Greater Durability and Longevity with Fiber Reinforced Asphalt Concrete

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Synopsis: Fiber reinforced asphalt concrete (FRAC) provides three-dimensional reinforcing. Based on advanced testing techniques conducted in this study, the fibers provided improved mixture characteristics as indicated by increased endurance limit and fatigue capacity. In addition, the FRAC mixtures showed better resistance to shear deformation, higher moduli values at high temperatures, and better resistance to crack propagation than conventional mixtures. The pavement design analysis showed that a reduced asphalt concrete layer thickness of about 30 to 40% could be achieved when using the FRAC mixture. Recent case histories discuss these benefits and how the fibers were used.

Key Words: fiber reinforced asphalt, durability, thickness reduction, advanced material testing

INTRODUCTION

Improving asphalt concrete mixtures performance is commonly accomplished by binder modification, increased thickness, or some type of two-dimensional reinforcement such as a fabric at the interface between compacted lifts. Some of these binder changes affect the binder strength or 'adhesive' strength of the binder between the aggregates. The thickness change affects the overall bearing capacity due to dimensional section properties. The fabric at the lift interface is a two-dimensional reinforcement holding the "continuing to deteriorate" asphalt concrete together with efficiency dependant upon top-down or bottom-up cracking through the thickness.

Whereas, the fabric acts as an anisotropic reinforcement, the addition of fibers provides an isotropic reinforcement or equal strength in three-dimensions. Once the asphalt cracks in any direction, the after-crack strength is reinforced due to the fibers in every direction stretching across the crack. A three-dimensional reinforcement eliminates the need to decide the top-down or bottom-up cracking behavior or any positioning of the reinforcement.

The secret to reinforcing almost any construction material is historical and simple; add fibers throughout the material to add strength, toughness, and durability. The fibers capitalize on this three-dimensional certainty by being strong and chemically inert synthetic fibers and materials that mix quickly and distribute uniformly in asphalt mixtures. Once distributed, the fibers act as a reinforcing for the binder and mixture, offering improvements to stability-related problems often incurred in conventional asphalt pavements.

TEST AND EXPERIENCE DATA

The fibers have been involved in a considerable amount of research throughout their product history since 1982. Though substantial data has been generated in conventional asphalt laboratory research programs, much of the most valuable information has come from testing of reinforced specimens that were cast from actual field-project batches. In addition, advancement in material characterization testing in the pavement community necessitated the need to conduct a laboratory program testing the fiber reinforced asphalt mixtures.

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In coordination with FORTA Corporation and the City of Tempe, Arizona, an asphalt mixture overlay was placed at Evergreen Drive (East of the Loop 101 and North of University Drive) in Tempe, Arizona. The designated road section within the construction project had two main asphalt mixtures: a control mixture with no fibers added, and a mixture that contained 0.45 kg fiber per 907 kg mixture (one pound of fibers per Avoirdupois, imperial, ton of asphalt mixture). Mixtures for laboratory testing were sampled during construction and brought back to the Arizona State University (ASU) laboratories. Mixture preparation included compaction of 150 mm (6 in.) diameter gyratory specimens for triaxial testing, and beam specimens prepared and compacted according to AASHTO TP8 test protocols. The target air void levels for the test specimens were those typically achieved in the field (about 7%). Rice gravities were determined for the loose mixtures, as well as thickness and bulk densities measured in preparation of the testing program. Laboratory experimental programs included: triaxial shear strength, dynamic (complex) modulus, and repeated load for permanent deformation characterization; flexural beam tests along with flexural toughness tests for fatigue cracking evaluation; indirect diametral tensile tests for thermal cracking mechanism evaluation; C* Integral test for crack growth and propagation evaluation. The data was used to compare the performance of the fiber-reinforced mixtures to the control mixture. Only the triaxial shear strength, dynamic modulus and crack propagation tests are reported in this paper for brevity.

