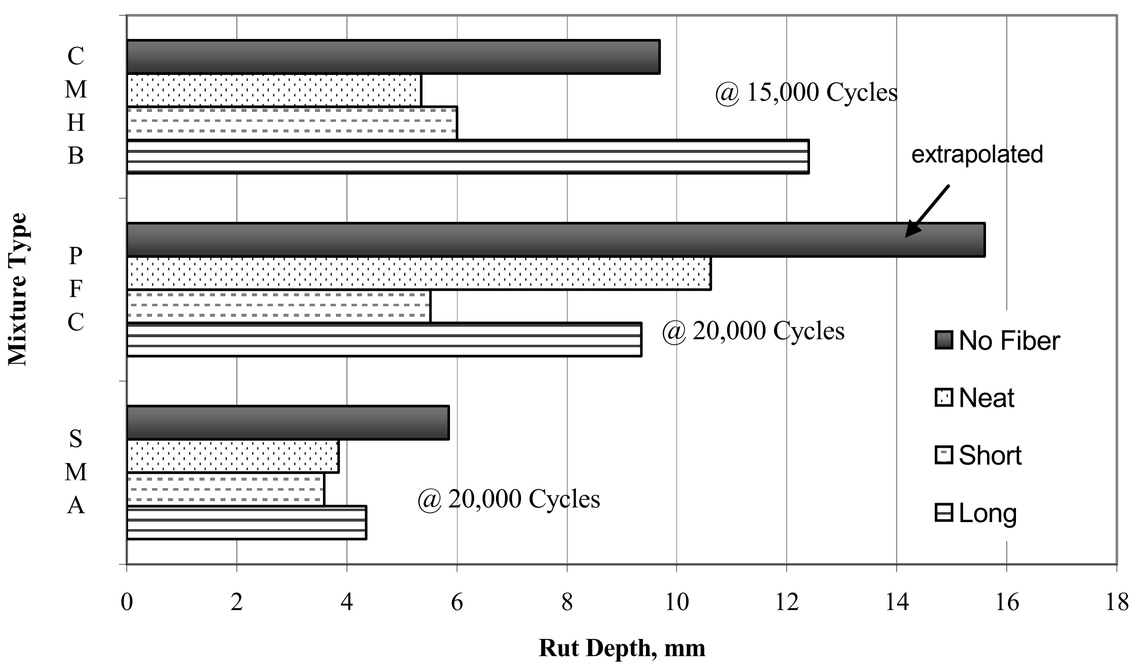

Figure 15. Hamburg Test Result for Different Mixtures.

COST COMPARISON OF DIFFERENT FIBERS

The authors believe that the recycled tire fibers should not require any special equipment or method for application in the HMA plant. They can be blown into a drum mix HMA plant in a similar way that other fibers are applied. Cellulose fibers are usually incorporated into the mixture in the form of pellets contained in plastic bag in a batch plant; the plastic bags are melted by heat and the fibers are dispersed in the mix.

Currently, the recycled tire fibers are wasted in the landfill; so there is no current market price. Therefore, the cost of these fibers will be nominal to cover the packing and shipping cost. The application of cellulose fiber in the SMA or OGFC mixes adds approximately $1.50/ton on average to the cost of the mix. Cellulose fibers are also produced mainly from post consumer products like waste paper. Mineral fibers are more expensive than cellulose fibers.

CHAPTER 5:
CONCLUSIONS AND RECOMMNEDATIONS

Two types of recycled tire fibers were evaluated to determine whether they can be used in different types of HMA mixtures as a replacement of currently used cellulose fibers or mineral fiber. In order to accomplish that objective, the researchers tested three different types of mixtures (SMA, PFC, and CMHB) with two different types of recycled tire fibers, one cellulose fiber, and no fiber. Compacted HMA specimens were prepared using all of these combinations and tested using several common laboratory test procedures. The laboratory tests used to evaluate the mixtures were: draindown test, dynamic modulus test, overlay test, indirect tensile strength test, and Hamburg wheel tracking test. Previous chapters provide detailed descriptions of these laboratory test procedures and their results.

