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LABORATORY STUDIES OF
ASPHALT CEMENTS

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PREFACE

The data contained in this bulletin are the results of research carried out jointly by the United States Bureau of Public Roads, the Minnesota Department of Highways, and the Institute of Technology of the University of Minnesota. The work was conducted during the years 1936, 1937, and 1938.

The authors wish at this time to acknowledge the assistance received in the preparation of this bulletin. Mr. John H. Swanberg of the Minnesota Department of Highways supplied many of the original ideas and, together with his staff, supplied valuable assistance. Mr. E. F. Kelly, chief of the Division of tests of the United States Bureau of Public Roads, together with his staff, supplied much valuable criticism and helpful data.

LABORATORY STUDIES OF
ASPHALT CEMENTS

INTRODUCTION

The development of the motor vehicle has affected both the use and the manufacture of asphalts. Previous to this development asphalt was obtained from a few established sources, while now, as a result of the great consumption of petroleum products by the motor vehicle, asphalt is obtained from many sources and by a variety of refining methods. Prior to the motor vehicle age, asphalt was used almost exclusively in high type pavements for city streets. Now the increasing importance of the rural highway in our transportation system has led to the extensive use of asphalt in low cost road construction.

The development of tests to measure the quality of asphalts for road and street purposes has not kept pace with changes in the source, manufacture, and use of the material. Engineers have found that the old test methods could not be depended upon to exclude unsatisfactory materials. As a result, numerous special tests have been developed. In many cases the special tests were not intended to directly measure quality but rather to identify certain products which had given unsatisfactory service or others which had been satisfactory. It was recognized that some good materials might be excluded or some poor materials accepted by such tests, but for the time being it appeared to be the safest course to follow. Naturally there has been considerable controversy concerning the special tests as well as the value of some of the old standard tests. It was this condition which lead to the establishment of this co-operative investigation.

SCOPE

PURPOSE OF THE INVESTIGATION

The primary purpose of this investigation was to study the physical and chemical properties of asphalts and to determine their comparative behavior in bituminous mixtures by means of mechanical tests performed both before and after accelerated laboratory exposure. The authors realize that as yet there are insufficient data available to formulate a specification in which asphalt cements are selected according to physical tests on mixtures. While the data presented herein show marked differences in the behavior of the asphalts, it is recognized that opinions may differ on the interpretation of the test results. The data are published in the hope that they will promote discussion and lead to further work which may ultimately result in better specifications for bituminous materials.

The main characteristics of an asphalt cement governing its suitability for highway purposes may be listed as follows:

1. Safety in handling.
2. Consistency.
3. Cementing qualities.
4. Durability.

It is believed that present tests are adequate for the measurement of the first two properties. On the other hand, it is not believed that present specifications or present testing methods adequately measure the other two items. This investigation was therefore primarily concerned with measuring the cementing qualities of the asphalts as determined by mechanical tests on mixtures containing them. These tests were performed both before and after exposure to accelerated weathering to determine durability under these conditions as a possible index of service behavior.

TYPES OF TESTS

In an endeavor to measure the relative cementing qualities of asphalts, tests have been made of specimens molded from mixtures of asphalt and standard Ottawa sand. The tests have included tensile strength and elongation, impact resistance, abrasion loss, and shear strength. The mixtures of asphalt and Ottawa sand have been exposed to heat and ultraviolet light in an attempt to measure the relative durability of the various asphalts. Additional tests have been made on specimens molded from sheet asphalt mixtures. The asphalts have been recovered from the various mixtures and the hardening during exposure determined. The tendency of water to displace asphalt has been measured. The relative adsorption of asphalts by powdered aggregate from a benzene solution has been measured. The standard specification tests for asphalts have been carried out together with such special tests as xylene equivalent, separation of asphalt into asphaltenes, resins, and oils, the determination of saponifiable matter, sulfur content and nitrogen content, the measurement of absolute viscosity, and ductility tension. Certain microscopic studies are included. Some observations and analyses of samples from existing pavements have also been included.

KINDS OF ALPHALTS USED

Twenty-four different asphalts in the 85-100 penetration class were included in this study. These asphalts comprise three samples refined from Mexican crude, two fluxed natural asphalts, and nineteen domestic asphalts from refineries located as follows:

Place	Samples
Arkansas	3
California	2
Illinois	2
Indiana	2
Kansas	2
Kentucky	1
Texas	3
Wyoming	4

After this study had been in progress for some time it was decided to test 50-60 penetration asphalts in the same manner. Nineteen samples of 50-60 penetration asphalts were then obtained, as far as possible from the same sources as the 85-100 penetration asphalts. The various 85-100 penetration asphalts are designated by letters which will be used throughout the report. A 50-60 penetration asphalt is designated by a letter followed by the figure 50. Identical letters indicate materials from the same source. It should be pointed out that the manufacturers did not in all cases supply materials which they would recommend for use. In several cases positive spot test materials were specially prepared for this investigation.

TESTS OF OTTAWA SAND MIXTURES

REASONS FOR USING OTTAWA SAND

All of the tests commonly used in asphalt specifications are made on the asphalt cement, whereas in actual practice, paving asphalts have always been used in combination with mineral aggregates. The asphalt serves as a glue to hold the particles of mineral aggregate together. In order to simulate field service conditions, it was considered desirable to make tests that would show the cementing action of asphalt films on aggregate. It was also believed that the performance of thin films on aggregates when exposed to artificial weathering conditions and later tested in molded specimens might prove to be a measure of the resistance of the asphalt to deterioration by the elements. Ottawa sand of a standard size (passing No. 20 sieve and retained on No. 30 sieve) was selected for the mineral aggregate for the following reasons: first, its standard nature should lead to reproducible results; second, since little if any stability is furnished by the aggregate, the physical tests on molded specimens should be primarily a test of the asphalt, and third, because of the ease of mixing and molding a large number of tests could be made in a given time. About 12,000 specimens were molded and tested during the course of this project.

PREPARATION OF THE MIXTURES

Mixtures were proportioned 98 per cent by weight of sand to 2 per cent by weight of asphalt. In the case of asphalts L and M, the weight of asphalt was increased in order to obtain 2 per cent of bitumen by weight. The above proportions resulted in a calculated average film thickness of about 5.5 microns. This is within the range of the calculated film thickness of sheet asphalt mixtures. In a study of the effect of greater film thickness some special tests were made with mixtures containing various percentages of asphalt. However, unless specifically noted otherwise, all test values for Ottawa sand mixtures presented in this report are for mixtures containing 2 per cent of asphalt.

The asphalt was heated (maximum 200° F.) in a graniteware mixing bowl to which was then added the Ottawa sand which had previously been heated to 250° F. The materials were then mixed for five minutes with a spatula. Five minutes was ample time for thoroly mixing the sand and asphalt.

