# Control of Asphalt Pavement Rutting with Asbestos Fiber

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Rutting-type failures are induced in miniature asphalt highway pavements with a traffic simulator machine, which duplicates critical factors of roadway temperature gradients, vehicle tire pressure, and accumulated wheel passes. An investigation was made of the beneficial effects various mineral additions produced in pavements exposed to severe service conditions.

Of the admixtures used, only a mixture containing fine chrysotile asbestos fibers prevented excessive rutting at normal and increased asphalt contents. Asbestos mixes have surprisingly low sensitivity to asphalt concentration over the range from 5.0 to 8.0 weight percent. With 85 to 100 penetration grade asphalt, asbestos raised the critical rutting temperature to levels reached by pavements on an extremely hot summer day. An additional elevation of about 20 F was achieved with 60 to 70 penetration asphalt and suitable control of fiber-asphalt ratios.

Bench scale temperature-susceptibility evaluations suggest simple laboratory test procedures can measure critical design properties of asbestos-asphalt mixtures. The static temperature indentation procedure appears to yield results that compare favorably with miniature highway traffic simulator machine performances.

Fiber linkage is a mechanism that may explain the resistance to rutting which asbestos imparts in asphalt paving mixtures. Selective adsorption on the short chrysotile asbestos fiber could bond or link together the heavy, viscous asphalt fraction. Pavement stability against rutting would then depend only on the strength of the heavy fraction, the amount present in the paving asphalt, and the proportion adsorbed by the asbestos fiber.

• RUTTING OF ASPHALT ROADS in severe service was recognized as an important shortcoming of certain flexible pavements several years ago. Often serious surface roughening appeared in traffic lanes exposed to many passes of heavily loaded wheels. Concern over the mechanism responsible for this rutting produced a laboratory traffic testing technique that duplicates all important features of this type of slab deterioration.

Early tests (1) showed the American Oil Company miniature highway test track was ideal for pavement rutting experiments. Observation of performance at the AASHO Road Test confirmed preliminary conclusions that the traffic simulator machine accurately reproduces actual highway distress conditions. In 12 days miniature highways are exposed to approximately 2,000,000 wheel passes and ruts nearly 2 in. deep formed in some specimen pavements. Accelerated rutting tests are conducted on 16 miniature highways simultaneously; they are exposed to traffic-like stresses in the laboratory equipment shown in Figure 1. A plastic tent encloses the experiment. Inside this transparent structure the full spectrum of highway stress conditions is created. The precise control over all loading and external climatic factors maintained during the laboratory traffic test runs is most helpful in determining causes for slab rutting. Numerical results pinpoint factors that help restrict rut actions to acceptable rates.

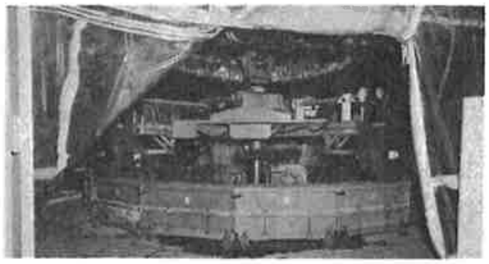

Figure 1. Laboratory traffic simulator machine.

Fourteen months of testing time was devoted to a series of experiments involving deep rutting*, followed by more than six months work with mineral admixtures. The specific objective of the admixture phase of the investigation was to develop mineral formulations that (a) did not rut, (b) remained free of other types of in-service defects, (c) could be mixed and laid down with standard asphalt highway construction equipment, and (d) were economically competitive with other types of pavements. Mineral admixtures tried include limestone dust, clay powder, carbon, and fine chrysotile asbestos fiber. Each was evaluated with a soft 85-100 penetration and a hard 60-70 penetration grade asphalt cement.

## HIGHWAY FABRICATION PRELIMINARIES

Miniature asphalt highways are built in the same way real road projects are constructed. Each test specimen is 12 in. wide, 16 in. deep, approximately 34 in. long, trapezoidal shaped, weighs about 600 lb and requires less than 1 gal of asphalt for its pavement. Figure 2 shows a new miniature highway specimen (Fig. 2a) and a cross-sectioned example that suggests an interior view of various structural layers employed in the construction (Fig. 2b). The lower section is soil; the central portion, crushed rock; and the upper part, hot-mix asphalt paving. Physical properties of the two lower materials are held constant in all miniature highways. Pavement properties related to aggregates and construction techniques are also kept constant. Asphalt pavement characteristics and roadway stress conditions are varied and comprise the factors under study.

Laboratory miniature highway construction begins with the soil subgrade. All specimens have a lower section of soft plastic clay. This is 9 in. thick and is placed in three 3-in. deep lifts. Moisture content, dry density, and support modulus are all controlled within close limits. Details are summarized in Appendix A.

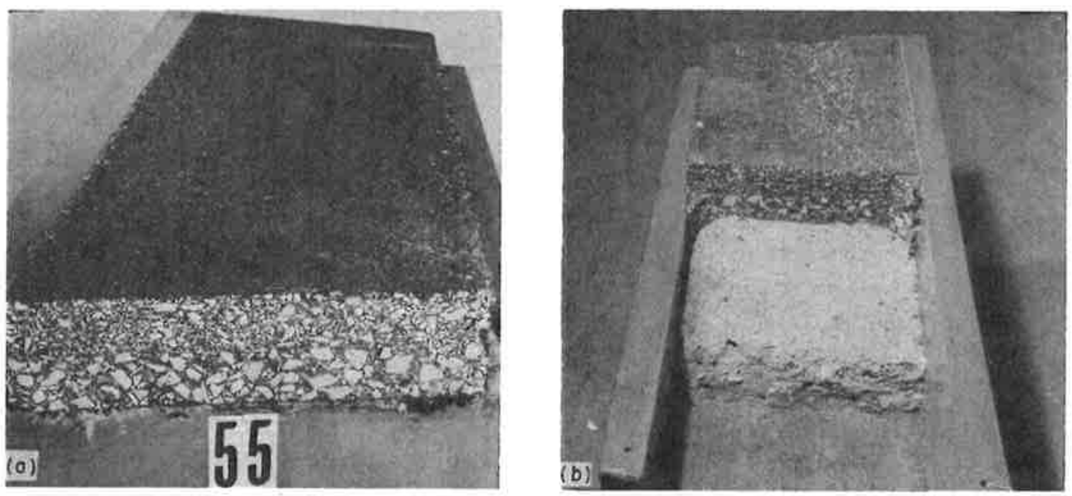


Figure 2. Miniature asphalt highway specimens: (a) new untested asphalt pavement and (b) interior view of highway.

*A paper covering details and conclusions has been offered to the Association of Asphalt Paving Technologists for presentation at the New Orleans Annual Meeting, Jan. 29-31, 1962.

Crushed limestone rock is used for the 4-in. thick waterbound base course. It is placed under controlled compaction conditions. Physical properties are summarized in Appendix B. Each completed base is allowed to dry in a circulating stream of warm air until the upper surface is dry. At this time, it is sealed with 0.10 gal per sq yd RC-O cutback liquid asphalt, sprayed on at a temperature of 140 F.

Miniature highways have a 1½-in. thick binder course and 1½ in. of surfacing. Rock and sand aggregate size gradation characteristics are not permitted to vary. This has the effect of holding aggregate friction constant. Thus, differences in mineral admixture performance are not masked by variations in pavement strength caused by nonuniform coarse and fine materials.

## MIXTURE FORMULATION

Miniature highway pavement mixture formulations are designed in the standard way. The Marshall method for the control of bituminous paving and Hveem stabilometer values are used to evaluate optimum asphalt content, stabilities, and flow values. In addition, the California Highway Department cohesiometer device is used to measure flexural strength. An optimum asphalt content is selected, taking proper account of the maximum stability, maximum unit weight, 5 percent void space, and 80 percent of the void space filled with asphalt. The compromise asphalt content to satisfy these requirements is 5.5 and 6.0 weight percent for binder and surface course aggregates, respectively. Actual asphalt contents used in miniature highway tests bracketed these two values.