CONCLUSIONS

The following conclusions are based on findings from the laboratory tests.

- Mixtures containing tire fibers, in most cases, outperformed the mixtures containing cellulose fiber and mixtures with no fiber.
- Draindown test results clearly revealed that recycled tire fiber can be used in SMA and PFC mixtures as a replacement for cellulose fiber (or mineral fiber) to prevent asphalt draindown during construction.
- The use of one percent short fiber appeared to be excessive. In several cases, those mixtures containing short tire fiber demonstrated poorer performance than other mixtures, including control mixture. Since the design asphalt content of the mixture was not modified upon the addition of fibers, the authors believe that one percent short fiber absorbed significant asphalt and yielded a mixture that was stiffer and less resistance to cracking.
- The presence of fiber in HMA mixtures produced mixed results for indirect tensile strength test. Tensile strength was improved for the SMA and PFC mixtures but was reduced for the CMHB mixture.
- Application of long tire fiber significantly improved the overlay test results for the PFC and CMHB mixtures but slightly decreased performance for SMA mixture.

- In most cases, the mixtures containing tire fibers outperformed the mixtures containing cellulose fiber and the control mixtures when they were tested for permanent deformation using Hamburg wheel tracking device.
- The dynamic modulus test did not clearly discriminate the performance of the different SMA mixtures.
- The incorporation of recycled tire fiber into HMA does not require any special technique or equipment beyond that typically used for handling other fiber products. Tire fibers can be mixed using similar procedure used for cellulose or mineral fiber. The cost of tire fiber will probably be less than cellulose fiber, particularly when tire fiber is available locally.

RECOMMENDATIONS

Based on these findings, the researchers offer the following recommendations.

- Fiber percentage should not be arbitrarily determined. It should be determined during the mixture design process (e.g., based on draindown criteria for SMA and PFC mixtures) so that the presence of fiber does not affect the effective asphalt content.
- Promising results of using recycled tire fibers in HMA, based on this laboratory study, warrants some field demonstration projects. These field projects can be implemented by coordination between state DOTs and paving contractors. The field demonstration type project will provide more long-term performance evaluation and identify any unpredicted problems that may occur during construction.
- Long tire fibers appear to be more promising than short fibers.

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APPENDIX

Mixture Design Summary

PaveTex Design Number: 2383 **Date: May 28, 2004**

Projects:	Loop 360, Travis County
CSJ:	1113-13-134
Mixture Type:	PFC
Stockpiles:	

Detla D-Rock	55%
Hanson 3/8- # 4	10%
Hanson 1/2"	34%
Hydrated Lime	1%

Asphalt : Marlin PG 76-22 S

Optimum Binder Content is 6.2% based on 20 % air voids

Mixture Properties at optimum Asphalt Content are :

Drain Down	0.07%
Bulk Specific Gravity:	1.915
Max. Specific Gravity:	2.395
Boil Test, Tex-530-C :	No Stripping

Based on Results summarized here and details documented in following sheets, this proposed mixture design meets requirements of Special Specification Item 3231

Figure A1. PFC Mixture Design Summary.

Combined Gradation

District:	Austin	CSJ #:	1113-13-134	Producer:	RTI
County:	Travis	Design #:	2383	Spec.Item:	3231
Highway:	Loop 360	Contractor:	J.D. Ramming	Type Mix:	PFC