LABORATORY TESTS, RESULTS AND ANALYSES

Triaxial Shear Strength Tests

The triaxial shear strength tests were conducted for the control and FRAC mixtures. Tests were carried out on cylindrical specimens, 100 mm (4 in.) diameter and 150 mm (6 in.) height at 54.4 °C (129.9 °F) (NCHRP 465, 2002). Unconfined and two confining pressures were used: 138 kPa and 276 kPa (20 and 40 psi). Two replicates were used at each confinement level. The specimens were loaded axially to failure at a strain rate of 1.27 mm/mm/minute (0.05 in./in./minute). Figure 1 presents a comparison example of the tests conducted for both mixtures at the 138-kPa (20 psi) confinement level. The plots represent before and after peak stress development during the test. For the FRAC mixture, it was observed that the peak stress developed and the time of its occurrence were higher when compared to those of the control mixture, a behavior that was attributed to the influence of the fibers in the mix. The fibers provided this additional reinforcement to the asphalt mix in resisting permanent deformation and retard the occurrence of shear failure. In addition, cumulative areas under the curve for the tested mixtures are indicative of the mixes' residual energy in resisting crack propagation post peak stress. In all tests, the fiber reinforced mixture showed higher residual energy than the control mixture. See Figure 1. Comparison of Stress-Time Plots at 138 kPa (20 psi) Confinement Level.

E* Dynamic Modulus Test

The E* Dynamic Moduli of control and FRAC mixtures were determined per AASHTO TP 62-03 standard (AASHTO TP 62-03). For each mix, three specimens, 100 mm (4-in.) diameter and 150 mm (6-in.) height, were tested at -10, 4.4, 21, 37.8 and 54.4 °C (°F), and 25, 10, 5, 1, 0.5, and 0.1 Hz loading frequencies. Figure 2 shows direct comparisons of E* values for selected test temperatures 4.4, 37.8 and 54.4 °C (14, 40, 70, 100, 130 °F) and a loading frequency of 10 Hz. It is observed that the moduli for the FRAC mixtures were higher than the control mixture, and therefore plays a positive role in resisting deformation. See Figure 2. Comparison of Measured Dynamic Modulus Values at 10 Hz.

Crack Propagation - C* Line Integral Test

C* is an energy rate or power integral test property. C* can be calculated using a power rate interpretation as follows (Abdulshafi, 1983, Abdulshafi and Kaloush, 1988):

$$C^* = -\frac{\partial U^*}{\partial a}$$

Where U* is the power or energy rate defined for a load p and displacement u by:

$$U^* = \int_0^u p\,du$$

Disc specimens were prepared from gyratory plugs. For each disc, a right-angle wedge was cut into the specimen to accommodate the loading device as shown in Figure 3 (a). Tests were conducted at 21.1 °C (70 °F). The load applied at a constant displacement rate and the crack length over time was measured for each test specimen. The displacement rates used were 0.127, 0.254, 0.381, 0.508, and 0.635 mm/minute (0.005, 0.010, 0.015, 0.020, and 0.025 in./minute) for both the control and FRAC mixtures. The data was used to determine the load as a function of displacement rate for various crack lengths. The power of energy rate input, U*, was measured as the area under the load displacement rate curve. The energy rate, U*, was then plotted versus crack length for different displacement rates and the slopes of these curves constituted the C*-integral. The C*-integral was plotted as a function of the displacement rate. Finally, the C* integral data were plotted as a function of the crack growth rate as shown in Figure 3 (b). In this figure, it is observed that the FRAC mixture has much higher C* and slope values compared to the control mixture. This is an indication that the FRAC mixture has much higher resistance to crack propagation. A unique observation of the FRAC mix specimens after the test was that the samples never split and they were difficult to split apart by hand. Most of the control mixture samples split at the end of the test. See Figure 3. for the C* Line Integral versus Crack Growth. The typical C* Test Setup is a wedge cut into a disk and measures crack growth at the wedge tip as a crude form of toughness testing for fracture mechanics properties.