EXPOSURE OF MIXTURES

Three thousand grams of the prepared mixture of Ottawa sand and asphalt were placed in a the small twin-pug mixer. (See Fig. 1.) The mixer was surrounded by a thermostatically controlled water bath. Three different methods of exposure were used.
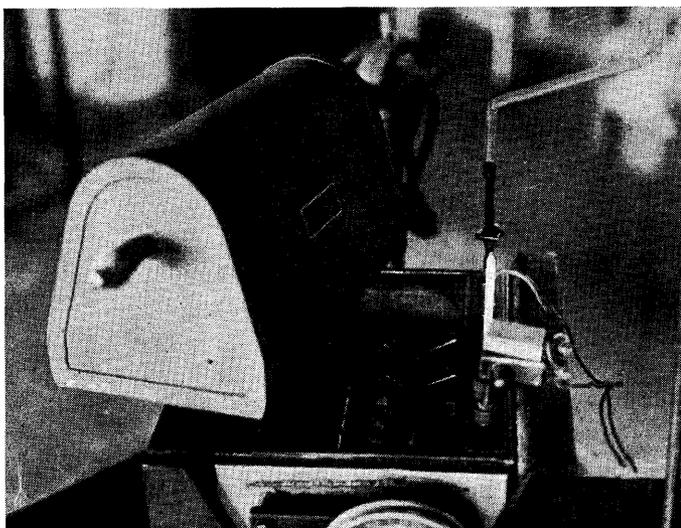
FIGURE 1. PUGMILL USED TO EXPOSE OTTAWA SAND AND ASPHALT MIXTURES

Heat, air, and ultraviolet light.—The mixture was continuously agitated (160 r.p.m.) beneath a 220-volt mercury arc in quartz. The temperature of the mixture was maintained at 180° F. After numerous preliminary studies an exposure period of 22 hours was established.

The efficiency of the type of ultraviolet lamp used decreases somewhat with usage but the manufacturers state that after the first 500 hours the decrease is at a very small rate. The lamp had been used over 1,000 hours in preliminary studies, but to further reduce any effect resulting from depreciation of the lamp, after the group of asphalts had been exposed and tested, another series of tests were made in reverse order. The average results were used. There was, however, no consistent trend of differences, so that variations in the concentration of the light

were apparently not a factor in this project. In a few cases where check tests did not agree, a third test was run. The lamp could not be placed close enough to the mixer to prevent the entrance of outside air. The mixture was thus exposed to the effects of ultraviolet light and oxidation while being agitated at a temperature of 180° F.

Heat and air.—In this exposure the mixture was agitated at 180° F. in the open mixer. In order to maintain this temperature of the mixture, the water in the surrounding bath had to be maintained at a higher temperature than when the lamp was used.

The standard weathering period of 22 hours was again used, and at least two runs were made with each asphalt. In order to study the effects of time of exposure, additional mixtures prepared from nine asphalts were exposed for 70 and 166 hours. Only mixtures prepared from 85-100 penetration asphalt were exposed to heat and air.

Heat and nitrogen.—In this method of exposure the mixture was agitated at 180° F. as in the other methods. In this case, however, a tight fitting cover was placed over the pugmill. Nitrogen was admitted through a perforated pipe in the bottom of the pugmill at a rate of 80 to 100 c.c. per minute. The excess nitrogen was allowed to escape through a small hole in the cover. Only mixtures prepared from 85-100 penetration asphalts were exposed to heat and nitrogen.

MOLDING OF SPECIMENS

Molded specimens to be used in testing were prepared both from freshly prepared mixtures and from mixtures after exposure. Four sizes of test specimens were molded. The briquettes used in the tensile strength and elongation test were prepared in the brass molds commonly used in making briquettes for testing Portland cement. All other specimens were cylindrical in shape, the sizes being as noted below:

Test	Diameter	Length
Abrasion	2 inches	1½ inches
Impact	1 inch	1 inch
Shear	1 inch	1½ inches

The mixed material was weighed, placed in a mold, and heated to 200° F. as indicated by a thermometer placed in the mixture. The die which was to be used in compacting the specimen, and which had previously been heated, was set in place in the mold, and the assembly was transferred to a small hydraulic press, where the molding pressure was maintained for one minute. A molding pressure of 190 pounds per square inch was used for the small specimens (one inch in diameter) and 150 pounds per square inch for all others. After cooling in the laboratory air, the specimens were removed from the molds. Specimens were then stored for 18 hours at a temperature near that at which they were to be tested and brought to the exact temperature one-half hour before testing.

The density of the molded material was obtained from the measurement of the weight, height, and diameter of two abrasion specimens prepared from mixtures both before and after exposure.

NATURAL WEATHERING OF MOLDED SPECIMENS

Natural weathering for a period of one year was obtained on the roof of the laboratory. Molded specimens were used in preference to loose mixtures to avoid the inclusion of an excessive amount of dust. The specimens for each 85-100 penetration asphalt consisted of five briquettes for the tension and elongation test, five 1×1 inch cylinders for the impact test, and ten $2 \times 1\frac{1}{2}$ inch cylinders for the abrasion test. Specimens for the shear test were not exposed upon the roof since previous tests had indicated that shearing strength was rather closely related to tensile strength.

A complete set of specimens was placed on the roof in October, 1936. A second complete set was started in May, 1937. The two sets were thus exposed during the same summer but during different winters. The specimens were placed near the ridge of a south-facing, sloping roof. They were not covered in any manner. The temperatures were determined at 1:00 p.m. by means of a thermometer inserted in the end of an abrasion specimen. The maximum temperature recorded was 144° F. on August 6. The average monthly temperatures at 1:00 p.m. between March 23 and December 5 are shown in Table I.

TABLE I

AVERAGE MONTHLY TEMPERATURES DURING NATURAL WEATHERING
READINGS AT 1:00 P.M.

Month	Degrees Fahrenheit	Month	Degrees Fahrenheit
March 23-31	55.0	August	111.4
April	68.9	September	100.2
May	91.7	October	67.4
June	101.9	November	52.2
July	117.3	December 1-5	40.2

There was some tendency for the specimens to crack and deform under the heat of the sun. This made it necessary to remold them before testing. When the exposure was completed, the specimens were washed with water to remove dust and were then allowed to dry before remolding. All specimens except those for the impact test were pressed into the molds intact, care being taken to retain the original formation as nearly as possible during the remolding process. Specimens were heated to 200° F. in the molds and then compressed in the manner previously described. When impact specimens were remolded without changing the original formation, it was found that the exposed end was too soft and loose to permit satisfactory testing. It was therefore necessary to crumble up all impact specimens and secure uniform distribution of the more severely exposed surfaces before remolding was carried out.

TESTING OF SPECIMENS

Abrasion test.—Ten cylindrical specimens $2 \times 1\frac{1}{2}$ inches, weighing about 1,260 grams (total) were placed in the Deval abrasion drum (Fig. 6.) The drum was then filled with water at a temperature of 60° F. and maintained at that temperature for 15 minutes. The drum, still filled with water, was then rotated through 500 revolutions, after which the specimens were dried and weighed. There was no breakage during the test, and no noticeable stripping of asphalt from the sand. The per cent loss in weight was recorded as the abrasion loss.

It should be pointed out that the characteristics of the Ottawa sand aggregate greatly accentuated the tendency to abrade. The test has been presented as a relative measure of the cementing values of the various asphalts, rather than as an indication of the relative abrasion which would occur in practice. It might also be pointed out that the test could be run without water and at 77° F. if the temperature could be adequately controlled. The test was originally run at room temperature in the dry condition and showed the same differences even to a more marked degree. Testing under water was introduced for more accurate temperature control. It was found that the cushioning effect of the water reduced the abrasion loss to the extent that it was necessary to go to a lower temperature (60° F.) in order to obtain differences of sufficient magnitude. Thus the differences disclosed by the abrasion test at 60° F. were comparable to those observed at room temperature or approximately 77° F.

Impact test.—The apparatus used is shown in Figure 7. The test was made by dropping a 100-gram weight, with a one-half inch diameter hemispherical projection at its bottom, on the 1×1 inch cylindrical specimens. The test was made at 77° F. The height of the drop was successively increased by one centimeter until a continuous crack at least 3/16 inches long appeared on both the top and one side of the specimen. The impact resistance was taken as the energy in gram centimeters of the blow producing the crack. Values presented are the average of five tests.

