Effect of Short Asbestos Fibers on Basic Physical Properties of Asphalt Pavement Mixes

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The results of comprehensive laboratory tests on asphalt paving mixtures with chrysotile asbestos are described. The main effect of the fiber appears to be on plastic strength as measured by static load tests. Static tensile strength of the control mix was increased as much as 20 times at standard asphalt contents by adding 3 percent 7M fiber. Similar increases in static compression strength were shown at asphalt contents higher than normal.

Static compression test data suggest that a wide range of flexibility characteristics might be attainable by adding asbestos, as a wide range of asphalt contents appears to be permitted.

Samples of asphaltic concrete removed from pavement mixes placed for service evaluation sustained a 510-psi concentrated compression load for 1 hr at 140 F without failure in laboratory tests.

Laboratory test results on control mixes suggest that use of a dynamic tension (cohesion) test at 140 F for measuring resistance to plastic deformation in mix design is justified. However, for pavement mixes with asbestos included, dynamic tests at 140 F do not appear to be adequate for measurement of resistance to plastic deformation.

Significant increases in dynamic tensile strength and repeated blow impact strength at 0 F were also evident when short asbestos fibers were included in pavement mixes.

The ability of short chrysotile fibers to prevent cracking in thin films of asphalt-filler mixes during accelerated weathering tests is described.

● CHRYSOTILE ASBESTOS is a hydrous magnesium silicate mineral ($Mg_6(OH)_8Si_4O_{10}$) with a fibrous structure. A few pertinent physical properties of chrysotile are given in Table 5, Appendix A, including tensile strength which is comparable per unit area to steel wire, The uniqueness of asbestos is in the fineness of its ultimate physical fiber size which accounts for its high flexibility and facilitates microscopic dispersion in a mixture.

A pertinent property is heat stability. Chrysotile may be heated at 350 F indefinitely with no change in tensile strength.

In addition, the surface of chrysotile fibers is electropositive. In asphaltic mixtures a chemisorption of the binder apparently occurs on the fiber surface which, together with its high surface area, makes for retention of excess binder chemically and mechanically.

The use of asbestos in connection with materials used in pavement construction is not new. For many years, asbestos has been a standard constituent of asphalt bridge

planks, bituminous joint filling compounds, seal-coating compounds, and more recently in paint for asphalt curbing and pavement.

In each of these materials asbestos serves a distinct purpose, such as: producing toughness in bridge planks and joint filling compounds, weather resistance in seal-coating compounds, and resistance to cracking in paint for asphalt mixes.

Patents were obtained by the Warren Brothers Company of Boston in 1917 and 1918 for the use of asbestos in sheet asphalts. Warren Brothers' special uses for this mix included bridge pavements to prevent bleeding of asphalt during hot weather service.

Asbestos in small quantities is being used at present in some cold laid asphalt pavements to prevent segregation of aggregate during placement. (Information has been received that the Russians have been experimenting with short asbestos fibers in bituminous pavements.)

Because of the interest of the Corps of Engineers at the Waterways Experiment Station, Vicksburg, Miss. and the Asphalt Institute in College Park, My., the Johns-Manville Co. recently initiated an evaluation of asbestos in hot-mix asphalt pavements. The results of these tests are presented here with other data to demonstrate changes which take place in the basic physical properties of asphalt pavement mixes when short asbestos fibers are included.

Interpretations of these results are limited because the science of pavement design is at present a complex one and the criteria for pavement performance are not readily determined from laboratory data.

The tests in most cases were not designed to show maximum physical changes, inasmuch as the degree of change desired in most physical properties of a pavement will have to be determined by service performance of test pavements.

TEST METHODS

Materials

The tests described relate to three types of compacted mixes: fine aggregate asphalt mixes prepared in the laboratory, asphaltic concrete sampled from pugmill mixes during placement of experimental asphalt pavements, and asphalt-filler mixes from the same source of materials as the fine aggregate mixes.

For the fine aggregate mix the aggregate gradation of the Asphalt Institute Type IVa Dense Graded Surface Mix (Table 6, Appendix A) was chosen arbitrarily. The gradations were taken from the approximate center of the range allowed for each fraction in the specification, with the coarse fractions (retained on a #8 sieve) withheld and the other fractions, including asphalt, filler, and fine aggregate increased proportionately.

The fine aggregate mix used was a natural sand obtained from a local producer of asphalt pavement mixes. The sand was water-washed to remove clay and then dried at 220 F before being fractioned by sieving in a standard Rotex machine (model #12). Grade #300 limestone filler was dried at 220 F before sieving to remove +200 mesh grains. To obtain sufficient -100, +200 mesh material for the IVa aggregate gradation, it was necessary to use part of the +200 mesh fraction removed from the filler.

The bitumen used in the fine aggregate asphalt and filler-asphalt mixes was 60 penetration asphalt made from Venezuelan crude in the Curacao Refinery of the Shell Oil Company (identification #90-056).

Tensile Test Procedure

Tensile specimens of the IVa mix were prepared by the method outlined in Appendix C, using an ASTM briquet gang mold (1).

The static tension tests were performed by means of the simple apparatus shown in Figure 1. For tests at 140 F, the entire apparatus was placed in a glass-doored oven. The load was increased in increments every 30 min until failure occurred. For tests at 75 F the load was increased in increments of 5 lb; at 140 F, 1 lb increments.

For static tensile tests, the ultimate strength was calculated by summation of the load in psi multiplied by the time that the sample sustained the load in each step of the test.

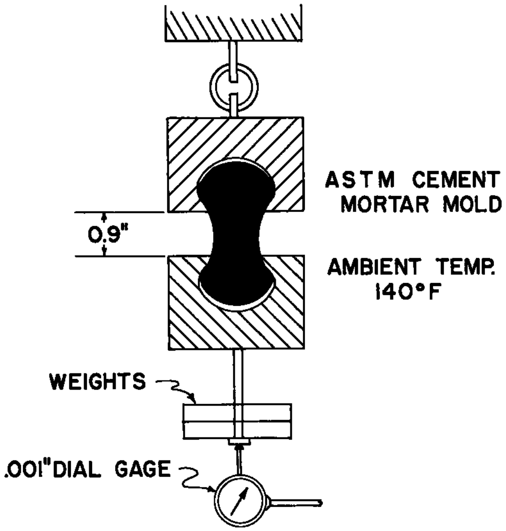

Figure 1. Static tension tests.

The criterion for failure was first visible cracking.

Stress movements were prevented in the dynamic tests by using a turnbuckle connection above the upper clamp and in all tests by lubrication of the inside of the clamp with silicone grease.

Use of this type of test for bituminous paving mixtures is not new. It was reportedly used in research by the Texas State Highway Department many years ago.

Dynamic tension tests were performed on a Scott X-3 testing machine. Each specimen was removed from a 140 F oven and tested immediately at a constant deformation rate of 1 in. per min. Failure occurred within 10 to 20 sec.

Static Concentrated Compression Tests

For static compression tests, specimens were prepared by the gyratory compaction method of the Texas Highway Department (2). To provide a 4-in. diameter briquette 2-in. in height 2,000-gram samples were used.

The hand gyratory equipment (Fig. 2) was mechanized simply. The bottom platen was mounted on the top of the specified hydraulic jack and guided by the four vertical columns which supported the upper platen. Fixed to the upper surface of the bottom platen was an 8-in. diameter rotary table driven by a compressed air motor. The base plate was attached to a cross slide (with hand wheel adjustment) mounted on the rotary table which allowed the die to be positioned off-center with respect to the center of the table at any desired distance. A ball thrust bearing between the base plate and the cross slide prevented transmission of rotational power from the rotary table to the base plate (and mold).

