A LABORATORY AND FIELD STUDY ON THE USE OF ELASTOMERS IN HOT-MIX EMULSIFIED ASPHALTS

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• ASPHALTIC materials used as paving mixtures are selected with respect to stability and durability design criteria. The stability design criteria require paving mixtures to have sufficient initial stability to withstand the applied traffic loads. The durability design criteria, however, are concerned with the performance of paving mixtures under the traffic and environmental factors to which pavements are exposed during their service lives. Not all paving mixtures fulfill these two design requirements. In recent years, researchers have explored various means of improving qualities of paving mixtures, among which is the use of rubber additives in the asphaltic systems.

Historically many asphalt-rubber pavements have been constructed throughout the world. Various types of latices such as butyl, styrene-butadiene, acrylonitrile butadiene, and neoprene have been used, and different means of incorporating these materials into the hot-mix process have been employed. Two popular methods are (a) rubberizing the asphalt cement before the pug mill and (b) injecting the rubber latex directly into the pug mill.

A test pavement was constructed by using the hot-mix emulsion approach because (a) it has proved very successful, especially in Indiana; (b) latex, commonly anionic, is readily compatible in an anionic asphalt-emulsion system; (c) the homogeneity of the latex asphalt-emulsion and the immediate release of steam when the emulsion contacts the hot aggregate facilitate the coating of the aggregate, ensure complete dispersion throughout the mix, and inhibit thin film oxidation; (d) storage characteristics are excellent; (e) rubberized emulsion is easily pumped at temperatures slightly above ambient; and (f) depolymerization of the rubber can be held to a minimum (thus the maximum effect of the polymer in the mix can be used because of the cooling effect of the steam released from the mix).

A test pavement was constructed at Ashland Chemical's new Carbon Black Plant under construction at Belpre, Ohio. This site was chosen to permit an accurate traffic count of the number of vehicles and the weight per axle load. Traffic control and accurate vehicle weight are difficult to control on a public road (1, 2).

Figure 1 shows the top view and lateral cross section of the test pavement. All of the sections were laid on a prepared subgrade using the Ohio Department of Highways' 402 mix specifications.

Sections A, B, and C were constructed using MS-2h emulsion having an asphalt content of 70 percent. Control section A is without additive. Section B contains 1½ percent by weight and section C 3.0 percent by weight of SBR solids based on the asphalt content of the MS-2h emulsion. The SBR rubber was added in the form of latex. Control section D was constructed with conventional 85- to 100-penetration asphalt cement. The MS-2h emulsion base was identical to the 85- to 100-penetration asphalt cement. Asphalt or rubberized asphalt containing 5.6 percent by weight of SBR solids was used in each of the test sections.

Four-in. core specimens and slab specimens were removed from the pavement immediately after construction and at 1- and 2-year intervals. The rheological, strength,

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and flexural fatigue characteristics of the asphalt-rubber mixtures were compared with control samples without additives at 0, 1, and 2 years to determine their relative durability under traffic loads and changing environmental conditions.

METHOD OF ANALYSIS

To investigate the engineering properties of the paving mixture, we sawed the cylindrical cores obtained from the pavement into samples 4 in. in diameter by 5 in. in length, which were used for compressive strength and compressive creep experiments. In addition, cylindrical specimens 4 in. in diameter and 2½ in. in length were prepared for Marshall stability evaluation. The unconfined compressive strength tests were conducted according to ASTM D 1074-60 at temperatures of 41, 77, 100, and 140 F. For such mixtures, a minimum of three samples were used at each temperature.

The compressive creep experiments were carried out on triplicate samples at 41, 77, 100, and 140 F and at stresses of 12, 6, 2, and 1 psi respectively. The specimens were preconditioned by applying and removing each stress twice. In the third cycle the load was maintained for a period of 1,500 sec during which creep deformation was recorded on a two-channel Sanborn recorder (3, 4).

The Marshall stability experiments were conducted on 4- by 2½-in. specimens according to ASTM D 1559, and the stability and flow were determined at 77, 100, and 140 F (5).