As in the case of the abrasion test, the impact test was performed to measure differences in the cementing action of asphalt rather than the tendency of an asphalt to fail under impact when used in a pavement. Some impact tests were also performed at 35° F. While similar differences in asphalts were disclosed, the impact resistance was so much lower that the test did not appear to be sufficiently delicate at low temperatures. The experimental errors had become too great. Furthermore, it was considered desirable to test asphalts at 77° F., since the various asphalts would thus be nearer to the same consistency.

Tension and elongation test.—This test was performed with an Amsler hydraulic testing machine sensitive to one-half pound. The load was applied at the rate of about 100 pounds in seven seconds. The elongation was read at the instant of maximum load. This was done

by means of two small dial gages (see Fig. 8), on opposite sides of the specimen. Sleeves in which the gages were mounted, were embedded in the specimens at the time of molding. The test was performed at 35° F., specimens being kept in a closed container maintained at the proper temperature up to the instant of testing. The time required to place the gages and complete the testing was less than 25 seconds. Values presented are the average of five specimens.

The tension and elongation test was also attempted at 77° F. but the specimens had so little strength that the results were questionable. However, the measurement of elongation at relatively low temperatures also seems preferable from a consideration of temperature contraction stresses. While temperature contraction stress would become increasingly important as the temperature was decreased, it must also be remembered that temperature contraction forces would be exerted at a much slower rate than in the elongation test.

Shear test.—As shown in Figure 10 this test was made in double shear. The two surfaces supporting the $1 \times 1\frac{1}{2}$ inch cylindrical specimens were $\frac{5}{8}$ inch apart, the cutter just fitting between them. The load was applied with the Amsler testing machine at the rate of 100 pounds in 7 seconds. The shearing strength in pounds per square inch was obtained by dividing the ultimate load by twice the cross-sectional area of the specimen. The shear test was made at 35° F. and 77° F. Values presented are the average of five specimens.

TEST DATA

Selection of exposure period.—The results of tests made on specimens prepared from Ottawa sand and asphalt mixtures which had been exposed to heat and air for various periods of time up to 166 hours are shown in Figures 2 to 5. Only nine 85-100 penetration asphalts were tested in this series, but the most extreme asphalts, as measured by these tests, were included. As illustrated in Figure 2 the various asphalts show considerable difference in the per cent loss in the abrasion test both before and after exposure. Figure 3 shows the test data from the impact test and Figure 4 shows that from the elongation test. It may be observed that asphalts *B, H, M,* and *P* have the lowest value for impact resistance and elongation as well as the greatest abrasion loss both before exposure and after most periods of exposure. Figure 5 shows tensile strength after exposure to heat and air. It may be seen that while tensile strength may increase with exposure for a time, most asphalts show a decrease in tensile strength after 22 hours exposure to heat and air. Asphalt *N,* however, continues to gain in tensile strength up to 166 hours of exposure. A study of Figures 2 to 4 indicates that substantially the same difference in asphalts may be determined after 22 hours of exposure as after 166 hours. In the case of impact resistance and elongation, 22 hours of exposure show the greatest difference be-
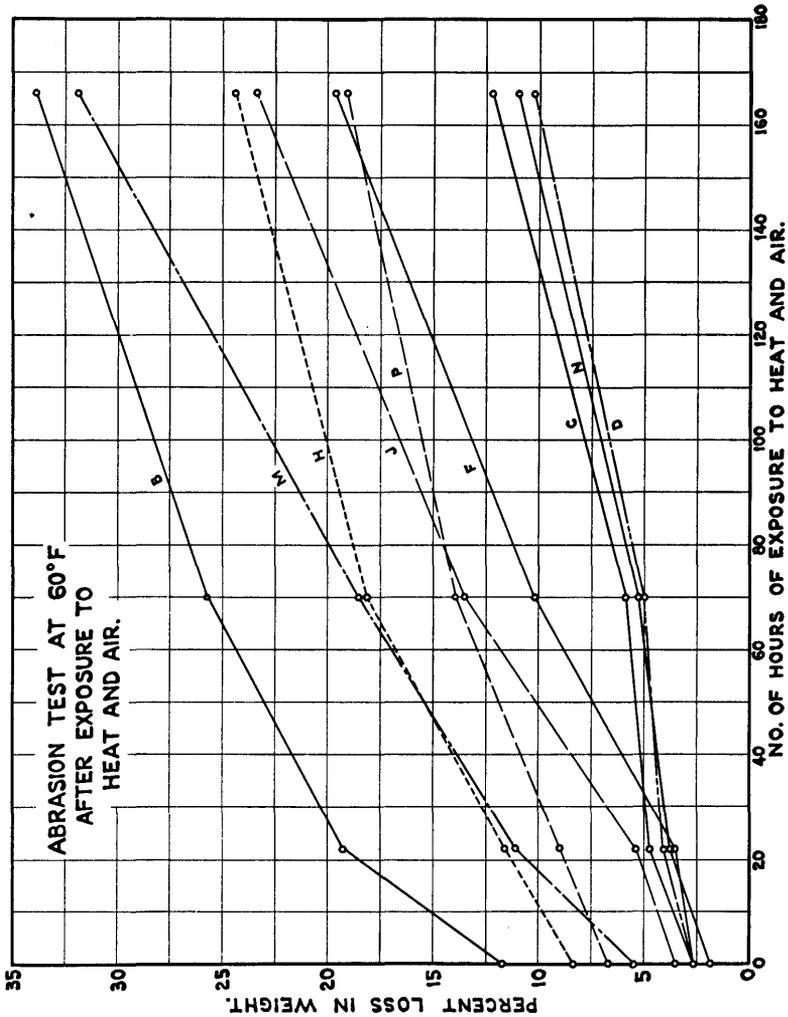
FIGURE 2

tween the various asphalts. In view of these facts, plus the added advantage of expediency in testing, a 22-hour period of exposure was adopted for the standard procedure. In view of Figure 5, however, caution must be used in drawing conclusions from strength tests after 22 hours of exposure. A summary of test data will be found in Tables XVI and XVII in the Appendix.

Abrasion loss.—The data from these tests are shown in Figure 6 where the asphalts are arranged in order of increasing loss after 22 hours exposure to heat and air. It will be observed that ultraviolet light has a marked effect, and that·some asphalts are more resistant

FIGURE 3

IMPACT TEST AT 77°F
AFTER EXPOSURE TO
HEAT AND AIR.

10

FIGURE 4

ELONGATION TEST AT 35°F
AFTER EXPOSURE TO
HEAT AND AIR.

ELONGATION AT FAILURE IN INCHES AT 35°F.

NO. OF HOURS OF EXPOSURE TO HEAT AND AIR.

