Laboratory Evaluation of Crumb Rubber Modified Mixtures Designed Using TxDOT Mixture Design Method

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The Texas Department of Transportation has developed a mixture design procedure for crumb rubber modified (CRM) asphalt concrete mixtures. Eight CRM mixtures were designed using this procedure. Four wet process mixtures and four dry process mixtures, in addition to one control mix, were considered for material characterization and performance evaluation using the asphalt aggregate mixture analysis system (AAMAS). The control mixture was designed using the conventional design method. It was determined that CRM has the potential to significantly improve the fatigue cracking performance of asphalt concrete pavements, but only when the wet method is used and the binder is properly designed. The dry process should produce mixtures with a reduced propensity for rutting, but may have an adverse effect on cracking. Fine and coarse rubber can be added dry to the dense graded mix (0.5 percent by weight of aggregate) without having any adverse effects on the performance. Although state transportation departments must comply with the existing legislative requirements, tire rubber, like any additive, should be used only to address a given mixture deficiency or expected deficiency in a given situation.

The use of crumb rubber modified asphalt concrete in paving applications has been a practice for many years. Legislation by federal and state governments required states to develop new procedures for effective utilization of crumb rubber in pavements. Several crumb rubber modified (CRM) pavements were constructed on an experimental basis in the state of Texas (*1*). Because there was a great deal of variation in the success and performance of these pavements, the Texas Department of Transportation (TxDOT) developed a new mixture design method for CRM hot-mix asphalt concrete based on the stone matrix concept. A research program was undertaken at Texas Transportation Institute (TTI) to evaluate the CRM mixtures for various distresses and to develop construction guidelines for their application.

RESEARCH PROGRAM

The research program undertaken at TTI consists of three phases. Only the results from Phase 2 of the research program are discussed here. The three phases of the program are

- Phase 1: laboratory evaluation of unmodified and modified CRM mixtures. The objectives included preparation of CRM binders to be used in hot-mix asphalt concrete; characterization of these binders and determination of appropriate test procedures for the binders.
- Phase 2: laboratory evaluation of CRM asphalt concrete. Asphalt Aggregate Mixture Analysis System (AAMAS) (*2*) was selected as a tool to evaluate CRM mixtures. Objectives include the determination of optimum rubber content that can be used in dense-graded mixtures and checking the adequacy of the CRM mixtures to be used in the surface layer of a flexible pavement.
- Phase 3: field evaluation of CRM mixtures and developing usage and construction guidelines.

Phase 1 of this project is completed and reported elsewhere (*3*). Phase 3 of this project is currently in progress at TTI. The scope of Phase 2 includes two gradations of crumb rubber (No. 10 size and No. 80 size), two aggregate gradations (dense and open), two rubber contents (10 percent and 18 percent), and two methods of incorporating rubber (wet and dry) in the mixture (a total of nine mixtures). All of the mixtures are shown in Table 1.

MATERIALS

Aggregates

The aggregates used for the mixture designs included a crushed limestone and field sand. Care was taken to eliminate the influence of aggregate properties in the evaluation process by obtaining aggregate from the same source. The crushed limestone was from Giffordhill in New Braunfels, Texas. Limestone screenings were from Georgetown, Texas, and the field sand was from a source near Hearne, Texas. Specific gravities of the aggregate are

- Bulk specific gravity of coarse limestone: 2.554;
- Bulk specific gravity of limestone screenings: 2.443; and
- Bulk specific gravity of field sand: 2.551.

Asphalt Cement

The asphalt cement used for this study was Texaco AC-10 from Port Neches, Texas. This asphalt was used for the design of all the mixtures, including the control mixture. All the binder properties are reported in Estakhri et al. (*3*). No additives were used in the blending process of asphalt cement with rubber.

Rubber

The rubber used in this study is from ground, whole tires. Two different sizes of CRM were used in this study: No. 10 mesh and No. 80 mesh. The source of rubber passing the No. 80 sieve size was

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TABLE 1 Gradation, Binder Content, and Mixture Designation for Control and CRM Mixtures

Sieve Size	Dense-Graded Mixtures			Open-Graded Mixtures					
	0% CRM Control Mix	0.5%[1] Fine CRM (DGF)	0.5%[1] Coarse CRM (DGC)	10%[2] Fine CRM Wet Process (10FW)	10%[2] Coarse CRM Wet Process (10CW)	18%[2] Fine CRM Wet Process (18FW)	18%[2] Coarse CRM Wet Process (18CW)	18%[2] Fine CRM Dry Process (18FD)	18%[2] Coarse CRM Dry Process (18CD)
Optimum Binder Content (%)[1]	5	5	5.75	8.2	8.2	8.2	8.2	8.2	8.2
	% Passing								
1/2"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3/8"	92.0	92.0	92.0	98.0	98.0	98.0	98.1	97.9	98.2
#4	60.0	60.0	60.0	42.5	43.7	41.1	46.1	42.2	49.0
#10	37.0	37.0	37.0	9.5	11.7	10.0	14.9	8.7	19.5
#40	21.0	21.0	21.0	7.5	9.2	8.5	11.6	6.8	15.1
#80	9.0	9.0	9.0	4.7	5.4	5.8	6.27	3.7	8.2
#200	4.0	4.0	4.0	3.0	3.3	4.5	3.75	2.1	4.6

[1] - By weight of the aggregate
[2] - By weight of asphalt cement

Rouse Rubber of Vicksburg, Mississippi. The source of rubber, passing the No. 10 sieve size, was from Granular Products of Mexia, Texas. Rubber passing No. 10 sieve size will hereafter be referred to as coarse rubber and rubber passing No. 80 sieve size as fine rubber.