	Delta D-Rock Lab # 4837 Capital Aggr.		Hanson 3/8- # 4 Lab # 4782		Hanson 1/2" Rock Lab # 4781		Hydrated Lime		Source 5 ? ?		Source 6 ? ?		Total % 100.0					
Sieve Size	RAP 55.0	Total %	Bin #1 10.0	Total %	Bin #2 34.0	Total %	Bin #3 1.0	Total %	Bin #4 0.0	Total %	Bin #5 0.0	Total %	Cumultive Pass	TxDOT Specs.			Sieve Size	Cum. % Retained
3/4"	100.0	55.0	100.0	10.0	100.0	34.0	100.0	1.0	100.0	0.0	100.0	0.0	100.0		-	100	3/4"	0.0
1/2"	99.0	54.5	100.0	10.0	98.0	33.3	100.0	1.0	100.0	0.0	100.0	0.0	98.8	90	-	100	1/2"	1.2
3/8"	78.0	42.9	79.7	8.0	16.4	5.6	100.0	1.0	100.0	0.0	100.0	0.0	57.5	35	-	60	3/8"	42.5
4	15.0	8.3	0.6	0.1	1.8	0.6	100.0	1.0	100.0	0.0	100.0	0.0	10.0	10	-	25	4	90.0
8	7.0	3.9	0.4	0.0	1.0	0.3	100.0	1.0	100.0	0.0	100.0	0.0	5.2	5	-	10	8	94.8
40	5.0	2.8	0.4	0.0	0.5	0.2	100.0	1.0	100.0	0.0	100.0	0.0	4.0		-		40	96.0
80	4.0	2.2	0.4	0.0	0.5	0.2	100.0	1.0	100.0	0.0	100.0	0.0	3.4		-		80	96.6
200	1.0	0.6	0.4	0.0	0.4	0.1	100.0	1.0	100.0	0.0	100.0	0.0	1.7	1	-	4	200	98.3
Pan																	Pan	
Asphalt Content of RAP in Bin # 1(If Applicable) =					?	%												

Asphalt Source & Grade:	Marlin PG 76-22S

Add 0.3% Cellulose Fibre

Asphalt Specific Gravity:	1.034

Notes: Mixing Temperature 325 F, Compaction Temperature 300 F

English	2"	1 1/2"	1"	3/4"	1/2"	3/8"	# 4	# 8	# 16	# 30	# 50	# 100	#200
Metric	50 mm	37.5 mm	25.0 mm	19 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm	0.600 mm	0.300 mm	0.150 mm	0.075 mm

Figure A2. PFC Mixture Aggregate Gradation.

Trial Blending

District:	Austin	CSJ #:	1113-13-134	Producer:	RTI
County:	Travis	Design #:	2383	Spec.Item:	3231
Highway:	Loop 360	Contractor:	J.D. Ramming	Type Mix:	PFC

