Evaluation of Physical Properties of Fine Crumb Rubber-Modified Asphalt Binders

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The results of a laboratory experiment aimed at evaluating the physical properties of asphalt binder containing fine crumb rubber modifier are outlined. Binder characterization procedures developed as part of the Strategic Highway Research Program (SHRP) were used in the analysis. The collective products of SHRP asphalt research are now called Superpave. The crumb rubber modifier used was produced from a wet ambient grind process. The maximum rubber particle size was 180 μm, with an average particle size of 74 μm. Testing showed that when compared with the base asphalts, the fine crumb rubber-modified binders were stiffer at high pavement temperatures, were less stiff at low pavement temperatures, and had approximately the same or slightly less stiffness at intermediate temperatures. The behavior of the asphalt rubber binders during rolling thin film oven (RTFO) aging was unlike that of the base asphalts. The fine rubber-modified binders tended to veil across the RTFO bottle during aging, or in other cases it congregated in a thick film around the perimeter of the RTFO bottle during the aging process. Viscosity tests showed that the asphalt rubber binders are subject to viscosity building when they are stored at high temperatures. No other difficulties were encountered in using the Superpave binder analysis procedures to characterize fine crumb rubber-modified binders.

This report summarizes a laboratory experiment aimed at characterizing the physical properties of paving asphalt cement modified with fine crumb rubber modifier (CRM). The Intermodal Surface Transportation and Efficiency Act of 1991 has mandated that state departments of transportation (DOTs) incorporate increasing amounts of scrap tires in asphalt pavements. Concurrently, state DOTs are in the process of implementing Strategic Highway Research Program (SHRP) asphalt research products. Thus, this experiment was principally aimed at determining whether this new method of testing and specifying asphalt binders was suitable for use with fine crumb rubber-modified (CRM) binders. Of particular interest in this analysis were those physical properties necessary to evaluate the rubber-modified asphalt according to the new Superpave performance graded binder specification, which has now been provisionally adopted by AASHTO as MP1 (*1*).

EXPERIMENTAL PLAN

Materials Tested

The rubber product used was a fine crumb rubber produced by Rouse Rubber Industries of Vicksburg, Mississippi. According to the manufacturer it was produced by wet ambient grinding from whole truck tires and is 100 percent finer than 180 μm, with an average particle size of 75 μm. Figure 1 illustrates the particle size distribution of the fine rubber used throughout this project.

It has been reported (*2,3*) that asphalt source and chemical composition interact significantly with various crumb rubbers with respect to binder properties. To minimize this effect asphalts from a single source were used in the study. However, asphalt cements from this one supplier were selected to encompass a wide variety of grades in use in the United States. For one asphalt cement grade another source was used to demonstrate the effect of asphalt source.

The source of the paving asphalt cement for most of the study was Coastal Refining & Marketing, Inc. Five asphalts were used, all meeting the requirements listed in Table 2 of AASHTO M226-80 (*4*). They were AC-2.5, AC-5, AC-10, AC-20, and AC-30. The fine rubber was blended in various concentrations with the asphalt cement to produce a binder on which physical properties were measured. An additional sample of AC-2.5 from Amoco Oil Company was also included in the experiment to demonstrate the effect of asphalt source on binder properties. Physical properties were also measured on the base asphalts.

Blending was accomplished by using a laboratory mixer operated at 3,000 rpm. The fine crumb rubber was slowly added to the asphalt over a period of approximately 5 min. The temperature of the binder during blending was maintained at 175°C. Mixing of the binder continued for a total of 1 hr while the temperature was maintained at 175°C. A single batch of blended material was held constant at 1 L.

Unaged Binder Properties

The unaged binder was tested to determine its viscosity at 135°C by using a rotational coaxial cylinder viscometer. The procedure outlined in ASTM D4402-87 (*5*) was used.

AASHTO TP5 (*6*) was used to measure the viscoelastic properties of the binders, which are complex shear modulus and phase angle. A constant stress dynamic shear rheometer (DSR) operated with parallel plate geometry was used to measure these properties. The maximum rubber particle size (180 μm) is less than the maximum particle size allowed (250 μm) by AASHTO TP5 for filled systems. The complex shear modulus (G^*) is a measure of the total stiffness of the binder and is the vector sum of the elastic and viscous components of binder stiffness. The phase angle (δ) is a measure of the degree to which the binder is acting like an elastic material. Low values of δ indicate a greater contribution of the elastic stiffness component to total stiffness. The parameter of interest, $G^*/\sin \delta$, was usually captured at a sufficient number of temperatures to bracket the specified minimum value of 1.00 kPa from AASHTO MP1.

