Marshall and Flexural Properties of Bituminous Pavement Mixtures Containing Short Asbestos Fibers

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Laboratory tests were made to evaluate the effects of the addition of short asbestos fibers on the properties of certain bituminous pavement mixtures made with typical Wisconsin aggregates. Tests included the determination of Marshall properties and of certain flexural properties, using a test method developed for the purpose. Continuous load-deflection relationships of the Marshall stability test were recorded, and the effects of a higher compactive effort on the Marshall properties were investigated.

The addition of the asbestos fibers generally improved the Marshall properties of the mixtures, and a greater range of asphalt contents could be used with less resulting loss of stability. Also, the properties of the mixtures containing the fibers tended to be affected less adversely by overcompaction. The addition of the asbestos fibers generally improved the flexural properties of the mixtures, particularly at higher temperatures.

•THE ADDITION of asbestos fibers has been shown to improve certain properties of many bituminous construction materials, and recent investigations have shown that these fibers may improve important physical properties of bituminous pavement mixtures. Promotional efforts by producers of these fibers and expressed interest by the U. S. Bureau of Public Roads suggested that an attempt should be made to evaluate the effectiveness of the fibers in improving the properties of bituminous pavement mixtures using typical Wisconsin aggregates. However, it was thought that before any large-scale pavement performance investigation be initiated, certain preliminary information should be obtained from laboratory tests. This minimal laboratory investigation was designed to yield this information.

SCOPE

This investigation included tests on three types of bituminous mixtures, each with and without the addition of short asbestos fibers in the amount of 2½ percent by weight of the total mineral aggregate. The three mixtures were as follows:

1. A surface course mixture using a crushed gravel aggregate.
2. A surface course mixture using an aggregate composed of a blend of crushed limestone and sand.
3. A binder course mixture using the same aggregate used in mixture 2.

The tests included the determination of the standard Marshall properties of compacted specimens having varied asphalt contents and the determination of the flexural properties of compacted beam specimens. The Marshall tests were made in accordance with standard procedures, except that continuous load-deformation relationships

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TABLE 1

PROPERTIES OF AGGREGATES

Property	Crushed Gravel for Surface Course Mixture	Crushed Stone for		Wisconsin Specifications	
		Surface Course Mixture	Binder Course Mixture	Surface Course Mixture	Binder Course Mixture
Gradation, % passing sieve:					
1¼-in.					100
1-in.			100		95-100
¾-in.			93	100	-
½-in.	100	100	77	95-100	65-90
⅜-in.	90	92	67	75-100	55-80
No. 4	67	68	50	45-85	40-65
No. 10	49	49	38	30-55	25-50
No. 40	22	26	20	15-35	10-30
No. 80	10	16	12	10-25	-
No. 200	6.0	10.5	7.3	5-12	3-12
Los Angeles wear test (% loss)	21	35		50 max.	
Sodium sulfate soundness test, 5 cycles, T 104-46 (% loss)	6.0	8.5		18 max.	
Plasticity	N. P.	N. P.		<6	
Crushed particles (%)	65	-		50 min.	

were recorded throughout the loading range. The flexural test specimens were molded at optimum asphalt contents and at asphalt contents of optimum plus 2 percent, and were tested at temperatures of both 40 and 100 F.

Also, for each of the two surface-course mixtures, Marshall specimens with asphalt contents of optimum and of optimum plus 2 percent were compacted using a higher compactive effort procedure and were tested for their Marshall properties.

MATERIALS

Both aggregates were composites of several similar materials from various sources. The properties of the aggregates are given in Table 1 along with the current applicable specification requirements.

The asphalt used in these tests was an 85-100 penetration grade asphalt cement. Its properties are given in Table 2.

Asbestos fibers were furnished by the Johns-Manville Company, Asbestos Fibre Division, Manville, N. J. It was designated as their 7M06 short asbestos fiber.