### Aggregate Blends

A single source of aggregate is used for all paving formulations (Materials Service Corporation, Chicago; crushed limestone rock from quarry at Thornton, Ill.; and sand from natural deposits derived from Lake Michigan). Crushed limestone and natural sand are sieved into several size fractions with a large screening machine, using high-precision laboratory control limits for sieve carryover. Mixture blending is to the exact proportions by weight given in Table 1. Enough oven-dry materials for a single course of one miniature pavement, about 110 lb, are carefully weighed out and placed in a covered metal container. Each individual layer of paving is batched in this way.

### Control Mixes

All pavements for the asbestos admixture study were constructed with straight vacuum-reduced paving asphalt from commercial production of the American Oil Company at Whiting, Ind. A 30-70 percent by volume blend of West Texas and Wyoming crude stocks was used to produce the two grades required. The 60-70 penetration asphalt was reduced directly to the specified grade in a 40,000-barrel per day pipe still; 85-100

TABLE 1

PAVEMENT AGGREGATE CHARACTERISTICS

| Course | Material | Sieve Size | % Blend Passing Sieve |
|---|---|---|---|
| Surface | Stone | ½-in. | 100 |
| | | No. 4 (4,760 μ) | 70 ± 0.1 |
| | Sand | No. 10 (2,000 μ) | 44 ± 0.2 |
| | | No. 40 (420 μ) | 26 ± 0.3 |
| | | No. 80 (177 μ) | 15 ± 0.3 |
| | Dust | No. 200 (74 μ) | 7 ± 0.3 |
| Binder | Stone | ¾-in. | 100 |
| | | ½-in. | 75 ± 0.1 |
| | Sand | No. 10 (2,000 μ) | 30 ± 0.1 |

penetration asphalt was a blend of the 60-70 penetration material and a 200-250 penetration asphalt which was also reduced directly to grade at the pipe still. Table 2 summarizes important specification properties for the two asphalts.

A set of control pavements was laid with each grade of asphalt. Limestone dust filler (Commercial limestone dust, furnished in 100-lb paper bags by the Material Service Corporation, Chicago) was the mineral addition in these formulations; 100 percent of this filler passed the No. 200 (74-μ) sieve screen. Four mixture formulations for control pavements are summarized in Table 3; the 10 percent asphalt content was not employed with the 60-70 penetration asphalt. The rutting of these pavements is the base of comparison for all admixtures of asbestos and other minerals.

The combined weight of the crushed rock, sand, and limestone dust are considered to constitute the base mixture or 100 percent weight. The quantity of asphalt required is calculated from this base. Thus, if, for example, the weight of all aggregate including limestone dust is 100 lb and 5.5 percent asphalt is used, the total mixture weight is 105.5 lb.

## Asbestos Admixtures

Asbestos pavements were fabricated at the asphalt contents listed for control pavements in Table 3. The asbestos addition was 2.5 percent for all formulations except the one employing 10.0 percent asphalt; this admixture had 14.0 percent asbestos added. Asbestos was substituted for an equal weight of aggregate.

Johns-Manville grade 7M06 chrysotile asbestos fibers were used. This grade was selected because it (a) is comparatively inexpensive, averaging about $50 per ton, (b) has medium bulk and adsorption, (c) is milled to short fiber size, (d) had demonstrated good mixing and laydown characteristics with standard highway construction equipment, and (e) has yielded good traffic durability characteristics in test road projects. Asbestos is available in standard grades numbered 3 through 9. The 7M part of the designation specifies a fiber that has 1 oz retained on a No. 10 sieve and 15 oz passing this sieve (Quebec standard testing machine method specified by the Quebec Asbestos Mining Association); the 06 symbol describes the "crudiness" or texture of the asbestos to be of medium bulk and adsorption. Altogether, 59 different standard grades of asbestos are available commercially. They range in cost from $600 to $25 per ton. The 7M06 fiber ranks near the bottom in 44th place if the various grades are listed in a descending cost order.

## Mixing Operations

Actual blending of miniature highway materials takes place in the mixer shown in Figure 3. This is a standard unit from a piece of highway construction machinery (a 3-cu ft, twin-shaft, opposed rotation pugmill mixing unit from a Model 804 Mix-all machine manufactured by Barber-Greene, Aurora, Ill.) modified to operate indoors with electric power and compressed air. Two fluid-type heating jackets, powered by four thermostatically controlled 750-watt immersion elements, provide basic heat. Mixing chamber temperature is controlled

TABLE 2

ASPHALT SPECIFICATIONS

| Specification Test | 60-70 Pen. | 85-100 Pen. |
|---|---|---|
| Penetration (0.01 cm) | 60 | 85 |
| Specific gravity, 77/77 F | 1.037 | 1.031 |
| Flash point (° F) | 620 | 615 |
| Loss on heating (%) | 0.016 | 0.010 |
| Penetration of residue: | | |
| 0.01 cm | 55 | 72 |
| Percent | 91.7 | 84.7 |
| Ductility (cm) | +150 | +150 |
| Bitumen Soluble $CCl_4$ (%) | 99.7 | 99.9 |
| Spot test | Negative | Negative |

TABLE 3

MIXTURE FORMULATIONS FOR CONTROL PAVEMENTS

| Asphalt Content (%) | |
|---|---|
| Binder | Surface |
| 4.5 | 5.0 |
| 6.0 | 6.5 |
| 7.5 | 8.0 |
| 10.0 | 10.0 |

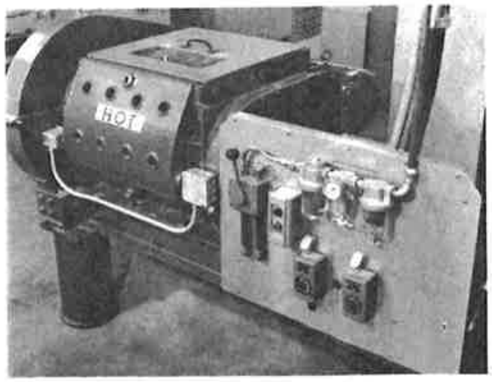

Figure 3. Laboratory hot-mixing plant.

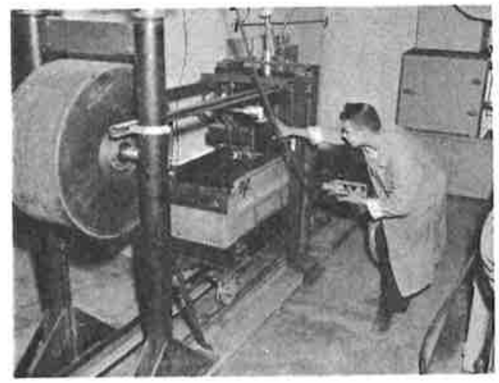

Figure 4. Laboratory asphalt paving machine.

TABLE 4

MIXING CYCLE FOR PUGMILL

| Operation in Cycle | Time (sec) Elapsed | Total |
|---|---|---|
| Dry aggregate blending | 60 | 60 |
| Asphalt addition | 20 | 80 |
| Basic mixing period | 90 | 170 |
| Admixture addition | 20 | 190 |
| Post additive mixing period | 120 | 310 |
| Discharge from mixer | 30 | 340 |

at 305 ±2.5 F. The bottom dump gate is at the mixing temperature with two 700-watt strip heaters.