11
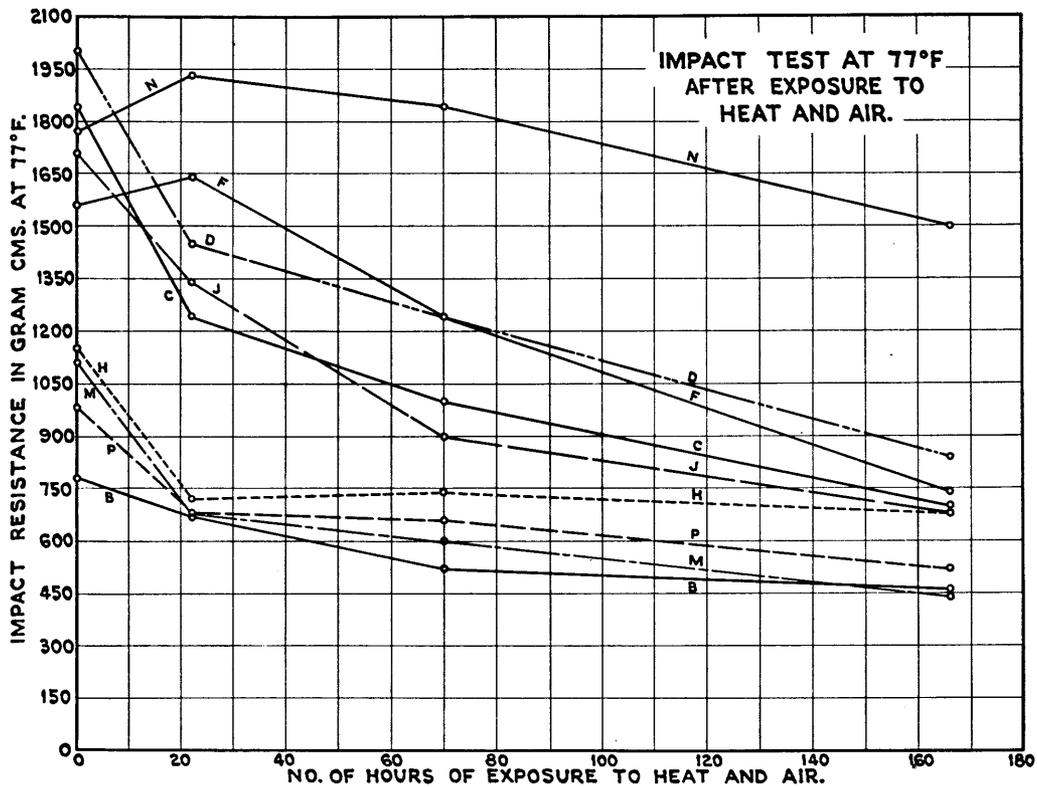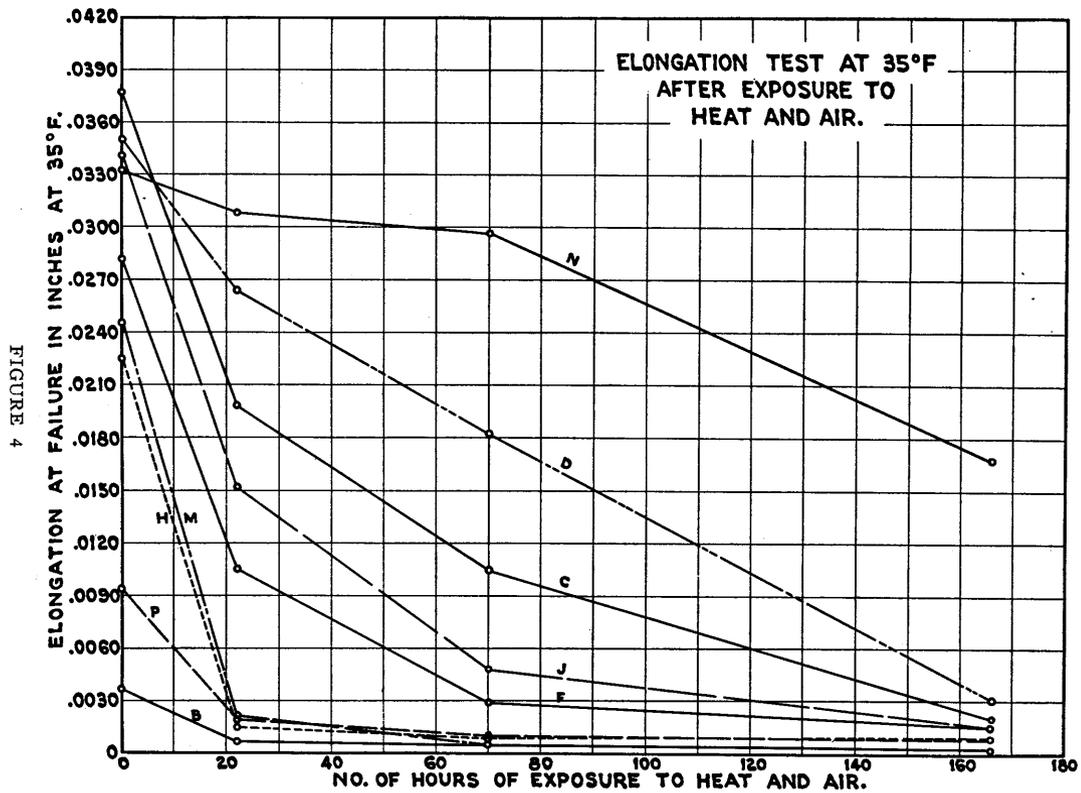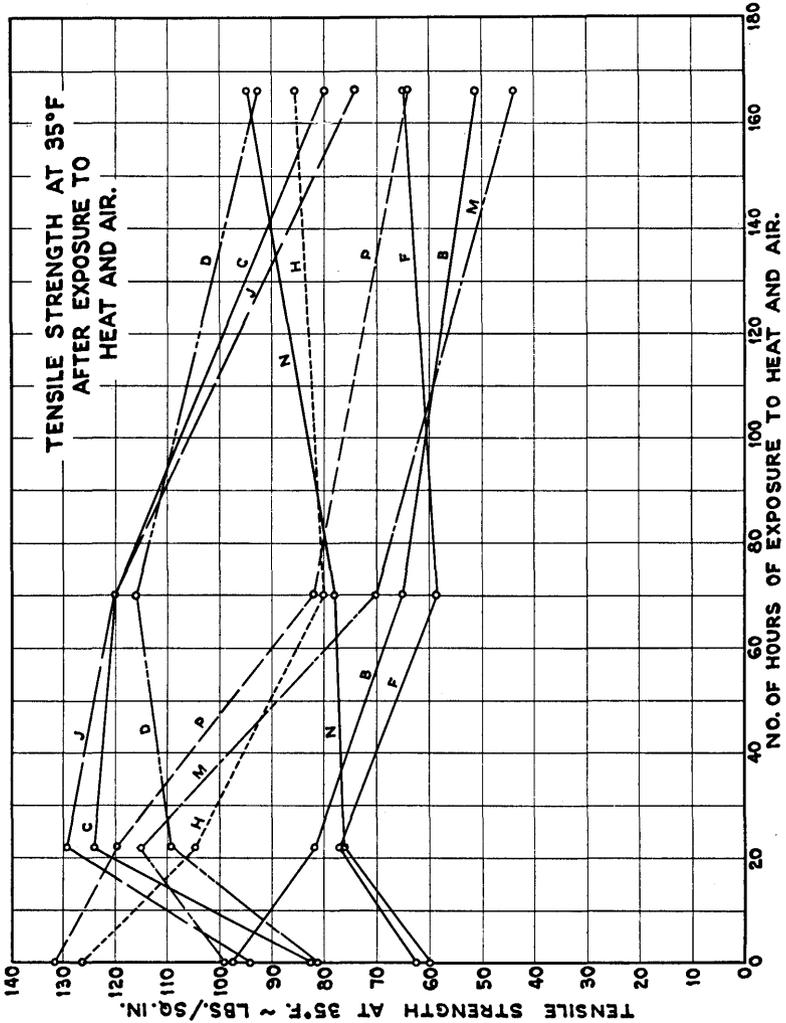
FIGURE 5

to it than others. It may also be seen that most of the 50-60 penetration asphalts show a higher abrasion loss than the corresponding 85-100 penetration asphalts. The high abrasion loss for specimens exposed to natural weathering may be explained by the fact that molded specimens were exposed in this case, and the outer surface of the specimen which was most severely exposed was the part to be worn away during the abrasion test.