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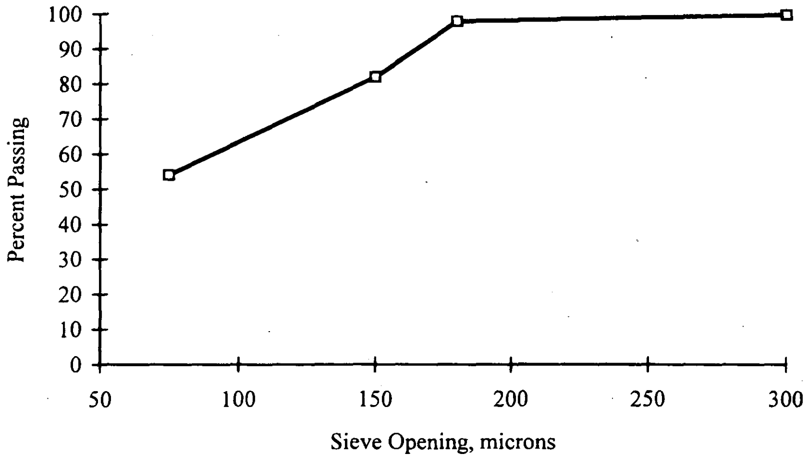


FIGURE 1 Particle size distribution of fine CRM.

Oven-Aged Binder Properties

The rolling thin film oven (RTFO) aging procedure, AASHTO T240 (*7*), was used to age the binders. To estimate the effect of the aging procedure, one binder was oven aged by using the thin film oven (TFO) as described by AASHTO T179-88 (*8*). The oven-aged binder was tested in the DSR to determine $G^*/\sin\delta$. Once again, $G^*/\sin\delta$ was captured at a sufficient number of temperatures to bracket the specified minimum value of 2.20 kPa. The parameter $G^*/\sin\delta$ measured and specified on unaged and oven-aged binder is intended to ensure that the binder is stiff enough to contribute to the overall rutting resistance of an asphalt mixture.

Pressure-Aged Binder Properties

RTFO residue was aged in a pressure aging vessel (PAV) according to AASHTO PP1 (*9*). The PAV residue was tested in the DSR to determine the parameter $G^*\sin\delta$. This parameter was measured at a variety of intermediate temperatures to verify that the PAV-aged residue exhibited a $G^*\sin\delta$ less than 5000 kPa. This specified limit is used in MP1 to ensure that a soft, elastic binder will be present to contribute to overall asphalt mixture resistance to fatigue cracking.

PAV-aged residue was also tested at low temperatures by using the bending beam rheometer (BBR) to measure creep stiffness (S) and logarithmic creep rate (m) as outlined in AASHTO TP1 (*10*). The AASHTO binder specification requires S to be less than 300 MPa and m to be greater than 0.300. These limits are used in MP1 to ensure that the aged binder is suitably soft at low temperatures to ameliorate low-temperature cracking.

Storage Properties

Because pumping and handling of asphalt rubber binders are of concern to many agencies, a limited experiment was performed to assess the viscosity characteristics of various blends. In this portion of the experiment various concentrations of fine mesh rubber were mixed with an AC-5, AC-10, AC-20, and AC-30 asphalt cement. As before, the viscosity of the blends was measured by using a rotational coaxial cylinder viscometer according to the procedures outlined in ASTM D4402–87. Three test temperatures, two shear rates, and two concentrations were tested.

TEST RESULTS

Table 1 illustrates the binder classifications for all binders tested. In Table 1 PG *XX-YY* is binder performance grade. *XX* refers to the high-temperature grade and is the average 7-day maximum pavement design temperature in AASHTO MP1. *YY* refers to the low-temperature grade and is the minimum pavement design temperature. For the materials tested the addition of fine rubber resulted in an increase in high-temperature grade and a decrease in low-temperature grade. A trend observed in these data is that 7.5 percent fine rubber increased the high-temperature grade by about one grade from that of the base asphalt. Fifteen percent fine rubber increased the high-temperature grade by two to three grades and the low-temperature grade by one grade. As expected AC-2.5 binders from two sources resulted in different performance properties.

In Table 1 a borderline grade is indicated when the m-value is within 0.010 of the specified value of 0.300. For example, the AC-20 with 7.5 percent rubber exhibited an m-value at -18°C of 0.296, which resulted in the classification of performance grade PG 70–22. Only a small increase in the m-value of 0.004 would have caused the binder to be classified as PG 70–28; hence, it is shown as a borderline grade.

In every case the low-temperature grade of asphalt rubber blends was controlled by the m-value. Only in the case of the neat AC-2.5 (Amoco) was the low-temperature grade influenced by the 5000-kPa limit placed on $G^*\sin\delta$.

The increase in high-temperature grade with the addition of fine-mesh rubber was a result of the increase in high-temperature stiffness as manifested by measured values for $G^*/\sin\delta$ (Table 2). Table 3 shows individual values for G^* and δ at various testing temperatures. The increase in $G^*/\sin\delta$ with increasing rubber concentration was almost entirely caused by an increase in G^*. The effect of δ was marginal, although higher rubber concentrations resulted in lower δ values.