MIXTURE DESIGN

Two methods were used for designing crumb rubber mixtures for laboratory characterization: TxDOT's standard method for mixture design (C-14) (*4*) and TxDOT's method for crumb rubber mixtures (Tex-232-F) (*4*).

One of the simplest and most economical methods of incorporating CRM into asphalt mixtures is by using a generic dry process, that is, by adding the CRM to the mixture as a part of the aggregate rather than preblending it with the asphalt cement. This process was evaluated along with the dense-graded aggregates. It is believed that one of the major concerns with using CRM in dense-graded mixtures is the concentration of CRM. In the past, concentration of CRM has typically been too high for this type of gradation (18 percent CRM or more, by weight of the binder). Therefore, standard mixture design procedures (*4*) were used to determine how much CRM could be added to a Texas Type D mixture (dry) still maintaining all requirements associated with standard mixture design (acceptable air voids and Hveem stability values).

Dense-graded mixtures were designed using two different gradations of CRM (No. 10 mesh and No. 80 mesh) and varying the concentration of CRM. Three concentrations of CRM were evaluated: 0.2, 0.5, and 0.8 percent CRM by weight of the aggregate. Of these three concentrations, it was found that 0.5 percent was the optimum concentration of CRM for dense-graded mixtures. These mixtures were then characterized by using AAMAS (*2*). Exact gradations, optimum binder contents, and mixture designations are given in Table 1.

Tex-232-F is a volumetric mixture design procedure for designing gap-graded crumb rubber mixtures. The mixture design philosophy is that crumb rubber particles fill the available voids and still maintain a stone-to-stone contact. The design criteria are a minimum of voids in the aggregate 20 percent; optimum laboratory density of 97 percent; and a minimum 17 percent volume of binder (asphalt cement + rubber). Preblending CRM and asphalt prior to incorporation into the hot-mix is known as the wet process. Two different percentages of rubber were added by the wet method, they are: 10 percent (coarse and fine rubber) and 18 percent (coarse and fine rubber) by weight of asphalt content. If rubber is added directly to the aggregate, it is called dry process. Two generic dry mixtures were also designed according to this procedure: 18 percent fine CRM and 18 percent coarse CRM (by weight of asphalt). For comparison purposes, the dry CRM concentrations are expressed herein as a percent of the asphalt content. Tex-232-F was originally developed to incorporate crumb rubber by the wet process, but these dry mixtures are also designed according to test method Tex-232-F and evaluated using AAMAS. Final gradations for all six mixtures mentioned are given in Table 1.

PREPARATION OF SAMPLES FOR MIXTURE EVALUATION

Using the gradations and binder contents given in Table 1, samples were prepared for the AAMAS testing program. Procedures described in *Standard Specifications for Construction of Highways, Streets and Bridges* (*4*) were strictly followed. Mixtures were kept in a forced draft oven at 135°C (275°F) for 3 hours to simulate the plant aging. All of the samples were molded using a California kneading compactor, the only modification in the fabrication procedure. This change was made because the AAMAS-recommended

gyratory testing machine is not available at TTI. So it was decided by the research team that the traffic densified samples be molded with a California kneading compactor for creep testing. The samples to be tested for permanent deformation properties were molded to an air void level of 2 to 3 percent to maintain the uniformity. CRM samples were allowed to cool to room temperature before extracting from the mold.

Some of the samples molded for testing were conditioned to simulate loading and environmental conditions. Other samples were conditioned to simulate moisture damage, temperature conditioning, and traffic densification. Unconditioned samples were also tested for the material characterization.

TESTING PROGRAM

All nine mixtures were evaluated using AAMAS. The test matrix is shown in Table 2 for each mixture considered. A total of 243 samples were molded for the testing program. The tests performed were resilient modulus, indirect tensile strength, indirect tensile creep, and compressive static creep. At a later stage in the program, dynamic creep test was added. This test was also performed at the same load level as static creep test, 414 kPa (60psi). A Poisson ratio of 0.35 was assumed for all the mixtures in calculating resilient modulus, indirect tensile strain, and strength. Dynamic creep tests were performed for 10 000 cycles; each cycle consisted of 0.1 seconds loading and 0.9 seconds unloading. These material properties were used in various distress models to predict the performance of the mixtures.

DISCUSSION OF TEST RESULTS

Resilient Modulus Test

Diametral resilient modulus tests were performed at three temperatures: 5°C (41°F), 25°C (77°F), and 40°C (104°F). These data are shown in Figure 1. The addition of CRM in the dense-graded mixtures caused a decrease in the resilient modulus at 5°C (41°F) and 25°C (77°F) compared to the control. All of the gap-graded crumb rubber mixtures had lower stiffness than the dense-graded mixtures at all three test temperatures. It appears that CRM may have some propensity for decreasing the mixture's temperature susceptibility, particularly the mixture made with 18-percent fine CRM by the wet process (18 percent FW). This mixture had the lowest stiffness at 5°C (41°F) and yet a relatively high stiffness at 40°C (104°F). This trend was not observed, however, for the two gap-graded mixtures made with 10 percent CRM (10 percent CW and 10 percent FW), which exhibited the lowest stiffness of all the mixtures at 40°C (104°F). This may be due to higher binder content in 10 percent CRM than for 18 percent CRM. It should be noted here that the volume of the binder remained the same for both 10 and 18 percent CRM, so the net asphalt content for 10 percent CRM is 0.5 percent higher than for 18 percent CRM.