It is also of interest to note the close similarity between the loss of unweathered mixtures and of those exposed to heat and nitrogen.
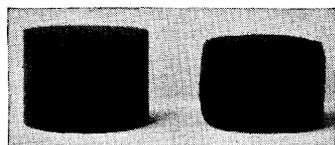
ABRASION SPECIMENS
BEFORE AND AFTER TESTING
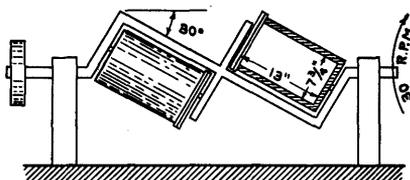
DEVAL ABRASION MACHINE
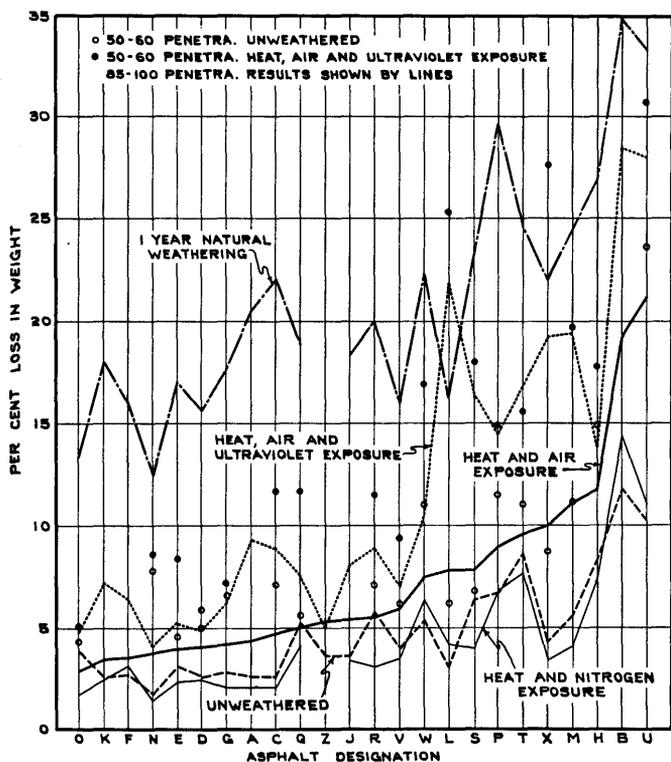
ABRASION TEST AT 60°F.
AFTER VARIOUS METHODS OF EXPOSURE

FIGURE 6

Impact resistance.—The data from these tests are shown in Figure 7, where the asphalts are arranged in order of decreasing resistance after exposure to heat and air. It may be seen that again the natural weathering proves to be the most severe. Attention is called to the wide differences in impact resistance of the unweathered mixtures. This appears to be particularly significant in view of the fact that the test is performed at 77° F. and the asphalts in the unweathered mixtures would have similar consistencies.
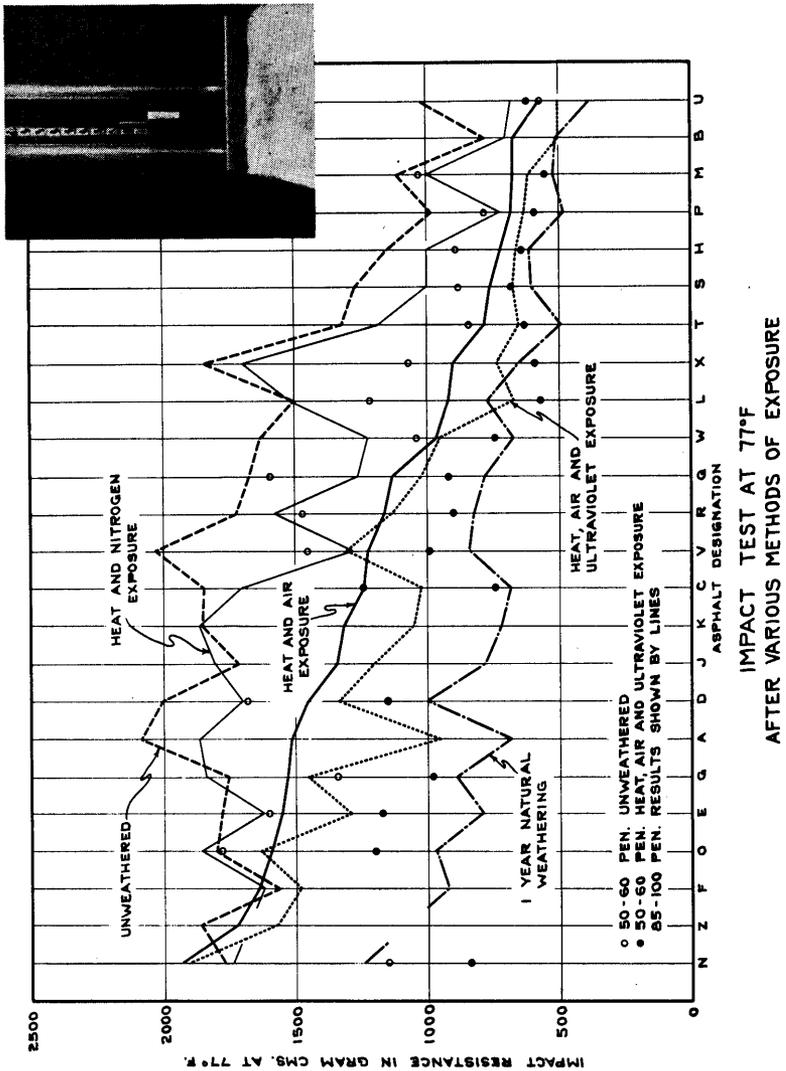
FIGURE 7

Elongation at 35° F.—The data for these tests are shown in Figure 8. It may be observed that mixtures subjected to exposure to heat, air, and ultraviolet light yield test results similar to corresponding asphalts subjected to natural weathering. It may be seen that the asphalts at the extreme right in Figure 8 show uniformly low elongation values for all methods of exposure except that carried out in an atmosphere of nitrogen. It will be noted that most of the 50-60 penetration asphalts have considerably less elongation after exposure to heat, air, and ultra-
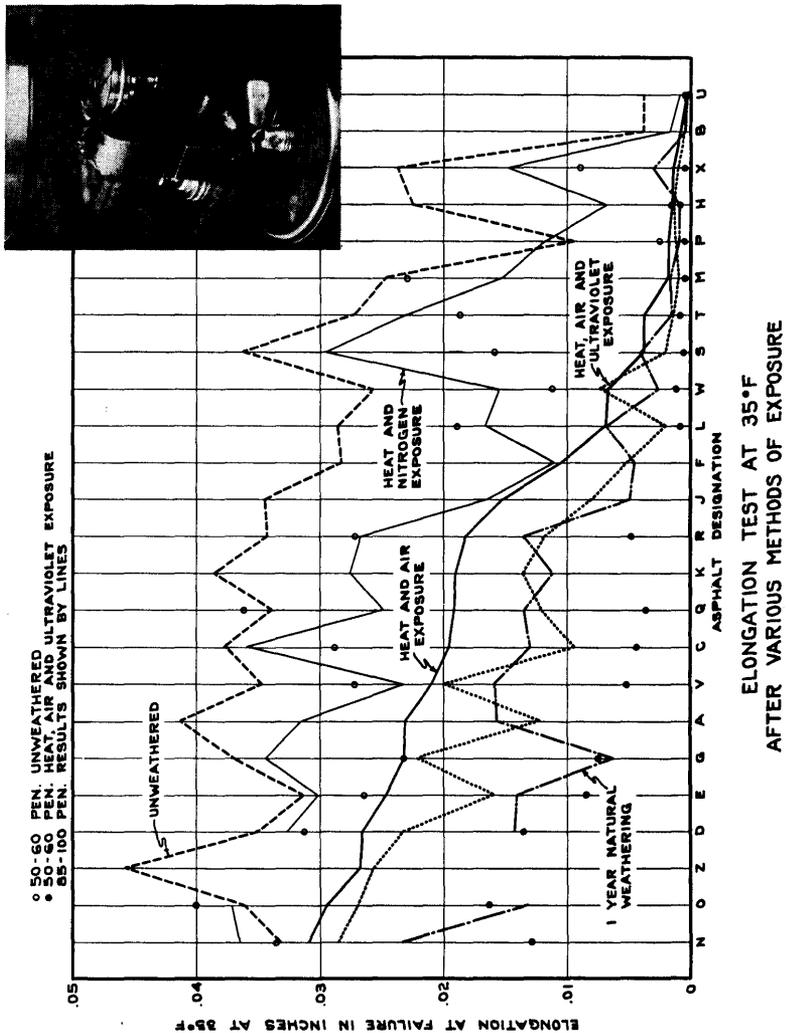
FIGURE 8