The "batched" aggregates and asphalt are preheated to the mixing temperature in electric ovens; individual, covered metal containers are used. Hot material is added to the mixer through a small door in the top cover plate of the machine. Mixing operations are continued until a completely homogeneous mass is obtained as determined by analysis of the distribution of component materials in various parts of several batches, each mixed for a different length of time. A total mixing cycle of 340 sec is employed. This time is divided into six operations which provide a basic mixing period plus a post-addition cycle for the asbestos and other minerals. Details of the complete mixing sequence are summarized in Table 4. Asbestos fibers are added at room temperature.

## Paving Procedure

The freshly prepared hot mix is stored in a 300 F oven in covered pails for 90 min. This simulates job transportation and finishing machine waiting periods. The miniature highway is then laid by the paving machine shown in Figure 4 which duplicates all actions of the equipment "spread" of a conventional asphalt paving contractor. It is a two-station machine, providing for hot finishing at the far end of the steel trackway and compaction rolling at the near end. A tamper bar delivers ⅛-in. strokes to the upper surface of the loose mix at a rate of 1,600 per min while the pavement moves forward at a screeding speed of 3 ft per min. Following laydown at 300 ±5 F, the pavement is allowed to cool to 275 ±5 F and rolling begins. This is accomplished with 16 passes of a steel roller at an operating speed of 15 ft per min. Contact pressures are summarized in Table 5. Physical measurements of specific gravity and air void properties were made before and following traffic, and the results are given in Table 6. Miniature test specimens develop the physical characteristics of actual highways.

## TRAFFIC TESTS

Pavement roughening progress is followed with precise vertical rut depth measurements. They are taken with the miniature highway profilometer instrument shown in

TABLE 5

COMPACTION ROLLING SEQUENCE

| Pavement Condition | Pavement Surface Temperature (° F) | Roller Load (lb/in.) | No. Passes |
|---|---|---|---|
| Freshly finished | 275 ± 5 | 34 | 2 |
| Rolling time, 5 min | 275 ± 5 | 55 | 3 |
| One hour old | 125 ±10 | 159 | 5 |
| Rolling time, 4 min | 125 ±10 | 200 | 3[a] |

[a]Asbestos pavement with 1.4 fiber-to-asphalt ratio given 3 additional passes.

TABLE 6

DENSITY PROPERTIES BEFORE AND FOLLOWING TRAFFIC[1]

| Traffic | Formulation | Fiber (%) | Asphalt (%) | Sp. Gr. (77 F) | Max. Theor. Sp. Gr. | Air Voids (%) |
|---|---|---|---|---|---|---|
| Before[2] | Standard Control | 0 | 8.0 | 2.42 | 2.46 | 1.6 |
| | Asbestos-Asphalt | 2.5 | 5.0 | 2.28 | 2.52 | 9.5 |
| | | | 6.5 | 2.20 | 2.43 | 9.5 |
| | | | 8.0 | 2.36 | 2.46 | 4.1 |
| | | 14.0 | 10.0 | 2.15 | 2.36 | 8.9 |
| Following[3] | Standard Control | 0 | 8.0 | 2.35 | 2.46 | 4.5 |
| | Asbestos-Asphalt | 2.5 | 5.0 | 2.23 | 2.52 | 11.5 |
| | | | 6.5 | 2.37 | 2.43 | 2.5 |
| | | | 8.0 | 2.43 | 2.46 | 1.2 |
| | | 14.0 | 10.0 | 2.31 | 2.36 | 2.1 |

[1]Pavements with 85 penetration asphalt.
[2]Test of 2- by 2- by 2-in. cubes cut from salvage ends of pavements.
[3]Test of 4- by 3-in. core diamond-drilled from adjacent to rut.

Figure 5. Five across-the-road profiles are measured. Exact elevations are determined at 12 points spaced along the length of each profile; 60-dial gage readings are taken to an accuracy of 0.005 ± 0.0025 in. An average rut depth is calculated from each set of measurements. Roughness evaluations are repeated several times during each traffic test with enough determinations to establish the relationship between wheel passes and change in slope of the rut depth function.

The four wheels of the traffic simulator machine operated over the miniature highways at a constant speed of 30 mph. Each hour, approximately 10,000 wheels pass over each of the 16 highways in the 14-ft diameter test track. Approximately 80 percent of the time, tire contact pressure simulated heavy truck wheel loads at 85 psi and the remainder of the time an ordinary car at 30 psi. Braking torque is applied to one pair of wheels and accelerating torque to the other pair of wheels 70 percent of the time and all ran freewheeling the remaining time. Torque level is varied from 50 to 150 ft-lb per wheel automatically on a preprogramed schedule. (Circular traffic testing machines have been used by several other investigators at various times over a period of perhaps 30 years. None incorporated all of the devices for applying and controlling the complete range of highway stress conditions which this device employs, particularly wheel torquing, heating, cooling, and freezing of pavements. Also, other machines did not use complete pavement structures including subsoil, could not handle 16 different pavements per test set, and apparently, from published data reports, did not produce pavement failures.)

Laboratory traffic tests are designed to study the progress of pavement roughening as the operative temperature is gradually elevated, beginning at temperature near the freezing point for water in the subgrade soil. Earlier work established the fact that asphalt pavement rutting was negligible at temperatures below about 80 F. (Several asbestos-asphalt highways were tested at temperatures as low as 26 F; no defects developed during the application of more than 5,000,000 passes of heavy-duty wheels.) Enough wheel passes were tallied at each of several operating temperature levels to establish a uniform rate of rutting at that temperature. Pavements are heated by radiation lamps; 250-watt industrial infrared and 275-watt erythermal ultraviolet sun lamps are combined to produce the required pavement surface temperatures. A test lamp bank which elevates the operating temperature to 135 F is shown in

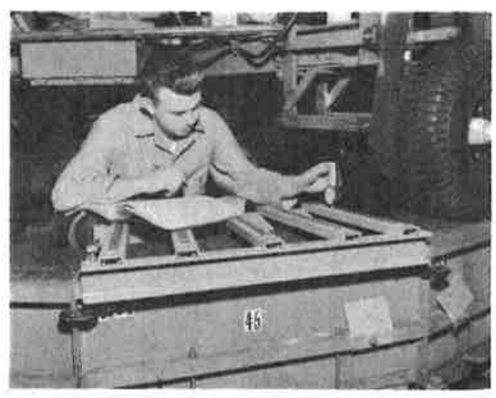

Figure 5. Roughness profilometer.

TABLE 7

TRAFFIC OPERATING TEMPERATURES

| Penetration Asphalt | Surface Temp. (° F) | No. Wheel Passes | No. Observations |
|---|---|---|---|
| 85 | 90 | 1,000,000 | 6 |
| | 115 | 1,000,000 | 6 |
| | 125 | 1,000,000 | 6 |
| | 135 | 1,000,000 | 7 |
| | 145[a] | 1,000,000 | 8 |
| | 155[a] | 300,000 | 3 |
| 60 | 90 | 500,000 | 4 |
| | 115 | 500,000 | 4 |
| | 125 | 500,000 | 4 |
| | 135 | 500,000 | 4 |
| | 145 | 500,000 | 5 |
| | 155[a] | 500,000 | 5 |
| | 165[a] | 500,000 | 6 |

[a]Pavements with fiber-to-asphalt ratios less than 0.4 and greater than possibly 0.8 would fail at temperatures below this level.