Figure 1 is the AAMAS chart for plotting the test results of total resilient modulus (unconditioned) versus temperature compared with the range of values that are appropriate for higher volume roadways. In general, the gap-graded crumb rubber mixtures have resilient modulus values that are considered to be too low based on this particular criterion. However, this criterion was developed for dense-graded asphaltic concrete mixtures and may not be applicable to gap-graded mixtures.

Indirect Tensile Strength Test

Indirect tensile strength tests were performed at 5°C (41°F,) 25°C (77°F), and 40°C (104°F). Figures 2 and 3, respectively, show the indirect tensile strengths and failure strains at 5°C (41°F). The tensile strength of the control mixture, which is a dense-graded (DG) mix, is 827 kPa (120 psi). The addition of dry fine and coarse rubber to a dense-graded mixture (DGF and DGC) did not cause a decrease in the tensile strength. Tensile strength and failure strain data at 5°C (41°F) for all three dense-graded mixtures (control, DGF, and DGC) were about the same. The remaining crumb rubber mixtures (which were gap-graded) exhibited a decrease in tensile

TABLE 2 Laboratory Test Plan for Control and CRM Mixtures

Test	Conditioning of Samples To Simulate Various Types of Distress					
	Unconditioned			Moisture Conditioning	Temperature Conditioning	Traffic Densification
Temperature, °C (°F)	5 (41)	25 (77)	40 (104)	25 (77)	5 (41)	40 (104)
Resilient Modulus	X	X	X	X	X	X
Indirect Tension Test	X	X	X	X	X	-
Indirect Tension Creep test	-	-	-	-	X	-
Compressive Static Creep Test	-	-	-	-	-	X
Compressive Dynamic Creep Test	-	-	-	-	-	X
Compressive Strength Test	-	-	-	-	-	X

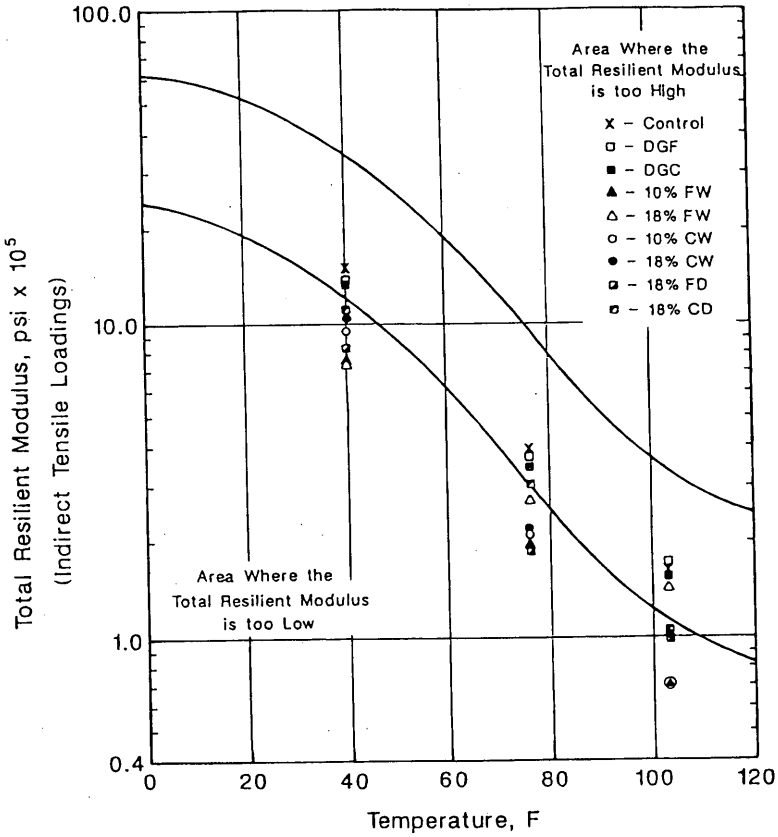

FIGURE 1 AAMAS plot showing resilient modulus versus temperature for control and CRM mixtures.