TABLE 2

PROPERTIES OF ASPHALT

Property	Value
Penetration, 100 g, 5 sec, 77 F	92
Specific gravity at 77 F	1.033
Flash point, C.O.C. (°F)	570
Loss on heating, 50 g, 5 hr at 325 F (%)	0.06
Penetration of residue (% of original)	87
Ductility at 77 F, 5 cm/min (cm)	110+
Solubility in CCl_4 (%)	99.9
Spot	Negative

TEST METHODS

Preparation of Mixtures

To insure uniformity between batches, the aggregates were separated into several size fractions and these fractions were then recombined in desired proportions for each batch. In the mixtures containing the asbestos fibers, the fibers comprised $2\frac{1}{2}$ percent by weight of the total mineral aggregate. The aggregates were heated to 270 F and the asphalt to 280 F, and these were then combined and mixed with a bowl-and-paddle type of mixer. The usual wet mixing time of 2 min was used for the nonasbestos mixtures, but this proved inadequate to assure complete and uniform mixing for the mixtures containing the asbestos fibers. For those, the heated aggregates were mixed dry for 1 min to assure uniform dispersion of the asbestos fibers and then the heated asphalt was added and the mixing continued for an additional 3 min. The compaction temperature for all test specimens was 250 ± 5 F.

Marshall Tests

The initial Marshall tests were made in accordance with standard test procedures. The test specimens were compacted with a mechanical compactor, and the voids determined using the Rice vacuum saturation procedures for obtaining the maximum void-free densities.

Continuous load-deformation measurements were recorded for one specimen representing each test condition for each of the mixtures. This was done as follows: A micrometer dial was mounted on the upper testing head and used in place of the conventional flow meter to measure flow deformation. A motion picture camera was used to record the load-deformation relationships through the complete loading range by photographing simultaneously the deformation dial and the load proving ring dial. To provide a complete picture of these relationships, the loading was continued past the indicated maximum loads and until the total deformations were about $\frac{1}{2}$ in. The load and deformation values were then read from the developed film and plotted.

Then for the two surface-course mixtures, standard Marshall test specimens were molded at both the optimum asphalt contents, as indicated by the peaks of the density curves for the nonasbestos mixtures, and at asphalt contents of optimum plus 2 percent. One series of specimens was compacted using standard compaction procedures, and another series was compacted using a considerably higher compactive effort as follows: Each end of each specimen was compacted with 50 distributed blows using the modified Proctor compaction hammer, followed by 50 additional blows using the Marshall compaction hammer. The specimens were then tested for their Marshall properties.

Flexural Tests

Flexural strength tests were made on specimens, representing each of the three types of mixtures, having optimum asphalt contents as indicated by the Marshall tests and also having asphalt contents of optimum plus 2 percent. One such series was tested at 40 F and another at 100 F.

The flexural specimens were fabricated as follows: Specimens 6 in. in diameter and about $2\frac{1}{2}$ in. in height were compacted using procedures outlined for the Hubbard-Field method of mix design (Fig. 1). Beam-type specimens 2 by 2 in. in cross-section and 6 in. in overall length were sawed from the cylindrical specimens using a diamond masonry saw. These were tested on a 5-in. span as a simple beam with center loading. The two end bearing points and the center loading point were fitted with rockers, and a 1-in. wide by $\frac{1}{8}$-in. thick steel bearing plate was used at each point to distribute the load and minimize local deformations. Figure 2 shows the testing apparatus devised for testing at 40 F. For testing at 100 F the load was applied with a motor-driven screw loading machine and loads were measured with a 60-lb capacity dynamometer. At both testing temperatures, the rate of loading was controlled at $\frac{1}{10}$ in. per minute. The testing was

Figure 1. Sawn flexural test specimen.

done in temperature-controlled rooms, and the temperatures of the test specimens were measured with thermometers embedded in dummy specimens stored adjacent to the test specimens. In all cases the test specimens were held at the test temperatures for a minimum of 2 hr before testing. The temperatures of all specimens at the time of testing were within ± 2 F of the respective nominal test temperatures.

Load-center deflection measurements were recorded through the loading range, and these data when plotted afforded data for computing values for stiffness and modulus of rupture for each test specimen. The values for stiffness represent the slope of the initial tangent to the load-deflection curve in terms of pounds of center load per inch of center deflection, and the value for modulus of rupture were computed as:

$$\text{Modulus of Rupture (psi)} = \frac{3\,P\,l}{2\,b\,d^2}$$

in which

P = maximum center load in pounds;
l = test span length in inches;
b = specimen breadth in inches; and
d = specimen depth in inches.