After preparation of mixes as specified by the Texas State Highway Department method, the mold with the mix inside and the base plate were placed on the cross slide in the center of the table. The bottom platen was lifted until a load of 50-psi gage pressure was observed. The cross slide was then positioned off-center by 0.1 in. using the hand wheel. Proper compaction of the sample was then achieved by the same procedure, and the criterion was the same as specified in the standard hand compaction method, except that the compressed air motor provided the gyration power (the speed of gyration was approximately 30 rpm). The sample was removed from the mold by use of an Arbor press after being cooled

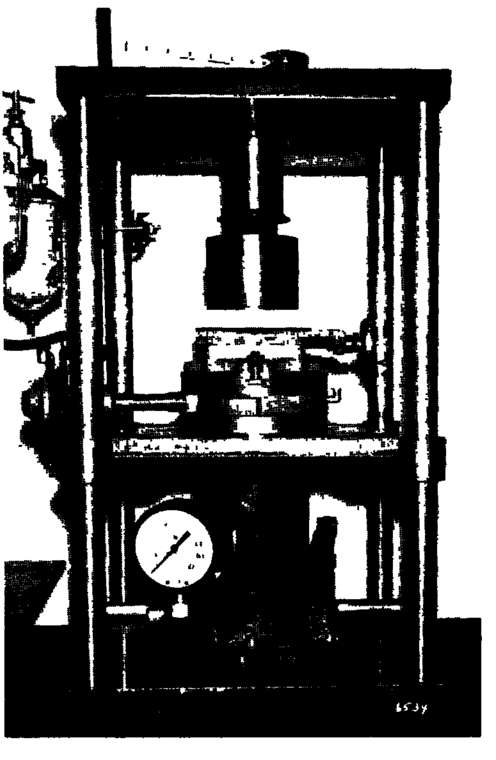

Figure 2.

in cold water for 2 min and was cured in air at room temperature for 48 hr before being tested.

The test was performed on the specimens immersed in a water bath at 140 F ± 1 deg. A cut-away schematic drawing of the apparatus is shown in Figure 3. During testing, the specimen rested in the bath on the base of a box frame which kept the loading rod positioned vertically but free to move up or down with a sliding fit inside a guide hole in the top of the frame. The base of the rod fitted into the top of the cylindrical indentor which transmitted the load to the sample.

Penetration of the indentor was measured with a 0.001-in. dial gage mounted with the foot resting on the top of the loading rod and decreasing the diameter of the indentor.

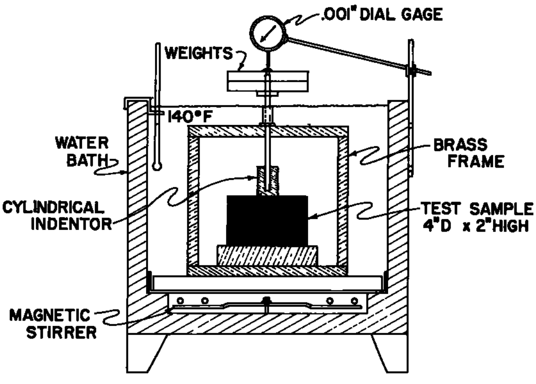

Figure 3. Static concentrated compression load test.

The load on the sample was increased incrementally (Table 1) by adding cyclindrical weights at the top of the loading rod and decreasing the diameter of the indentor. Each load was applied for 1 hr or until failure occurred.

ASTM Compression Tests

To compare the results of several different types of compression tests, the ASTM test D-1074-58-T (3) was performed on samples taken from experimental pavement mixes placed in Buffalo, N.Y. in August 1959. The standard procedure was followed except that the pugmill samples were reheated to 290 F before compaction. In addition, the test machine required controlling the rate of loading (10,000-lb per min) instead of rate of deformation.

Repeated Blow Impact Test

A ball drop test was used to measure impact strength of asphaltic concrete at 0 F. The method in general is a simplified version of the ASTM test D-3-18 (4).

The 500-gram samples of several mixes placed as test strips were reheated to 290 F, compacted according to the procedure specified in ASTM Method D-1074-58-T.

TABLE 1

Step	Diameter of Indentor, (in.)	Load	
		lb	psi
1	1.00	10	13
2	1.00	20	25
3	0.50	25	127
4	0.35	25	260
5	0.25	25	510

The compacted specimens were cured at room temperature for 48 hr before density, and void measurement (ASTM). The nominal thickness of each 4-in. diameter specimen was 1 in.

Each specimen was conditioned at 0 F for 24 hr before testing. The test was performed in a cold room at 0 F with the specimen supported on a concrete base. A steel

ball, approximately 0.9 lb in weight was dropped from a measured height and guided vertically by a steel tube of sufficient inside diameter to allow free fall. The tube was supported rigidly on a stand. A cord attached to the top of the ball permitted measurement of drop height from a scale marked on the outside of the tube. Drop heights were measured from the top surface of the sample. The ball was then positioned at the desired drop height inside the tube by suspension from the cord.

In each test the drop height was increased in increments of 3 in. starting with a 6-in. drop height. The drop height at which cracking was first visible was taken as maximum drop height. The summation of drop heights, including the maximum, was multiplied by the ball weight to determine total impact strength.

Asphalt Weatherability Tests

The thin-film weatherability test involves rather comprehensive methods which have been used for many years in research on industrial asphalts. The test includes film and panel preparation, exposure in standard weathering machines, and a method of measuring the degree of film failure, all of which are described in detail in ASTM Methods D-1669-59T, D-529-59T, and D-1670-59T, respectively.

Basically, film preparation consisted of pressing hot asphalt-filler mixes on a stainless steel plate between heated platens with metal spacer plates adjacent to the coated plate to insure the desired film thickness.

The films were exposed horizontally in Atlas Weatherometer machines in which the air temperature, cold water spray, and carbon arc radiation were alternated in prescribed cycles (Appendix B).

Film failure was measured by use of a spark tester to detect microscopic cracks. The method consists basically of passing a high voltage electrode (9,000 volts) across the face of the film and counting the spark discharges per unit area by placing a photographic paper between the film and the electrode.

TEST RESULTS

Tensile Tests

Figure 4 shows a comparison of tensile strengths of the IVa fine aggregate samples with 4 percent total mineral filler content (Fig. 5) under three different testing conditions: static loading at 140 F, dynamic loading at 140 F, and static loading at 75 F. It should be noted again that the weight percentages given are all based on the original proportions which included approximately 50 percent coarse aggregate.

Perhaps the most obvious conclusion from this comparison is that the relative difference in tensile strength between standard and asbestos mixes are much greater under static loading at 140 F than under dynamic loading at 140 F. Under static loading the asbestos samples were as much as 20 times stronger than the standard samples, considering the load multiplied by the time as static strength. Under dynamic loading, however, the asbestos mix showed a maximum about 85 percent greater strength than the control mix.

In addition, the extensibility at failure of the samples under static loading at 140 F appears to be considerably less than under dynamic loading at 140 F especially in the case of the asbestos mixes. Extensibility under static loading at 140 F also appears to be significantly less than at 75 F.

There appears to be much greater similarity in comparative values between the static tests at 75 F and the dynamic tests at 140 F than between the static tests at 140 F and the dynamic tests at 140 F or between the results of static test at 75 F and the static tests at 140 F.

The results of dynamic tensile tests at 140 F appear to be similar to typical Marshall Stability Data for asphaltic concrete (Appendix C). A correlation between cohesional (tensile) strength and Marshall has been demonstrated before (5).