violet light, than do the corresponding 85-100 penetration asphalts. This indicates that the consistency of the asphalt has a marked effect on the elongation value and hence temperature susceptibility would also have its effect since the test was carried out at 35° F. However, actual temperature contraction stresses would become important at still lower temperatures, altho as previously pointed out the stress would be applied much more slowly than in the elongation test.

It is also of interest to note that in general the same asphalts occur at the extreme right in each of Figures 6, 7, and 8.
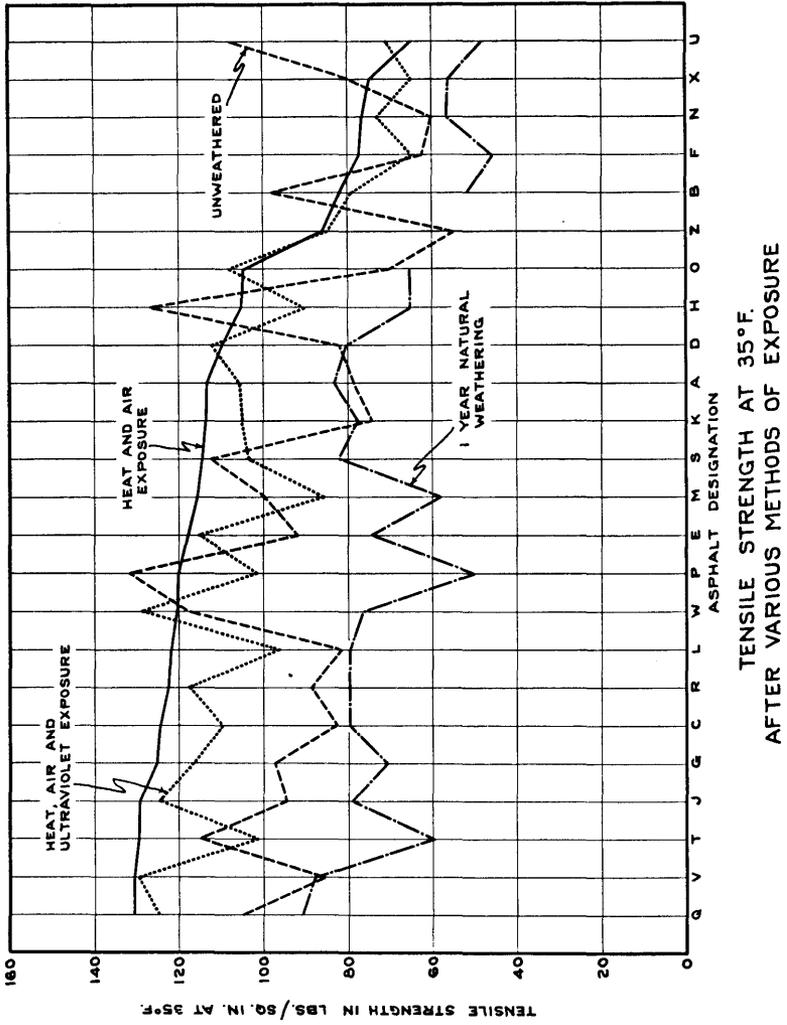
FIGURE 9

Tensile strength.—Data from tensile strength tests at 35° F. are presented in Figure 9. The asphalts are arranged in order of decreasing tensile strength after 22 hours exposure to heat and air. As previously pointed out in a consideration of Figure 5, some asphalts may continue to gain in strength with continued exposure beyond the 22-hour period, while others show a decrease in strength at 22 hours of exposure. It may be seen that the five asphalts showing a decrease in tensile strength at 22 hours exposure to heat and air (*B, H, P, U,* and *X*) are to be found in the right-hand portion of Figures 6, 7, and 8. This may be
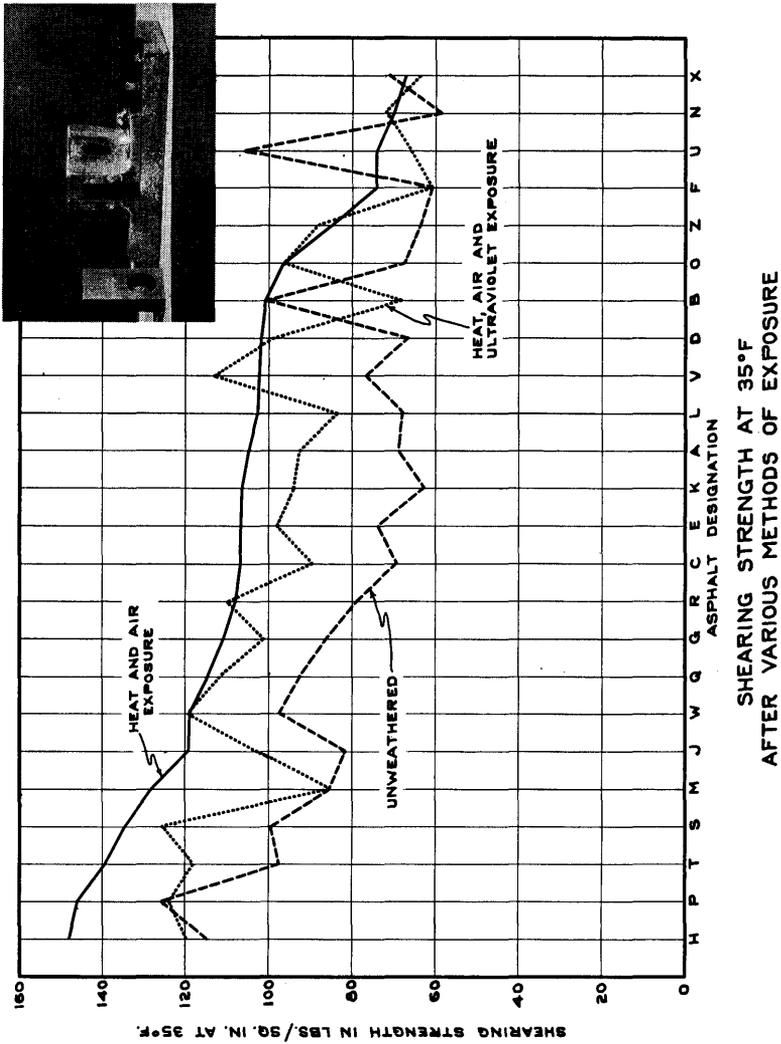
FIGURE 10