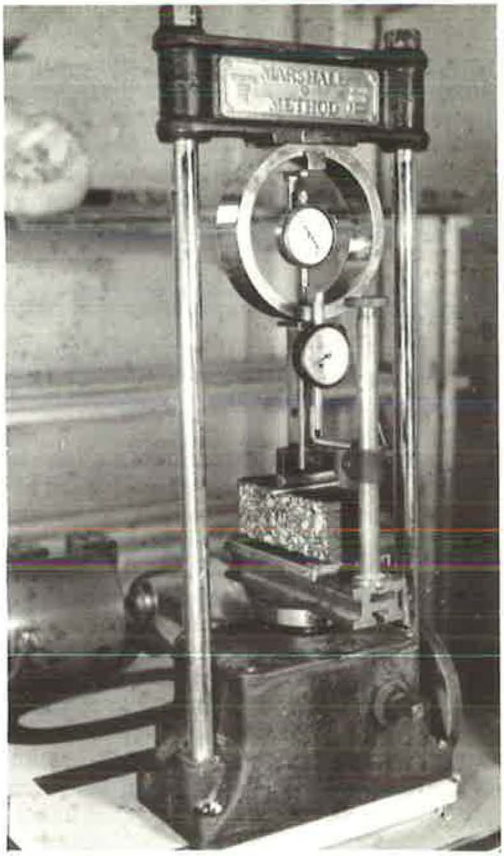


Figure 2. Low temperature flexural test apparatus.

TEST RESULTS

Marshall Design Tests

The test data are shown in Table 3 and Figure 3. For the crushed gravel surface course mixture, the addition of the asbestos fibers had no appreciable effect on the compacted density at any of the included asphalt contents but resulted in considerably higher stabilities at all asphalt contents. The addition of the asbestos fibers resulted in higher indicated void contents at all asphalt contents by amounts ranging from 0.6 to 0.8 percentage points. Flow values were essentially the same at all but the higher asphalt contents where the addition of the asbestos fibers resulted in slightly higher values.

For the crushed stone surface course mixture, the addition of the asbestos fibers resulted in lower compacted densities at all asphalt contents. Stability values were not affected greatly by the addition of the fibers in the range of likely optimum asphalt contents, but at the lower asphalt contents, the stabilities of the asbestos mixtures were slightly lower, and at the higher asphalt contents they were slightly higher than those of the corresponding nonasbestos mixtures. The voids in the asbestos mixtures were about 2.0 percentage points higher at the lowest asphalt content, and about 1.4 percentage points lower at the highest asphalt content as compared to the corresponding nonasbestos mixtures. The addition of the asbestos fibers had no appreciable effect on the flow values at any of the included asphalt contents.

For the crushed stone binder course mixture, the addition of the asbestos fibers resulted in lower compacted densities at all asphalt contents. The addition of the asbestos fibers had little effect on the indicated stabilities, except at the higher asphalt contents where the asbestos mixtures showed slightly higher stabilities than did the

TABLE 3

SUMMARY OF MARSHALL TEST DATA

Without Asbestos Fibers					With Asbestos Fibers				
Asphalt Content (% by wt.)	Bulk Density (pcf)	Stability (lb)	Flow (0.01 in.)	Voids (%)	Asphalt Content (% by wt.)	Bulk Density (pcf)	Stability (lb)	Flow (0.01 in.)	Voids (%)
(a) Crushed Gravel Surface Course Mixture									
4.75	148.6	1,153	8	4.9	4.75	148.5	1,291	7	5.6
5.5	150.0	1,235	8	3.0	5.5	150.1	1,550	8	3.6
6.25	149.9	1,375	10	2.0	6.25	150.1	1,491	8	2.6
7.0	149.2	1,122	11	1.4	7.0	149.2	1,301	14	2.2
7.75	147.9	858	14	1.2	7.75	148.0	1,081	18	2.0
(b) Crushed Stone Surface Course Mixture									
4.75	152.1	2,256	9	5.1	4.75	148.9	1,809	8	7.1
5.5	152.6	2,109	9	3.9	5.5	151.0	2,028	11	4.5
6.25	152.2	1,655	12	3.3	6.25	151.4	1,841	12	3.1
7.00	151.4	1,248	14	3.0	7.0	150.8	1,462	15	2.2
7.75	149.7	889	21	3.2	7.75	149.4	1,195	19	1.8
(c) Crushed Stone Binder Course Mixture									
4.0	152.2	2,136	8	6.1	4.0	149.4	2,086	12	8.6
4.75	153.5	2,085	10	4.1	4.75	151.3	2,024	10	6.2
5.5	153.7	1,768	11	2.7	5.5	151.8	1,864	12	4.7
6.25	152.7	1,175	16	2.1	6.25	151.6	1,479	16	3.5
7.00	151.2	929	23	1.7	7.00	150.7	1,140	22	2.8
					7.75	149.4	954	33	2.2

corresponding nonasbestos mixtures. The voids in the compacted asbestos mixtures were higher at all asphalt contents than those of the corresponding nonasbestos mixtures by amounts ranging from 1.1 to 2.5 percentage points. The addition of the asbestos fibers had no appreciable effect on the indicated flow values at any of the included asphalt contents.