Static Compression Tests

Static concentrated compression tests with incremental increase in load were per-

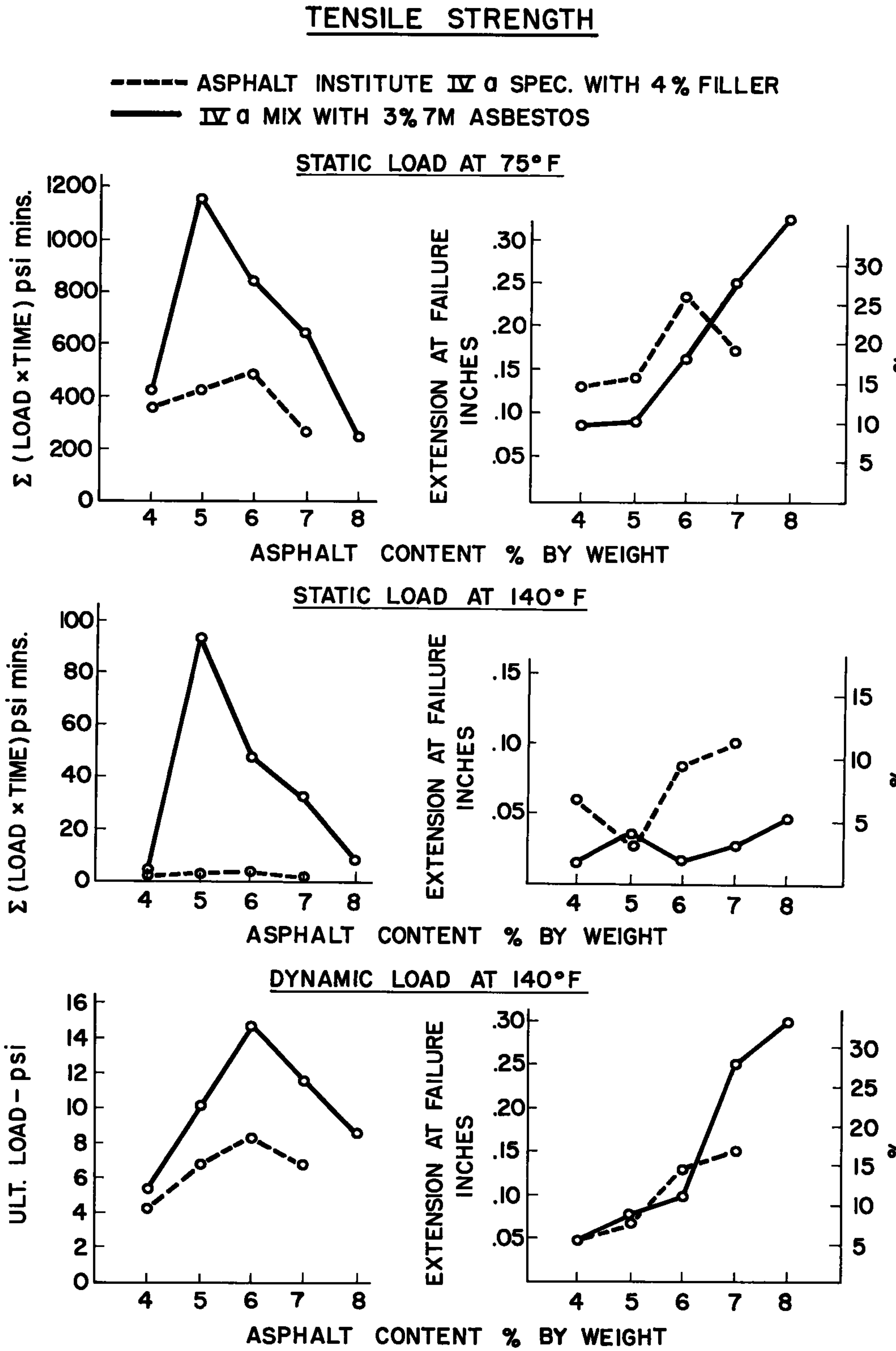
TENSILE STRENGTH
ASPHALT INSTITUTE IV a SPEC. WITH 4% FILLER
IV a MIX WITH 3% 7M ASBESTOS
STATIC LOAD AT 75° F
Σ (LOAD × TIME) psi mins.
1200
1000
800
600
400
200
0
EXTENSION AT FAILURE INCHES
.30
.25
.20
.15
.10
.05
30
25
20
15
10
5
%
4 5 6 7 8
ASPHALT CONTENT % BY WEIGHT
STATIC LOAD AT 140° F
Σ (LOAD × TIME) psi mins.
100
80
60
40
20
0
EXTENSION AT FAILURE INCHES
.15
.10
.05
15
10
5
%
4 5 6 7 8
ASPHALT CONTENT % BY WEIGHT
DYNAMIC LOAD AT 140°F
ULT. LOAD - psi
16
14
12
10
8
6
4
2
0
EXTENSION AT FAILURE INCHES
.30
.25
.20
.15
.10
.05
30
25
20
15
10
5
%
4 5 6 7 8
ASPHALT CONTENT % BY WEIGHT

Figure 4.

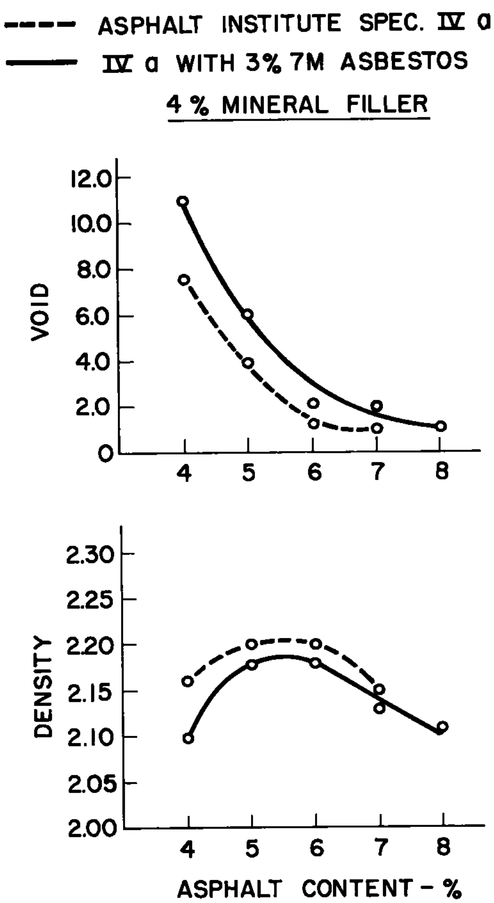

Figure 5. Average density and void content for tension test samples.

formed on mixes based on the Asphalt Institute IVa aggregate gradation in which the coarse aggregate was withheld, keeping all other constituents in the same relative proportions. The asphalt used was 60 penetration.

In Figure 6, the static compression test results are shown for samples with 4 percent mineral filler compacted by the gyratory method (a mechanized model of the Texas State Highway Department hand gyratory compaction method) which simulates actual pavement compaction procedure.

Maximum static compression strength was approximately 30 psi-hr for the control mix and 230 psi-hr for the asbestos mix. The maximum occurred at 5 percent asphalt content in the control mix but at 7 percent asphalt content in the asbestos mix. More directly, the maximum compression load sustained for 1 hr by the strongest control sample at 140 F was 25 psi. The maximum load sustained by the asbestos samples was 127 psi.

While penetration at failure in the standard samples increased continuously as asphalt content was increased, the asbestos mixes showed a peak in the curve at 5 percent asphalt content (the asphalt content at which maximum static tensile strength occurred in the same mix). The decrease in penetration at 6 percent asphalt content was followed by a second higher peak at 7 percent asphalt content which paralleled the peak in the strength curve. One of the asbestos samples with 8 percent asphalt content evidenced complete penetration of the indentor without cracking.

The void contents of these samples with 4 percent mineral filler (Fig. 5) indicate that compaction at 5 percent asphalt content in the standard mix was duplicated at approximately 6½ percent asphalt content in the asbestos mix. Compaction in the standard mix at 6 percent asphalt was duplicated at 8 percent asphalt content in the asbestos mix.