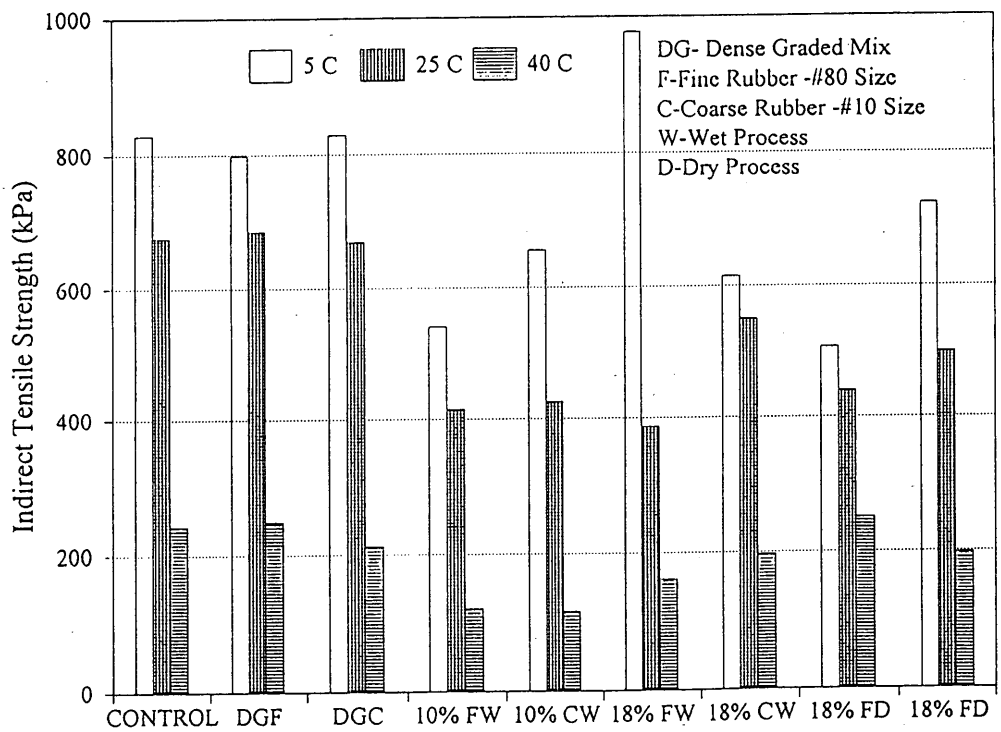

FIGURE 2 Indirect tensile strength for control and CRM mixtures at three different temperatures.

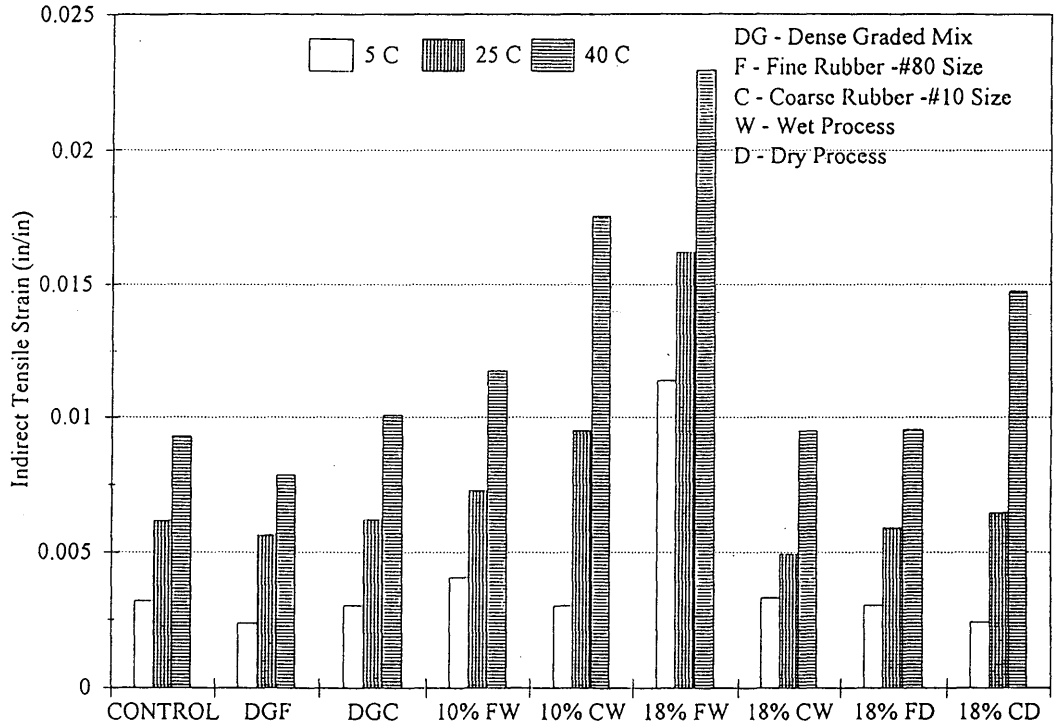

FIGURE 3 Indirect tensile strain for control and CRM mixtures at three different temperatures.

strength ranging from 15 to 35 percent except the 18 percent FW. This mixture displayed a significant increase in tensile strength over the control mixture. Tensile strain at failure was also much higher for 18 percent FW when compared to the other mixtures.

While the tensile strengths for 5°C (41°F) decreased for most of the gap-graded rubber mixtures as compared with the control, there was no decrease in the tensile strain at failure for these mixtures. In fact, the tensile strain at failure for the gap-graded rubber mixtures was as good or better than the control in most cases.

Tensile strengths and failure strains at 25°C (77°F) follow a similar trend in the data as observed for 5°C (41°F). As one would expect, tensile strength of bituminous mixtures greatly decreases at 40°C (104°F). The two gap-graded mixtures made with 10 percent FW and 10 percent CW had the lowest tensile strengths. This may be due to the higher net asphalt content available than any other mixture. Failure strains for the gap-graded crumb rubber mixtures were generally higher than the control and dense-graded crumb rubber mixtures. One mixture seemed to stand-out from all others in terms of having significantly higher failure strains at all three test temperatures: the gap-graded mixture 18 percent FW. The properties of the binder used in this mixture (18 percent FW) also support this conclusion and are presented in Estakhri et al. (*3*).

Creep Test

Static Compressive Creep Test

Static compressive creep tests were performed at 40°C (104°F) at 414 kPa (60 psi) with 1 hour loading period and 1 hour recovery period. Total compressive creep modulus was calculated at different times. Besides the creep modulus criteria, there are other parameters measured in this creep test worth discussion: total creep strain, log-log slope of the steady state creep curve, and strain recovery.

Creep strain, for a given stress level, is plotted versus time, and the creep strain is divided into three stages (*5*). In the first, or primary, stage, the rate of deformation increases rapidly. In the second, or "steady state," region, the deformation rate is constant as is the angle of slope (rate of deformation). The third is the failure stage (tertiary), in which the deformation again increases rapidly.