The Marshall test load-deformation relationships are shown in Figure 4. The peaks of the curves represent the stability values, and the deformations at these peaks represent the flow values. For the mixtures containing the asbestos fibers, the loads, after reaching their maximums, did not drop off as greatly or as rapidly as did those for the corresponding nonasbestos mixtures, but continued to carry an appreciable part of the maximum loads even after total deformations of up to about ½ in. This was true for each of the three mixtures at all of the included asphalt contents.

Effects of High Compactive Effort on Marshall Properties

The test data for the effects of high compactive effort on Marshall properties are shown in Table 4 and Figure 5.

Crushed Gravel Surface Course Mixtures.—At optimum asphalt content, the higher compactive effort resulted in greater densities for both the nonasbestos and the asbestos mixtures, the increase for the asbestos mixtures being considerably less than for the nonasbestos mixtures. At the higher asphalt content, the higher compactive effort resulted in higher density for the nonasbestos mixture but in slightly lower density for the mixture containing asbestos. This apparent anomaly may be related to the observed behavior of the asbestos mixture during compaction. The mixture became quite elastic and showed considerable rebound, and the top surfaces of the specimens after compaction showed considerable convexity.

At optimum asphalt content, the higher compactive effort resulted in considerable increase in stability for the nonasbestos mixture, but caused very little change in the stability of the asbestos mixture. However, the asbestos mixtures compacted by either procedure showed higher stabilities than did the corresponding nonasbestos mixtures. At the higher asphalt content, the higher compactive effort resulted in slightly higher stability for the nonasbestos mixture but in slightly lower stability for the asbestos mixture. Again the asbestos mixtures compacted by either compaction procedure showed higher stabilities than did the corresponding nonasbestos mixtures.

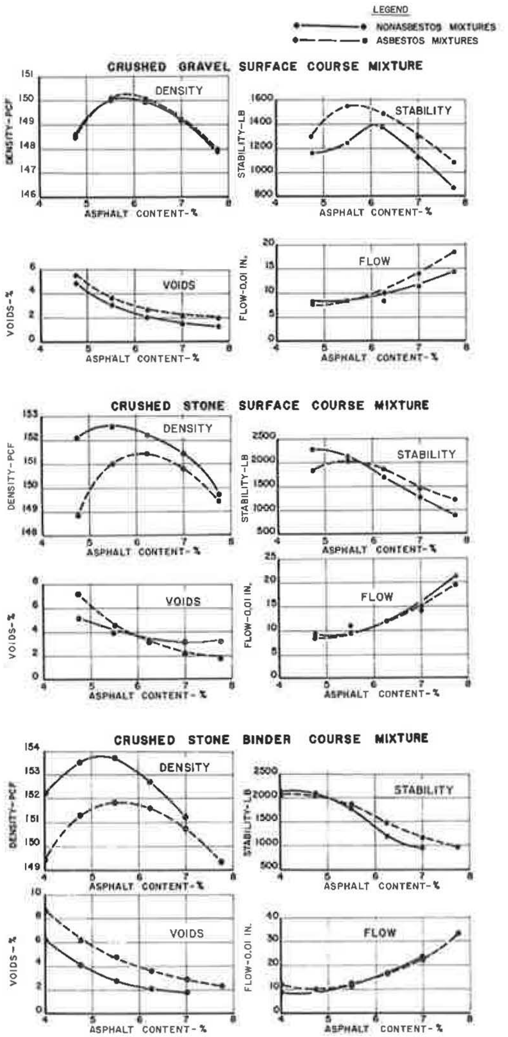


Figure 3. Marshall test data.

