Characterization of Crumb Rubber-Modified Binder Using Strategic Highway Research Program Technology

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The objective of the study was to characterize several different types of crumb rubber-modified binders and to develop information relating their properties. Different concentrations, gradations, and asphalt cement sources were evaluated to determine what effect these had on the properties of the modified binders. The asphalt cement and rubber were reacted at 177°C (350°F) until the stiffness had reached a maximum level. Tests were performed to evaluate both the reaction properties and the final properties of the binders. The concentration was found to have the largest effect on the final properties of the binders. The asphalt cements used in the study had little effect on the rubber-asphalt cement reaction. Strategic Highway Research Program (SHRP) binder properties indicated that the asphalt rubber binder performed better than an AC-20 asphalt cement used for comparison. Conventional asphalt tests were also performed on the mature binders. The softening point was found to produce results similar to those of the SHRP tests and may offer a method for field verification for asphalt rubber binders.

Since the enactment of 1038B of the Intermodal Surface Transportation Efficiency Act the use of crumb rubber-modified asphalt cements has become a topic of increased interest to the transportation industry. Insufficient information is available to make well-founded decisions regarding the use and properties of crumb rubber-modified asphalt cements. Mix properties as well as binder properties are needed to evaluate different sizes of rubber, asphalt type, and the concentration of rubber that could optimize the properties of hot-mix asphalt (HMA).

OBJECTIVE

The objective of the National Center for Asphalt Technology (NCAT) crumb rubber study was to evaluate the use of crumb rubber-modified binders for use in HMA pavements.

SCOPE

The study used conventional asphalt cement binder tests and the Strategic Highway Research Program (SHRP) asphalt cement binder tests to evaluate changes in the properties of the modified binder created by the addition of crumb rubber modifier. The factors evaluated were asphalt cement supplier, size and gradation of the rubber particles, and concentration of rubber added. Two sources of AC-10 asphalt cement were evaluated with four different gradations of rubber. Five different concentrations of each gradation, including the zero concentration, were evaluated with each asphalt cement source. An AC-20 asphalt cement was also included in the study for comparison. The actual tests used to evaluate the binders are discussed further in the section Plan of Study.

The mix portion of the study addressed fatigue and rut resistance of crumb rubber-modified asphalt in a densely graded aggregate HMA. This paper presents the results of only the binder phase of the overall study.

PLAN OF STUDY

The study was broken into a matrix of four gradations of rubber, five concentrations of rubber, two sources of AC-10, and one source of AC-20. Table 1 provides a schedule of the binders that were tested during the study. A binder consisted of one concentration of a particular gradation of rubber being mixed with a specific AC-10. The rubber concentrations chosen were 0, 5, 10, 15, and 20 percent by weight of asphalt cement. Zero percent was considered to be a control binder for each asphalt cement type. The gradations of rubber chosen were GF16, GF40, GF80, and GF120, as provided by Rouse Rubber Company of Vicksburg, Mississippi. The GF number represents the nominal maximum sieve size of the rubber. Results of particle size analysis for the rubber are given in Table 2. An AC-20 was chosen as a control to represent a binder currently used in many parts of the country and for which these rubber-modified binders may be a replacement.

The tests chosen to characterize the asphalt rubber binders are given in Figure 1 and are discussed in the following sections.

Brookfield Viscometer

Since the conventional capillary viscometers have been shown to be inappropriate for use in evaluating crumb rubber particles suspended in asphalt, the Brookfield rotational viscometer was chosen (*1*). The rotational viscometer was applicable for the binder with suspended particles and was also viewed as a possible method of field verification for the binders (*2*). The viscometer was used to monitor the reaction of the asphalt cement with the rubber particles at 177°C (350°F). As the reaction continued the viscosity rose to a peak and leveled at that point or slightly below that peak.

Dynamic Shear Rheometer

The dynamic shear rheometer (DSR), like the Brookfield viscometer, was used to characterize the binders as the reaction between the rubber and the asphalt took place. The DSR was also used to char-

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TABLE 1 Crumb Rubber Binder Schedule

Base Asphalt	Concentration	GF16	GF40	GF80	GF120
AC-10-A	0%	X			
	5%	X	X	X	X
	10%	X	X	X	X
	15%	X	X	X	X
	20%	X	X	X	X
AC-10-B	0%	X			
	5%	X	X	X	X
	10%	X	X	X	X
	15%	X	X	X	X
	20%	X	X	X	X
AC-20-C	0%	X			

acterize the binders in their final original stage, after the thin film oven (TFO) aging and after aging in the pressure aging vessel (PAV). The "original" stage refers to a completely reacted asphalt rubber binder before any of the aging techniques. The DSR tests were conducted according to AASHTO Provisional Standard TP5 (*3*) with one deviation. The gap used with the 25-mm plate was set at 2 mm so that any large rubber particles would not interfere with the test. The gap normally used with asphalt cement is 1 mm (*3*). The original and TFO test (TFOT) binders were tested at 52°C, 58°C, 64°C, 70°C, and 76°C. A complex modulus reaction curve was gathered at 55°C to be consistent with data that were collected previously under SHRP specification 7G. The material tested after treatment by PAV and TFOT was characterized at lower temperatures by using the 8-mm spindle and a 2-mm gap. The temperatures selected for this stage of testing were 7°C, 13°C, 19°C, 25°C, and 31°C. These temperatures were chosen because most of the United States is characterized by climates with these temperatures.

Bending Beam Rheometer

The bending beam rheometer (BBR) was chosen to evaluate the cold temperature properties of the binders. BBR test were performed in accordance with AASHTO TP1 (*3*). The temperatures selected for the BBR tests were −12°C and −24°C. This range of temperatures is typical of areas that now use AC-10 and AC-20 asphalt cements.

Direct Tension

The direct-tension (DT) tester was also used to evaluate the cold temperature properties of the binders. The DT tests were performed according to AASHTO TP3 (*3*). The same temperatures used in the BBR tests (−12°C and −24°C) were used in the DT tests to remain consistent.

Penetration and Softening Point

Penetration and softening point tests are being used in many states to specify a crumb rubber-modified binder. Therefore, penetration and softening point testing was included to tie the characteristics of these binders to the current data base. These tests were performed according to ASTM D5 and AASHTO T53–91, respectively.