PAVEMENT THICKNESS DESIGN AND CONSIDERATION

The results of the laboratory study were used as input into the Mechanistic Empirical Pavement Design Guide (MEPDG) computer program (Guide for MEPDG, 2004). This was done to predict field performance per the MEPDG, and to evaluate the impacts on varying pavement design thicknesses. A total of 10 runs were performed for each of the control and FRAC mixtures for the following conditions.

- Two traffic levels, 1500 and 7000 Annual Average Daily Traffic (AADT), representing an intermediate and high traffic levels.
- Five Asphalt Concrete (AC) layer thicknesses, 50 to 150 mm (2 to 6 in.) over a constant thickness base of 200 mm (8 in.).
- Climatic conditions: Phoenix, Arizona, USA
- Design life: 10 years

The distresses evaluated as output were rutting and fatigue cracking. Distress versus thickness trends for the two traffic levels were very similar but with different magnitude. Figure 4 (a) shows the relationship between total rutting and thickness for both mixtures at the 7000 AADT (~50 million ESALs). It can be observed that for a rutting criterion not to exceed 10 mm (0.39-in.) during the design period of 10 years, the control mixture AC pavement thickness needed is 140 mm (5.51 in.); whereas the FRAC layer thickness needed would be 90 mm (3.54 in.); a saving of about 50 mm (1.97 in.) in the total AC layer thickness. Figure 4 (b) shows the fatigue cracking predicted by the MEPDG. The results show similar trends, in that lower fatigue cracking is predicted for the FRAC mixture. The results, as shown, are also dependent on the AC layer thickness. This agrees with observations in the MEPDG manual, where for very thin AC layer pavement system, fatigue cracking may not be of a concern due to the compressive nature of strains throughout the AC layer (Guide for MEPDG, 2004). See Figure 4 (a) Pavement Rutting Evaluation using the Mechanistic-Empirical Pavement Design Guide (b) Pavement

Fatigue Cracking Evaluation using the Mechanistic-Empirical Pavement Design Guide. These results were reported and used by customers on projects.

CONCLUSIONS

The laboratory test results in this study showed that the use of a fiber blend in the asphalt mixture improves the mixture's performance in several unique ways. The FRAC mixtures showed better resistance to shear deformation. The measured Dynamic Modulus E* values were higher for the FRAC mix. At 54.4 °C (130 °F), the increase in modulus was 50%. The relationships between crack growth rates and C* line integral values showed that the FRAC mix had about 40 times higher resistance to crack propagation than the control. The pavement design analysis showed that a reduced AC layer thickness of about 30 to 40% could be achieved when using the FRAC mixture. This value will vary slightly depending on the traffic level used in the analysis.

Recent projects have included an open graded friction course on an airport, residential driveways, airfield inlays as prevention against foreign object damage, and ground level parking ramp ground floor.

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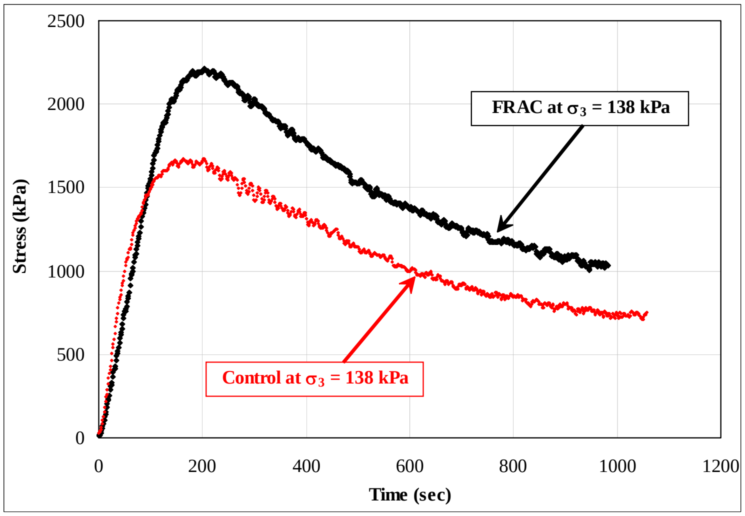

Figure 1. Comparison of Stress-Time Plots at 138 kPa (20 psi) Confinement Level.