At optimum asphalt content, the higher compactive effort resulted in considerable reduction in void content for both the non-asbestos and asbestos mixtures, the reduction for the asbestos mixtures being somewhat less. Also, for either compactive effort the voids in the asbestos mixtures were greater than those in the corresponding nonasbestos mixtures. At the higher asphalt content, the higher compactive effort reduced the voids in the non-asbestos mixture to about 0. 4 percent which may be a dangerously low value, whereas for the asbestos mixtures, the higher compactive effort actually resulted in slightly higher void content, the possible reason for which was discussed when considering the densities of these mixtures.

Flow values generally increased with the increased asphalt content, greater compactive effort, and addition of the asbestos fibers.

Crushed Stone Surface Course Mixtures.—At optimum asphalt content, the higher compactive effort resulted in greater densities for both nonasbestos and asbestos mixtures, the increase for the asbestos mixtures being considerably less than that for the nonasbestos mixtures. At the higher asphalt content, the higher compactive effort resulted in slightly higher densities for both nonasbestos and asbestos mixtures.

At optimum asphalt content, the higher compactive effort resulted in slightly reduced stability for the nonasbestos mixture and in slightly increased stability for the asbestos mixture. At the higher asphalt content, the higher compactive effort resulted in very little change in the stabilities of either the nonasbestos or the asbestos mixture. The asbestos mixtures under either compaction procedure with either asphalt content showed higher stabilities than did the corresponding nonasbestos mixtures.

At optimum asphalt content, the higher compactive effort resulted in lower void contents for both the nonasbestos and the asbestos mixtures, the reduction being slightly less for the asbestos mixture. At the higher asphalt content, the higher compactive effort resulted in slightly lower void contents for both the nonasbestos and the asbestos mixtures. Also, for either compactive effort, the asbestos mixtures had lower void contents than did the corresponding nonasbestos mixtures.

Flow values increased with increased asphalt content and with greater compactive effort, but generally the asbestos mixtures had lower flow values than did the corresponding nonasbestos mixtures.

Flexural Properties of Beams

The load-deflection data from the flexural tests are shown in Figure 6. Table 5 gives the properties of the test specimens including values for stiffness and modulus

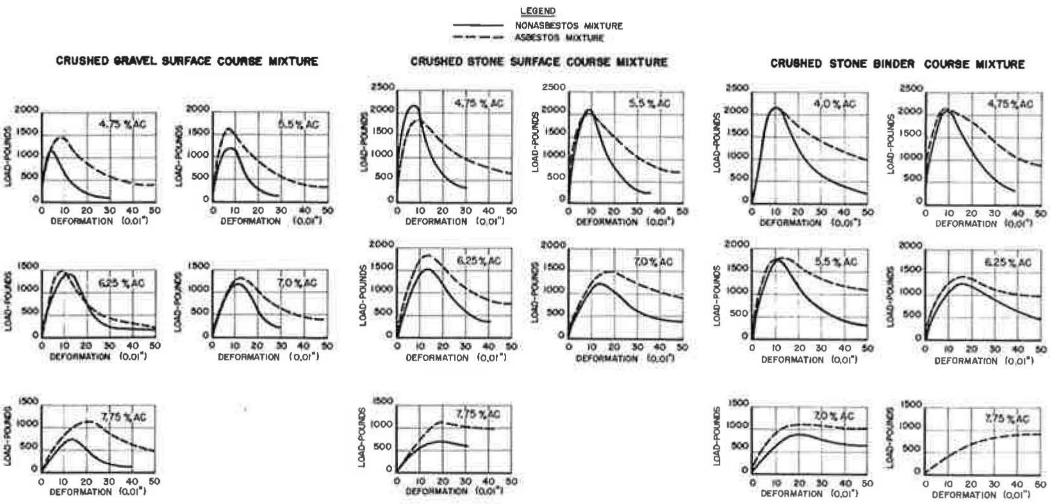


Figure 4. Marshall load-deformation relationships.