The AAMAS uniaxial creep curves for all of the mixtures are presented in Figure 4. None of the mixtures appeared to reach the tertiary creep region within the 1-hour loading period. Uniaxial creep data for all the mixtures are shown in Table 3. A log-log slope of the creep versus time of loading curve (as shown in Table 3) of less than 0.25 is indicative of a mixture that will not become unstable (reach tertiary creep) within the testing period of 3,600 sec (*6*). All of the mixtures shown here have a slope less than 0.25. When observing the curves in Figure 4 and the slope data in Table 3, it appears that some mixtures have significantly higher slopes than others. However, each of these slopes represents an average of three tests. A statistical analysis performed on these data revealed that none of these mixtures is significantly different from the other in terms of slope of the creep curve in the steady-state region.

After the one hour loading period in the creep test, there is a 1-hour recovery period. The percent strain recovered at the end of the 1-hour recovery is shown in Table 3. It appears from this data that the two dense-graded CRM mixtures (DGF and DGC), which have a similar gradation as the control, have much better recovery than the control. The dense-graded fine CRM mixture had a higher creep stiffness at 3,600 sec than the dense-graded coarse CRM mixture. However, the dense-graded coarse CRM mixture had a better recovery. Of the gap-graded rubber mixtures, 10 percent FW, 10

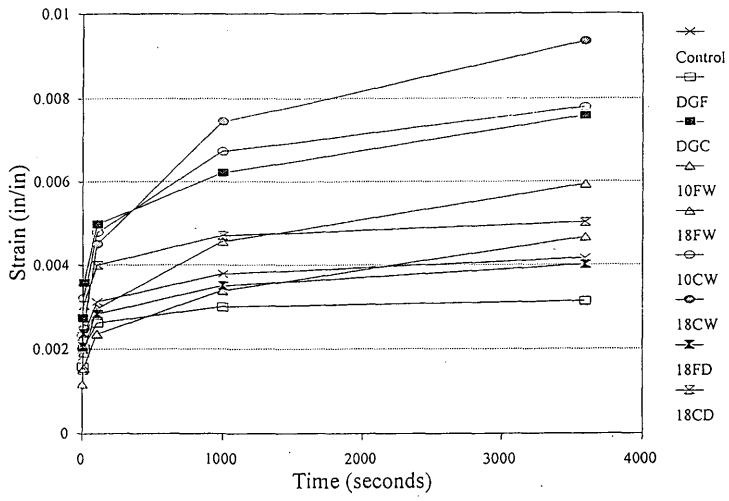

FIGURE 4 Plot showing strain versus time for control and CRM mixtures for uniaxial static creep test.

percent CW, and 18 percent CW had better recovery than the control mixture.

Based on the total strain at the end of the test, the mixtures were grouped into three categories in order to rank the mixtures from best to worst. The following criteria were arbitrarily selected for categorizing the mixtures using the total strain at the end of the static creep test.

- Category 1: total strain < 0.005 in./in.,
- Category 2: total strain between 0.005 and 0.0075 in./in., and
- Category 3: total strain between 0.0075 and 0.010 in./in.

Category 1 mixtures were the best in terms of total strain at 1 hour. It should again be emphasized that these criteria were arbitrarily selected for ranking the mixtures for comparison with each other (see Table 4).

Repeated Load Uniaxial Creep Testing

The repeated load uniaxial creep test was performed to more closely simulate wheel loading than the static creep test. The primary difference between a repeated load creep test and a static test is the plastic deformation that occurs between loading applications. Deformation is highly dependent on number of cycles. This permanent deformation or relative movement among particles is most effectively produced under dynamic loading conditions as the dynamic effect of each repetition produces some level of relative movement.

All of the creep tests performed in this study (both repeated and static load creep), were performed without confining pressure. The gap-graded rubber mixtures analyzed in this study were very similar in gradation to a stone mastic type of mixture. When creep tests are performed on these mixtures without confining pressure, the

TABLE 3 Uniaxial Static and Repeated Load Creep Data (σ_1 = 414 kPa (60 psi)) for Control and CRM Mixtures

Mixture Type	Static Creep Test			Repeated Load Creep Test		
	Log-Log Slope of Steady state Creep Curve	Strain @ End of 3600 Seconds, (in/in)	Strain Recovery, %	Log-Log Slope of Steady State Creep Curve	Strain @ End of 10000 Cycles, in/in	Strain Recovery, %
Control	0.078	0.004153	13	0.423	0.007079	1.4
DGF	0.030	0.003145	21	0.360	0.004149	3.0
DGC	0.067	0.005227	34	0.313	0.011609	3.0
10% FW	0.111	0.005033	9	0.463	0.016657	0.3
10% CW	0.098	0.007767	4	0.428	0.018085	0.7
18% FW	0.165	0.005931	20	0.324	0.014358	1.8
18% CW	0.180	0.009015	3	0.356	0.015528	2.8
18% FD	0.072	0.003383	29	0.365	0.013312	2.3
18% CD	0.049	0.005010	15	0.328	0.018772	4.9

TABLE 4 Ranking of Laboratory Mixtures (from Best to Worst) Based on Total Strain at End of Test Period for Both Static and Repeated Load Creep Tests

Ranking Category	Based on Static Creep Test	Based on Repeated Load Creep Test
Category 1	DGF Control 18%FD	DGF Control
Category 2	DGC 18%FW 18%CD 10%FW	18%FD DGC 18%FW
Category 3	10%CW 18%CW	18%CD 10%FW 10%CW 18%CW

mixtures may lack the lateral support that is present in the field. It is believed that because of the aggregate interlock that exists in a dense-graded mixture, unconfined uniaxial creep properties may be better for dense-graded mixtures than for stone mastic-type mixtures. However, field performance may be better for the latter. This important factor must be kept in mind when reviewing unconfined uniaxial creep properties for both dense- and gap-graded mixtures. It is appropriate to compare or rank gap-graded mixtures against each other, but it may not be appropriate to compare gap-graded mixtures to dense-graded mixtures.