TABLE 2 Particle Size Analysis of Crumb Rubber Modifier

Sieve No.	Percent Passing			
	GF16	GF40	GF80	GF120
10	100	100	100	100
16	95.5	100	100	100
20	75.0	100	100	100
30	56.5	95.0	90.9	100
40	39.5	90.9	83.1	100
80	6.4	20.7	28.0	95.0
100	3.0	13.2	21.0	94.6
120	–	9.0	16.1	87.0
140	–	7.0	12.1	80.2

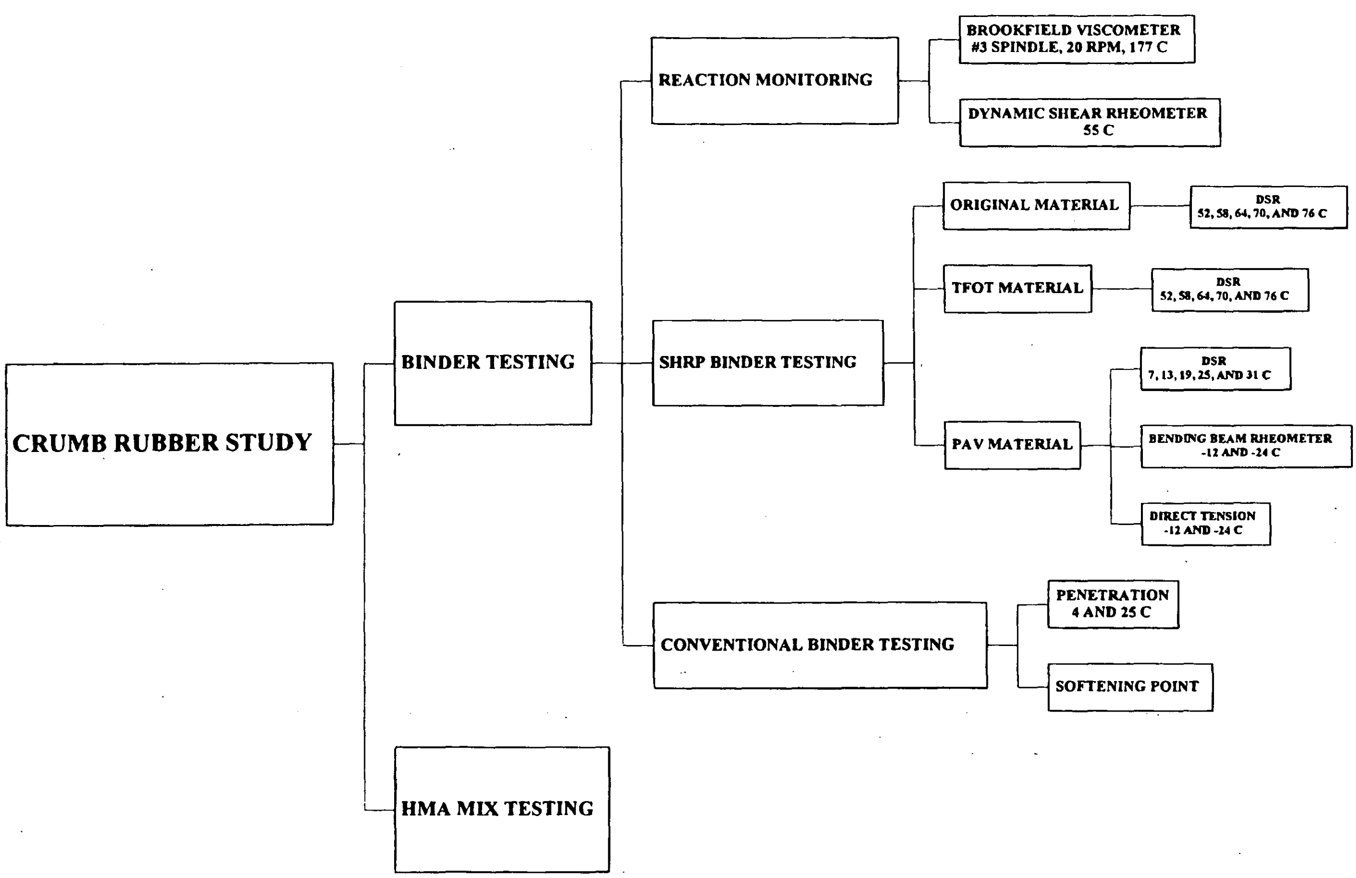

FIGURE 1 Test schedule for binder portion of crumb rubber study.

RESULTS AND DISCUSSION OF RESULTS

Binder Testing

The asphalt rubber binder was prepared by heating the base AC-10 to 177°C (350°F) in an asphalt dispensing pot. The corresponding percentage of dry crumb rubber was added by weight of asphalt cement. After the rubber was added to the asphalt cement the stiffness of the mixture will rise. There was an initial increase in the stiffness of the mixture that dealt with suspending solid particles in a fluid. However, the stiffness continues to rise, indicating that some sort of reaction is taking place.

Reaction Monitoring

The stiffness with time was measured by using the Brookfield viscometer and DSR. The stiffness increased for 2 to 5 hr and then began to decrease slightly. The reaction was monitored until a stiffness peak was noted and confirmed with another test.

Brookfield Viscosity

Viscosity curves for different concentrations of GF80 with AC-10-A are presented in Figure 2 as a typical plot for any given size. The increase in viscosity for increased percentages of rubber is typical for all of the different gradations and asphalt cement types used in the present study.

The procedure for the measurement of viscosity was to use the Brookfield RV series no. 3 spindle at 20 rotations per minute with the Brookfield DV-III viscometer. At several points in the reaction the spindle was lowered into the well-blended binder for 1 min with no rotation to allow the temperature to calibrate. The rotations were begun (time zero), and the first viscosity reading was taken at 1 min, the next one was taken at 2 min, and the third one was taken at 3 min. The three readings were averaged to obtain a viscosity at that average time in the reaction. Four to 10 viscosity tests were performed on each binder during the reaction process. It was noticed early in the testing that after the spindle began rotating the viscosity would continually drop. It is believed by the researchers that the rubber particles were being centrifugally forced away from the spindle so that the rubber concentration in the fluid being measured was lower than that in the entire mixture. Therefore, the viscometer procedure presented earlier was followed rigorously to avoid inconsistencies.

No clear trend in the data was found regarding the effect of gradation on the reaction rate of the binders. The datum points showed extensive scatter. Several conditions contributed to the high scatter of the points, including different operators, difficulty in maintaining temperature, and the method and amount of mixing done to the binder before the measurement of viscosity.