Aggregate	TB-1
D-Rock	50
3/8- # 4	0
1/2" Rock	49
Lime	1
?	0
?	0
Total	100

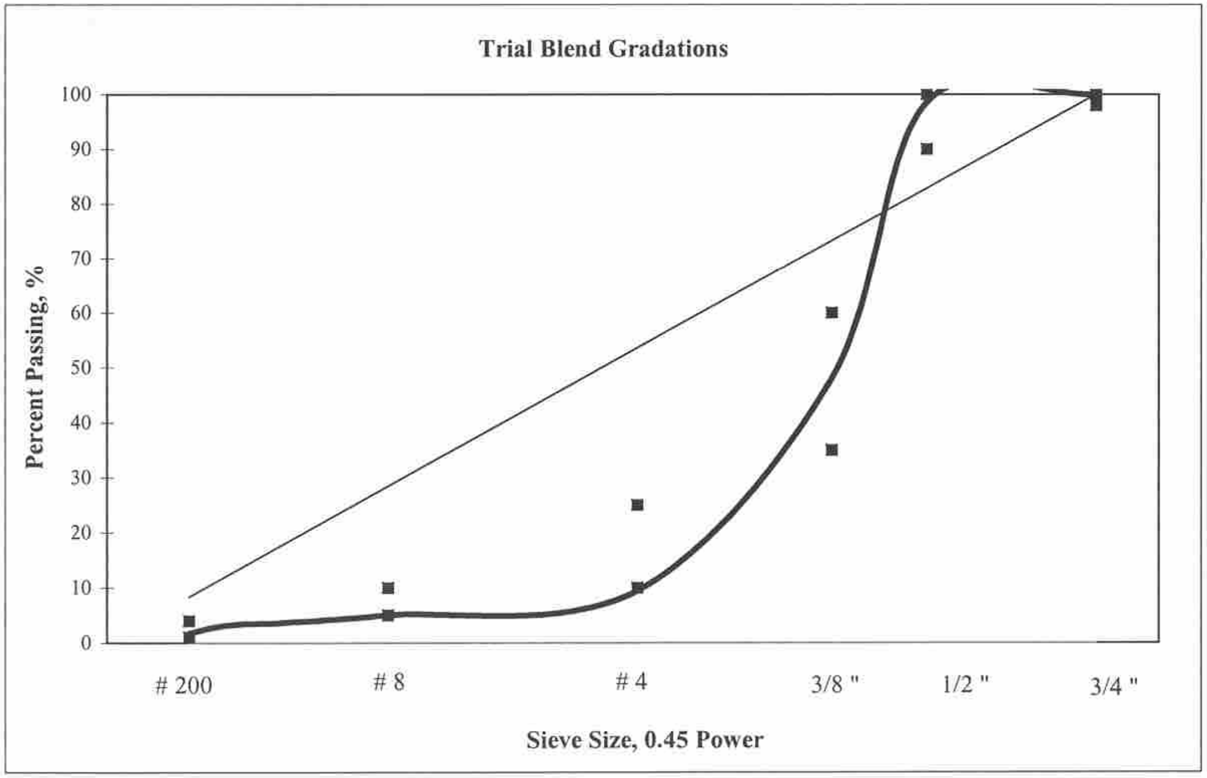

Figure A3. PFC Mixture Aggregate Gradation Curve.

TEXAS DEPARTMENT OF TRANSPORTATION

BRYAN DISTRICT LABORATORY

HMACP MIXTURE DESIGN : COMBINED GRADATION

Refresh Workbook

File Version: 01/28/04 14:02:38

SAMPLE ID:	HCC17BRAY10202	SAMPLE DATE:	03/21/2002
LOT NUMBER:	01	LETTING DATE:	
STATUS:	COMP	CONTROLLING CSJ:	
COUNTY:		SPEC YEAR:	1993
SAMPLED BY:	VARGAS, PABLO (222, 400,	SPEC ITEM:	
SAMPLE LOCATION:		SPECIAL PROVISION:	
MATERIAL:	QCQA1CMHBC	MIX TYPE:	Type_CMHB_C
PRODUCER:	Young Materials		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:		STATION:		DIST. FROM CL:	

	Bin No.1	Bin No.2	Bin No.3	Bin No.4	Bin No.5	Bin No.6	Bin No.7
(handwritten)	8,000	3200	3600	BIN FRACTIONS (3400)	1500	300	
Aggregate Source:	Hanson	Hanson	Hanson	Hanson	Young Materials	Chemlime	
Aggregate Number:	C Rock	D Rock	F Rock	Dry Scr.	Sand	Lime	
Sample ID:	New Braunsfels	New Braunsfels	New Braunsfels	New Braunsfels	Riverbend		
Rap:(Yes/No), % Asphalt:							
Individual Bin (%):	40.0 Percent	16.0 Percent	18.0 Percent	17.0 Percent	7.5 Percent	1.5 Percent	Percent