The "drop-off" in static compressive strength for the control mix as asphalt content was increased paralleled the drop-off in tensile strength (dynamic and static) and the typical rapid decrease in stability shown in standard mix design tests, which involve dynamic loading. Therefore, any of the dynamic tests could be used to determine the optimum asphalt content for static compressive strength.

However, the static compressive strength of mixes with asbestos did not show this progressive decrease as asphalt content was increased (as occurred in the tensile tests). This implies that the asbestos produced an effect apart from cohesional strength and suggests that "dynamic" mix design tests at 140 F could not be used to determine the optimum asphalt content for static compressive strength of paving mixes which contain asbestos fiber.

Asphaltic Concrete Mixes.—The static concentrated compression test was performed on samples removed from pavement mixes (N.Y. State DPW Physical Research Project No. 11) placed on a Thruway in Buffalo, N.Y. In Figure 7, typical load vs time curves are shown for these mixes after compaction at 260 F by the ASTM compression test method. The standard 2A mix sustained the 127-psi load at 140 F but failed almost immediately under the 260-psi load. The experimental mix with 1.3 percent 7M asbestos and approximately the same asphalt content showed approximately the same static strength as the standard 2A mix but evidenced almost twice the penetration at failure as was shown by the standard mix. Mix C also containing 1.3 percent asbestos, but with asphalt content increased 1 percent to 8.5 percent, evidenced a marked increase in strength and sustained both the 260-psi load for 1 hr and in one case the 510-psi load without plastic failure and without cracking. A third experimental mix (B) with 2.5 percent asbestos and 8.5 percent asphalt content also sustained the maximum load of 510 psi without failing. In mix B and mix C, and initial yield under 510-psi load was followed by a unique strength recovery which was not observed in the static compression tests on the IVa mixes with the coarse aggregate withheld. (However, similar strength recoveries were noted in the static tensile test with asbestos mixes at 7 percent and 10 percent total mineral filler content, but at a much lower strength.)

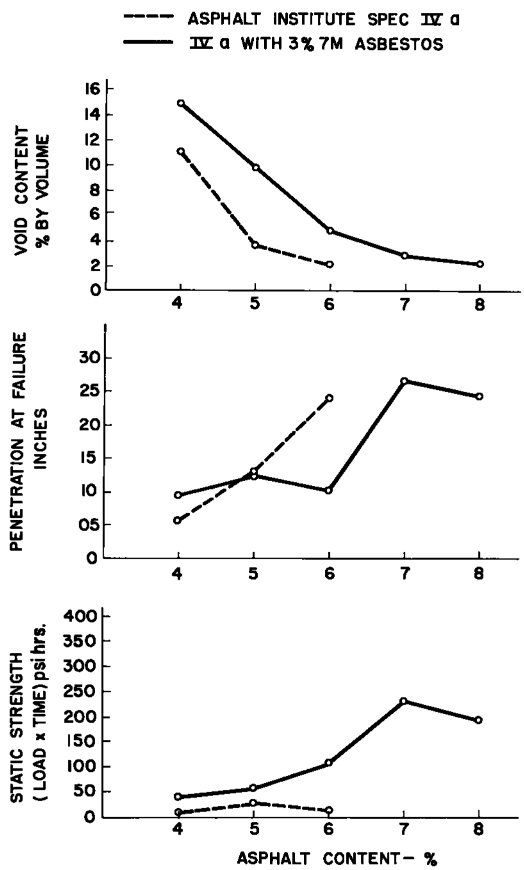

Figure 6. Static concentrated compression test at 140 F, 60 penetration asphalt, 4 percent mineral filler.

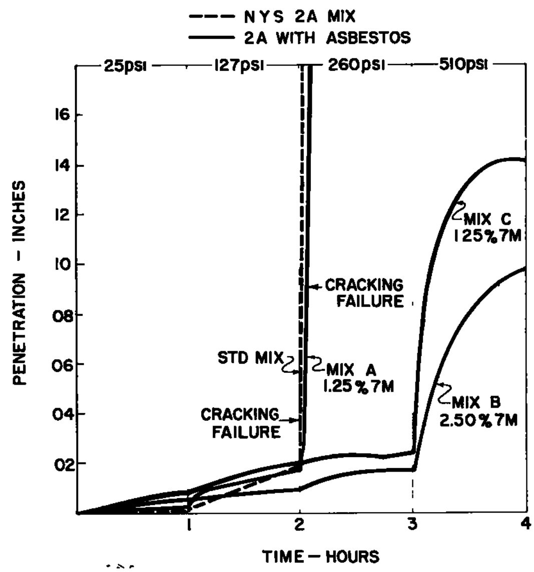

Figure 7. Static concentrated compression tests at 140 F on pavement mixes placed in Buffalo, N.Y.

The difference in static compression strength between mixes A and C, both with 1.3 percent asbestos, is at least partly due to the greater compaction allowed by the higher asphalt content.

Marshall stability and flow properties (measured by the Buffalo Crushed Stone Company on the samples removed from mixes and compacted while still hot) for these

TABLE 2

COMPRESSION TEST RESULTS ON SAMPLES OF MIXES PLACED ON THE SCAJACADA CREEK EXPRESSWAY IN BUFFALO, N.Y.

Mix	Asb.[1] Cont. (%)	Asph.[2] Cont. (%)	Density[3] (gm/cc)	Void Cont.[3] (% vol.)	Static Conc. Comp. Test[3]: Max. Load[4] (psi)	Total Strength (psi-hr)	Pen. at Fail. (in.)	Comp. Strength[5] (psi)	Marshall Values[6]: Stab. (lb)	Flow (0.01 in.)
2A[7]	0	7.6	2.28	3.9	127	172	0.05	615	886	22
Mod. 2A:										
A	1.3	7.8	2.29	3.0	127	141	0.09	775	1245	16
B	2.5	8.4	2.28	2.2	510	922	- [8]	872	1098	34
C	1.3	8.6	2.33	0	510	861	0.47	664	673	53

[1]Type 7M06. [2]60 penetration. [3]Samples compacted by method described in ASTM D-1074-58T. [4]Sustained, 1 hr. [5]ASTM method at 75 F. [6]Tests performed at Buffalo Crushed Stone Corp. under direction of J. F. Morgan, Jr. [7]Control mix; N.Y. State Dept. Public Works specification for bituminous top course. [8]No failure.

mixes are given in Table 2, which shows that the maximum increase in Marshall stability is roughly comparable to that shown by the Marshall test data previously described.

One pertinent question seems to beg an answer at this point. In light of the rather marked increase in static tensile and compression strength of asbestos mixes, is the moderate increase in maximum load the only evidence in the Marshall test of the effect of adding asbestos? According to the report of the producers of the experimental asphalt mixes (report of Experimental Bituminous Mixes produced in Buffalo Crushed Stone Corporation plant #1 on August 11, 1959—Cooperative program with New York State Department of Public Works, Physical Research Project No. 11), "All specimens