TABLE 4

EFFECTS OF HIGH COMPACTIVE EFFORT ON MARSHALL PROPERTIES

Asphalt Content (% by wt.)	Degree of Compaction	Properties of Compacted Mixtures							
		Without Asbestos Fibers				With Asbestos Fibers			
		Bulk Density (pcf)	Stability (lb)	Flow (0.01 in.)	Voids (%)	Bulk Density (pcf)	Stability (lb)	Flow (0.01 in.)	Voids (%)
(a) Crushed Gravel Surface Course Mixture									
5.7	Standard	149.6	1,120	7	3.0	150.3	1,640	8	3.2
	High	152.3	1,410	10	1.3	152.1	1,675	13	2.0
7.7	Standard	147.4	625	15	1.6	148.1	995	16	2.1
	High	149.3	715	22	0.4	147.3	855	31	2.5
(b) Crushed Stone Surface Course Mixture									
5.5	Standard	152.4	2,005	9	4.1	152.0	2,030	9	4.0
	High	154.8	1,830	18	2.6	153.6	2,365	15	2.9
7.5	Standard	150.0	875	23	3.4	149.6	1,105	20	2.1
	High	150.3	835	35	3.2	149.8	1,145	31	2.0

of rupture obtained from the load-deflection curves. The latter data are shown in Figures 7 and 8 for easier comparisons. In Figure 7, when tested at 40 F those mixtures containing the asbestos fibers showed higher moduli of rupture as compared to those of the corresponding nonasbestos mixtures, except in the case of the crushed stone surface course mixture at optimum asphalt content and the crushed stone binder course mixture at optimum asphalt content. When tested at 100 F, the mixtures containing asbestos fibers had higher moduli of rupture in all cases as compared to the nonasbestos mixtures, though the difference is quite small in the case of the crushed stone surface course mixture having optimum asphalt content.

In Figure 8, the stiffness values of the mixtures tested at 40 F containing asbestos fibers were equal to or greater than those of the corresponding nonasbestos mixtures in all cases, the greatest difference being for those mixtures having the higher than optimum asphalt contents. When tested at 100 F, the stiffness in all cases was greatly increased by the addition of the asbestos fibers.

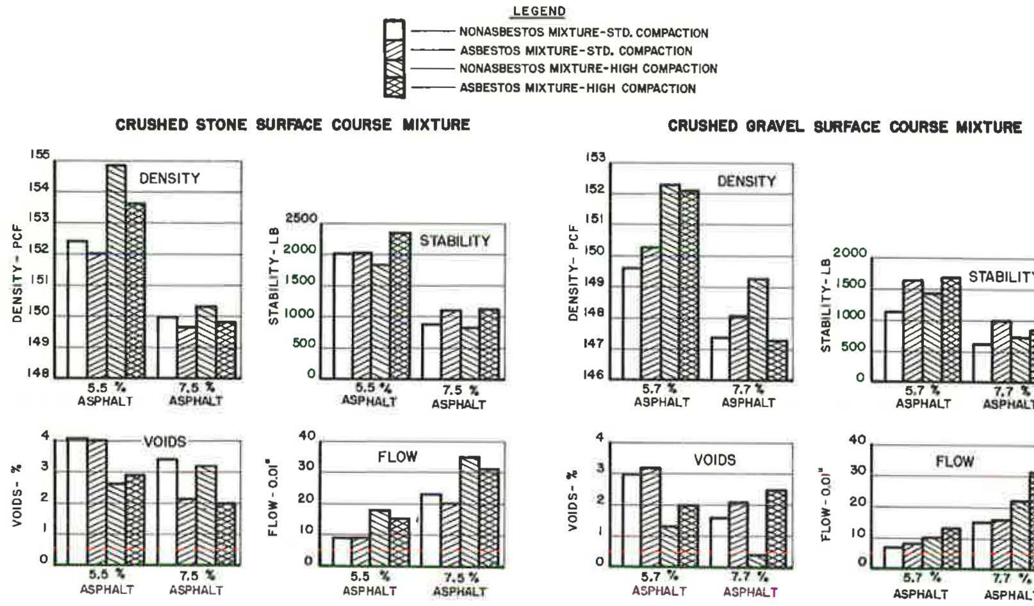


Figure 5. Effects of high compactive effort on Marshall properties.