DSR

Slightly before or slightly after the viscosity of the binder was determined, a sample was taken for testing with the DSR. The Bohlin rheometer was used in the constant strain mode to measure the

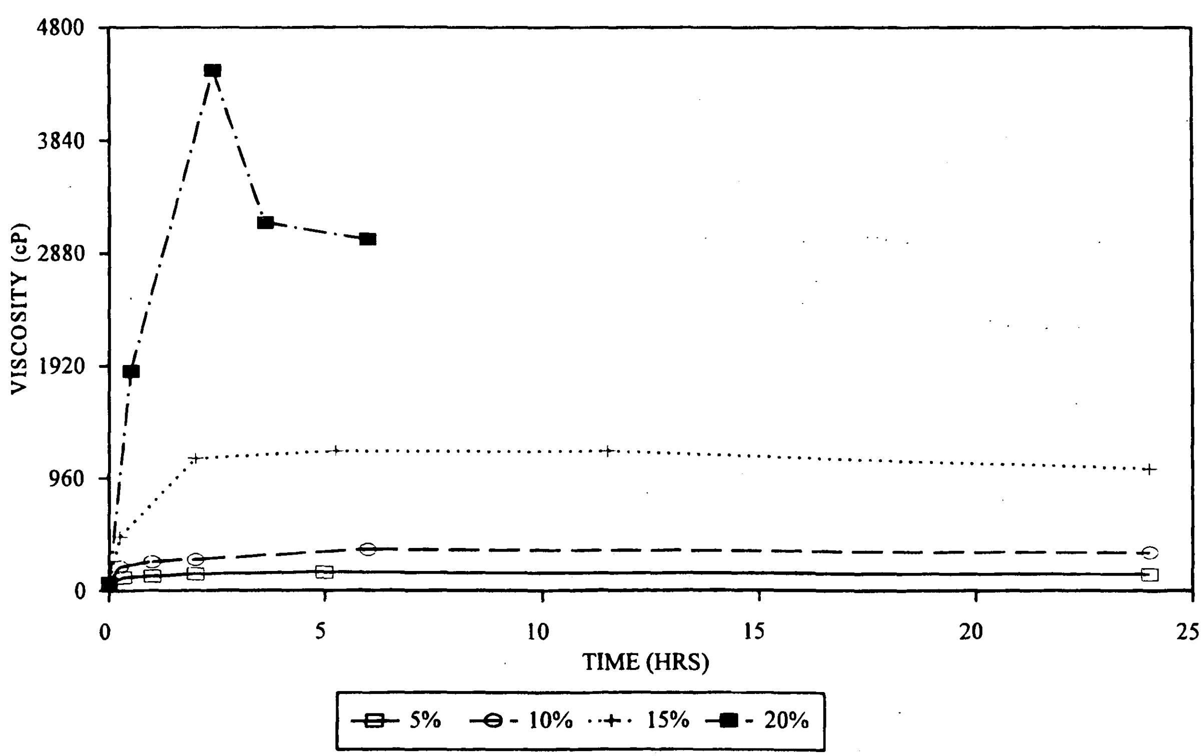

FIGURE 2 Viscosity versus reaction time for AC-10-A with four concentrations of GF80.

complex modulus of the material. The dynamic shear test for reaction observation was performed at 55°C for all binders. This temperature was chosen because when the study began SHRP specification 7G was applicable and 55°C was one of the performance graded specification temperatures.

As with viscosity, the complex modulus rises for 3 to 5 hr, but it then stabilizes or drops slightly. The higher the concentration of rubber, the higher the complex modulus. Again, these test data showed no clear trends regarding differences in reaction rates for different gradations of rubber. The dynamic shear provides a more consistent means of characterizing the reaction of asphalt and crumb rubber, but it is not suited to be a field verification device like the Brookfield viscometer may be.

SHRP Binder Tests

SHRP binder tests were performed on the two base AC-10 asphalt cements, the AC-20 asphalt cement, and the rubber-modified binders to evaluate the rubber-modified binders in comparison with an asphalt cement. The tests performed are indicated in Figure 1. The characterization process began as soon as the binder had reached the mature stage in the reaction, that is, maximum stiffness as measured by the viscometer and the dynamic shear tester. The first step was to evaluate the original binder and to age the material in the TFO. The TFO was used instead of the rolling thin film oven because the asphalt rubber was found to migrate out of the bottles in the rolling thin film oven, resulting in a smoke problem. On completion of the TFOT the dynamic shear test was performed on a sample of the material. The remaining material was placed in the PAV for 20 hr of aging at a pressure of 2.1 MP (300 lb/in.^{2}) and a temperature of 100°C (*3*). After the aging in the PAV was completed the material was removed and the air bubbles were eliminated in accordance with AASHTO procedures. The material was again sampled for testing with the DSR, and specimens for the BBR and DT tester were prepared.

DSR

Characterization of the original material by the DSR showed an increase in the $G^*/\sin\delta$ parameter (where G^* is the complex shear modulus and δ is the phase angle) when rubber was added. Figure 3 shows the original data, with those for AC-20-C also included. The trend for the original data is that stiffness increases with concentration and that there is little variation in $G^*/\sin\delta$ between different gradations of rubber. Figure 3 indicates that there is very little difference between the two asphalt cement types. From Figure 3 most of the asphalt rubber binders met the criteria of $G^*/\sin\delta$ exceeding 1 kPa at 64°C. From Figure 4 there appears to be little difference between the two types of AC-10 for original and TFO- and PAV-aged asphalts. Both of these binders meet the AASHTO criteria in MP1, Standard Specification for Performance Graded Asphalt, and received a grading of PG 58–22. (The -22 portion of the grading will be demonstrated later.) Figure 5 shows the relationship of dynamic shear parameters versus temperature at the different stages of testing. The effect of increasing rubber content can