TABLE 1 Classifications of Fine CRM Binders According to AASHTO MP1

Material	Performance Grade	Borderline Performance Grade[1]
AC-2.5 (Coastal)	PG 46-28	-
10% Fine CRM	PG 52-34	-
20% Fine CRM	PG 58-34	PG 58-40
AC-2.5 (Amoco)	PG 46-28	-
7.5% Fine CRM	PG 58-34	-
15% Fine CRM	PG 70-34	PG 70-40
20% Fine CRM	PG 70-34	-
AC-5 (Coastal)	PG 58-28[2]	-
7.5% Fine CRM	PG 58-28	-
15% Fine CRM	PG 70-34	-
AC-10 (Coastal)	PG 58-22	-
7.5% Fine CRM	PG 64-22	PG 64-28
15 % Fine CRM	PG 70-28	-
AC-20 (Coastal)	PG 64-22	-
7.5% Fine CRM	PG 70-22	PG 70-28
7.5% Fine CRM (TFO)	PG 70-22	-
15% Fine CRM	PG 82-28	-
20 % Fine CRM	PG 82-28	-
AC-30 (Coastal)	PG 64-22	-
7.5% Fine CRM	PG 76-22	-
15% Fine CRM	PG 82-28	PG 82-34

[1] Borderline grade indicates that $0.290 \leq m < 0.300$ at grading temp shown.

[2] Base asphalt was borderline PG 52-28 because $G^*/\sin\delta = 1.01$ kPa.

Table 4 shows G^* and δ values for RTFO-aged binders. As with unaged binders, the stiffness parameter $G^*/\sin\delta$ increases with increasing rubber concentration. Again, the effect is almost entirely due to G^*, with very little contribution of δ. A higher rubber concentration resulted in a lower δ value.

During this testing fine rubber-modified binders exhibited unusual RTFO aging characteristics. Two scenarios were observed. Harder base asphalt (AC-20 and AC-30) with 15 percent or more fine rubber tended to veil across the RTFO bottle during the aging procedure. In some cases the bottle was not coated along its entire length, even after the 85-min aging period. The softer asphalts containing fine rubber tended to flow around the perimeter of the bottle, but without a level of material continually in the bottom of the bottle, which is the trait exhibited by normal paving asphalts. Figure 2 illustrates these effects.

TABLE 2 $G^*/\sin\delta$ (kPa) Values for Fine CRM Binders (Unaged)

Material	Testing Temperature, °C						
	46	52	58	64	70	76	82
AC-2.5 (Coastal)	1.85	0.76	-	-	-	-	-
10% Fine CRM	-	2.41	1.10	0.53	-	-	-
20% Fine CRM	-	-	2.17	1.14	0.62	-	-
AC-2.5 (Amoco)	2.12	0.95	-	-	-	-	-
7.5% Fine CRM	-	-	1.54	0.75	-	-	-
15% Fine CRM	-	-	-	-	1.11	0.64	-
20% Fine CRM	-	-	-	-	1.55	0.92	-
AC-5 (Coastal)	-	-	1.01	-	-	-	-
7.5% Fine CRM	-	-	1.61	-	-	-	-
15% Fine CRM	-	-	-	2.34	1.21		-
AC-10 (Coastal)	-	-	1.83	0.87	-	-	-
7.5% Fine CRM	-	-	3.93	1.87	-	-	-
15 % Fine CRM				-	1.81	1.23	-
AC-20 (Coastal)	-	-	2.58	1.15	-	-	-
7.5% Fine CRM	-	-	-	-	1.42	-	-
7.5% Fine CRM (TFO)	-	-	-	-	1.42	-	-
15% Fine CRM	-	-	-	-	-	2.93	1.65
20% Fine CRM	-	-	-	-	-	-	2.10
AC-30 (Coastal)	-	-	-	1.70	0.79	-	-
7.5% Fine CRM	-	-	-	-	2.25	1.23	-
15% Fine CRM	-	-	-	-	-	4.01	2.17