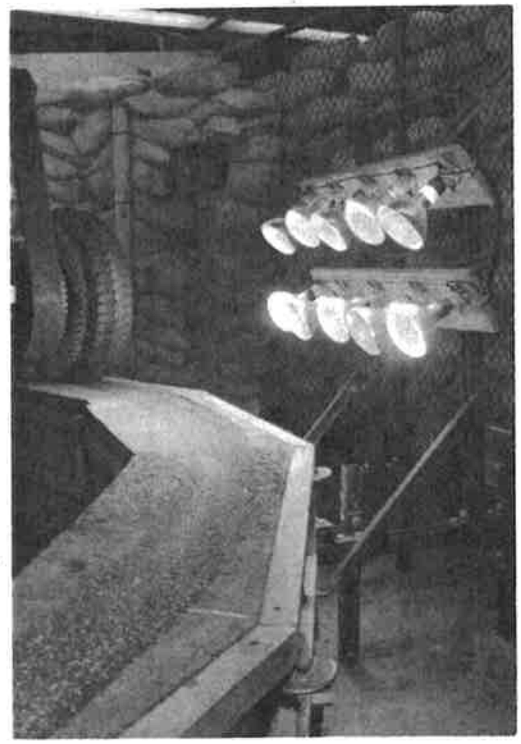

Figure 6. Lamp bank for elevated temperature tests.

Figure 6 and data relating temperature, number of wheel passes, and frequency of roughness measurement are summarized in Table 7.

Three types of auxiliary data were obtained to supplement direct traffic performance testing. Conventional stability tests were made on core samples removed from miniature highways. Specification data were determined on asphalt recovered from them. The form of the temperature gradients established in the pavements were measured with thermocouples set at the following depths: $^5/_{16}$, $^5/_8$, 1, $1^7/_8$, and $2^1/_2$ in. Numerical results of representative auxiliary tests are summarized in Appendix C.

## PAVEMENT PERFORMANCE RESULTS

Pavement roughening actions are followed by plotting rut depth measurements. Several profiles are used for each test highway. Each time the operating temperature is elevated, the slope of the plot of accumulated rut depth vs wheel passes steepened. After a period of time which varied depending on the actual temperature and asphalt penetration grade, it was observed that this slope flattened when asbestos and certain other minerals were present. The phenomenon did not occur with control pavements containing limestone or with most of the other mineral additions tested.

With asbestos it was further observed that the "flattening" effect did not occur after a certain critical operating temperature was exceeded. This is shown by Figure 7. This plot suggests a very convenient method of comparing and relating the relative performance of many different paving formulations. The accumulated rut depth following 500,000 wheel passes,, at each of an orderly sequence of operating temperatures, is an adequate measure of pavement roughening. This procedure saves laboratory expense because traffic testing at each condition can be stopped after about 500,000 load applications are tallied. Because safety considerations limit 30-mph machine speeds to pavements with ruts no deeper than about 1.8 in., this procedure has the advantage of allowing several individual temperature conditions to be investigated with each specimen without exceeding the maximum rut depth.

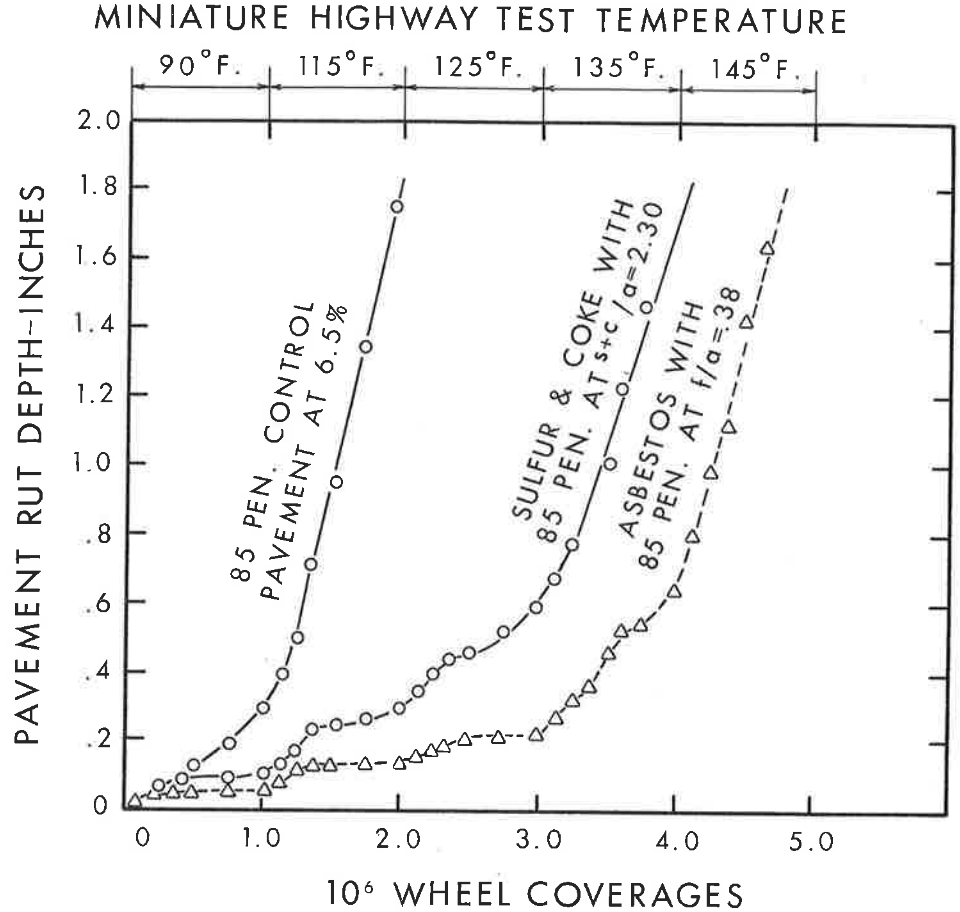


Figure 7. Typical traffic performance at elevated temperatures.

## Pavement Asphalt and Temperature Resistance Effects

Rut depths plotted on Figures 8 through 11 represent cumulative totals after 500,000 wheel passes at each of the several temperature levels indicated. The performances of control and asbestos admixture formulations are summarized for 85 and 60 penetration asphalts at various concentrations. The percent asphalt content of asbestos pavements is found by dividing 2.5 by the fiber-to-asphalt ratio for all ratios of 0.5 or less and by dividing 14.0 by the other ratio. (Ratios are calculated for surface course; a pavement with 2.5 percent asbestos and 6.5 percent asphalt in this course has a fiber-to-asphalt ratio of 2.5/6.5 = 0.385.) None of the control pavements exhibits a critical temperature, but the average slope flattens as the asphalt content and penetration decrease. All of the asbestos pavements have critical temperatures; they are elevated by decreasing asphalt penetrations and by increasing the fiber-to-asphalt ratio to a maximum of about 0.5. Critical temperatures range from 123 to 135 F with 85 penetration asphalt and from 128 to 158 F with 60 penetration asphalt.

The observed effect of asphalt content in the miniature pavements is typical of most standard paving formulations and, for a given type of asphalt, is possibly the controlling highway performance factor.

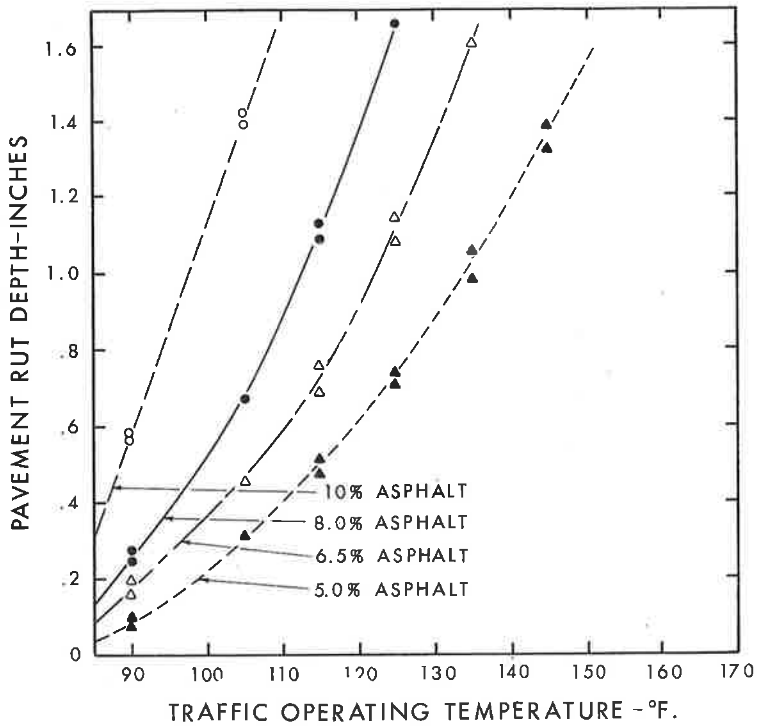


Figure 8. Performance of control pavements with 85 penetration asphalt.