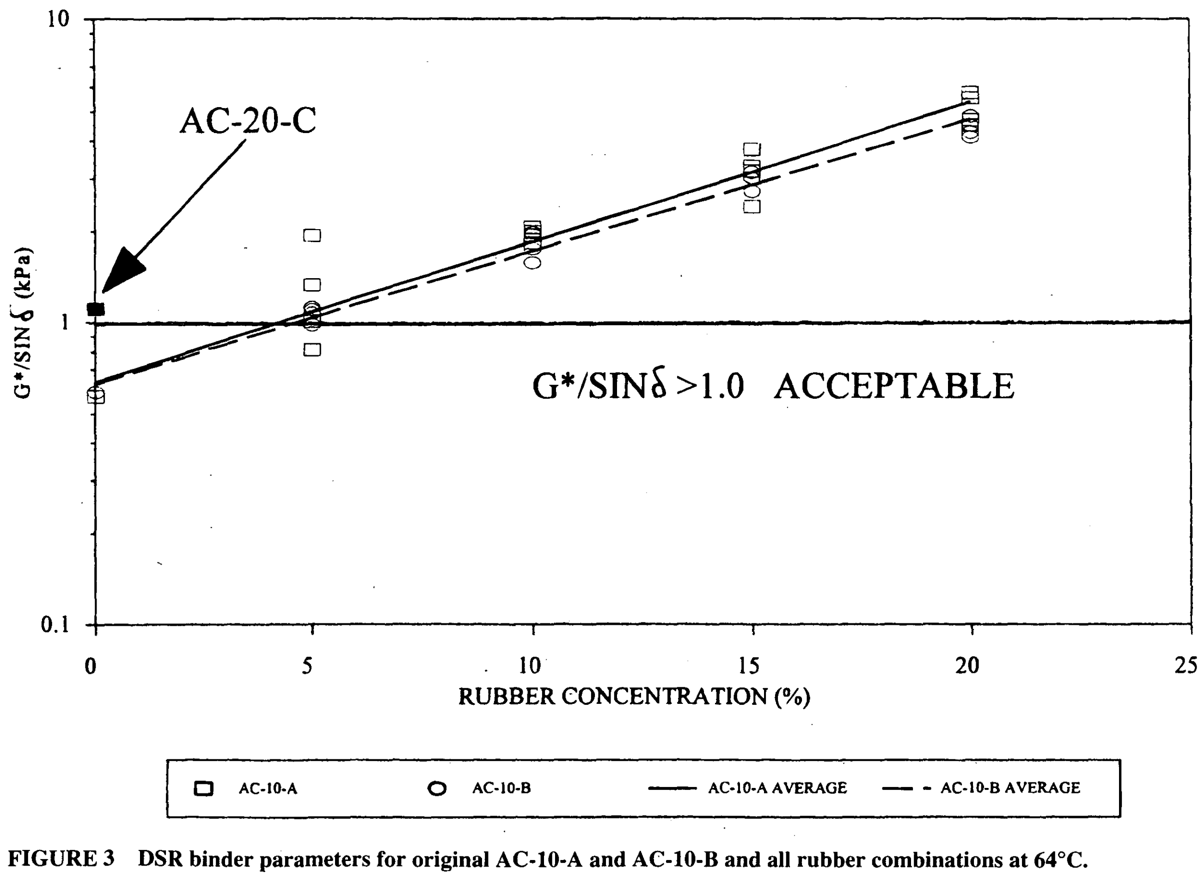

FIGURE 3 DSR binder parameters for original AC-10-A and AC-10-B and all rubber combinations at 64°C.

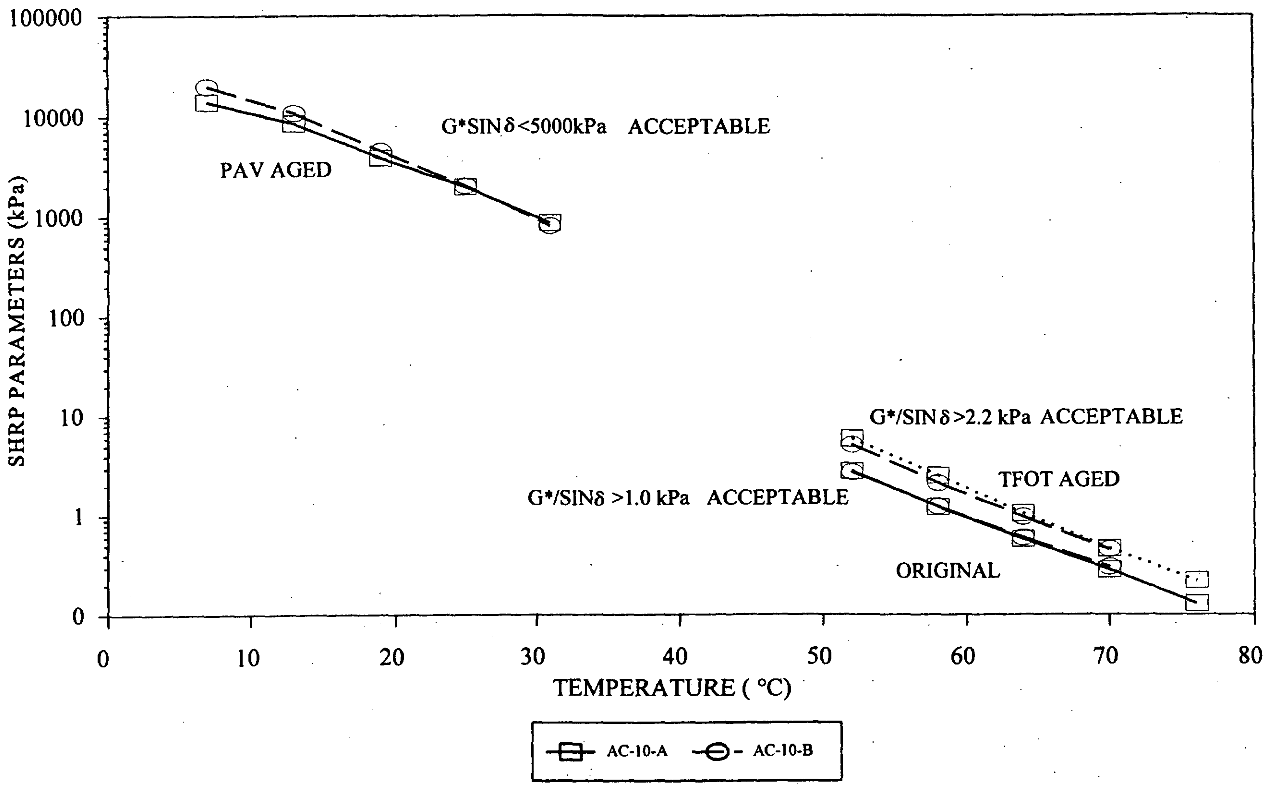

FIGURE 4 DSR SHRP parameters for base AC-10 asphalt cements used in crumb rubber study.