Combined Gradation: Total Bin 100.0%

Sieve Size:	Sieve Size (mm)	Bin No.1 Cum.% Passing	Bin No.1 Wtd Cum. %	Bin No.2 Cum.% Passing	Bin No.2 Wtd Cum. %	Bin No.3 Cum.% Passing	Bin No.3 Wtd Cum. %	Bin No.4 Cum.% Passing	Bin No.4 Wtd Cum. %
7/8"	22.400	100.0	40.0	100.0	16.0	100.0	18.0	100.0	17.0
5/8"	16.000	100.0	40.0	100.0	16.0	100.0	18.0	100.0	17.0
3/8"	9.500	9.3	3.7	76.5	12.2	100.0	18.0	100.0	17.0
No. 4	4.750	3.7	1.5	6.1	1.0	67.1	12.1	78.5	13.3
No. 10	2.000	3.6	1.4	3.6	0.6	6.9	1.2	49.3	8.4
No. 40	0.425	3.3	1.3	2.9	0.5	3.9	0.7	27.3	4.6
No. 80	0.180	3.1	1.2	2.7	0.4	3.6	0.6	21.7	3.7
No. 200	0.075	2.7	1.1	2.4	0.4	3.4	0.6	18.2	3.1

Sieve Size:	Bin No.5 Cum.% Passing	Bin No.5 Wtd Cum. %	Bin No.6 Cum.% Passing	Bin No.6 Wtd Cum. %	Bin No.7 Cum.% Passing	Bin No.7 Wtd Cum. %	Cum. % Passing	Within Spec's	Lower Type_CMHB_C Specification Limits	Upper Type_CMHB_C Specification Limits	Individual % Retained	Cumulative % Retained	Sieve Size
7/8"	100.0	7.5	100.0	1.5		0.0	100.0	Yes	98.0	100.0	0.0	0.0	7/8"
5/8"	100.0	7.5	100.0	1.5		0.0	100.0	Yes	95.0	100.0	0.0	0.0	5/8"
3/8"	100.0	7.5	100.0	1.5		0.0	59.9	Yes	50.0	70.0	40.1	40.1	3/8"
No. 4	97.4	7.3	100.0	1.5		0.0	36.7	Yes	30.0	45.0	23.2	63.3	No. 4
No. 10	91.5	6.9	100.0	1.5		0.0	20.0	Yes	15.0	25.0	16.7	80.0	No. 10
No. 40	60.7	4.6	100.0	1.5		0.0	13.2	Yes	6.0	20.0	6.8	86.8	No. 40
No. 80	13.0	1.0	100.0	1.5		0.0	8.4	Yes	6.0	18.0	4.8	91.6	No. 80
No. 200	5.9	0.4	100.0	1.5		0.0	7.1	Yes	5.0	8.0	1.3	92.9	No. 200

Not within specifications # Not cumulative

Asphalt Source & Grade:	Fina 64-22	Binder Percent, (%):	4.6	Specific Gravity of Asphalt:	1.025

Remarks:

Contractor's Mix Design # YBHCMHBC01-F64 by D. Doyle TxDOT Certification # 250

Test Method:	Tested By:	Tested Date:
Tx207		04/12/02
Tx208		
Tx210		
Tx227		
Tx228		
Tx229		
Tx231		
Tx236		

Reviewed By:	Completed Date:
	04/12/02

Authorized By:	Authorized Date:
DARLENE C. GOEHL	06/21/02

Figure A4. CMHB Mixture Design Aggregate Gradation.

TEXAS DEPARTMENT OF TRANSPORTATION
BRYAN DISTRICT LABORATORY

HMACP MIXTURE DESIGN : SUMMARY SHEET

File Version: 01/28/04 14:02:38

SAMPLE ID:	HCC17BRAY10202	SAMPLE DATE:	03/21/2002
LOT NUMBER:	01	LETTING DATE:	
STATUS:	COMP	CONTROLLING CSJ:	
COUNTY:		SPEC YEAR:	
SAMPLED BY:	VARGAS, PABLO (222, 400,4	SPEC ITEM:	
SAMPLE LOCATION:		SPECIAL PROVISION:	
MATERIAL:	QCQA1CMHBC	MIX TYPE:	Type_CMHB_C
PRODUCER:	Young Materials		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:		STATION:		DIST. FROM CL:	