TABLE 3 ***G*/sin δ* Values for Fine CRM Binders (Unaged)**

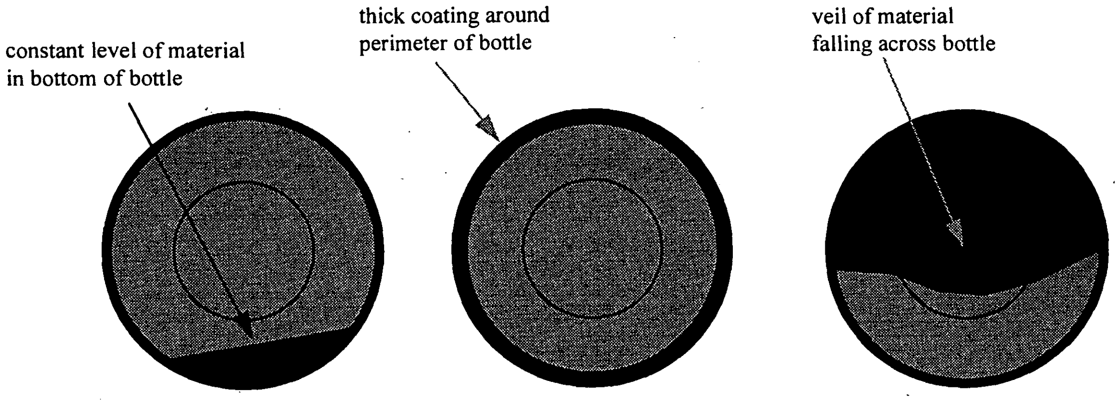
Material	Test Temp (°C)	G* (kPa)	δ (degrees)	G*/sin δ (kPa)
AC-2.5 (Coastal)	58	-	-	-
10% Fine CRM		1.11	81.63	1.13
20% Fine CRM		2.01	74.98	2.17
AC-2.5 (Amoco)	70	-	-	-
7.5% Fine CRM		-	-	-
15% Fine CRM		1.08	75.81	1.11
20% Fine CRM		1.50	74.95	1.55
AC-5 (Coastal)	58	1.00	87.07	1.01
7.5% Fine CRM		1.60	84.06	1.61
15% Fine CRM		-	-	-
AC-10 (Coastal)	64	0.87	87.39	0.87
7.5% Fine CRM		1.86	83.54	1.87
15 % Fine CRM		-	-	-
AC-20 (Coastal)	82	-	-	-
7.5% Fine CRM		-	-	-
7.5% Fine CRM (TFO)		-	-	-
15% Fine CRM		1.60	75.66	1.65
20% Fine CRM		2.03	75.08	2.10
AC-30 (Coastal)	76	-	-	-
7.5% Fine CRM		1.17	72.74	1.23
15% Fine CRM		3.78	70.43	4.01

To investigate the effect of the oven aging procedure, one sample (AC-20 with 7.5 percent fine CRM) was aged in the TFO and tested. For this binder the method of oven aging did not affect the final classification, although the RTFO-aged binder was less stiff when it was tested at 70°C. As noted previously only a small change in the *m*-value at −18°C would have caused the RTFO-aged sample to be classified differently. The TFO-aged sample was not borderline with respect to the *m*-value. Table 5 shows a more direct comparison of the various parameters of interest. For this binder the method of oven aging did not have a great effect on binder stiffness. The most significant difference between the two aging methods was the *m*-value at −18°C.

Table 6 shows the values of *G**/sin δ before and after RTFO aging. These data compare the increase in *G**/sin δ of modified binders with those of the base asphalts after RTFO aging. No consistent trend in these data exists. The base asphalts exhibit an

TABLE 4 ***G*/sin δ* (kPa) Values for Fine CRM Binders (RTFO)**

Material	Test Temp (°C)	G* (kPa)	δ (degrees)	G*/sin δ (kPa)
AC-2.5 (Coastal)	58	-	-	-
10% Fine CRM		1.79	78.35	1.83
20% Fine CRM		2.100	74.98	2.17
AC-2.5 (Amoco)	70	-	-	-
7.5% Fine CRM		-	-	-
15% Fine CRM		2.07	68.65	2.23
20% Fine CRM		3.37	66.89	3.66
AC-5 (Coastal)	58	2.39	84.10	2.40
7.5% Fine CRM		4.19	75.07	4.33
15% Fine CRM		-	-	-
AC-10 (Coastal)	58	3.97	83.40	3.99
7.5% Fine CRM		6.35	74.19	6.60
15 % Fine CRM		-	-	-
AC-20 (Coastal)	82	-	-	-
7.5% Fine CRM		-	-	-
7.5% Fine CRM (TFO)		-	-	-
15% Fine CRM		2.50	69.77	2.66
20% Fine CRM		3.66	67.87	3.95
AC-30 (Coastal)	-	-	-	-
7.5% Fine CRM		-	-	-
15% Fine CRM		-	-	-



Normal Aging for Paving Asphalt

Low Concentration Fine CRM in Soft Asphalt

High Concentration Fine CRM in Hard Asphalt

FIGURE 2 RTFO aging characteristics of fine rubber binders (end view of bottle).