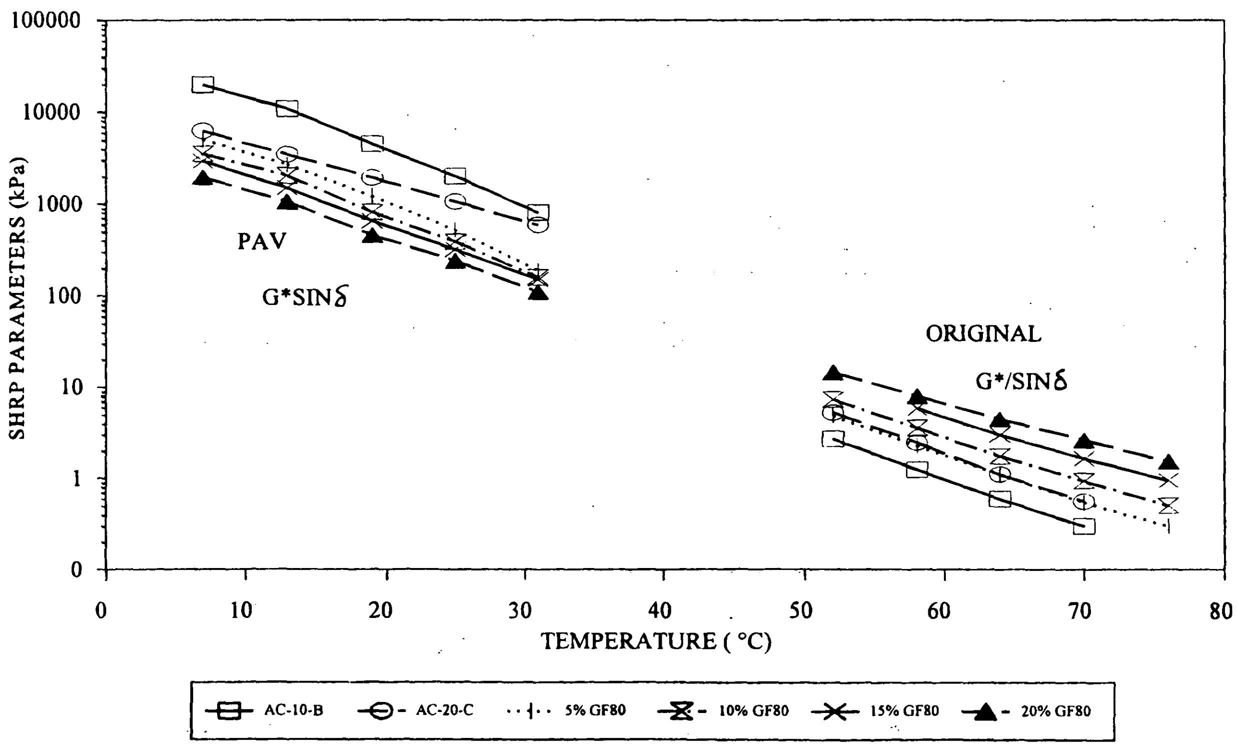

FIGURE 5 DSR SHRP parameters for AC-10-B, AC-20-C, and all concentrations of GF80 and AC-10-B in original and PAV stages. (DSR binder stiffness, AC-10-B, AC-20-C, and CRM binders.)

be seen at the higher temperatures in original materials because $G^*/\sin\delta$ increases as the concentration increases.

Characterization of the TFOT material indicates dynamic shear results similar to those for the original stage. Figure 6 shows that $G^*/\sin\delta$ increases as the percentage of crumb rubber is increased. From these graphs there is no clear trend that the properties of aged material differ for different gradations of rubber, but $G^*/\sin\delta$ is affected by concentration. At 64°C a minimum of 10 percent rubber material must be added to AC-10 to achieve a stiffness of greater than 2.2 after TFO aging. It is apparent that the $G^*/\sin\delta$ for the AC-10-A binders is slightly higher than that for the AC-10-B binders.

Figure 7 shows the relationship of the binder stiffness after the PAV procedure for both AC-10 and the AC-20. Most of the rubberized binders meet the criteria of $G^*\sin\delta < 5{,}000$ at 7°C. The rubber seems to make the rubber-modified binder more elastic at the intermediate temperatures, whereas it makes the modified binder stiffer at higher temperatures.

In summary for SHRP DSR testing, there appears to be little difference in how the different asphalt sources react with the rubber particles. As shown earlier the gradation or size of the rubber has little effect on the stiffness of the binder in all three stages of DSR testing. According to DSR, when trying to produce a rut- and fatigue-resistant rubber-modified binder, the concentration of rubber is the only factor that matters. Considering only the final properties the cheapest gradation of rubber could be chosen without any detrimental effects to the modified binder. The base asphalt cements used in the study appear to have little effect on the reaction between the rubber and the asphalt cement.

BBR

BBR applies a 100-g static load to an asphalt beam for 4 min while measuring the deflection of the beam throughout the duration of the test. The beam is simply supported, and the BBR creep stiffness can be found through the basic deflection equation involving the modulus of elasticity of the beam. Since the deflection of the beam changes with time, the stiffness is also a function of time. An asphalt cement's ability to endure low temperatures over the long term has been shown to be proportional to the slope of the log stiffness-versus-time curve, or *m*. If this value is greater than 0.30 at the lowest sustained pavement temperature, the asphalt will perform adequately according to AASHTO MP1 (*3*). A higher *m*-value indicates better stress relaxation characteristics and, therefore, less susceptibility to thermal cracking. AASHTO TP1 states that the *m*-value determined at 1 min into the test should be used to grade the binder (*3*). The BBR *m*-value (at 1 min) must exceed 0.30 at the given temperature to pass; also, the BBR creep stiffness at 1 min must be below 300 MPa to pass the test.

The characterization of asphalt rubber binder in the BBR has shown a decrease in BBR creep stiffness as rubber is added to asphalt cement (*4*). The effect of concentration is seen in Figure 8, which shows the BBR creep stiffness versus the gradation of rubber at different concentrations. The stiffness continually drops as the rubber concentration increases for both temperatures, but the drop in stiffness is more significant at the lower temperature. The BBR *m*-value for AC-10-B increases with rubber concentration (Figure 9).