The beam specimens of 1½ by 1½ by 15 in., which were prepared from pavement slabs, were subjected to flexural fatigue and flexural strength measurements. In the flexural fatigue experiments, a deflection of 0.035 in. was imposed on the beams at a rate of 15 cpm, and the stiffness modulus was determined for various cycles of load repetition. The flexural strength tests (modulus of rupture) were conducted according to ASTM C 293-64 (5, 6, 7, 8).

In addition to determining the engineering properties of the pavement cores, we analyzed the asphaltic binder extracted from the pavement. The Immerex Method of extraction (ASTM D 2172) with a solvent system especially developed by Ashland Asphalt Research and the Abson method of recovery (ASTM D 1856) were used in this process. Physical and rheological experiments such as penetration (ASTM D 5), softening point (ASTM D 36), and viscosity were conducted on the extracted binder (5).

ANALYSIS AND DISCUSSION OF RESULTS

Strength Evaluation

To investigate the effect of rubber additives on the strength characteristics of paving mixtures, we used two independent methods of testing in this study: unconfined compressive strength and Marshall stability tests. These tests were conducted on four mixtures at various testing temperatures.

The results of unconfined compressive strength of asphaltic mixtures at 0, 1, and 2 years in service are given in Table 1. The comparison of these experimental data indicates that the phenomena of age-hardening and age-softening have taken place in the paving mixtures. Control mixture D, after 1 year in service, exhibited age-hardening at all test temperatures. Age-hardening is also evident from the strength data of the other three mixtures at 140 F. The decrease in the strength of mixtures A(1), B(1), and C(1) at temperatures of 41, 77, and 100 F after 1 year in service is the evidence of the age-softening phenomenon.

The strength of the paving mixtures after 2 years in service exhibits a somewhat different trend. At 140 F there is a reverse trend of age-softening for the four mixtures studied. At 41 F, the age-softening trend for mixtures A(2), B(2), and C(2) is reversed. A similar reversal of age-softening is apparent for these mixtures at the other test temperatures. The age-hardening trend is continued for material D(2) at temperatures of 41, 77, and 100 F.

The comparison of the Marshall stability data at various test temperatures for materials A, B, C, and D at ages of 0, 1, and 2 years indicates a very similar trend. These data are given in Table 2. It is interesting to note that the percentage of increase in the Marshall stability of mixture D due to aging is substantially higher than the percentage of change in the other mixtures. The age dependency of the compressive strength and Marshall stability of these four mixtures is indicated by the strength-ratio service-life relations shown in Figures 2, 3, 4, and 5. The similarity between Marshall stability data and compressive strength is quite apparent.

In summary, the observed trend of the variation of mixture strength (compressive strength and Marshall stability) with age indicates that control mixtures D(0), D(1), and D(2) have substantially age hardened. This age-hardening may eventually lead to brittleness and could cause cracking of the pavement. Mixtures B and C, which contain the rubber additives, first exhibit age-softening after 1 year in service and then, in a reversal trend, appear to be approaching initial strength characteristics. That is, for all practical purposes, age-hardening has been retarded in these mixtures. Mixture A (control mixture with 0 percent additive) appears to be exhibiting a continuous trend of age-softening.

Flexural Response

The results of the flexural fatigue experiments conducted on asphaltic beams confirm the previously described phenomena of age-hardening and age-softening. Control mixture D with 85- to 100-penetration asphalt cement exhibits a substantial age-hardening characteristic. On the other hand, mixture A, with 0 percent additive, follows an age-softening trend (Fig. 6). The rubberized mixtures B and C, which exhibited an age-softening after the first year in service, have slightly age hardened in the second year and are approaching the initial flexural fatigue characteristics. However, a comparison of the stiffness modulus as calculated from fatigue equations (Table 3) indicates that mixture C(2), even after 2 years in service, has remained superior to the other mixtures. Mixture B(2), with 1½ percent rubber additive, exhibits better flexural fatigue characteristics than do mixtures A and D. Mixtures A(2) and D(2) appear to have similar characteristics after 2 years in service.