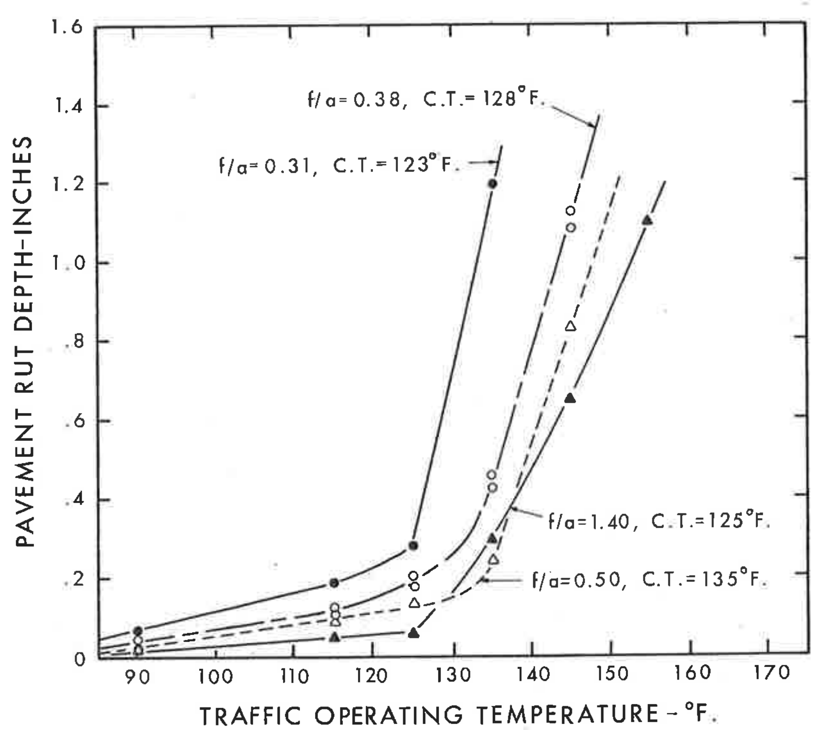


Figure 9. Performance of asbestos pavements with 85 penetration asphalt.

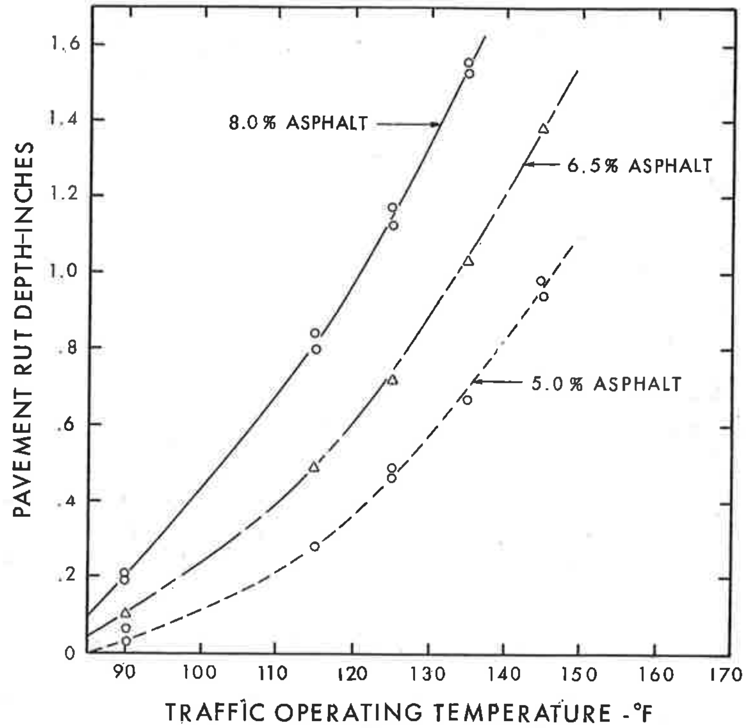


Figure 10. Performance of control pavements with 60 penetration asphalt.

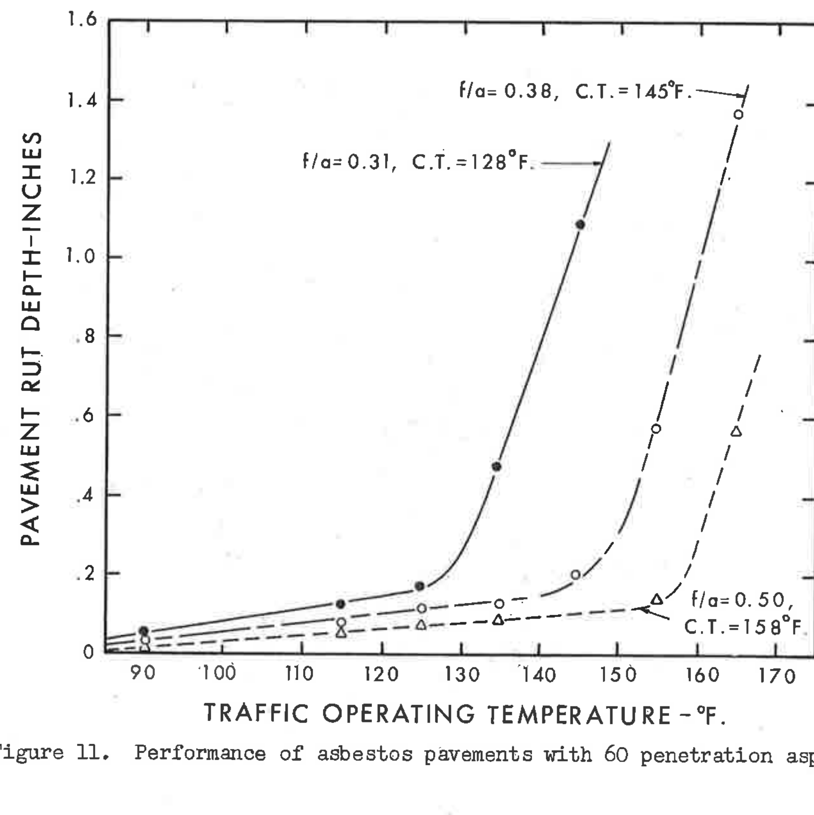


Figure 11. Performance of asbestos pavements with 60 penetration asphalt.

In asbestos-asphalt mixtures, the effect of increasing asphalt content is present but not an important factor at temperatures below the critical value for traffic rutting. Above this temperature, asphalt content is as critical with asbestos as in the standard mixes. Although the fiber-to-asphalt ratios varied from 0.3 to 1.4 and the asphalt contents from 5.0 to 10.0 percent, the critical temperature for all these formulations remained relatively unaffected. Also, above the critical temperature, all asbestos formulations showed greatly increased rutting rates. Even more surprising is the minor effect of asphalt content in asbestos formulations which is in sharp contrast to its critical role in ordinary asphaltic mixes. Inasmuch as the range of asphalt contents tested with asbestos fiber in the traffic simulator device probably includes the maximum levels needed or desired, the temperature-resistance effect is the factor that controls performance.