an indication that strengths of mixtures are reduced as the asphalt becomes more brittle. Strengths after natural weathering are reduced for all asphalts except *A, K,* and *V.* It is quite probable that the strengths after natural weathering have been reduced by the stripping of asphalt from the aggregate by rainfall. This would tend to complicate the comparison of natural weathering with other forms of exposure. Some tensile strengths were measured at 77° F., but these tests were discontinued when the unweathered mixtures were found to be so weak (about 10 pounds per square inch) that the values obtained were ques-
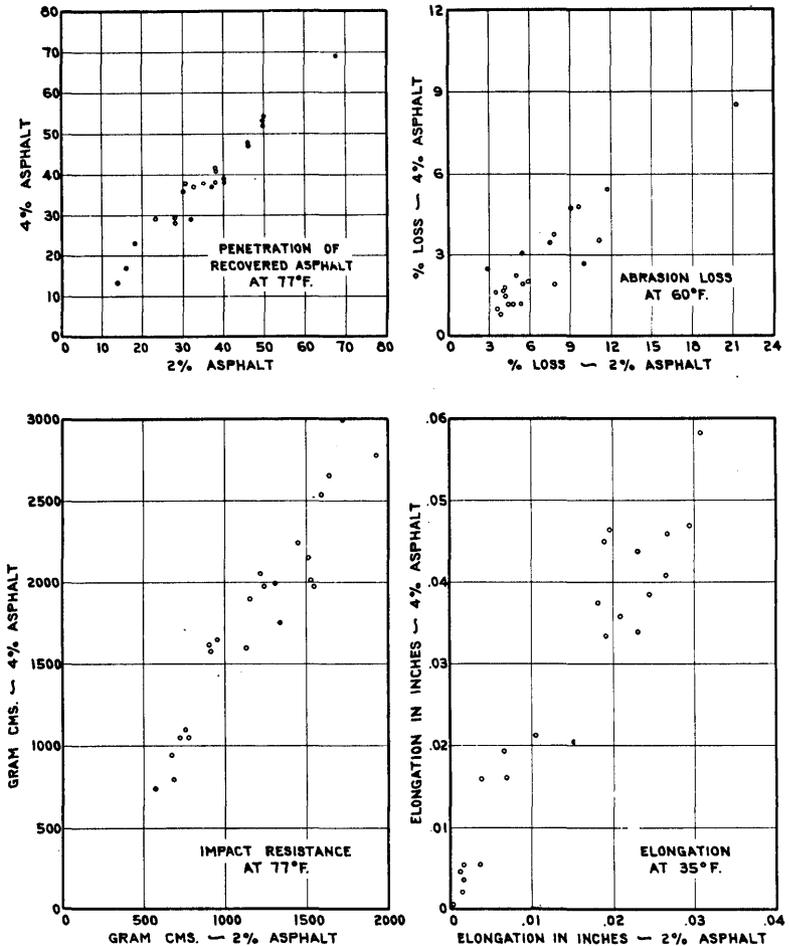
EFFECT OF PER CENT OF ASPHALT IN MIXTURES UPON TEST VALUES AFTER EXPOSURE TO HEAT AND AIR

FIGURE 11

tionable. Thus it may be seen that strength tests are greatly affected by the consistency of the asphalt. Figure 20 shows a continued hardening of the asphalt with continued exposure altho Figure 5 indicates a rather early attainment of maximum strength under exposure. Thus it seems probable that the strength of mixtures increases with increasing consistency of the asphalt to some optimum value. Beyond this value, brittleness or a lack of cementing qualities may tend to decrease the strength of a mixture even tho the viscosity of the asphalt may increase.
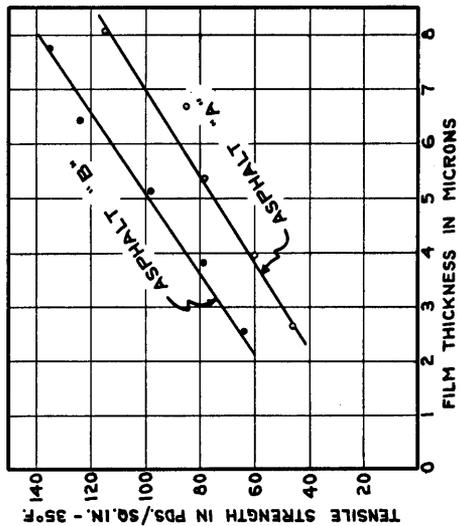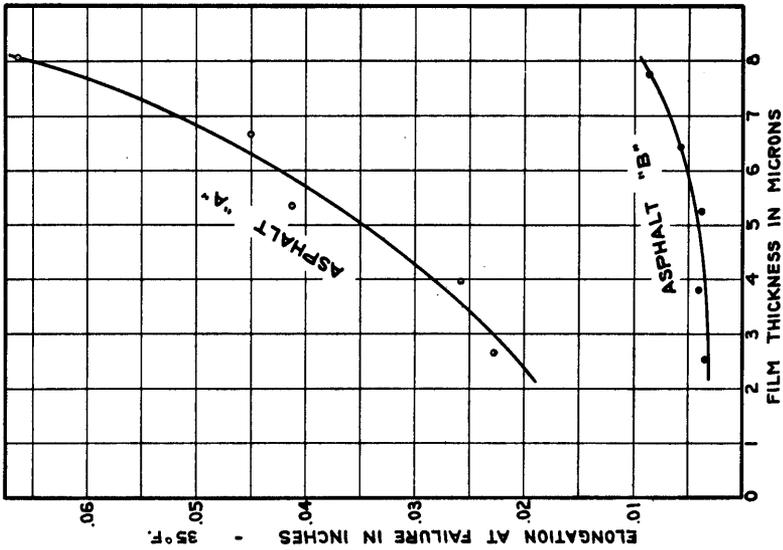
FIGURE 12

Shearing strength.—Data from the shear test are presented in Figure 10, where the asphalts are arranged in order of shearing strength at 35° F. after exposure to heat and air. It may be seen that only asphalts *U* and *X* show a decrease in shearing strength during heat and air exposure, while asphalts *B, P, U,* and *X* show a decrease in strength during exposure to heat, air, and ultraviolet light. Shearing strength of mixtures is also greatly affected by the consistency of the asphalt as

may be seen in Tables XVI and XVII (Appendix) where results of tests made at 77° F. are shown. Figure 22 later in this report shows the relation between shearing strength at 77° F. and penetration of the recovered asphalt.

Effect of the thickness of asphalt film upon the test properties of mixtures.—Figure 11 shows a comparison of test results for mixtures containing 2 per cent asphalt with those containing 4 per cent. Tests were made after the standard exposure to heat and air. While it may be seen that increasing the asphalt content increases the resistance to a given test, the same relative differences between asphalts are present in both groups of mixtures.

Figure 12 shows the relation between average film thickness and the tensile strength and elongation of the molded specimens. It may be seen that even with a greater film thickness, the elongation of asphalt *B* is much less than that of asphalt *A*.

Density of molded specimens.—The densities of molded specimens prepared from mixtures before and after exposure will be found in Table XVI (Appendix). It may be seen that the densities of the mixtures prepared from the various asphalts show very little variation. In each case the density is greater after exposure. The increase in the per cent of fines due to the abrasive wear of the sand during the 22 hours exposure probably accounts for this increase in density. Changes in the consistency of the asphalts during exposure, with a resulting change in the molding properties of the mixtures, may also have influenced the void contents.