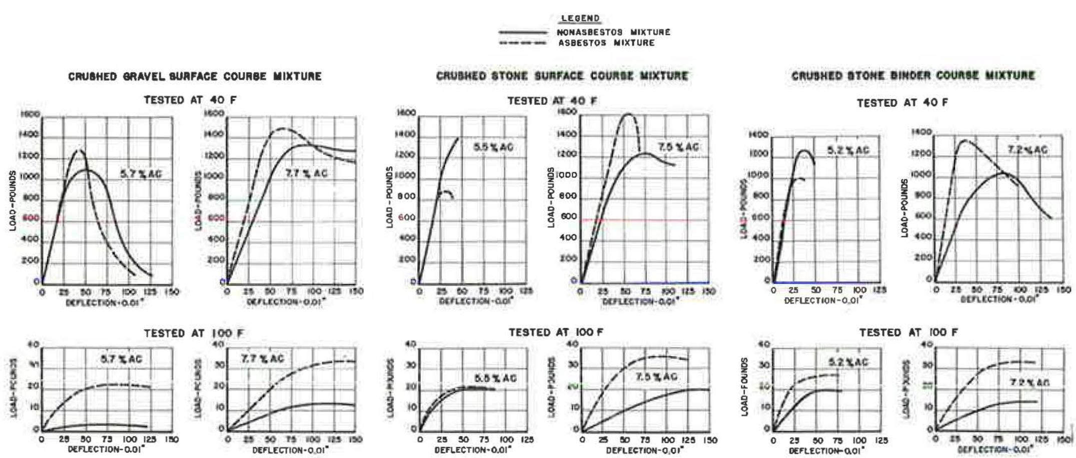


Figure 6. Flexural load-deflection relationships.

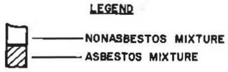
ANALYSIS OF TEST RESULTS

In the design of bituminous paving mixtures, the primary properties considered include stability and durability. Stability or resistance to plastic deformation, particularly at high temperatures, is necessary to preclude rutting, shoving, or other forms of pavement displacement, and durability is important in maintaining the structural integrity and surface characteristics of the pavement under exposure to weather and traffic. Flexibility and fatigue resistance are also important, particularly at lower temperatures, if the pavement is to conform to variations in base elevations, and to flex repeatedly under traffic without cracking. It is generally recognized that durability, flexibility, and fatigue resistance improve with increases in asphalt content, but it is also recognized that increased asphalt content may result in lowered stability.

TABLE 5

SUMMARY OF FLEXURAL TEST DATA

Test Temperature (°F)	Asphalt Content (% by wt.)	Without Asbestos Fibers: Bulk Density (pcf)	Voids (%)	Maximum Center Load (lb)	Stiffness (lb/in.)	Modulus of Rupture (psi)	With Asbestos Fibers: Bulk Density (pcf)	Voids (%)	Maximum Center Load (lb)	Stiffness (lb/in.)	Modulus of Rupture (psi)
(a) Crushed Gravel Surface Course Mixture											
40	5.7	146.1	5.3	1,100	3,280	1,030	145.0	6.5	1,280	3,600	1,200
	7.7	146.5	2.2	1,320	2,120	1,240	147.5	2.4	1,490	3,120	1,400
100	5.7	146.3	5.2	4	10	4	145.6	6.2	23	76	22
	7.7	145.3	3.0	14	18	13	147.5	2.4	34	40	32
(b) Crushed Stone Surface Course Mixture											
40	5.5	148.8	6.3	1,400	4,000	1,000	144.1	8.9	880	4,000	820
	7.5	149.0	4.0	1,250	2,600	1,170	148.9	2.6	1,620	3,400	1,520
100	5.5	148.5	6.5	21	96	20	144.5	8.7	22	120	21
	7.5	149.3	3.8	20	20	19	149.5	2.2	36	88	34
(c) Crushed Stone Binder Course Mixture											
40	5.2	149.9	5.6	1,280	4,400	1,200	146.2	8.7	1,000	4,960	940
	7.2	150.1	2.1	1,040	2,200	970	150.0	2.8	1,350	4,960	1,270
100	5.2	150.6	5.2	20	48	19	146.9	8.2	28	104	26
	7.2	150.5	1.8	14	20	13	150.1	2.8	34	80	32



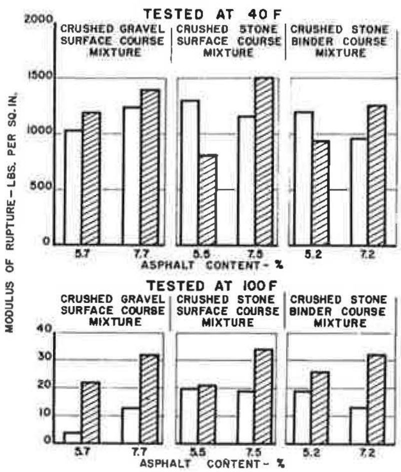


Figure 7. Modulus of rupture of beam specimens.