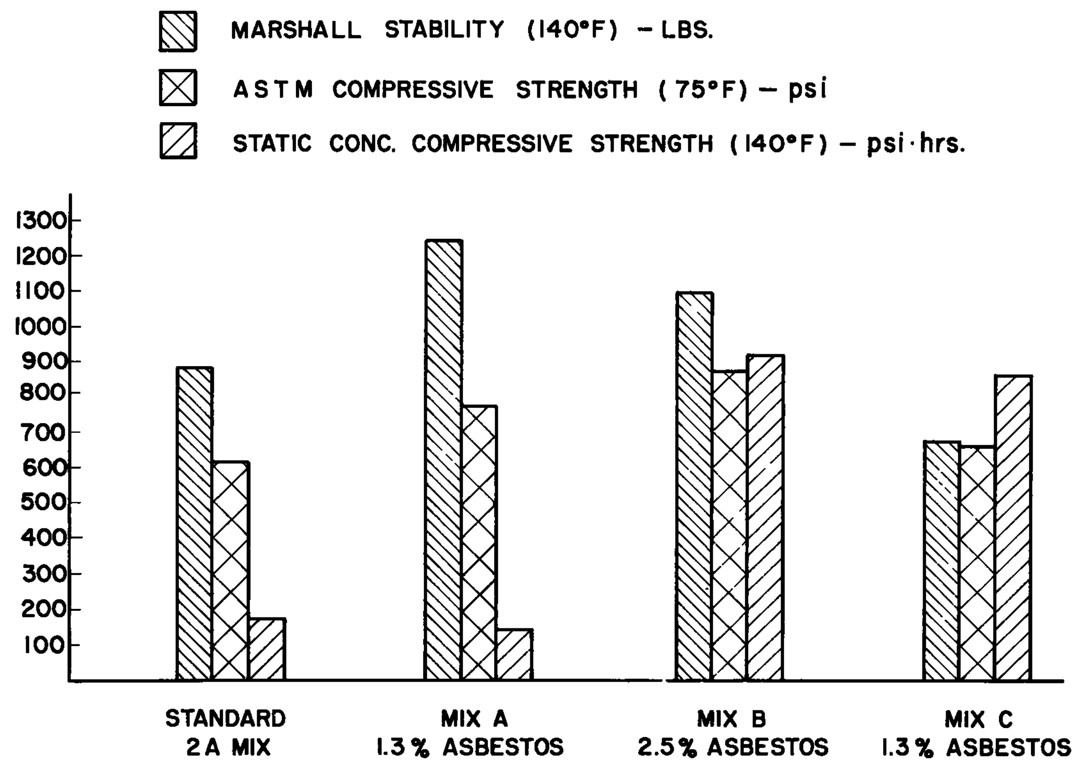

Figure 8. Compressive strength of pavement mixes placed in Buffalo, N.Y.

of mixes A, B, and C when reaching maximum stability, or load, remained at that value throughout the limit of distortion permitted by the equipment. The control mix after reaching maximum stability or load then fell off in value in the normal or expected manner as distortion continued." Similar Marshall test results have been reported from other sections of the country.

Comparison of Three Results on Test Pavement Mixes in Buffalo, N.Y.—Table 2 also gives the relative compressive strengths of the experimental mixes tested by the Marshall method, the ASTM compression test, and a static concentrated compression test (penetration test).

Void contents are believed to be of relative value only, because of errors inherent in the method of measurement. Because the densities and void contents of the Marshall samples are not known, comparing Marshall stability with the results of the other two tests may not be completely justified. However, Figure 8 shows results of these three compression tests.

These comparisons bear out the previous contention that use of the standard Marshall test criteria by itself, or any dynamic test, to evaluate asbestos-asphalt mixes might not be necessarily adequate.

TABLE 3

SUMMARY OF REPEATED BLOW IMPACT TESTS AT 0 F (SAMPLES TAKEN FROM PAVEMENT MIXES PLACED AS TEST STRIPS IN NEW JERSEY AND NEW YORK STATE)

Specification	Mix	Asbestos Content[1] (% by wt)	Asphalt (% by wt)	Asphalt Pen.	Density (g/cc)	Void (% by vol)	Impact Strength Max. Drop (in.)	Impact Strength Total[2] (ft/lb)
N.J. FA-BC	Std.	0	6	82	2.33	7.9	21	5.9
	Mod.	2	6		2.26	9.9	33	14.3
N.J. MA-BC	Std.	0	6	60	2.36	8.6	26	9.0
	Mod.	3	7		2.38	4.7	37.5	18.4
N.Y. State 2A	Std.	0	7.6	60	2.26	3.9	25.5	8.7
	Mod. (A)	1.3	7.8	60	2.29	3.0	30	12.0
	Mod. (C)	1.3	8.6	60	2.33	0	33	14.3
	Mod. (B)	2.5	8.4	60	2.27	2.2	37.5	18.4

[1]7M fiber.
[2]Summation of drop heights to failure multiplied by weight of ball.

It can be seen that the asbestos mix which showed the highest Marshall stability displayed the lowest static compressive strength.

Mix C, although lowest in Marshall stability, showed a static (concentrated) compressive strength more than twice that of the standard, even though the void content was effectively reduced to zero. In addition, mix C showed the greatest penetration under concentrated loading without cracking.

In general, the results of the asbestos mixes showed that as asphalt content was increased, void content decreased, Marshall stability decreased and static compressive strength increased.

Repeated Blow Impact Test

The results of impact tests at 0 F on specimens of asphaltic concrete made in the laboratory from samples taken from pugmill mixes are given in Table 3.

Failure in all cases was by transverse cracking of the 4-in. diameter briquettes. Fracture of the coarse aggregate particles at impact failure suggests that the impact strength of the matrix (as measured by this test) was roughly equivalent to that of the coarse aggregate.

Repeated blow impact strength at 0 F was apparently proportional to asbestos content and asphalt content. The maximum increase in impact strength was 47 percent measured by maximum drop height and 110 percent measured by total impact load in the New York State 2A mix with 2.5 percent total weight 7M asbestos.

Thin-Film Weatherability Tests

A series of accelerated weathering tests on thin films of tar emulsion containing short asbestos fiber were performed by the Corps of Engineers at Vicksburg in 1957. The favorable results of their tests prompted similar tests at the Johns-Manville Research laboratory on several grades of paving asphalt with mineral filler added in the proportions similar to the filler-asphalt ratio used in asphaltic concrete.

The purpose was to measure the comparative ability of a standard filler and short asbestos fibers to maintain the structural integrity of the thin films of asphalt between fine aggregate and/or mineral filler grains.

In Figures 9 through 12, typical visual failure is shown for thin films of 82 penetration asphalt after 100 hr of accelerated weathering (cycle A). Figure 9 shows a film of

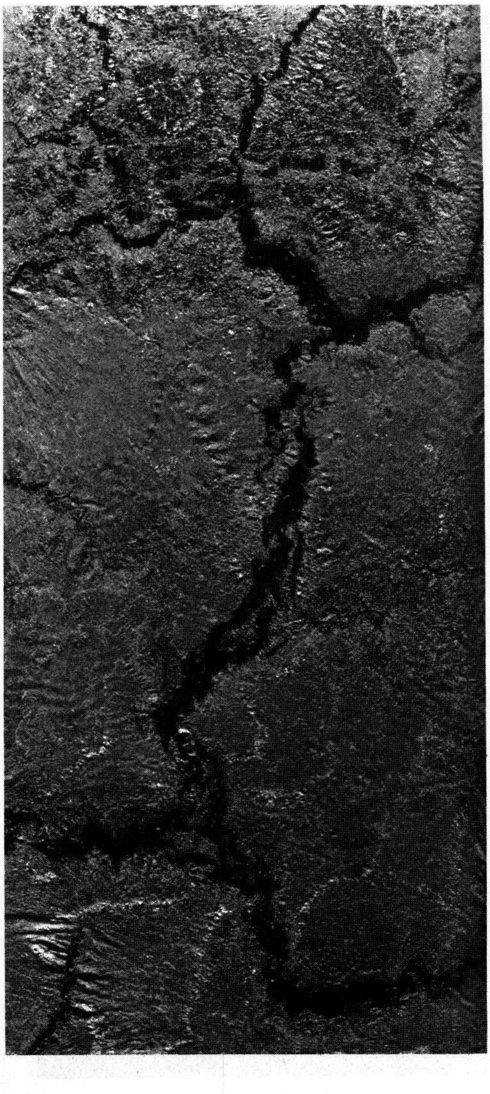

Figure 9. Thin film (0.010 mil) of 82 penetration asphalt without mineral filler after 100 hr of accelerated weathering.