## Static Indentation Test Procedure

A simple laboratory procedure was devised and a series of tests conducted in an attempt to measure the same type of temperature effects shown by the miniature highway. Fine aggregate mixtures consisting of sand, limestone dust, asphalt, and Johns-Mansville chrysotile asbestos fiber were tested by the static indentation device shown in Figure 12. This test is conducted with the specimen immersed in a water bath at 75 F. A 200-psi sustained load is applied at the center of a 4-in. diameter specimen, 2½ in. high, through a flat bottom indentor that is 0.33 in. in diameter. The temperature is raised at 1 F per min and the corresponding penetrations of the indentor are measured to 0.001 in. ever 2 min. The temperature at which the indention rate suddenly increased is measured as the critical temperature.

Numerical values for the critical temperature of two series of static indention tests are summarized in Table 8; the first set of the series was run on a 85-100 penetration asphalt and the second on a 40-50 penetration material. These data suggest how the critical temperature varies with increasing fiber-to-asphalt ratios in test cylinders.

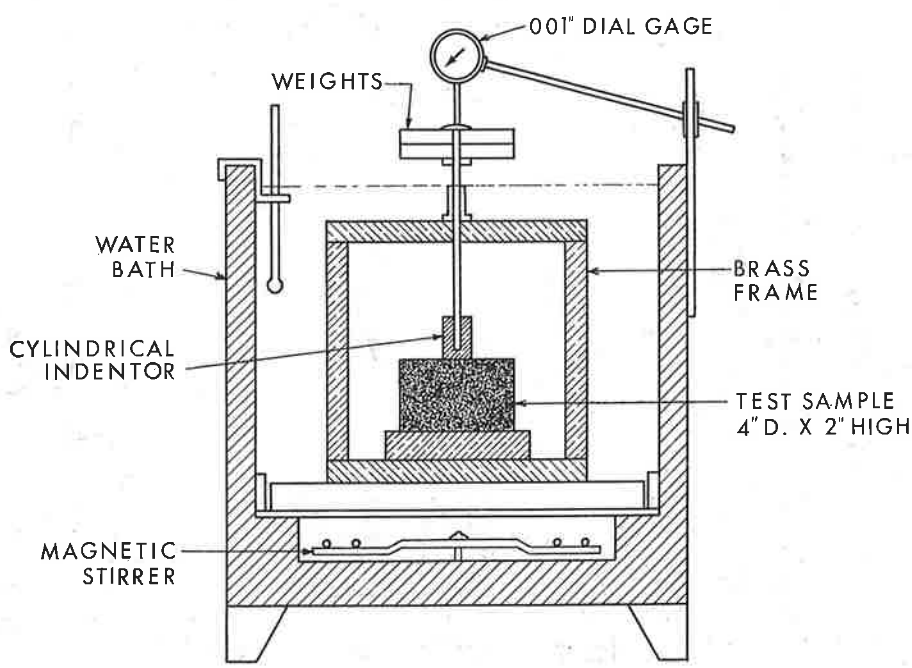


Figure 12. Static indentation test apparatus.

TABLE 8

CRITICAL TEMPERATURE STATIC INDENTATION TEST RESULTS

| Asphalt Penetration Grade | Asbestos Content (%) | Fiber/Asphalt Ratio | Void Content (%) | Indentation Data | |
|---|---|---|---|---|---|
| | | | | Critical Temp. (°F) | Indent. Depth (in.) |
| 85-100[a] | 0 | 0 | 8.2 | 84 | 0.037 |
| 85-100 | 2.5 | 0.24 | 5.3 | 102 | 0.025 |
| | 3.5 | 0.33 | 3.7 | 117 | 0.024 |
| | 4.5 | 0.43 | 4.7 | 141 | 0.042 |
| | | 0.52 | 5.2 | 129 | 0.031 |
| | 6.5 | 0.62 | 6.8 | 112 | 0.028 |
| 40-50[a] | 0 | 0 | 7.1 | 102 | 0.038 |
| 40-50 | 2.5 | 0.24 | 7.7 | 121 | 0.051 |
| | 3.5 | 0.33 | 6.4 | 126 | 0.040 |
| | 4.5 | 0.43 | 4.2 | 138 | 0.032 |
| | 5.5 | 0.52 | 4.7 | 142 | 0.033 |
| | 6.5 | 0.62 | 5.2 | 150 | 0.046 |
| | 7.5 | 0.72 | 5.1 | 169 | 0.053 |
| | 9.5 | 0.91 | 7.0 | 173 | 0.061 |
| | 10.5 | 1.00 | 7.5 | 186 | 0.075 |
| | 11.5 | 1.10 | 7.5 | 184 | 0.055 |

[a]Venezuelan crude asphalt.

They are plotted in Figure 13; the critical temperature increased as the ratio was increased up to approximately 0.5 with 85-100 penetration asphalt and about 1.0 with 40-50 penetration material. In the 85-100 plot, the critical temperature reached a maximum value at a temperature of about 140 F; this maximum value increased to nearly 190 F with the 40-50 penetration asphalt.

Thus, as with the dynamic miniature highway traffic tests, static indentation tests suggest that the ability of asbestos to increase temperature resistance is directly related to the penetration of the asphalt. The static tests also suggest it is feasible to develop a simple laboratory test that correlates with the miniature highway critical temperature results.

## RESULTS

In an extensive asphalt durability study completed in 1942 the statement is made that "it is well known that road durability increases as asphalt content increases (2). Work concerning the effect of asphalt content on resistance to cyclic bending reported in 1958 states "it might be concluded that the reduction in strength due to repeated flexing is least for specimens containing the largest amount of asphalt and increases as the asphalt content decreases" (3). Thus, it appears that for good long-term structural resistance to weathering, increased asphalt content for standard flexible pavements is a desirable property.

The beneficial effect obtained with modest asbestos additions in paving formulations containing hard and soft asphalt is shown by the bar charts in Figure 14. With asphalt contents as high as 8.0 weight percent, asbestos admixtures reduce rutting about 80 percent whenever dense traffic operates over pavements at or close to the critical temperature. Figures 15 and 16 show the rutting obtained with a standard pavement at 115 F and an asbestos-asphalt formulation at 135 F. Both pavements have an 85 penetration asphalt content of 8.0 percent, and the asbestos specimen has a 2.5 percent fiber addition. The standard pavement was exposed to 1,850,000 and the asbestos to 4,120,000 wheel passes.

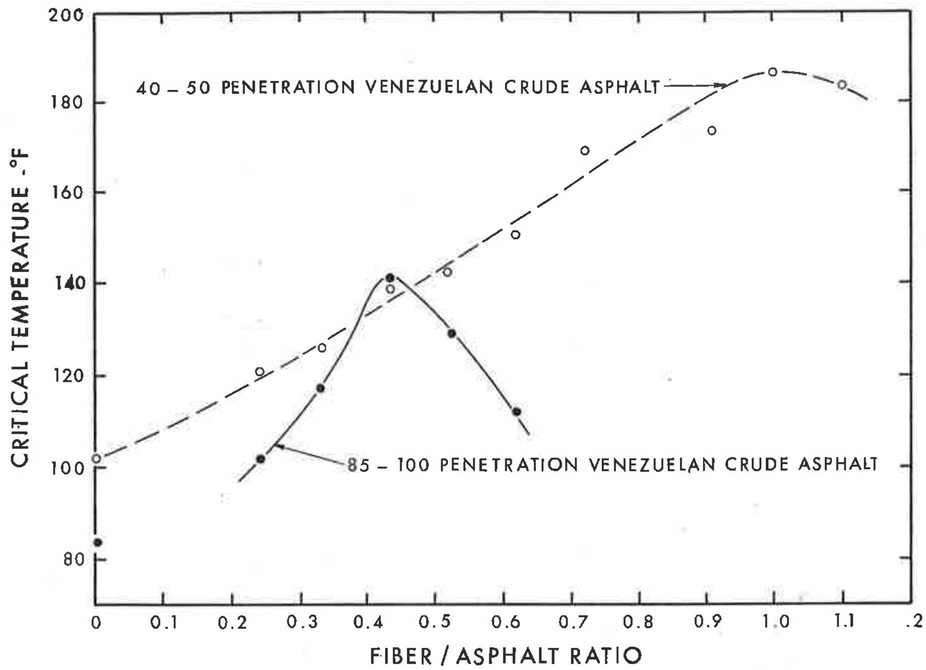


Figure 13. Results of static indentation tests of temperature resistance effect.