The result of flexural strength as measured by the modulus of rupture indicates that (Fig. 6) the rubberized mixtures B(2) and C(2) are superior to the other mixtures. With respect to age-hardening phenomena, again it is noted that mixture D(2) has substantially age hardened, whereas the relative changes in the other mixtures are negligible.

Rheological Response

In this study, asphaltic specimens were subjected to uniaxial compressive creep experiments at temperatures of 41, 77, 100, and 140 F. The creep stresses were respectively 12, 6, 2, and 1 psi for these temperatures. After two cycles of preconditioning, the deformation of specimens for the third loading cycle was recorded, and the creep compliance J(t), which is strain per unit stress, was determined. Figures 7 and 8 show two typical creep curves after 1 and 2 years in service.

The comparison of creep compliance of four mixtures indicates that, after 1 year in service, age-softening (corresponding to higher creep deformation) has taken place in mixture C(1). Age-hardening, corresponding to the reduction in creep deformation, has occurred in mixture D(1). After 2 years in service, however, the change in the creep compliance of mixtures A(2), B(2), and C(2) is insignificant as compared to the change in the creep compliance of D(2). Mixture D(2) has continued to age harden. This observation is in agreement with the age-hardening and age-softening phenomena discussed previously.

It is well known that rheological behavior of asphaltic mixtures similar to other viscoelastic materials depends on two parameters: time and temperature. In this study, the creep data after 1 year in service were subjected to time-temperature superposition principles, and the temperature-dependent function a_T was determined. The a_T-T relation for four mixtures is shown in Figure 9. Similarly, a typical master curve, developed after superimposing the rheological data, is shown in Figure 10. From the comparison of a_T-T relation for four mixtures, it is apparent that mixture C(1) is the least temperature-dependent material, whereas D(1) is the most dependent.

Figure 1. Test pavement.

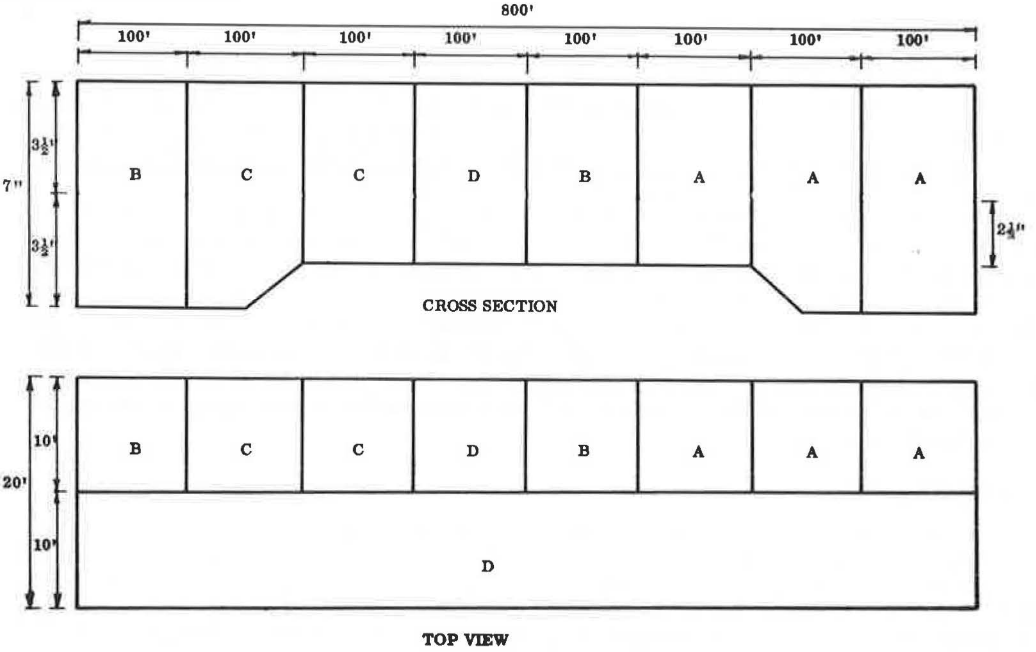


Table 1. Compressive strength of asphaltic mixtures.