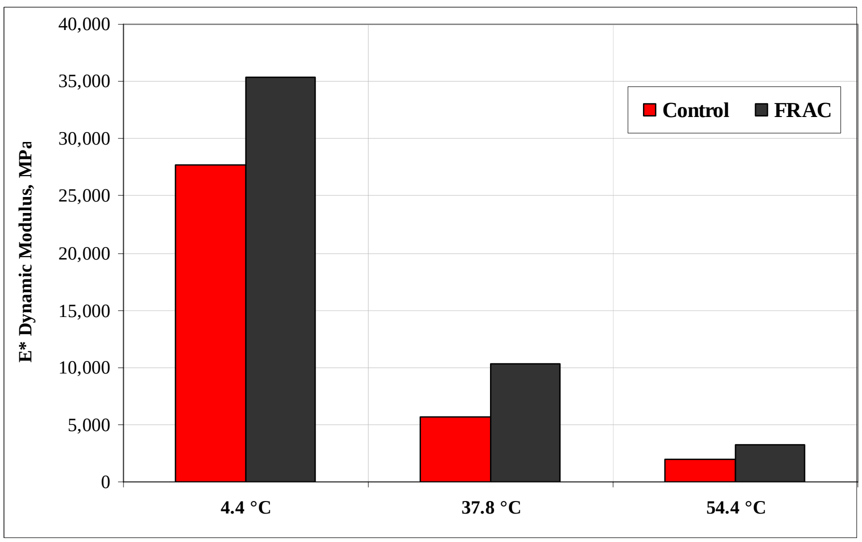

Figure 2. Comparison of Measured Dynamic Modulus Values at 10 Hz.