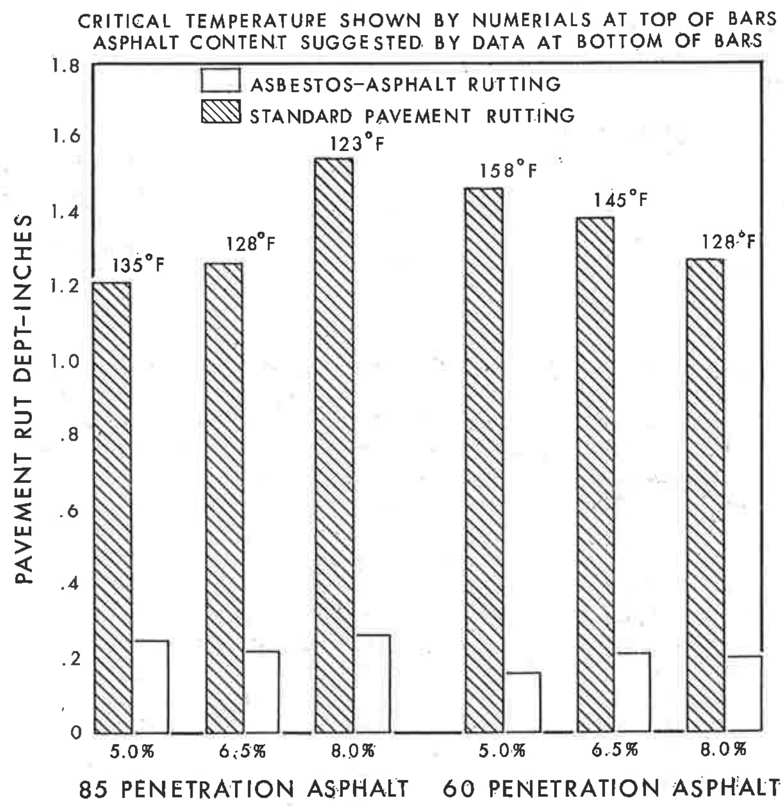


Figure 14. Beneficial effect of asbestos in asphalt paving.


Figure 15. Standard pavement rut after 115 F test.

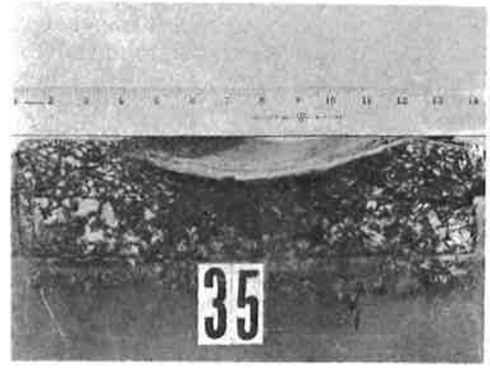


Figure 16. Asbestos pavement rut after 135 F test.

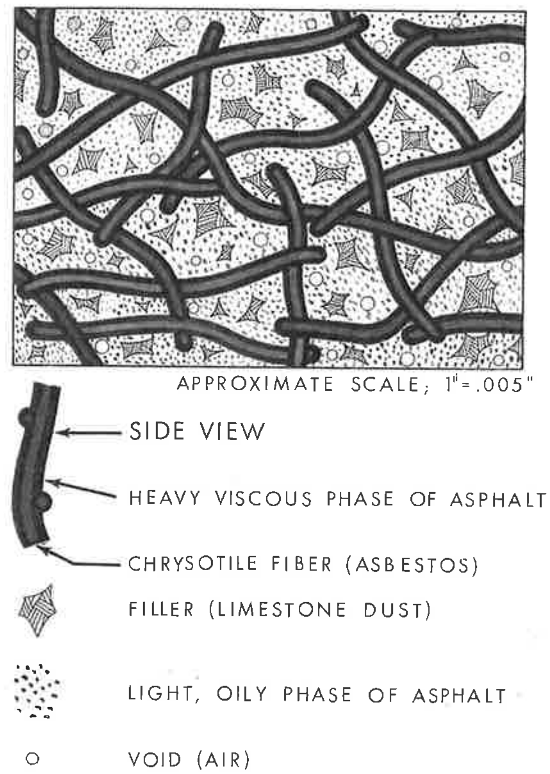


Figure 17. Schematic micrograph asbestos-asphalt fiber linkage mechanism.

The cost of asbestos presently averages about $50 and asphalt $25 per ton. Use of 2.5 percent 7M asbestos would therefore make the cost of the fiber approximately equal to the cost of the asphalt. Inasmuch as 2.5 percent asbestos was more than sufficient to produce rutting resistance superior to the best standard pavements (5 percent AC) tested, it is possible that less than 2.5 percent fiber may be sufficient to control rutting, with proportionate reduction in cost of including the fiber.

Rutting performance records of several mineral additives were compared with those of the chrysotile asbestos fibers. Limestone dust and fine clay powder did not exhibit critical temperatures and both rutted excessively under heavy wheels operating at elevated temperatures. Carbon improved the critical temperature and reduced rutting but it was not as effective as the asbestos.

It is a difficult task to define an acceptable mechanism for the superior rutting resistance which asbestos fiber imparts to ordinary asphalt paving mixtures exposed to elevated temperature service. The following hypothesis, which developed from work at several laboratories, is helpful in providing an understanding of the behavior of asbestos in paving. Several investigators have studied filler-asphalt-solvent mixtures of various minerals, including asbestos, and find they have a pronounced affinity for certain heavy, polar fractions of the asphalt. If the fibers present in a paving formulation are preferentially coated with the more stable fraction of the asphalt, a superior bonding action between fibers, at points of close proximity, is a likely possibility. The strengthening effect of this inter-fiber linkage would be expected to depend on the cohesion of the heavy fraction at a given temperature instead of the cohesion of the whole asphalt. This concept is shown in Figure 17 and provides a mechanism for concentrating mixture stability throughout the entire paving structure.

Fiber linkage would be expected to depend on the length, shape, condition, and concentration of the fibers; also the proportion of the asphalt capable of being adsorbed together with the chemical and physical properties of this layer should affect performance. With a high penetration asphalt, having a relatively low proportion of the heavy material, a given amount of asbestos fiber might be expected to adsorb and stabilize all of that fraction. In such a formulation additional fiber might decrease the effective coating on all fiber surfaces, thus offering no appreciable increase in fiber linkage or critical temperature rutting resistance of pavements.

## CONCLUSIONS

Records of traffic simulator machine tests on standard asphalt formulations that have performed satisfactorily in the field without rutting provide a firm basis for estimating probably field performances of special or unconventional paving mixtures after comparable miniature highway tests. The following conclusions describe beneficial traffic service potentials of asbestos and a few other mineral admixtures. They appear to relate directly to the field performance of these pavements on a flexible base, inasmuch as the testing conditions duplicate all extreme loading conditions met at high ambient temperatures during actual service with full-scale roads. The results and conclusions drawn from them may not be directly related to the performance of these mixes on an extremely rigid base.