TABLE 5 Comparison of Classification Test Parameters as Function of Oven Aging

AC-20, 7.5% Fine CRM (Coastal)		
Parameter	Oven Aging Technique	
	RTFO	TFO
Tests on Unaged Material		
G*/sin δ @ 70° C	1.42 kPa	
Tests on Oven Aged Residue		
G*/sin δ @ 70° C	3.60 kPa	3.91 kPa
Tests on PAV Residue		
G*sin δ @ 16° C	4955 kPa	5293 kPa
G*sin δ @ 19° C	3640 kPa	3950 kPa
S @ -12° C	104 MPa	99 MPa
m @ -12° C	0.355	0.345
S @ -18° C	212 MPa	227 MPa
m @ -18° C	0.296	0.277

TABLE 6 Comparison of Increase in *G*/sin δ* for Fine CRM Binders

Material	Test Temp (°C)	G*/sin δ unaged	G*/sin δ RTFO aged	Increase (%)
AC-2.5 (Coastal)	46	1.85	3.73	101.6
10% Fine CRM	52	2.41	3.71	53.9
20% Fine CRM	64	1.14	1.55	36.0
AC-2.5 (Amoco)	46	2.12	5.29	149.5
7.5% Fine CRM	58	1.54	3.31	114.9
15% Fine CRM	70	1.11	2.23	100.9
20% Fine CRM	70	1.55	3.66	136.1
AC-5 (Coastal)	58	1.01	2.41	138.6
7.5% Fine CRM	58	1.61	4.33	168.9
15% Fine CRM	70	1.21	3.17	162.0
AC-10 (Coastal)	58	1.83	3.99	116.9
7.5% Fine CRM	64	1.87	3.03	62.0
15% Fine CRM	70	1.81	4.00	121.0
AC-20 (Coastal)	64	1.15	2.40	108.7
7.5% Fine CRM	70	1.42	3.60	153.5
7.5% Fine CRM (TFO)	70	1.42	3.91	175.4
15% Fine CRM	82	1.65	2.66	61.2
20% Fine CRM	82	2.10	3.95	88.1
AC-30 (Coastal)	64	1.70	4.00	135.3
7.5% Fine CRM	76	1.23	2.86	132.5
15% Fine CRM	82	2.17	3.93	81.1

TABLE 7 ***G*/sin δ* Values for Fine CRM Binders**

Material	Test Temp (°C)	G* (kPa)	δ (degrees)	G*sin δ (kPa)
AC-2.5 (Coastal)	13	7009	45.43	4993
10% Fine CRM		3644	48.43	2726
20% Fine CRM		2851	47.91	2116
AC-2.5 (Amoco)	13	5073	46.64	3688
7.5% Fine CRM		5475	39.86	3509
15% Fine CRM		4095	39.79	2621
20% Fine CRM		3219	39.08	2029
AC-5 (Coastal)	16	5209	44.59	3657
7.5% Fine CRM		3635	43.87	2519
15% Fine CRM		-	-	-
AC-10 (Coastal)	16	7820	37.82	4795
7.5% Fine CRM		4455	39.14	2812
15 % Fine CRM		-	-	-
AC-20 (Coastal)	19	8314	39.79	5321
7.5% Fine CRM		5756	39.23	3640
7.5% Fine CRM (TFO)		-	-	3950
15% Fine CRM		5528	35.74	3229
20% Fine CRM		5326	35.30	3078
AC-30 (Coastal)	19	9725	38.54	6059
7.5% Fine CRM		7481	37.50	4554
15% Fine CRM		6091	35.71	3555

increase in *G*/sin δ* ranging from about 100 to 150 percent. This roughly matches the specification value of 120 percent, which results from the minimum specified values of 1.00 and 2.20 kPa for unaged and RTFO-aged binders, respectively. For the rubber-modified binders this increase is considerably more variable, with values ranging from about 36 to 175 percent.

Table 7 shows values of *G*sin δ* for PAV residue for the various materials. In every case the addition of rubber facilitated a decrease in *G*sin δ*. At these intermediate temperatures (approximately 10°C to 20°C) the effect of the rubber on *G*sin δ* was almost entirely due to *G**. In other words the profound reduction in *G*sin δ* was caused by a large reduction in *G** and not δ. The intermediate testing temperatures shown in Table 7 were chosen in a range for binder classification purposes. At these temperatures binders containing fine-mesh rubber exhibited a lower *G** value than the base asphalt. At high temperatures (see Tables 2, 3, and 4) the unaged rubber blends exhibited higher *G** values than the base asphalts. In other words the effect of fine-mesh rubber on *G*sin δ* must be less profound at higher intermediate temperatures. To demonstrate this phenomenon a temperature sweep was performed on the PAV-aged residues of four samples: AC-5, AC-20, and these two binders with 10 percent fine rubber. Figure 3 shows the results of that experiment. All four binders have very similar stiffness values in the range from 30°C to 40°C. On the basis of this limited experiment hotter climates would tend to favor neat asphalts or possibly neither with respect to fatigue life since the neat asphalts exhibit less stiffness at higher interme-