Temperature (deg F)	Compressive Strength, psi											
	A(0)	A(1)	A(2)	B(0)	B(1)	B(2)	C(0)	C(1)	C(2)	D(0)	D(1)	D(2)
41	709.8	455	605	710.0	358	480	710.8	334	446	590	755	1,070
77	301	200	191	315.0	182	184	385.7	158	198	230	342	485
100	109.2	120	103	124.7	87.5	64.5	141.7	91	64	57.7	143	141
140	13.7	71.5	21.4	12.0	74.5	18.3	18.3	59.5	19	6.3	83.5	33.4

Table 2. Marshall stability of asphaltic mixtures.

Temperature (deg F)	Marshall Stability, lb											
	A(0)	A(1)	A(2)	B(0)	B(1)	B(2)	C(0)	C(1)	C(2)	D(0)	D(1)	D(2)
77	4,536	4,195	3,544	5,275	3,747	4,300	4,711	4,319	3,825	4,650	6,159	5,800
100	2,566	2,513	2,280	2,555	1,980	1,538	2,589	1,849	2,180	1,597	2,281	2,932
140	518	888	951	353	654	518	671	1,125	651	370	952	851

Figure 2. Age dependency of Marshall stability, mixture C.

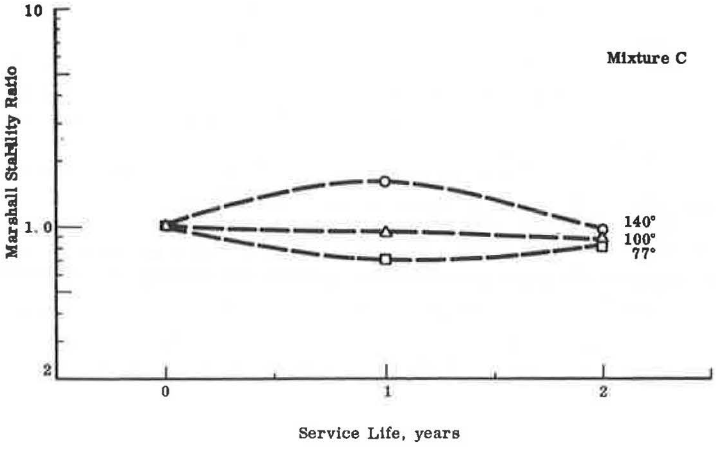


Figure 3. Age dependency of compressive strength, mixture C.

Figure 4. Age dependency of Marshall stability, mixture D.

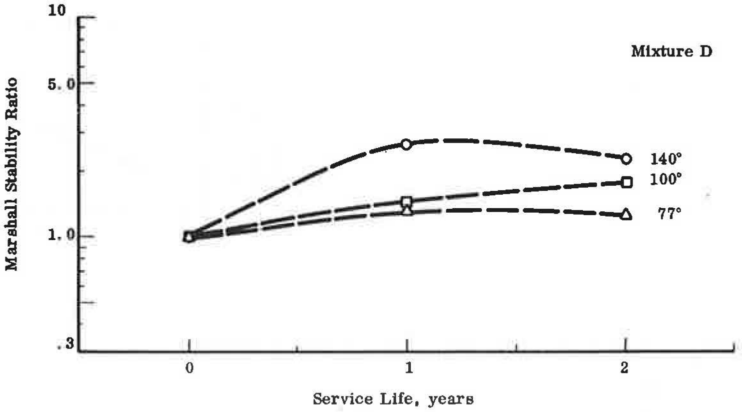


Figure 5. Age dependency of compressive strength, mixture D.