The repeated load uniaxial creep curves for all the mixtures are presented in Figure 5. Tabulated data are shown in Table 3. The samples were subjected to 10 000 load cycles in the repeated load creep test. As shown in Figure 5, the dynamic loading causes the samples to deform at a much higher rate (as evidenced by the greater slope of the secondary portion of the curve) than in the static creep test. The slopes for these mixtures are also shown in Table 3. As in the static creep test, none of these mixtures is significantly different (statistically) from the other in terms of slope in the steady state portion. The percent strain recovery for all the mixtures (Table 3) is very low, which is probably to be expected after 10 000 load cycles.

As with the static creep data, the mixtures were categorized and ranked according to the total strain at the end of 10 000 load cycles. Based on the total strain at the end of the test, the mixtures were grouped into three categories. The criteria arbitrarily selected for categorizing the mixtures using the total strain at the end of the static creep test were

- Category 1: total strain < 0.010 in./in.,
- Category 2: total strain between 0.010 and 0.015 in./in., and
- Category 3: total strain between 0.015 and 0.020 in./in.

Based on these criteria the laboratory mixtures can be categorized as above in Table 3 (Category 1 mixtures being the best in terms of total strain) and compared with the rankings of the mixtures based on static creep tests. Because the repeated load creep test is more rigorous than the static creep test, some mixture rankings changed slightly. Both the DGF and control mixtures remained in Category 1 after repeated load creep testing; however, the 18 percent FD dropped to Category 2. The DGC and 18 percent FW remained in Category 2 while the 18 percent CD and 10 percent FW dropped to Category 3. Mixtures designated as 10 percent CW and 18 percent CW remained in Category 3.

PERFORMANCE EVALUATION OF MIXTURES

Check for AASHTO Structural Layer Coefficient

The only material property that is considered in designing flexible pavements is resilient modulus at 20°C (68°F) in the form of structural number. As layer coefficient decreases, the thickness required for a particular structural number increases. Layer coefficient is directly proportional to resilient modulus. From Figure 1, clearly, all CRM mixtures have resilient modulus values lower than dense-graded mixtures. So the thickness required for CRM mixtures will be much higher than required for dense-graded mixtures for a particular traffic level.

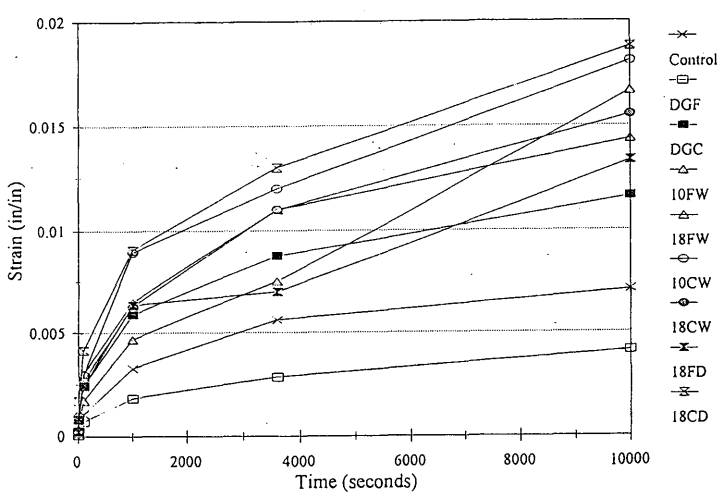

FIGURE 5 Plot showing strain versus time for control and CRM mixtures for uniaxial repeated load creep test.

Check for Resistance to Fatigue Cracking

Figure 6 presents the evaluation criteria by which fatigue potential is evaluated in AAMAS based on the mixture properties of indirect tensile strain at failure and diametral resilient modulus. If the total resilient modulus and indirect tensile strains at failure for a particular mixture plot above the standard mixture (FHWA fatigue curve is recommended), it is assumed that the mixture has better fatigue resistance than the standard mixture. From Figure 6, it appears that all of the mixtures, except one, have about the same fatigue potential and are inferior to the standard mix in terms of fatigue resistance potential as characterized by the FHWA relationship. This means that most of the CRM mixtures tested in this study are more fatigue susceptible than the AAMAS standard mixture but may not be anymore susceptible than conventional dense-graded Type D mixtures currently used in Texas. The mixture produced with 18 percent fine CRM by the wet method has significantly better fatigue resistance than the others.

Check for Resistance to Rutting

One method of evaluating rutting potential was recommended for use by AAMAS as a "rough" guideline for mixture evaluation. This method is a graphical solution by which uniaxial creep data can be compared to criteria for predicting rutting potential. The uniaxial creep test was performed, as described earlier, on samples that were 4 in. (10.2 cm) high × 4 in. (10.2 cm) in diameter and were molded to air void contents less than 3 percent to simulate traffic densification. The samples were loaded under static conditions at 60 psi (414 kPa) for 1 hour with a 1-hour recovery period. The creep modulus data are shown in Figure 7 along with AAMAS criteria.

According to Figure 7, the creep moduli of all the mixtures tested were considered to have low to moderate rutting potential. The dense-graded mixture with fine (dry) CRM seems to be most rut resistant, while the gap-graded, 18 percent coarse CRM (wet) mixture appears to be least rut resistant.