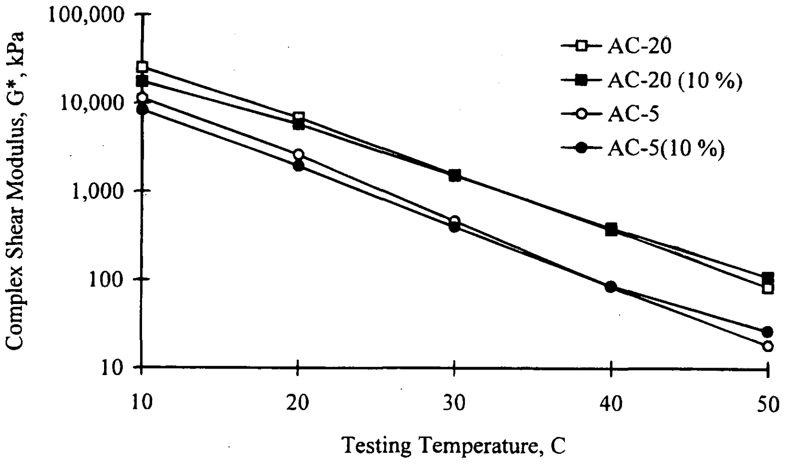


FIGURE 3 **Complex shear modulus characteristics of PAV-aged fine rubber binders.**

TABLE 8 Creep Stiffness and Logarithmic Creep Rate for Fine CRM Binders

Material	Test Temp (°C)	Creep Stiffness (MPa)	Creep Rate
AC-2.5 (Coastal)	-24	337	0.279
10% Fine CRM		219	0.318
20% Fine CRM		143	0.361
AC-2.5 (Amoco)	-24	-	-
7.5% Fine CRM		199	0.316
15% Fine CRM		138	0.336
20% Fine CRM		114	0.331
AC-5 (Coastal)	-24	350	0.265
7.5% Fine CRM		243	0.288
15% Fine CRM		174	0.304
AC-10 (Coastal)	-18	200	0.289
7.5% Fine CRM		131	0.298
15 % Fine CRM		118	0.321
AC-20 (Coastal)	-18	251	0.276
7.5% Fine CRM		212	0.296
7.5% Fine CRM (TFO)		227	0.277
15% Fine CRM		163	0.309
20% Fine CRM		132	0.306
AC-30 (Coastal)	-18	306	0.286
7.5% Fine CRM		232	0.287
15% Fine CRM		96	0.335

diate temperatures. Cooler climates would tend to favor the fine rubber binders since they exhibit less stiffness at lower intermediate temperatures. However, the technical literature and anecdotal experience with the performance of pavements containing fine crumb rubber binders seem to support neither assertion. This limited experiment coupled with field observations of real pavement performance suggests that intermediate temperature binder rheology alone is not sufficient to predict mixture fatigue behavior when using fine rubber binders. Sweeping comparisons of relative fatigue behavior on the basis of neat versus rubber-modified binders may be very tenuous.

Table 8 compares the creep stiffnesses of binders at various temperatures. These data show that an increase in rubber concentration results in a decrease in *S* and an increase in the *m*-value. The increase in the *m*-value is the reason that the addition of fine rubber resulted in lower low-temperature binder grades. One possible reason for this result is that higher concentrations of fine rubber may result in less aging through the RTFO because of the observed aging behavior illustrated in Figure 2. Less aging may also be the result of the presence of antioxidants in tire compounds. Another possible reason is that at low temperatures the rubber component is softer than the base asphalt, resulting in the same type of softening effect seen at intermediate temperatures for the parameter $G^*\sin\delta$. A third possible reason is that the rubber releases a constituent that has a softening effect on the asphalt at lower temperatures.

The viscosity of each blend was measured at 135°C (Table 9). In all cases the fine rubber caused an increase in binder viscosity at 135°C compared with that of the base asphalt. AASHTO MP1 requires that the viscosity at 135°C be less than 3 Pa·sec. Several of the binders violated this requirement. However, MP1 states that the viscosity criterion may be violated if the supplier warrants that the asphalt can be pumped and mixed at safe temperatures.

To assess the effects of fine-mesh rubber on handling characteristics, the viscosities of various blends of asphalt and fine-mesh rubber were tested. The following factors were evaluated:

- Asphalt grade (AC-5, AC-10, AC-20, and AC-30),
- Test temperature (150°C, 175°C, and 200°C),
- Rubber concentration (0, 10, and 20 percent), and
- Shear rate (20 and 50 rpm).

Figures 4 through 7 show the effects of these factors on blend viscosity. Several trends emerged from this experiment. First, there is a large increase in viscosity by increasing the concentration from 0 to 10 percent and from 10 to 20 percent. All blends shear thinned at all test temperatures. For the neat asphalts the viscosity test results

TABLE 9 Viscosity of Fine CRM Binders

Material	Viscosity at 135° C (Pa·s)
AC-2.5 (Coastal)	0.135
10% Fine CRM	0.485
20% Fine CRM	2.378
AC 2.5 (Amoco)	0.158
7.5% Fine CRM	0.480
15% Fine CRM	2.215
20% Fine CRM	6.550
AC-5 (Coastal)	0.190
7.5% Fine CRM	0.750
15% Fine CRM	1.800
AC-10 (Coastal)	0.240
7.5% Fine CRM	1.217
15 % Fine CRM	3.225
AC-20 (Coastal)	0.400
7.5% Fine CRM	1.175
15% Fine CRM	4.750
20% Fine CRM	12.687
AC-30 (Coastal)	0.490
7.5% Fine CRM	1.275
15% Fine CRM	5.425