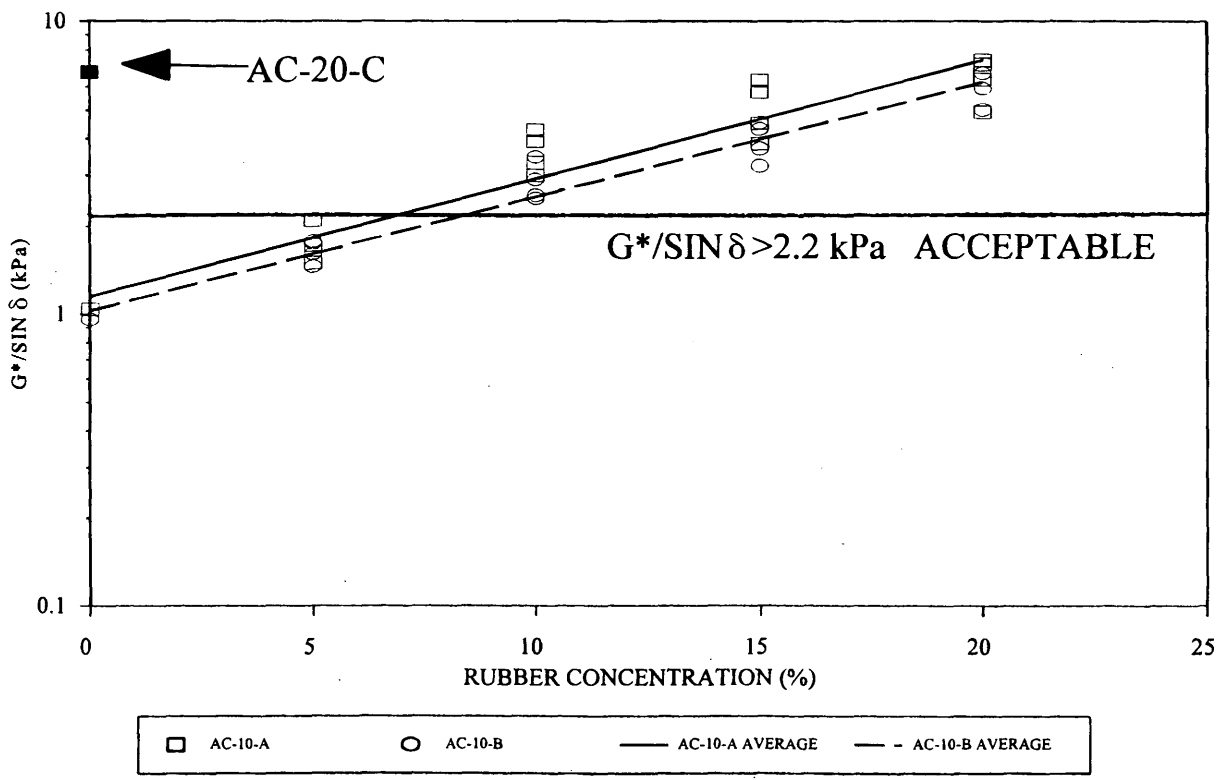

FIGURE 6 DSR SHRP parameters for AC-10-A and AC-10-B with all combinations of rubber after TFO aging at 64°C.

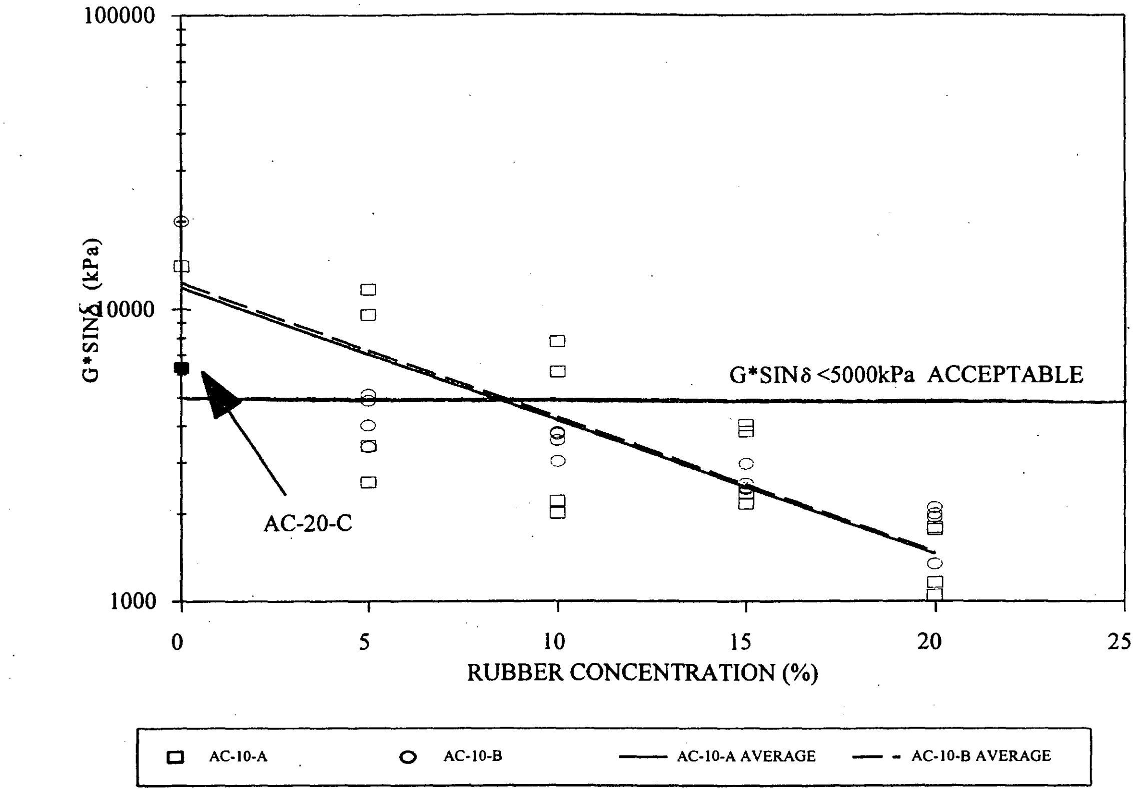

FIGURE 7 DSR *G/sin δ values for AC-10-A and AC-10-B with all combinations of rubber after PAV aging at 7°C.**