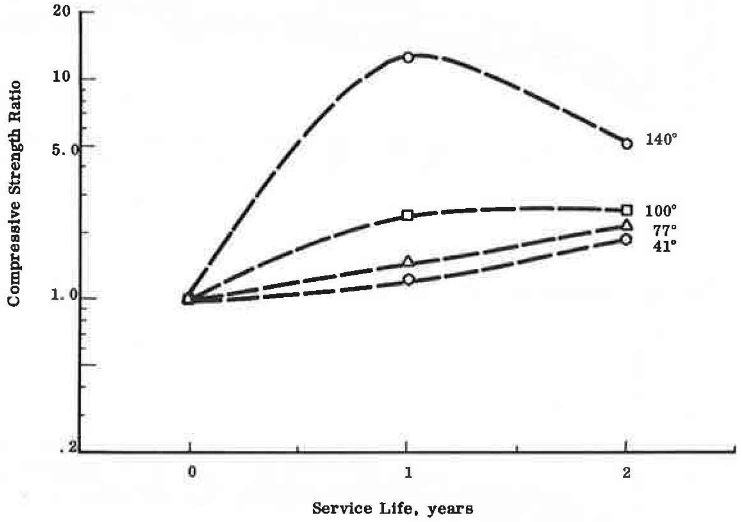


Table 3. Variation of stiffness modulus with age.

	Flexural Fatigue, Stiffness Modulus, psi × 10^3											
Cycles	A(0)	A(1)	A(2)	B(0)	B(1)	B(2)	C(0)	C(1)	C(2)	D(0)	D(1)	D(2)
10	87.7	76.2	72.0	106.6	70.2	94.0	108.2	75.6	96.0	29.7	54.2	67.0
100	72.1	55.2	46.0	85.0	50.0	71.0	91.0	56.5	73.0	24.0	39.5	51.0
1,000	63.7	42.0	37.8	65.3	38.5	54.8	69.1	37.5	51.0	22.5	33.0	39.8
5,000	51.2	33.0	27.0	53.5	32.0	43.5	51.0	28.5	35.5	18.2	28.7	30.0

Figure 6. Flexural fatigue characteristics of mixtures.

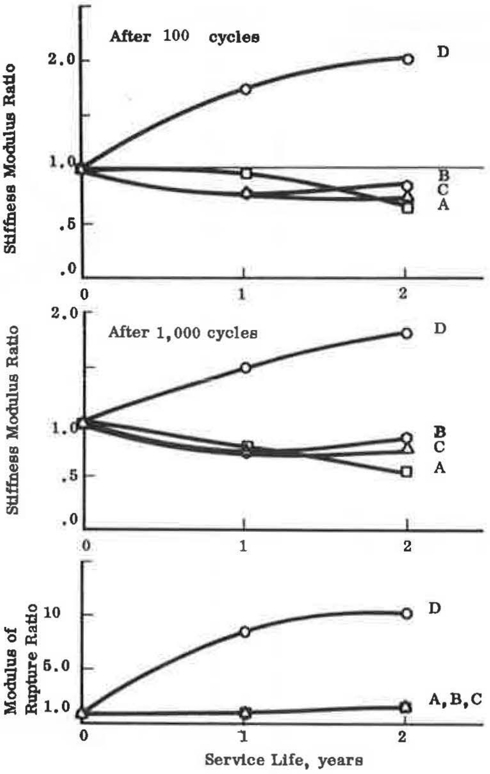


Figure 7. Typical creep curve, mixture 1 year in service.

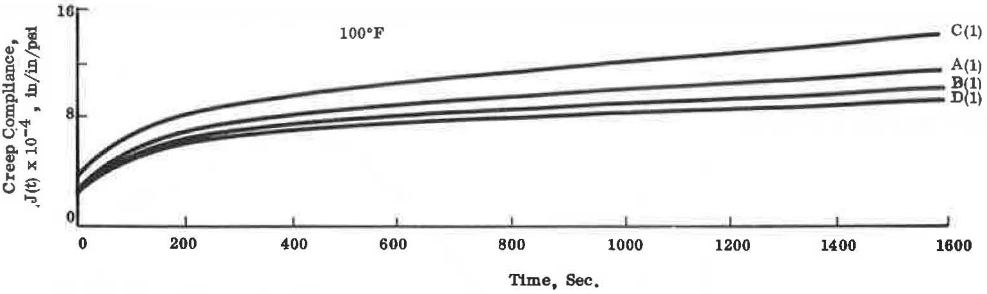


Figure 8. Typical creep curve, mixture 2 years in service.