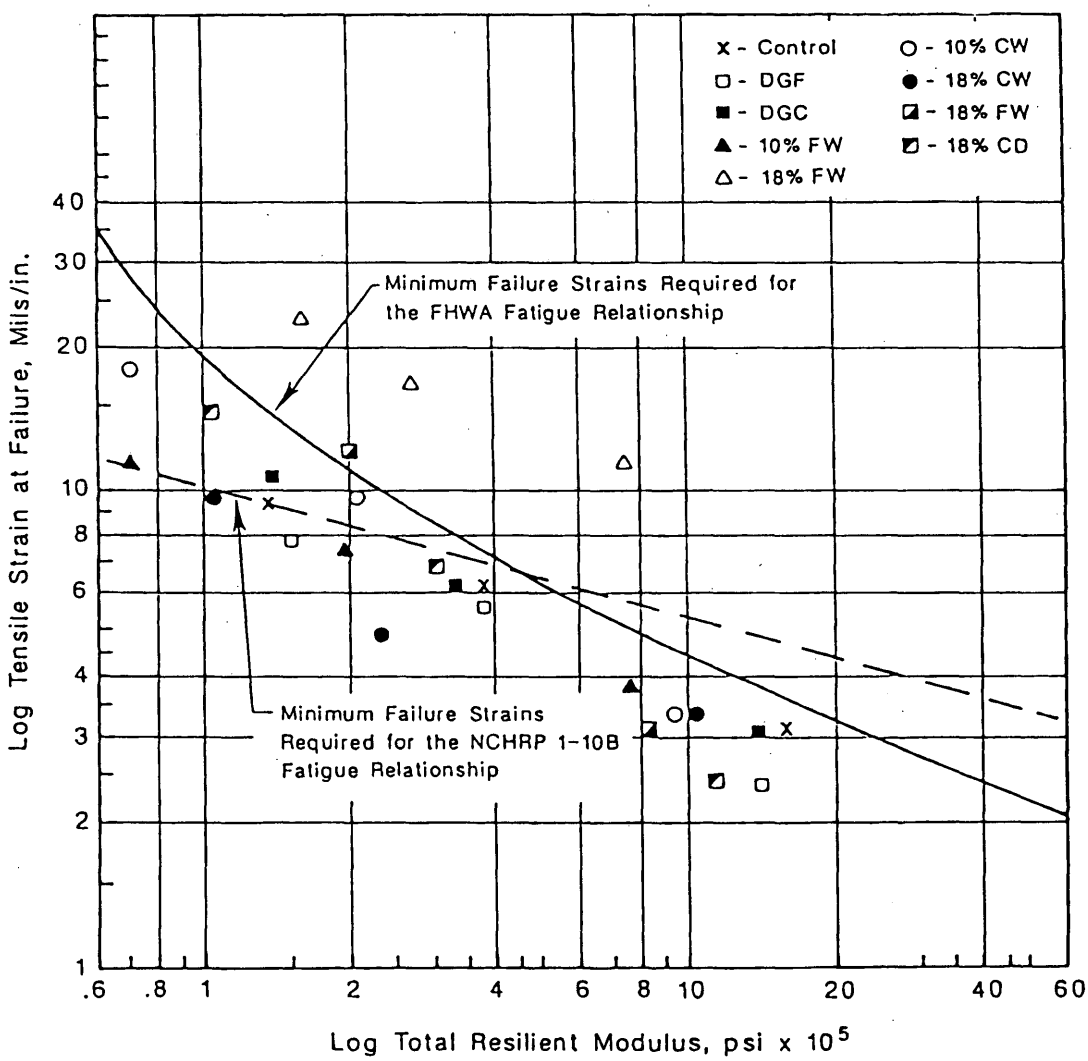

FIGURE 6 AAMAS chart showing resilient modulus versus tensile strain for control and CRM mixtures.

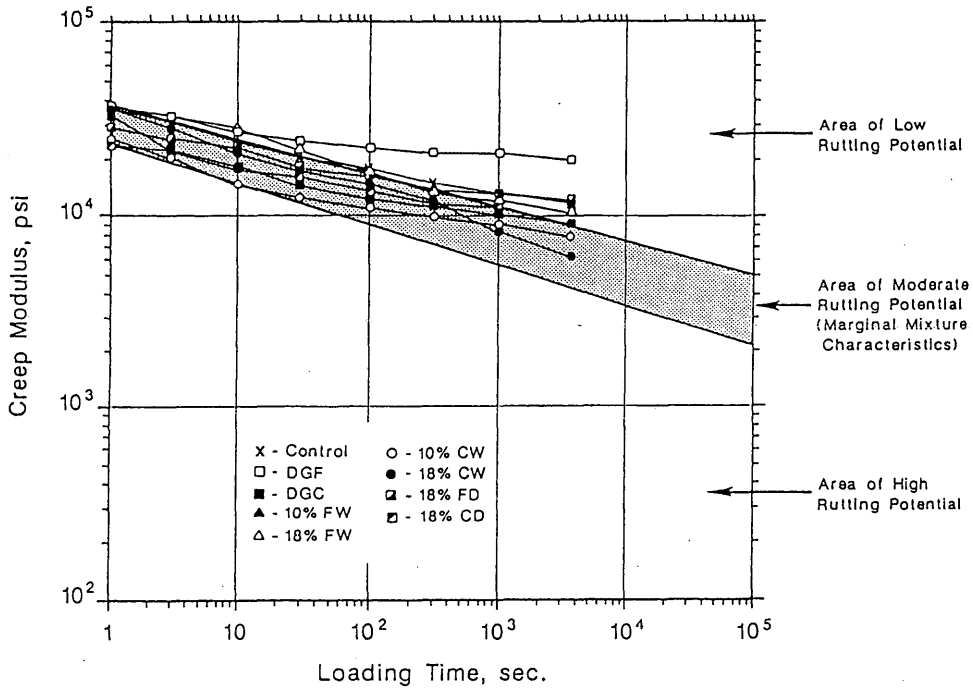

FIGURE 7 AAMAS chart for rutting potential for surface layers of asphalt concrete pavements.