Target Density:	**96.5**	Percent

Asphalt Content (%)	Specific Gravity Of Specimen (Ga)	Maximum Specific Gravity (Gr)	Effective Gravity (Ge)	Theo. Max. Specific Gravity (Gt)	Density from Gt (Percent)	VMA (Percent)	Hveem Stability (%)	Static Creep: Creep Stiffness (psi)	Static Creep: Perm. Strain X1000 (in/in)	Static Creep: Slope of SS Curve X 10^9 (in/in/Sec)
3.50	2.306	2.447	2.577	2.456	93.9	14.0				
4.00	2.327	2.431	2.578	2.438	95.4	13.6				
4.50	2.333	2.425	2.592	2.421	96.4	13.9				
5.00	2.331	2.409	2.593	2.404	97.0	14.4				
5.50	2.325	2.393	2.595	2.387	97.4	15.1				

Effective Specific Gravity	2.587

Optimum Asphalt Content:	**4.6**
VMA @ Optimum AC:	**14.0**

Interpolated Values	
Specific Gravity (Ga):	**2.333**
Max. Specific Gravity (Gr):	**2.422** ✓
Theo. Max. Specific Gravity (Gt):	**2.418**

Figure A5. CMHB Mixture Design Summary.

Mixture Design Summary

PaveTex Design ID : 2415 10/21/2004

Project: IH 35, McLennan County

CSJ : 0015-01-192

Mixture Type: SMA-D

Stockpiles:

Hanson- Oklahoma 3/4"	41.5%
Hanson- Perch Hill Grade 4	37.0%
Hanson- Perch Hill Man Sand	12.0%
Industrial Mineral Mineral Filler	8.5%
Hydrated Lime	1.0%

Cellulose Fibre : 0.3 %

Asphalt Wright PG 76-22 TR

Optimum Asphalt Content is 6.1 % based on 4 % air voids at 75 Gyrations

Mixture Properties at optimum Asphalt Content are :

VMA:	17.8%
VFA:	78%
Bulk Specific Gravity:	2.351
Max. Specific Gravity:	2.450

Based on Results summerized here and details documented in following sheets, this proposed mixture design meets requirements of SMA Specifications

Figure A6. SMA Mixture Design Summary.

TEXAS DEPARTMENT OF TRANSPORTATION

HMACP MIXTURE DESIGN : COMBINED GRADATION

Refresh Workbook

File Version: 01/28/04 14:02:18

SAMPLE ID:	PaveTex Design # 2415	SAMPLE DATE:	9/22/2004
LOT NUMBER:		LETTING DATE:	
STATUS:	IH 35	CONTROLLING CSJ:	0015-01-192, etc
COUNTY:	McLennan	SPEC YEAR:	1993
SAMPLED BY:		SPEC ITEM:	346
SAMPLE LOCATION:		SPECIAL PROVISION:	
MATERIAL:	SMA-D	MIX TYPE:	HD_SMA_.5_inch
PRODUCER:	Young Materials		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:		STATION:		DIST. FROM CL:	

BIN FRACTIONS

	Bin No.1	Bin No.2	Bin No.3	Bin No.4	Bin No.5	Bin No.6	Bin No.7	Total Bin
Aggregate Source:	Hanson- OK	Hanson- Perch Hil	Hanson- Perch Hil	Industrial Minerals	Hydrated			
Aggregate Number:	3/4" Rock	Grade 4	Man. Sand	Mineral Filler	Lime			
Sample ID:								
Rap?, Asphalt%:								
Individual Bin (%):	41.5 Percent	37.0 Percent	12.0 Percent	8.5 Percent	1.0 Percent	0.0 Percent	0.0 Percent	100.0%