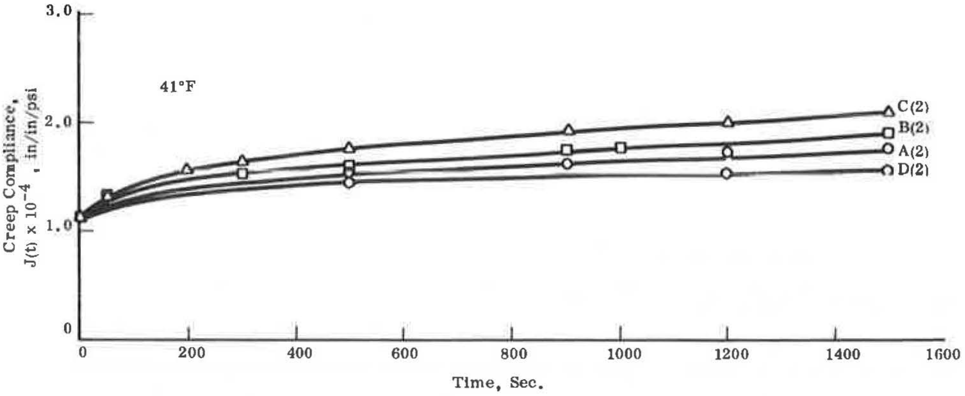


Figure 9. a_T-T relation for four mixtures.

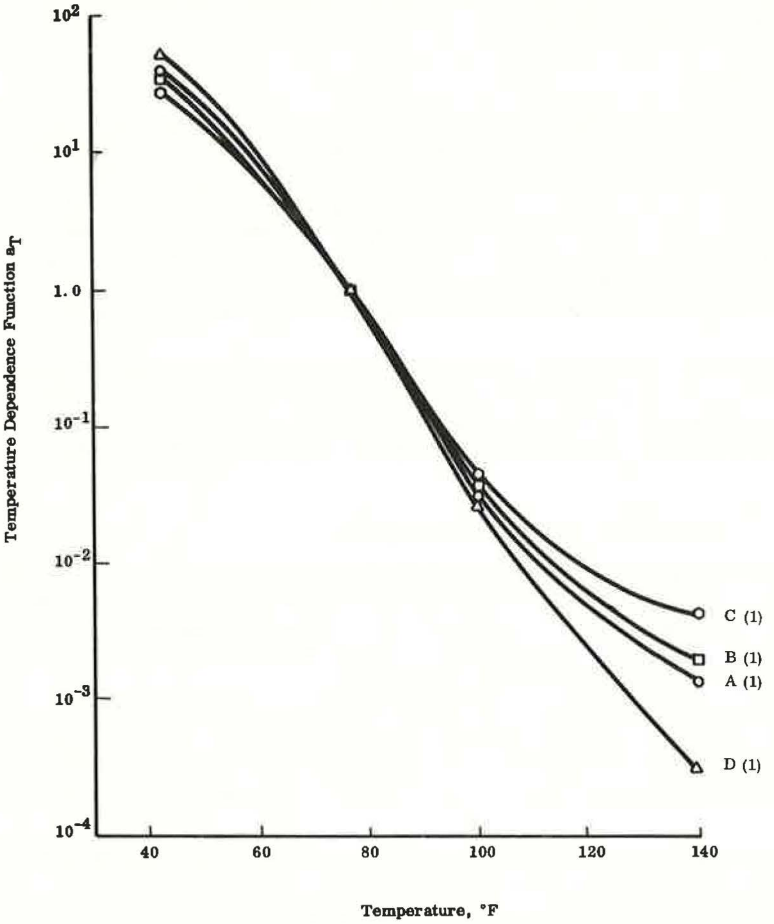
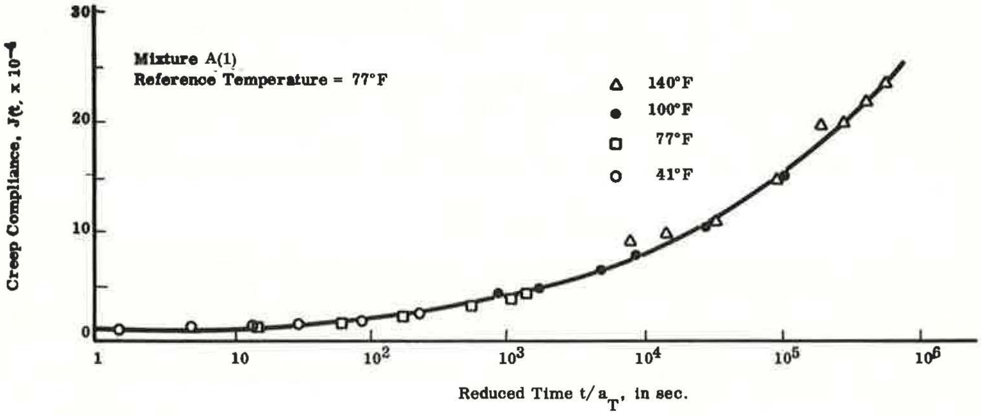