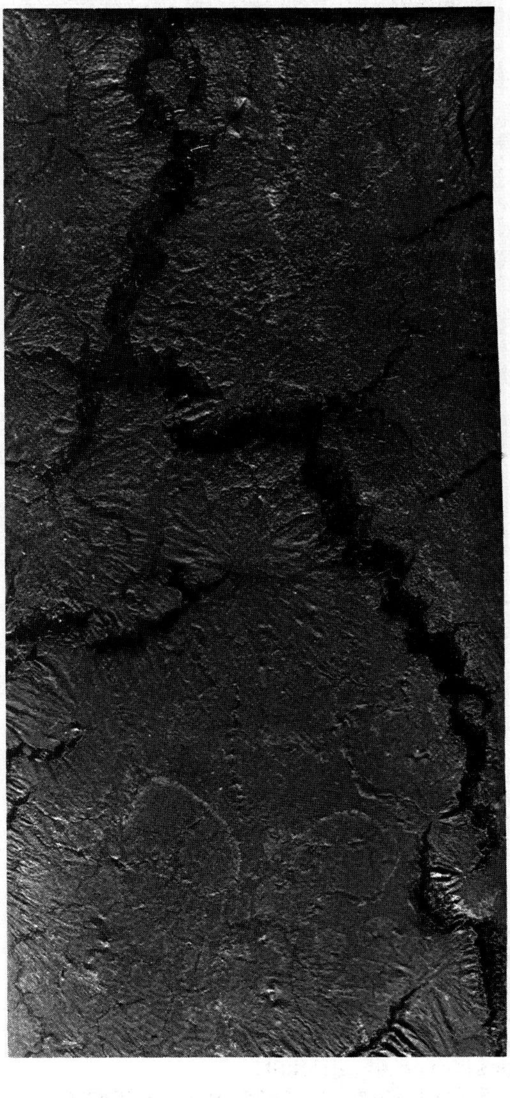

Figure 10. Film (0.011 mil) of 82 penetration asphalt with 50 percent by weight limestone filler (-200M) after 100 hr of accelerated weathering.

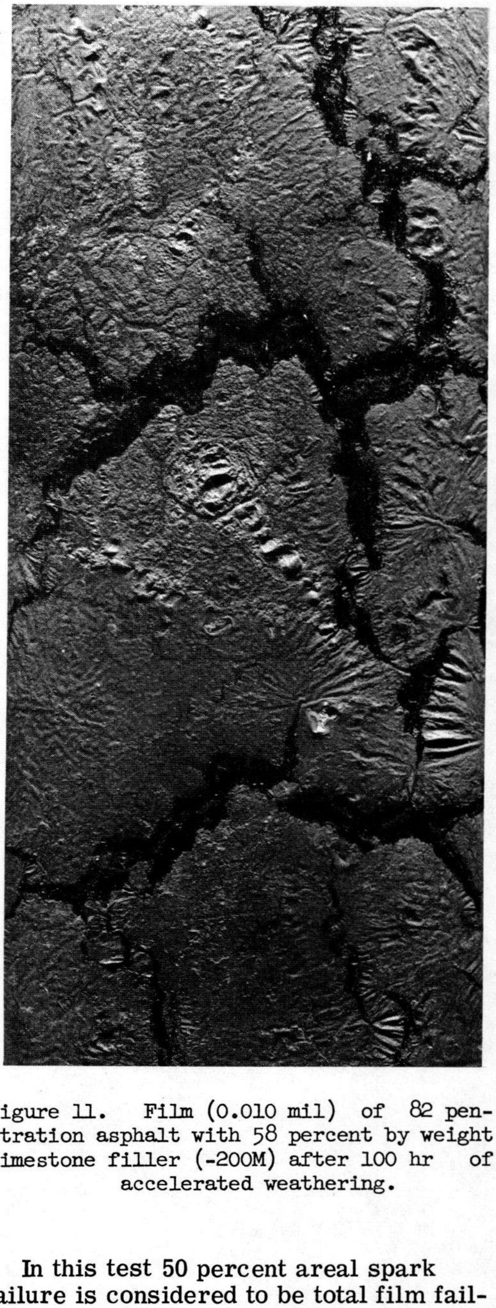

Figure 11. Film (0.010 mil) of 82 penetration asphalt with 58 percent by weight limestone filler (-200M) after 100 hr of accelerated weathering.

In this test 50 percent areal spark failure is considered to be total film failure, and due to the chance occurrence of air bubbles in the original film, areal spark failure of less than 5 percent is not considered significant.

Film failure in these tests is apparently the result of repeated exposure to cyclic high and low temperatures combined with the chemical or physical changes resulting from the combined effects of air, deionized water and ultra- a mixture of 50 percent and 57 percent -200 mesh limestone filler, respectively, and 82 penetration asphalt. Figure 12 shows films in which 20 percent by weight of limestone was replaced by an equal weight of 7M asbestos.

The results of exposure of these films in standard weatherometer machines, the intermittent use of a spark test to detect microscopic holes, and a photographic trace of these holes to measure film failure quantitatively is shown in Figure 13.

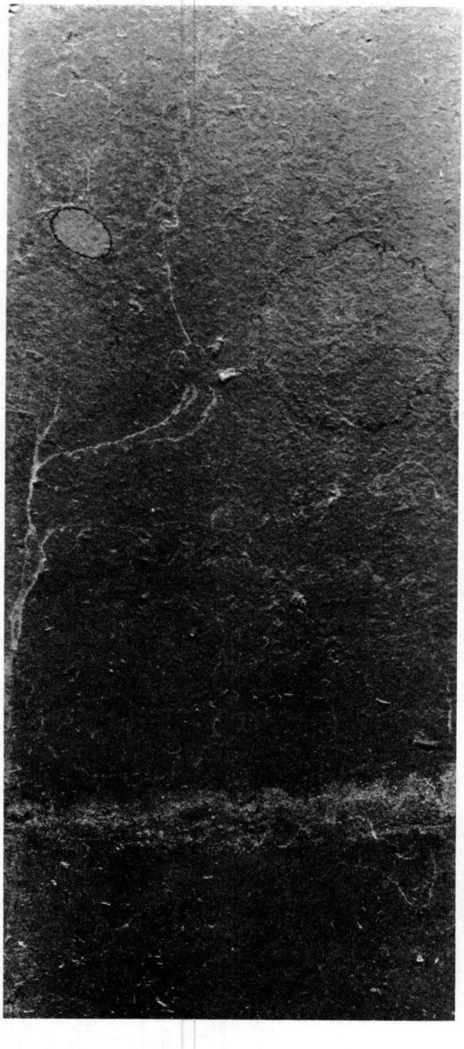

Figure 12. Film (0.012 mil) of 82 penetration asphalt with 30 percent limestone and 20 percent asbestos after 100 hr of accelerated weathering (rough surface is original film surface).