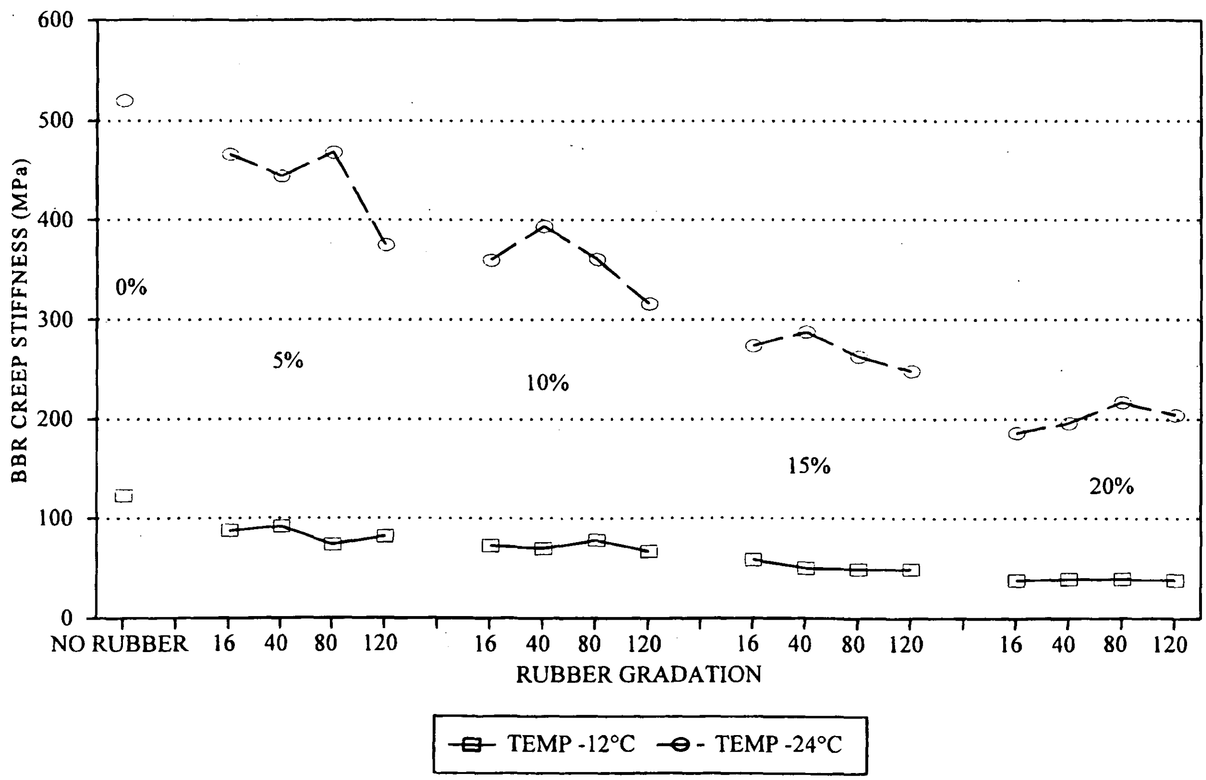

FIGURE 8 BBR creep stiffness for AC-10-B with all combinations of rubber at −12°C and −24°C.

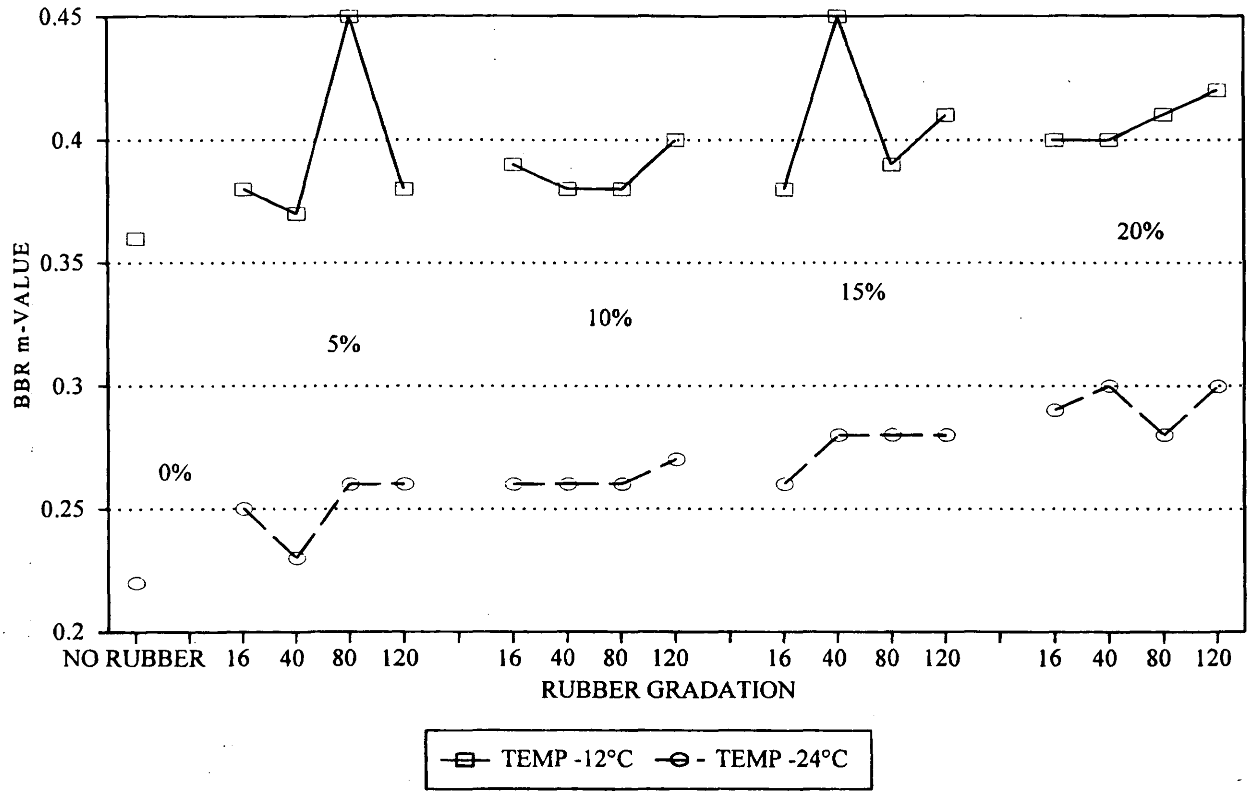

FIGURE 9 BBR *m*-value for AC-10-B with all combinations of rubber at −12°C and −24°C.