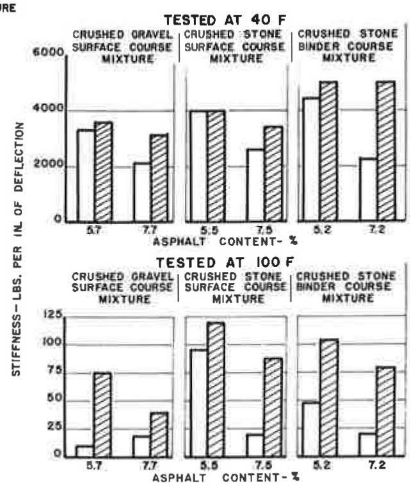


Figure 8. Stiffness of beam specimens.

Stability or Resistance to Plastic Deformation

The Marshall design test data indicate that for the crushed gravel surface course mixture, the addition of the asbestos fibers resulted in increased stabilities at all included asphalt contents, and that the asphalt content could be increased appreciably without loss of stability as compared to that of the nonasbestos mixture having optimum asphalt content. For the crushed stone surface course mixture and for the crushed stone binder course mixture, the addition of the asbestos fibers had little effect on the Marshall stabilities in the range of likely optimum asphalt content, for both mixtures, increases in asphalt content above the optimum resulted in less reduction in stability for the asbestos mixture.

The load-deformation data for the Marshall test specimens indicate that for each of the three mixtures at all included asphalt contents, the addition of the asbestos fibers resulted in greater retained load-carrying ability of the test specimens after the indicated maximum loads. Although the importance of this increased load-carrying ability of the test specimens may not be readily evaluated, it does reflect an increase in resistance to plastic deformation which possibly could contribute to improved pavement performance.

Also, for the two surface course mixtures at asphalt contents of both optimum and optimum plus 2 percent, when compacted with either standard or high compactive effort, those mixtures containing the asbestos fibers showed higher Marshall stabilities than the corresponding nonasbestos mixtures did.

The flexural data for beam-type specimens tested at 100 F indicate that for all three mixtures, at asphalt contents of either optimum or optimum plus 2 percent, the moduli of rupture of the asbestos mixtures were greater than those of the corresponding nonasbestos mixtures by amounts ranging from 5 to 450 percent, and that the flexural stiffness values for the asbestos mixtures were greater than those of the corresponding nonasbestos mixtures by amounts ranging from 25 to 660 percent.

Flexibility at Low Temperatures

The flexural test data for the specimens tested at 40 F indicate that the addition of the asbestos fibers resulted in increased stiffness for all three mixtures having asphalt contents of either optimum or optimum plus 2 percent, except in the case of the crushed stone surface course mixture having optimum asphalt content where the addition of the asbestos fibers caused no change in stiffness. Although increased stiffness indicated in these tests may be considered an indication of lowered flexibility, for the two surface-course mixtures, the asbestos mixtures having higher than optimum asphalt contents had lower indicated stiffness values than did the corresponding nonasbestos mixtures having optimum asphalt contents. Also, the mixtures containing the asbestos fibers had higher moduli of rupture at asphalt contents of either optimum or optimum plus 2 percent, as compared to the nonasbestos mixtures except for the crushed stone surface course mixture at optimum asphalt content, or for the crushed stone binder course mixture at optimum asphalt content.

CONCLUSIONS

This investigation, though designed to yield certain basic information regarding the effects of the addition of asbestos fibers on certain of the properties of bituminous paving mixtures, is not broad enough in scope to cover all the variables existing in bituminous pavement construction. Also, it is fully recognized that small-scale laboratory test data cannot be reliably extrapolated to predict the behavior of pavements under field conditions. However, within the scope of this investigation and under the conditions of testing and evaluation, it is indicated that the addition of the asbestos fibers to bituminous pavements mixtures will generally improve the Marshall properties of the mixtures and allow the use of a greater range of asphalt contents with less resulting loss of stability and thus contribute to improved durability, flexibility, and fatigue resistance.

It is also indicated that the Marshall properties of mixtures containing the asbestos fibers tended to be affected less adversely by overcompaction.

The flexural test data indicate that the addition of the asbestos fibers generally improved the flexural properties of the mixtures, particularly at higher temperatures.

Certain of the data would indicate that bituminous mixtures containing crushed gravel aggregates may be benefited more by the addition of the asbestos fibers than would similar mixtures containing crushed stone aggregates.

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