Sieve Size:	Sieve Size: (mm)	Bin No.1 Cum.% Passing	Bin No.1 Wtd Cum. %	Bin No.2 Cum.% Passing	Bin No.2 Wtd Cum. %	Bin No.3 Cum.% Passing	Bin No.3 Wtd Cum. %	Bin No.4 Cum.% Passing	Bin No.4 Wtd Cum. %	Bin No.5 Cum.% Passing	Bin No.5 Wtd Cum. %	Bin No.6 Cum.% Passing	Bin No.6 Wtd Cum. %	Bin No.7 Cum.% Passing	Bin No.7 Wtd Cum. %	Combined Gradation: Cum. % Passing	Lower & Upper HD_SMA_.5_inch Specification Limits: Lower	Upper	Within Spec's	Restricted Zone HD_SMA_.5_inch	Within Spec's	Individual % Retained	Cumulative % Retained	Sieve Size
3/4"	19.000	100.0	41.5	100.0	37.0	100.0	12.0	100.0	8.5	100.0	1.0	100.0	0.0	100.0	0.0	100.0	100.0	100.0	Yes			0.0	0.0	3/4"
1/2"	12.500	90.9	37.7	99.0	36.6	100.0	12.0	100.0	8.5	100.0	1.0	100.0	0.0	100.0	0.0	95.8	85.0	99.0	Yes			4.2	4.2	1/2"
3/8"	9.500	47.7	19.8	72.0	26.6	100.0	12.0	100.0	8.5	100.0	1.0	100.0	0.0	100.0	0.0	67.9	50.0	75.0	Yes			27.9	32.1	3/8"
No. 4	4.750	2.7	1.1	2.0	0.7	97.3	11.7	100.0	8.5	100.0	1.0	100.0	0.0	100.0	0.0	23.0	20.0	32.0	Yes			44.9	77.0	No. 4
No. 8	2.360	2.0	0.8	1.0	0.4	66.5	8.0	100.0	8.5	100.0	1.0	100.0	0.0	100.0	0.0	18.7	16.0	28.0	Yes			4.3	81.3	No. 8
No. 200	0.075	0.8	0.3	0.2	0.1	5.5	0.7	69.0	5.9	100.0	1.0	100.0	0.0	100.0	0.0	8.0	8.0	12.0	Yes			10.7	92.0	No. 200

Not within specifications # Not cumulative

Asphalt Source & Grade:	PG 76-22TR	Binder Percent, (%):	6.1	Asphalt Spec. Grav.:	1.034

Remarks:

Add .3% Cellulose Fibre. Mix at 325 F and Mold at 300 F. Mold at 75 Gyrations.

Figure A7. SMA Mixture Design Aggregate Gradation.

TEXAS DEPARTMENT OF TRANSPORTATION

HMACP MIXTURE DESIGN : SUMMARY SHEET

File Version: 01/28/04 14:02:18

SAMPLE ID:	PaveTex Design # 2415	SAMPLE DATE:	9/22/2004
LOT NUMBER:		LETTING DATE:	
STATUS:		CONTROLLING CSJ:	0015-01-192, etc
COUNTY:	McLennan	SPEC YEAR:	McLennan
SAMPLED BY:		SPEC ITEM:	346
SAMPLE LOCATION:		SPECIAL PROVISION:	
MATERIAL:	SMA-D	MIX TYPE:	HD_SMA_.5_Inch
PRODUCER:	Young Materials		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:		STATION:		DIST. FROM CL:	

Target Density:	**96**	Percent

Asphalt Content (%)	Specific Gravity Of Specimen (Ga)	Maximum Specific Gravity (Gr)	Effective Gravity (Ge)	Theo. Max. Specific Gravity (Gt)	Density from Gt (Percent)	VMA (Percent)
5.00	2.325	2.488	2.687	2.489	93.4	17.8
5.50	2.335	2.465	2.681	2.471	94.5	17.9
6.00	2.350	2.453	2.689	2.453	95.8	17.8
6.50	2.362	2.435	2.688	2.435	97.0	17.8
7.00	2.371	2.423	2.696	2.417	98.1	18.0

Effective Specific Gravity:	2.688

Optimum Asphalt Content:	**6.1**
VMA @ Optimum AC:	**17.8**

Interpolated Values	
Specific Gravity (Ga):	**2.351**
Max. Specific Gravity (Gr):	**2.450**
Theo. Max. Specific Gravity (Gt):	**2.450**

Remarks:

Figure A4. SMA Mixture Design Details.