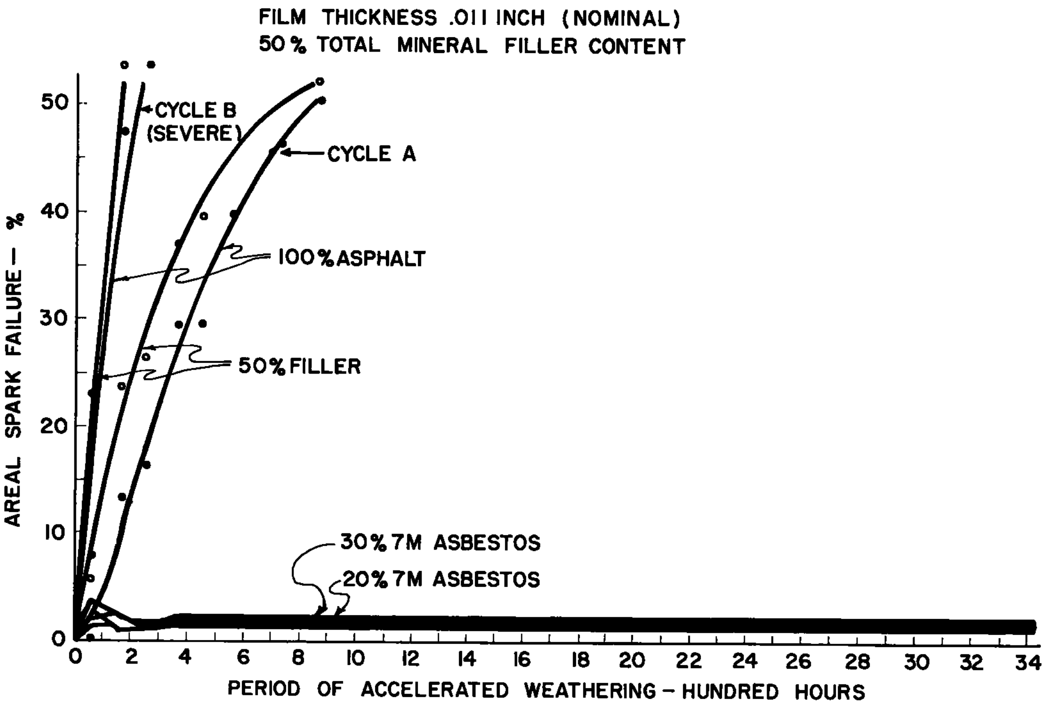

Figure 13. Weatherability of thin films of 60 penetration asphalt (weatherometer cycles A and B).

violet rays which simulate weathering conditions. The test measures the reaction of each film to the cumulative internal stresses which result from these conditions.

Films of pure 60 penetration asphalt of 11-mil thickness showed rapid film failure with a progressively decreasing rate of failure. Total film failure (50 percent areal spark failure) was at 900 hr of accelerated weathering under the moderate weathering cycle (A) and at 200 hr under the extreme weathering cycle (B).

Films of 60 penetration asphalt with 50 percent limestone filler (-200 mesh) showed no significant improvement in over-all rate of film failure at either weathering cycle.

In films of asphalt with or without 50 percent limestone filler, the rate of film failure under severe weathering was approximately six times faster than identical films tested under the less severe weatherometer cycle.

Films containing 20 percent and 30 percent short asbestos fiber showed no measureable film failure through to the end of the test period (3,400 hr).

Severity of accelerated weathering appeared to have no effect on the ability of the fiber to maintain structural integrity of the film.

DISCUSSION OF RESULTS

Asphalt Content

It is generally agreed that except for the effect on plastic strength, an increase in asphalt content in standard asphaltic concrete mixes would be desirable.

If the static concentrated compressive strength is a valid measure of resistance to plastic deformation, then, based on previously described data, use of 3 percent 7M asbestos allows an increase in asphalt content of 2 percent total weight of mix. For a significant increase in static compressive strength, asphalt content should be increased by at least 1 percent above the standard mix.

However, if maximum cohesional (tensile) strength were used as the criterion for optimum asphalt content, asphalt content of the mix with 3 percent asbestos would be

kept the same as the standard mix or decreased slightly, depending on the type of test (static or dynamic) and temperature of the test.

The question which logically follows is why increase asphalt content? Most of the reasons suggested for increased asphalt content seem to be related to flexibility properties. (One other reason for increasing asphalt content, independent of flexibility, is increased weather resistance (of surface courses).

Flexibility

Although resistance to plastic deformation appears to be considered by paving engineers to be the most important strength characteristic of bituminous pavement at elevated service temperatures, flexibility is generally considered to be the main strength property of importance at normal or low ambient temperatures.

Flexibility of an asphalt pavement has been defined by Monismith in two ways which reflect the viscoelastic nature of asphalt paving mixes: the ability "to conform to variations in the base and subgrade elevations of the pavement structure and the ability to bend repeatedly without fracture (6)," or simply conformability and flexural fatigue.

According to Monismith ..."the greater the amount (of asphalt)..... the more able should be the mixture to conform to base and subgrade variations. From the standpoint of fatigue resistance, it would also appear that the greater the amount of asphalt, the better able would be the mixture to withstand repeated deflections since the asphalt would exist in thicker films (6)."

The first point has apparently been established from field and laboratory evaluations. In general, the static load extensibility and penetration (1) of the control mix in the Johns-Manville Research Center tests bears out this conclusion that extensibility at failure (a measure of conformability) varies with asphalt content. However, although extensibility at failure of the control mix under static loading at 75 F showed a progressive increase as asphalt content was increased up to 6 percent, it decreased from 6 to 7 percent asphalt content. In addition, the extensibility of the control mix under dynamic and static loading at 140 F appears to be approaching a maximum at 7 percent asphalt content.

In the asbestos-asphalt mixes, the data show that extensibility under static loading at 75 F increased continuously as asphalt content was increased up to 8 percent asphalt (the maximum asphalt content tested).

From the standpoint of flexibility, the fact that asbestos allows a large increase in asphalt content of standard paving mixes may be the most important consideration.

Monismith (6) has presented data which demonstrate that flexural fatigue strength at 75 F increased as asphalt content increased. His data also showed a large increase in modulus of rupture (dynamic flexural strength) due to increasing asphalt content in a standard asphaltic concrete.

The fact that a high static load strength was maintained in the asbestos mix as asphalt content was increased up to 8 percent (or greater) and extensibility or penetrability increased progressively suggests that it may be possible to obtain a wide range of flexibility characteristics. On a resilient base, a pavement with a large increase in asphalt content might be desirable. For a thin pavement, with inherent high flexibility, possibly a small increase in asphalt content might conceivably be best.

Asbestos Content

In general, results to date suggest the following. Based on thin-film weatherometer tests, adequate stabilization of the asphalt-filler during weathering would require 1 percent total weight 7M asbestos. For essentially complete stabilization 2 percent 7M would be required. The amount required probably is less for low penetration asphalts and may conceivably be higher for high penetration asphalts.

Although the strength tests described herein pertain mostly to mixes with 3 percent 7M asbestos, limited tests with other fiber contents suggest that strength properties are proportional to fiber content, with compaction characteristics and total mineral filler content controlling this relationship at low and high asphalt contents, respectively.

On a strength basis, the amount of fiber desired would be dependent on how much of any type of strength was desired.

From the standpoint of resistance to plastic deformation alone, it appears possible from static compression tests that as little as 1 percent asbestos might be adequate for some mixes with the asphalt content determined by the test criterion (increased asphalt content for optimum static strength, standard asphalt content—5 to 6 percent—for optimum dynamic strength).

With the possible exception of resistance to plastic deformation, even an approximate idea of how much strength, flexural, impact, etc. would require field evaluation of test strips with varying fiber content, asphalt content, and total mineral filler content.

CONCLUSIONS

Because of the difficulties involved in extrapolation of small-scale laboratory test results to pavements under service conditions, the following tentative conclusions do not necessarily apply generally to all pavement mixes or to pavement performance which can only be determined by field evaluation.

The conclusions relating to pavement strength at high temperatures are based on the assumptions that plastic strength of asphalt pavement is of critical importance rather than elastic strength and that a static load test is a valid, if somewhat rigorous, measure of plastic strength.

The test data suggest that asbestos fibers may greatly increase plastic strength of asphalt mixes while allowing a relatively wide range of asphalt contents, which should permit a corresponding range of flexibility characteristics as desired.

Based on the test data, the use of dynamic tension (cohesion) tests to determine optimum asphalt content for maximum plastic compressive strength would be justified for the control (standard) mix, but not for the asphalt mixes with asbestos included.