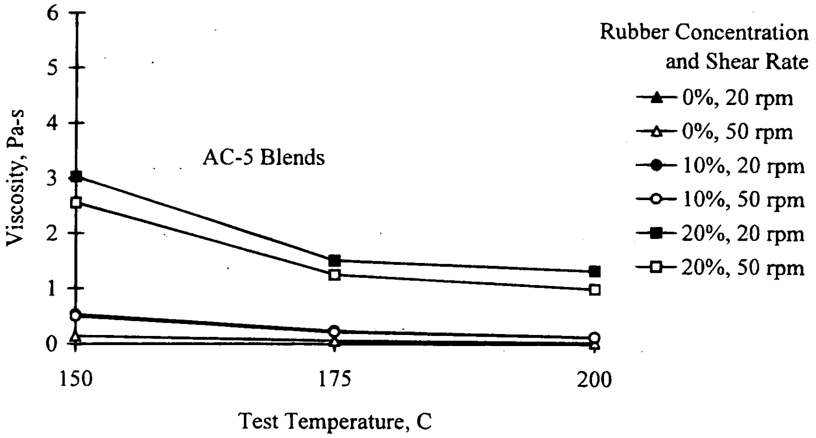


FIGURE 4 Effects of test temperature, rubber concentration, and shear rate on viscosities of AC-5 blends.

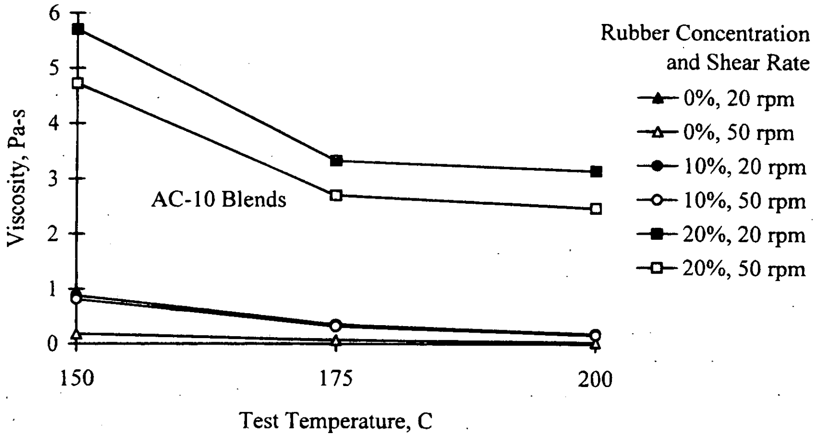


FIGURE 5 Effects of test temperature, rubber concentration, and shear rate on viscosities of AC-10 blends.

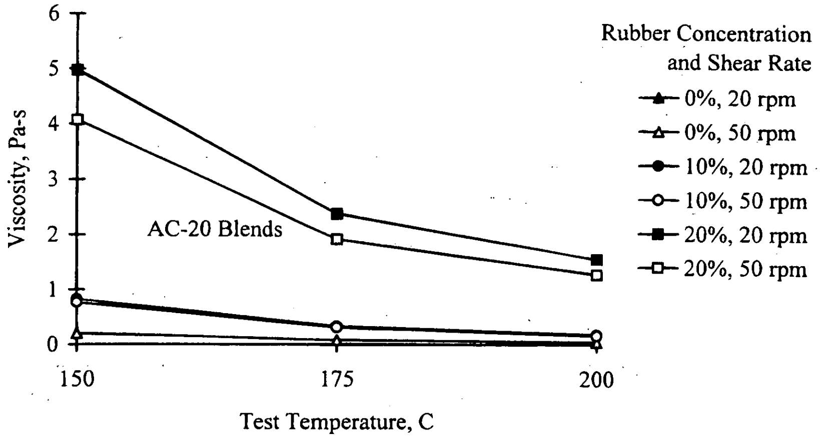


FIGURE 6 Effects of test temperature, rubber concentration, and shear rate on viscosities of AC-20 blends.