1. All standard asphalt pavements developed serious rutting problems at high-service temperatures.
2. This rutting was reduced to an acceptable value (AASHO test road criteria) by lowering the asphalt content 15 to 20 percent below levels considered practical or desirable by most bituminous paving technologists.
3. Chrysotile asbestos fiber was the most effective mineral tested and the only admixture that reduced rutting below critical levels at the highest operating temperatures.
4. The asbestos permitted a large increase in asphalt content, from 30 to 50 percent, above that used in standard asphalt mixes yielding acceptable performance records.
5. A 2.5 percent asbestos addition produced the desired reduction in rutting at temperatures up to 140 F.
6. The factor that appears to control miniature highway rutting is a temperature-resistance effect associated with a fiber linkage mechanism apparently not well understood by asphalt paving technologists.
7. Other mineral admixtures produced improved rutting resistances at normal asphalt contents but not at the higher-than-normal levels.

An implication of these conclusions is that the strength of asbestos-asphalt mixtures may be relatively independent of void content. Future traffic simulator tests on similar pavements compacted to an initial low-void condition are needed to evaluate this possibility. Perhaps the most interesting part of the completed work is the large increase in asphalt content permitted by asbestos admixtures and the great improvement in asphalt highway durability which they may be expected to facilitate.

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# *Appendix A*

SUBGRADE SOIL PROPERTIES

| Slab Formulation-Admixture Type | Asphalt Content[a] (%) | Soil Moisture Content[b] (%) | Soil Density[c] (pcf) | California Bearing Ratio[d] |
|---|---|---|---|---|
| Standard Control: | | | | |
| With 85 pen. asphalt | 5.0 | 26.8 | 101.2 | 3.4 |
| | 6.5 | 26.9 | 102.0 | 3.6 |
| | 8.0 | 27.0 | 102.1 | 3.8 |
| | 10.0 | 26.9 | 101.9 | 3.2 |
| With 60 pen. asphalt | 5.0 | 27.1 | 102.4 | 3.8 |
| | 6.5 | 26.9 | 101.8 | 3.2 |
| | 8.0 | 26.8 | 101.5 | 3.1 |
| Asbestos-Asphalt: | | | | |
| With 85 pen. asphalt | 5.0 | 26.9 | 102.3 | 3.4 |
| | 6.5 | 26.8 | 101.9 | 3.3 |
| | 8.0 | 27.0 | 102.3 | 3.7 |
| | 10.0 | 26.8 | 101.3 | 3.2 |
| With 60 pen. asphalt | 5.0 | 27.0 | 101.8 | 3.5 |
| | 6.5 | 27.2 | 101.9 | 3.4 |
| | 8.0 | 27.0 | 102.2 | 3.8 |

[a]Of $1\frac{1}{2}$-in. surface course.
[b]Percent of oven-dry soil by weight.
[c]In situ density by Soiltest, Inc., Volumeasure technique (balloon displacement) after subgrade soil is compacted in three layers with Chicago Pneumatic Co. Model 1-C air rammer.
[d]Measured in situ with standard hand-operated jack; liquid limit of soil, 48 percent; plasticity index, 29 percent.

# *Appendix B*

## ROCK BASE CHARACTERISTICS

Aggregate Properties:

Type - Crushed limestone for waterbound macadam
Source - Thornton, Ill., quarry of Material Service Corp.

Aggregate Size Gradation:

| Sieve Size | % Blend Passing Sieve |
|---|---|
| 3/4-in. | 100 |
| 1/2-in. | 75 ±5 |
| No. 4 (4,760 μ) | 55 ±5 |
| No. 8 (2,380 μ) | 40 ±5 |
| No. 16 (1,190 μ) | 25 ±5 |
| No. 200 ( 74 μ) | 12 ±3 |

In Situ Base Course Properties:

| Course | Thickness (in.) | Moisture Content (%) | CBR Avg. Value |
|---|---|---|---|
| Upper | 2.0 ±0.1 | 11.5 ±1.5 | 85 |
| Lower | 2.0 ±0.2 | 11.5 ±1.5 | 81 |

# *Appendix C*

## MIX DESIGN COMPACTION PROCEDURE

Method:

1. Gyratory compaction technique.
2. 50-blow Marshall equivalent.

Procedure:

1. Miniature highway aggregates oven dried at 350 F.
2. Asbestos conditioned at room temperature without any predrying.
3. Miniature highway asphalt heated to 300 F.
4. Constituents mixed for 1 min. at 300 F.
5. Compaction mold heated to 250 F.
6. Compacted 50 gyrations in gyratory compactor machine under 200-psi load at a $1^0$ angle of gyration.
7. Compaction temperature 285 F.
8. Leveling off load of 200 psi for 30 sec.
9. Temperature cure period of 48 hr at 140 F.
10. Standard Marshall and Hveem stability tests at 140 F following cure period.

MIX DESIGN STABILITY VALUES

| Pavement Asphalt (penetration) | Type of Mixture Formulation | Percent Asphalt | Fiber/Asphalt Ratio | Void Content (%) | Specific Gravity Ratio | Hveem (%) | Stability (lb) | Marshall Flow (in.) |
|---|---|---|---|---|---|---|---|---|
| 85 | Standard Control | 4.75 | 0 | 4.7 | 2.41 | 41 | 1,810 | 0.08 |
| | | 8.0 | 0 | 0[a] | 2.41 | 7 | 1,035 | 0.22 |
| | Asbestos-Asphalt | 5.0 | 0.50 | 7.0 | 2.32 | 31 | 1,115 | 0.12 |
| | | 6.5 | 0.38 | 1.0 | 2.42 | 29 | 1,935 | 0.11 |
| | | 8.0 | 0.31 | 0[a] | 2.39 | 6 | 1,155 | 0.16 |
| | | 10.0 | 1.40 | 0.5 | 2.27 | 7 | 1,455 | 0.28 |
| 60 | Standard Control | 4.75 | 0 | 3.2 | 2.45 | 44 | 2,440 | 0.07 |
| | | 8.0 | 0 | 0.1 | 2.41 | 7 | 1,000 | 0.23 |
| | Asbestos-Asphalt | 5.0 | 0.50 | 3.1 | 2.42 | 51 | 3,050 | 0.09 |
| | | 6.5 | 0.38 | 0.2 | 2.44 | 27 | 2,340 | 0.10 |
| | | 8.0 | 0.31 | 0[a] | 2.39 | 7 | 1,330 | 0.18 |
| | | 10.0 | 1.40 | 0.8 | 2.27 | 9 | 1,785[b] | -[b] |

[a]Specimens flushed.
[b]Marshall stability leveled off and held load through the maximum deformation permitted by test device.

PROPERTIES OF RECOVERED 85 PENETRATION ASPHALT

| Type of Mixture Formulation | Percent Asphalt | Fiber/Asphalt Ratio | Extracted Asphalt | | |
|---|---|---|---|---|---|
| | | | Penetration (cm) | Ductility (cm) | Ash (%) |
| Standard Control | 8.0 | 0 | 0.37 | +150 | 2.1 |
| Asbestos-Asphalt | 5.0 | 0.50 | 0.23 | +150 | 1.4 |
| | 6.5 | 0.38 | 0.33 | +150 | 2.2 |
| | 8.0 | 0.31 | 0.31 | +150 | 2.5 |
| | 10.0 | 1.40 | 0.31 | +150 | 2.6 |

TEMPERATURE GRADIENTS

| Depth to Thermocouple (in.)[a] | Control Pavement[b] | Asbestos-Asphalt Pavement[b] |
|---|---|---|
| 0 | 155 | 142[c] |
| 0.3 | 156 | 140 |
| 0.6 | 151 | 134 |
| 1.0 | 147 | 130 |
| 1.9 | 140 | 124 |
| 2.5 | 131 | 118 |

[a]Below pavement upper surface.
[b]With 6.5 percent asphalt.
[c]Radiation lamp energy had to be increased about 8 percent to bring this temperature up to 155 F in a second test run.

# *Appendix D*

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