Figure 10. Master curve.



The comparison of creep compliance after 2 years in service at various loading times and test temperatures also indicates that the temperature dependency of mixture C(2) differs from that of the other three mixtures.

Properties of Asphaltic Binder

As was indicated previously, the asphaltic binders, extracted and recovered from the paving mixtures, were subjected to standard physical and rheological experiments. In this report, the results of penetration and softening point tests are examined. It is noted that the softening point of the control mixture D has increased with age, indicating an age-hardening trend. The age-softening trend, however, is observed in the other three mixtures. The greatest softening effect is observed in mixture A(2). The examination of penetration data also indicates that penetration of material is reduced with age, whereas there is a trend for increase in penetration for the other three mixtures.

In brief, the data on physical properties of asphaltic binders such as softening point, penetration, and ductility confirm the previous observations on the strength and rheological behavior of these mixtures. A comparison of viscosity data on extracted asphalts is in progress at the present time and appears to be supporting the previous conclusions.

SUMMARY AND CONCLUSIONS

In this report, the experimental data on four paving mixtures after 0, 1, and 2 years in service are examined. Mixture A is an emulsified hot-mixed asphaltic mixture with 0 percent latex additive. Mixtures B and C are emulsified hot-mixed asphaltic mixtures with 1½ percent and 3 percent rubber additive. An 85- to 100-penetration asphalt cement with no additives was used in the control mixture D.

The significance of rubber additives in the mixture behavior was investigated by performing compressive strength, creep, flexural fatigue, flexural strength, and Marshall stability tests on asphaltic mixtures. The extracted and recovered binders were also treated for physical characteristics. The following are conclusions reached from this study.

1. The evaluation of engineering properties of mixtures at 0 year in service indicates that mixture C with 3 percent additive is superior to the other mixtures.
2. The evaluation of engineering properties after 1 year in service indicates an age-hardening trend for mixture D. Mixtures A, B, and C show slight age-softening effects.
3. The evaluation of engineering properties after 2 years in service indicates that mixture D has continued its age-hardening trend. Mixture A with 0 percent additive follows an age-softening trend. Rubberized materials B and C appear to be approaching their initial engineering characteristics.
4. Mixture C, with 3 percent rubber additive, has remained superior to the other mixtures as related to temperature susceptibility. This mixture is the least temperature susceptible, and mixture D is the most temperature dependent. The superiority of mixture C is also apparent from flexural strength and flexural fatigue data.

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