Check for Resistance to Moisture Damage

The moisture damage evaluation (tensile strength and resilient moduli ratios) of AAMAS is simply used as a means of accepting or rejecting a mixture. Both values should exceed 0.80 for a dense-graded mixture. Tensile strength ratio, shown in Figure 8, is the tensile strength after moisture conditioning divided by the tensile strength of unconditioned specimens tested at 25°C (77°F). All of the mixtures exceeded the minimum requirement of 0.80 for tensile strength ratio.

Resilient modulus ratio is calculated as the modulus value after moisture conditioning divided by the modulus of unconditioned

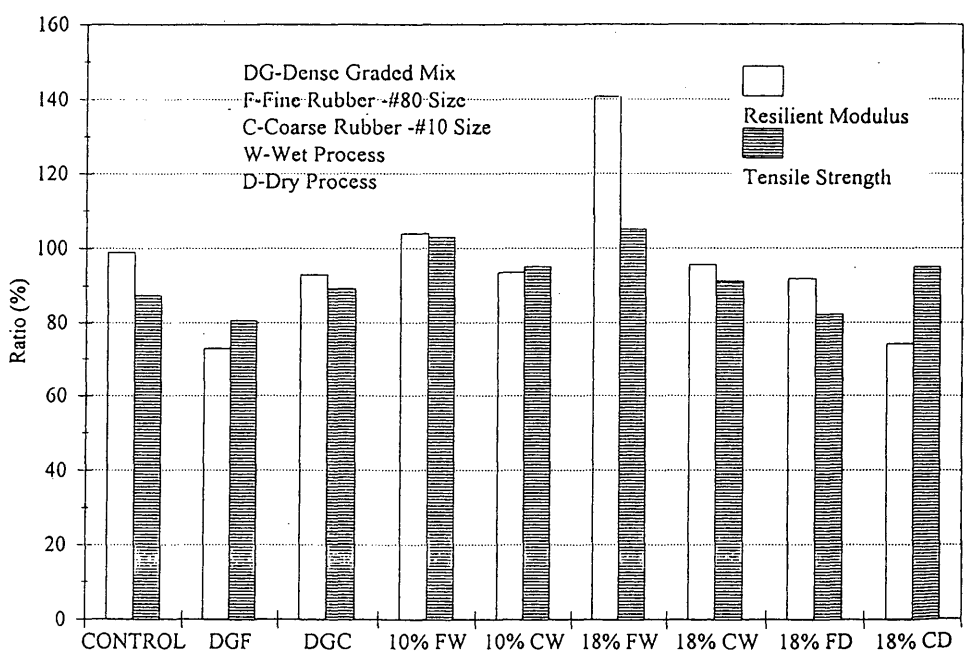

FIGURE 8 Plot showing resilient modulus ratio and tensile strength ratio for control and CRM mixtures.

specimens. This test is also performed at 25°C (77°F). All of the mixtures except two exhibited excellent resilient modulus ratios (see Figure 8). The dense-graded mixture produced with fine CRM and the gap-graded mixture produced with 18 percent coarse, dry CRM had resilient modulus ratios below the minimum recommended value of 0.80. These mixtures have one thing in common: both contain rubber that was added to the mixture as a dry process. However, the other mixtures that used a dry process (18 percent FD and DGC) had very good resilient modulus ratios. The mixture produced with 18 percent fine CRM by the wet process (18 percent FW) had resilient modulus values significantly larger after moisture conditioning. This may be attributed to this mixture's having a high degree of saturation (70 percent) and the development of pore water pressure during the testing procedure.

CONCLUSIONS

1. Results from this laboratory study indicate that acceptable performance may be obtained with CRM in dense-graded mixtures at lower concentrations of rubber (0.5 percent by weight of aggregate). The dense-graded laboratory mixtures evaluated in this study contained CRM, added dry, as part of the aggregate.
2. TxDOT's (volumetric) mixture design procedure for asphalt-rubber mixtures can be used to incorporate rubber of any size or process (wet or dry).
3. Mixtures designed with TxDOT's CRM mixture design procedure generally produced mixtures that are considered very rut resistant. This is particularly effective at higher concentrations of rubber (10 percent or more by weight of asphalt content).
4. CRM has the potential to significantly improve the fatigue and thermal cracking performance of asphalt concrete pavements, but only when the wet method is used and the binder is properly designed. A significant improvement in fatigue characteristics was observed with a particular mixture: 18 percent FW.
5. The wet process should produce asphalt mixtures (if binder is properly designed) that inhibit cracking and *may* inhibit rutting. The dry process, on the other hand, produces mixtures with reduced propensity for rutting but may have adverse effects on cracking. In the dry process, the rubber exists as discrete particles. Discrete particles in asphalt will normally intensify the propensity for cracking but may enhance rutting resistance.
6. The present laboratory testing suggests if acceptable performance can be obtained by CRM mixtures, AASHTO thickness design procedure may not be applicable to CRM mixtures.
7. Although state transportation departments must comply with the existing legislative requirements, crumb rubber, like any modifier, should be used only to address mixture deficiency or expected deficiency in a given situation.

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