Relatively large increase in dynamic tensile strength at 75 F and 140 F of the control mix and in repeated blow impact strength at 0 F were obtained by the addition of chrysotile (asbestos).

Thin-film accelerated weathering tests suggest that inclusion of short asbestos fibers effectively maintains structural integrity of the asphalt exposed at the surface for an indefinite period of time.

ACKNOWLEDGMENTS

The author would like to thank George Clarvoe and his staff for their advice and assistance throughout the evaluation. Special thanks should be given to Charles Bloom for his help in the weatherability tests. Frank Hunt and J.J. Scanlan were indispensable in carrying out the laboratory evaluation. Foster Hulsizer of the Mechanical Section designed the mechanization of the Texas gyratory compaction apparatus.

John Griffith, Ben Kallas, and Harry Thompson of the Asphalt Institute offered valuable advice during the survey which preceded the laboratory investigation.

The advice and criticism of paving technicians throughout the country are gratefully acknowledged.

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Appendix A

TABLE 4

Quebec Stand. Classif.		Minimum Wt.[1] (Oz)			
Group	Sample	½ Mesh	4 Mesh	10 Mesh	Pan
3:	3R	2	8	4	2
4:	4K	0	4	9	3
5:	5R	0	0	10	6
6:	6D	0	0	7	9
7:	7D	0	0	5	11
	7F	0	0	4	12
	7H	0	0	3	13
	7K	0	0	2	14
	7M	0	0	1	15
	7R	0	0	0	16

[1]Quebec Standard test, Canadian Chrysotile Asbestos Classification.

TABLE 5

PHYSICAL PROPERTIES OF CANADIAN CHRYSOTILE ASBESTOS

Specific gravity[1]	2.55
Fiber diameter[2] (in.)	0.000000706 to 0.00000118
Fibrils[1] in 1 in. (no.)	850,000 to 1,400,000
Tensile strength[1,2] (psi)	100,000 to 355,000

[1]Badollet, M.S., Canadian Mining and Metall. Bul., Trans., 54:151-160 (Apr. 1951).
[2]Zukowski, R., and Gaze, R., Nature, 183:35-51 (Jan. 1959).

TABLE 6

COMPOSITION OF TYPE IVa DENSE-GRADED SURFACE MIX[1]

Sieve Sizes	Percent Passing by Weight[2]	
	Asphalt Institute Spec.	Fine Aggregate Mix
½ in.	100	-
⅜ in.	80-100	-
#4	55-75	-
#8	35-50	40
#30	18-39	21
#50	13-23	15
#100	8-16	9
#200	4-10	4

[1]See Ref. 1. Bitumen content for Asphalt Inst. Spec., 3.5 to 7.0 percent; for fine aggregate mix, 3 to 8 percent.
[2]For the Johns-Manville Research Center laboratory evaluation all aggregate retained on a #8 screen was excluded, increasing the weight proportions of the other constituents—asphalt, filler, andfine aggregate fractions so as to obtain the same relative proportions which would exist in a mix with the coarse aggregate included.

TABLE 7

PHYSICAL PROPERTIES OF ASPHALT[1] USED FOR IVa FINE AGGREGATE LABORATORY MIXES AND THIN FILM WEATHEROMETER SAMPLES

Penetration Grade	60	82
Penetration, mm/10 100 g for 5 sec	60	82
Specific gravity	1.023	1.023
Heat susceptibility (5 hr at 325 F)		
Loss on heating (%)	0.025	0.039
Penetration, mm/10	55	69

[1]From Venezuelan crude at Curacao refinery, Shell Oil Co.

TABLE 8

BUFFALO CRUSHED STONE CORPORATION NEW YORK STATE SPECIFICATION 2A FOR TOP COURSE OF BITUMINOUS PAVEMENT[1]: ROTAREX EXTRACTION OF 500-g SAMPLE

Passing	Retained	Control Mix (%)	Mix A (%)	Mix B (%)	Mix C (%)
1 in.	½ in.	None	None	None	None
½ in.	¼ in.	6.8	4.6	6.6	5.8
¼ in.	⅛ in.	24.2	26.4	21.8	24.8
⅛ in.	40	20.0	17.7	25.3	22.9
40	80	23.4	21.7	20.2	20.8
80	200	15.0	16.3	11.0	11.2
200	-	5.0	4.2	4.2	4.6
Asbestos		None	1.3	2.5	1.3
Asphalt cement		7.6	7.8	8.4	8.6
		102.0	100.0	100.0	100.0

Note: All aggregates were limestone.
[1]Placed on the Scajacada Creek Expressway, August 1959 as part of Physical Research Project No. 11 of the New York State DPW, Bureau of Physical Research.

Appendix B

DESCRIPTION OF WEATHEROMETER CYCLES USED IN THE THIN FILM WEATHERABILITY TESTS

Cycle A

Below are shown the successive steps in one 21-hr cycle which was repeated each day for five successive days per week:

Step	Time Period	Condition
1	1.0 hr	Cold water spray (deionized water at 40 F).
2	1.5 hr	Radiation from single carbon arc ultraviolet lamp. Black bulb temperature 140 to 145 F. Air temperature 115 to 120 F.
3	2.0 hr	Cold water spray (as in Step 1 above).
4	16.5 hr	Light exposure (as in Step 2 above).

Cycle B

Continuous ultraviolet radiation for 21 hr (as described under Cycle A).
Every 51 min, a 9-min duration of cold water spray (40 F, deionized).
Specimens were exposed in the horizontal position 9 in. below the carbon arc with the length of the plate pointing toward the (vertical) axis of machine rotation and the inside end of the plate 8 in. from the axis.

Appendix C

TENSILE TEST SAMPLE PREPARATION

The following procedure was used to prepare the tensile test samples of the IVa fine aggregate mixtures. Each operation is listed in the chronological order. Only one sample (130 gs) was prepared from each batch (300 gs) of mix:

1. Aggregate and mineral filler fractions were combined and preheated at 350 F.
2. The asphalt was heated to a temperature of 300 F with constant stirring.
3. The aggregate, mineral filler, and asbestos (asbestos was added purposely without preheating or drying) were mixed in a preheated 5-qt stainless steel bowl for 30 sec.
4. The preheated asphalt was added to the aggregate mixture and mixed by hand for 30 sec.
5. 120 gs of the mixture was then placed by hand into a briquet gang mold which had been preheated to 250 F and wiped with a rag saturated with silicone lubricant.
6. With the mortar mold clamped rigidly onto a ½-in. steel plate (also preheated) the mixture was compacted at a load of 3,000 psi for a period of 2 min with a top plunge preheated at 250 F with the same configuration as the mold, allowing for 0.005-in. clearance between the plunge and the inside dimensions of the mold all the way around.
7. With the top plunger bearing against a spherically based compression block, a load of 3,000 psi was applied to the mixture in the mold for a period of 2 min.
8. The sample was removed from the mold after cooling for 2 min. in cold water.

The following procedure describes the methods used to determine density and void contents:

1. After curing at room temperature for 48 hr, the dry weight and weight under water after 1-min immersion were taken. The difference in weight was taken as the bulk volume.
2. The density was determined by dividing the dry weight by the bulk weight.
3. The absolute volume of each sample was determined by summing up the product of the weight percentage multiplied by the dry weight of the sample divided by the specific gravity for each constituent in the mix:

$$\sum \left(\frac{\text{wt } \%}{\text{Sp. G}} \text{ x dry sample wt} \right)$$

4. The approximate void content in percent by volume was calculated by subtracting the absolute volume from the bulk volume and dividing by the bulk volume.

Appendix D

MARSHALL TEST DATA BY THE CHICAGO TESTING LAB. ON ASPHALTIC CONCRETE