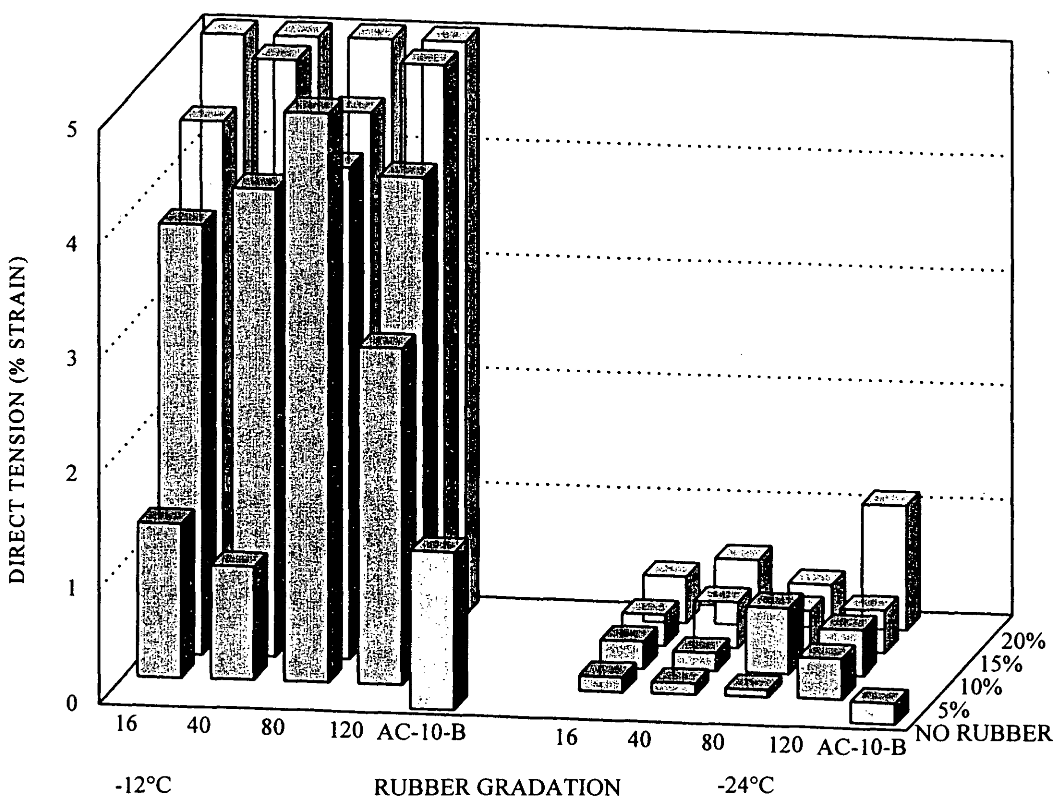

FIGURE 10 Direct tension strain at failure for AC-10-B and all combinations of rubber at −12°C and −24°C.

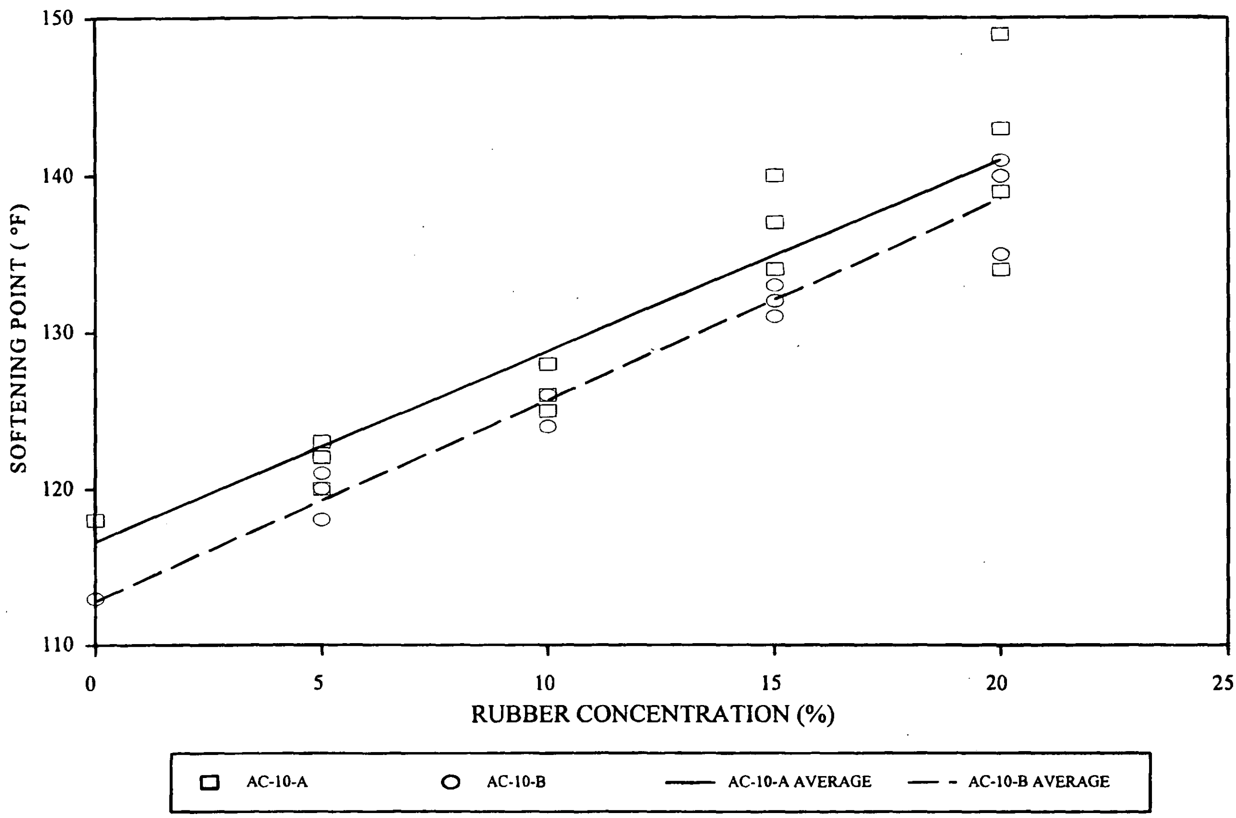

FIGURE 11 Softening point for AC-10-A and AC-10-B with all combinations of rubber.

DT Test

The DT test was the final SHRP test used to evaluate the crumb rubber binders. This test was performed at −12°C and −24°C by using the standard rate of strain of 1 mm/min (*3*). The data from the direct tension test are presented in Figure 10. As Bahia and Davies (*4*) reported, the strain at failure seems to increase as the rubber concentration increases. Also, the strain at failure decreases as the temperature decreases. The data showed considerable scatter.

Conventional Binder Tests

Conventional binder tests were included in the study to tie the data to the existing data base of binder properties. The conventional tests presented are easily performed and are being used for field verification for the modified binder.

Penetration

The penetration test was performed in this series of tests to establish a data base with which to compare the data for the modified binders. The penetration tests were performed at 4°C and 25°C according to ASTM D5. Compared with the original base asphalt cement, the data indicated a decrease in the penetration of the binder at 25°C as the rubber concentration increased. The penetration at 4°C presents no clear trend in the data. Because of the variability observed in the study, it is concluded that this conventional test may not be appropriate for evaluating crumb rubber-modified asphalt.

Softening Point

The softening point test was also performed to provide a data base for conventional binder tests. Figure 11 presents the data accumulated through softening point testing. The data indicate that the softening point increases with increasing rubber concentration and that the size of the particles has no effect. This confirms work done by Chehovitz (*1*).

CONCLUSION

Based on the research performed for this phase of the crumb rubber study, the following conclusions are made.

1. As shown from the DSR, BBR, DT, and softening point tests, the concentration of rubber seems to be the major contributor for the increased stiffness of the asphalt rubber binder at high temperatures and the lower stiffness at the low temperatures.
2. Those same tests indicated that the gradation of the rubber was not a factor in the change in stiffness.
3. The softening point test provides a quick, easy check of the modified binder and may complement the Brookfield viscosity test in the field.
4. The crumb rubber provides a lower temperature susceptibility, as shown in the BBR test.
5. As seen in the DSR test the crumb rubber provides a more rut-resistant binder in the original and TFOT stages and a softer, less brittle binder in the PAV test stage.

6. DSR data typically indicate that rubber binders made with the two AC-10 sources used in the study have similar properties.

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