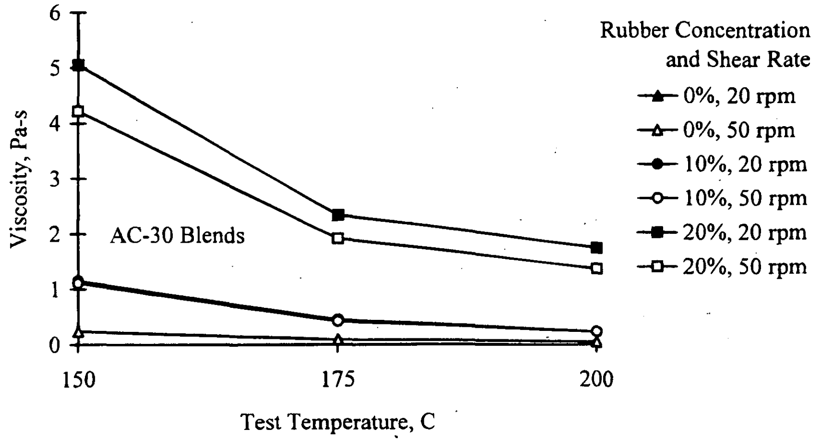


FIGURE 7 Effect of Test Temperature, Rubber Concentration, and Shear Rate on viscosity of AC-30 blends.

were identical for the two shear rates (i.e., the lines of data in Figures 4 through 7 coincide for the neat asphalts).

One unexpected result was the relatively small decrease in viscosity for the 20 percent fine rubber blends when the testing temperature was increased from 175°C to 200°C. This effect was also evident, but to a lesser degree, for the 10 percent blends. The effect is clearly caused by the presence of the fine-mesh rubber since the same phenomenon did not occur with the neat asphalts. During these tests it was observed that when changing test temperature, the viscosity would briefly stabilize when the sample equilibrated at the test temperature and then would begin to rise slowly. This effect was also observed by Bahia and Davies (*2*). Thus, it is possible that an additional asphalt rubber reaction is occurring at these relatively high test temperatures and that this reaction causes a stiffening of the binder. Although this stiffening is not sufficient to completely overcome the effect of test temperature, the net effect is to impede the effect of temperature on viscosity, which flattens the slope of the temperature-viscosity plot between 175° and 200°C.

To estimate the effect of storage time at elevated temperature on viscosity, a simple experiment was performed. One liter each of AC-20 and AC-30 containing 10 percent fine rubber was mixed as normal at 177°C. A sample of neat AC-20 was also tested. The viscosity at 175°C was measured immediately after blending and after 4, 24, 48, and 72 hr. Figure 8 shows the test results. After an initial increase in viscosity between blending and 4 hr, the viscosity begins a gradual increase with time. The rate of increase is approximately the same for the fine rubber binders and neat asphalt.

CONCLUSIONS

The analysis presented here shows that fine mesh rubber affects binder physical properties and classification according to the AASHTO performance graded binder system. For the asphalts tested the addition of a small amount of fine rubber resulted in a binder that was generally classified one high-temperature grade

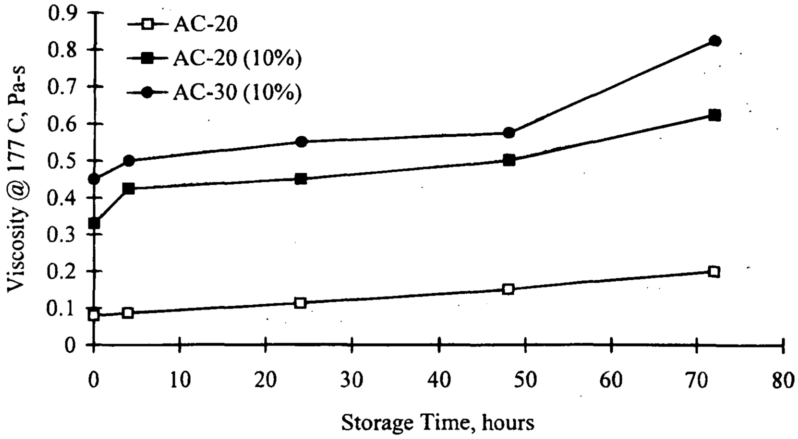


FIGURE 8 Effect of storage time on viscosity.

higher than that of the base asphalt. For the asphalts tested the addition of a moderate amount of rubber resulted in a binder that was generally classified two or three high-temperature grades higher and one low-temperature grade lower than those of the base asphalt. It is well known that the asphalt source and rubber composition have a profound effect on the physical properties of an asphalt–rubber blend. The present study was limited in scope because it generally involved only one asphalt source and one rubber source.

Other than the curious binder behavior during RTFO aging, no problems were encountered by using the Superpave methods of binder characterization required by AASHTO MP1. DSR, BBR, and PAV did not exhibit any difficulties in characterizing fine rubber-modified asphalt. However, the study suggests that the current AASHTO procedure, which uses RTFO, may or may not be producing a properly aged sample when used to analyze asphalt binders containing fine-mesh rubber.

Viscosity test results showed that at typical storage and handling temperatures, asphalt binders containing fine-mesh rubber are very viscous. Furthermore, rotational viscosity testing showed that at normal storage and handling temperatures, viscosity slowly increases with time. This suggests that when testing fine-mesh rubber binders, the thermal history of the samples must be carefully controlled if repeatable test results are to be achieved. It also suggests that field storage time will have a great effect on the handling characteristics of fine-mesh rubber binders.

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