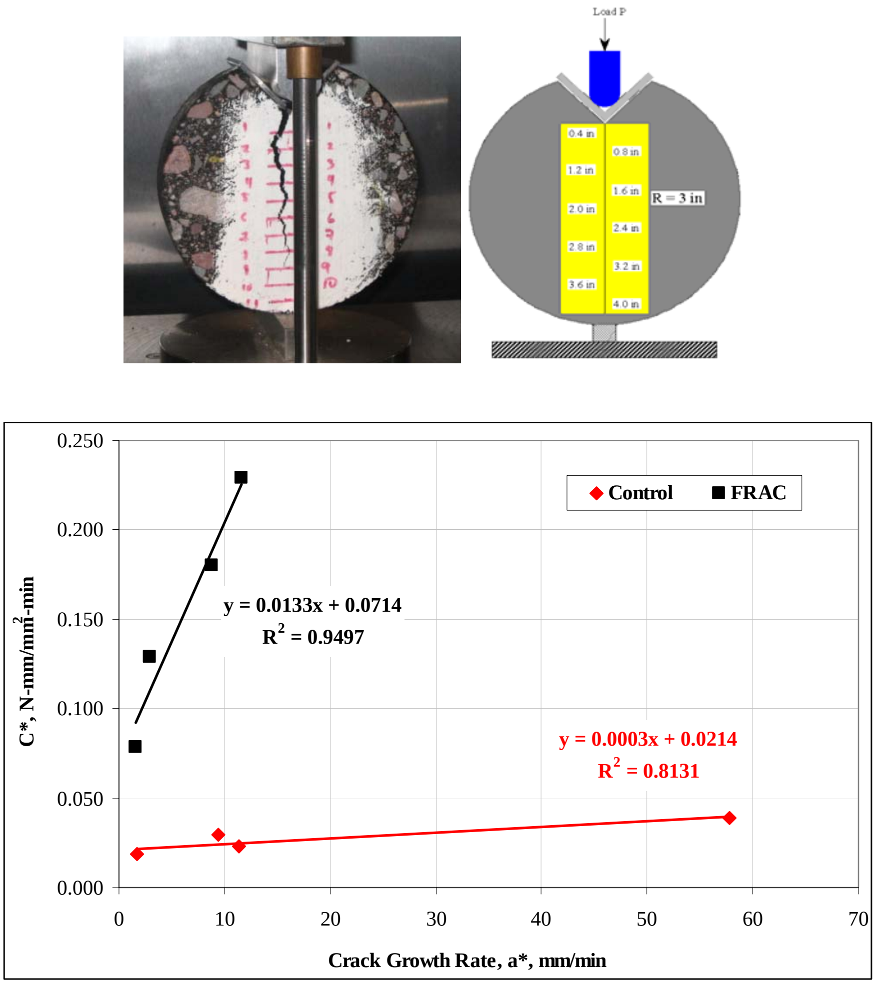

Figure 3. (a) Typical C* Test Setup (b) C* Line Integral versus Crack Growth Rate.

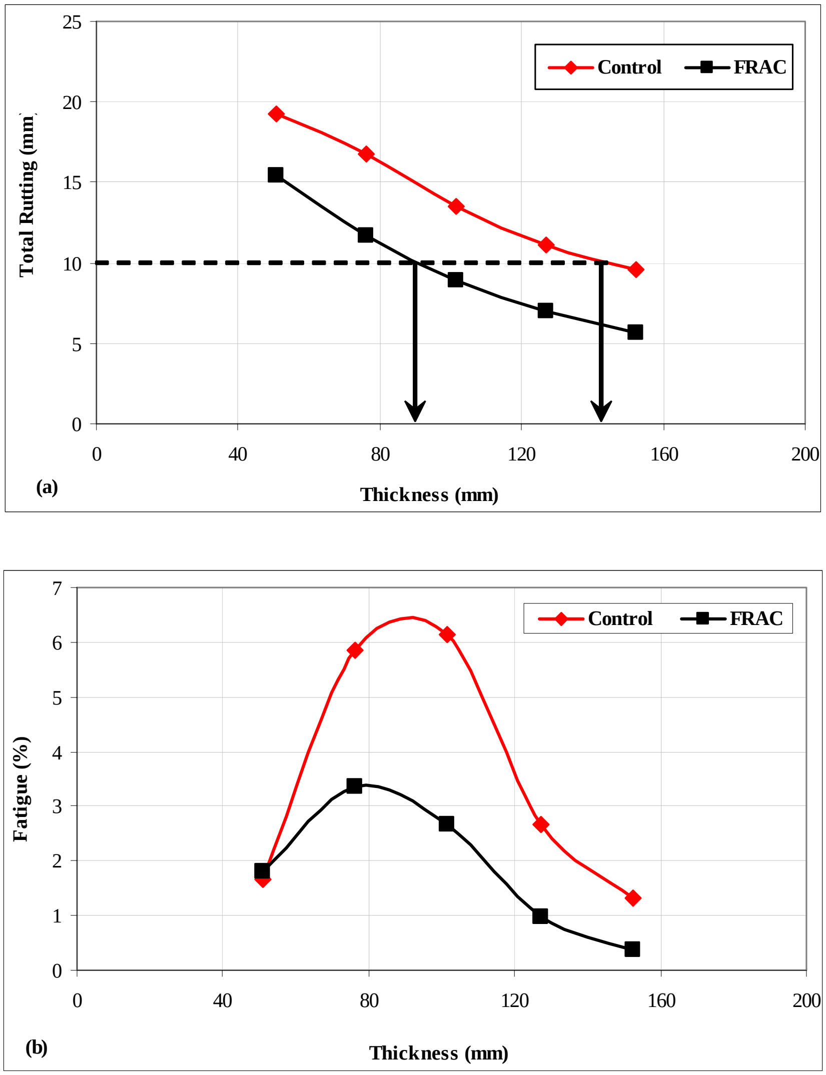

Figure 4 (a) Pavement Rutting Evaluation using the Mechanistic-Empirical Pavement Design Guide (b) Pavement Fatigue Cracking Evaluation using the Mechanistic-Empirical Pavement Design Guide.