TESTS OF SHEET ASPHALT SPECIMENS

These tests included the artificial weathering of small molded specimens, measurements of the coefficient of thermal expansion of sheet asphalt beams, testing of the beams in flexure at −10° F., and measurements of tensile strength and elongation at −10° F.

PREPARATION OF MIXTURES

The sand used was a combination of local sands separated into the sizes shown in Table II. The sand was predominately silica ranging from approximately 60 per cent silica, 10 per cent basalt, 10 per cent dolomite, and 20 per cent minor constituents in the larger sizes, to almost pure silica in the part passing the 100-mesh sieve. Limestone dust was used for filler.

The asphalt content was proportioned by volume, the asphalt comprising 22.0 per cent of the absolute volume of the mixture. This was equivalent to an asphalt content of 9.5 per cent by weight when the specific gravity of the asphalt was 1.000. The computed film thickness was 6.0 microns. Fifty-sixty penetration asphalts were used in the small

cylindrical specimens exposed to artificial weathering and 85-100 penetration asphalts were used for all other specimens. The aggregate, which was thoroly dry mixed, was heated to 350° F. in the mixing bowl. The 50-60 penetration asphalt, heated to 300° F. was then weighed into the bowl. The materials were then mixed with a spatula until a homogeneous mixture resulted. In the case of 85-100 penetration asphalts the aggregate was heated to only 325° F. and the asphalt to 275° F.

TABLE II

GRADING OF AGGREGATE IN SHEET ASPHALT MIXTURES

SIEVE NO.	TOTAL PER CENT PASSING
10	100
20	96.7
30	91.1
40	82.1
50	70.4
80	43.5
100	29.0
200	14.5

MOLDING OF SPECIMENS

Beams for measuring coefficient of expansion were $2 \times 2 \times 10$ inches. Briquettes for measuring tensile strength and elongation were similar to those used in Ottawa sand tests, shown in Figure 8 (p. 15).

Specimens for artificial weathering were cylindrical in form $1\frac{1}{4} \times 1\frac{1}{4}$ inches, with the edges rounded to a $\frac{1}{4}$-inch radius by means of the special double plungers used in molding.

The mixed material was weighed into a mold and then heated in an oven until the mixture reached the molding temperature as indicated by a thermometer in the mixture. A temperature of 275° F. was used for 50-60 penetration asphalts and 250° F. for 85-100 penetration asphalts. The material was firmly tamped into place, after which the previously heated plunger was set in position in the mold, and the assembly transferred to the press for compaction. The small specimens were compacted in a screw press at a pressure of 3,000 pounds per square inch. The beams were compacted in a 50,000-pound testing machine at full load, resulting in a molding pressure of 2,500 pounds per square inch. When the proper molding pressure was reached, the specimen was covered with cold water and allowed to cool five minutes under load.

As the per cent of air voids present in the cylindrical specimens might have an effect on the resistance to artificial weathering, the air voids were determined. The density of each of two groups of five specimens was determined for each asphalt by the method of immersed weights. Knowing the proportion and density of the component parts,

the percentages of air voids were calculated. The values are presented in Table III. It may be seen that the two asphalts, whose specimens have the highest per cent of air voids, have the highest xylene equivalent and the lowest furol viscosity at 275° F. as shown in Table XIX (Appendix). Voids in the 2×2×10 inch beams were determined in only three cases. These determinations indicated a somewhat lower void content than cylindrical specimens made from the corresponding 50-60 penetration asphalt. The voids for beams made from asphalts *B, C,* and *E* were 6.3, 4.9, and 5.8 per cent, respectively.

TABLE III

VOIDS IN CYLINDRICAL SHEET ASPHALT SPECIMENS

ASPHALT*	PER CENT VOIDS			ASPHALT	PER CENT VOIDS		
	Group 1	Group 2	Aver.		Group 1	Group 2	Aver.
V-50	5.56	5.59	5.6	Q-50	6.28	6.21	6.2
G-50	5.60	5.76	5.7	T-50	6.19	6.64	6.4
P-50	5.64	5.96	5.8	Y-50	6.37	6.55	6.5
N-50	5.86	5.87	5.9	R-50	6.90	6.23	6.6
M-50	6.09	6.17	6.1	D-50	6.61	6.65	6.6
H-50	5.96	6.35	6.2	W-50	6.61	6.81	6.7
S-50	6.17	6.16	6.2	E-50	7.10	6.63	6.9
C-50	6.24	6.16	6.2	X-50	7.04	7.30	7.2
O-50	6.34	6.11	6.2	U-50	8.23	7.88	8.1

* A 50-60 penetration asphalt is designated by a letter followed by the figure 50.

ARTIFICIAL WEATHERING AND TESTING OF SMALL MOLDED SPECIMENS

The specimens, comprising five for each asphalt, were mounted on the circumference of two bicycle wheels (see Fig. 13) which were slowly rotated (2.4 r.p.h.) under the ultraviolet light. At the bottom of each revolution the specimen dipped under water. The specimens were rotated under the ultraviolet lamp 17 hours out of each 24. During the remaining seven hours the specimens were alternated at one-hour intervals between immersion in water and storage in a freezing room at −10° F. Thus the specimens received three cycles of freezing and thawing per day. Over the week ends the specimens were continuously rotated under the ultraviolet lamp for 65 hours. At intervals of two weeks the specimens were removed from the wheel and given 1,000 revolutions in the Deval abrasion machine with the drums filled with water at 60° F. The specimens were exposed for a total of 176 days of artificial weathering. This included 3,419 hours under the ultraviolet light, 345 cycles of freezing and thawing, and 15,000 revolutions in the abrasion machine.

Figures 14, 15, and 16 show the specimens at the end of the artificial weathering test. Specimens are arranged according to the appearance of the surface after testing. The number appearing below a specimen indicates the number of days of weathering received by that specimen. A study of the specimens revealed two types of deterioration: first, a

cracking of certain specimens and second, a wearing away of the surface material. It is believed that the method of support was at least partly responsible for the cracking of the specimens. They were supported between a pair of thumbtacks which exerted a slight pressure on the ends of the specimens. It will be observed, however, that a tendency
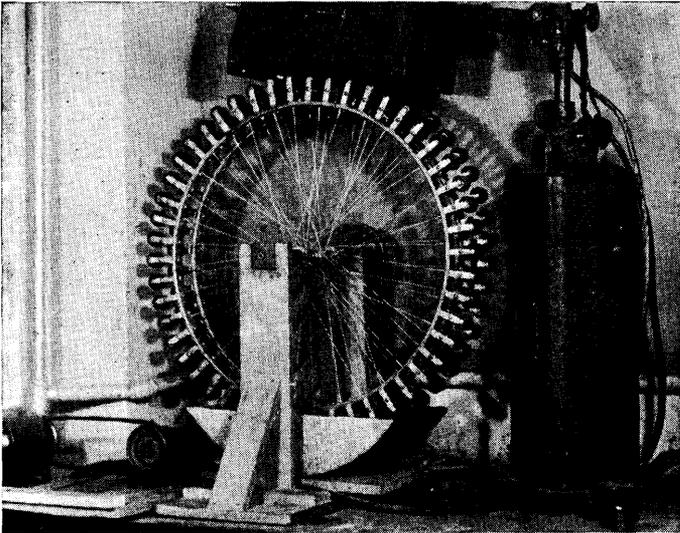
FIGURE 13. DEVICE FOR THE ARTIFICIAL WEATHERING OF
SHEET ASPHALT SPECIMENS

to crack seems to be characteristic of certain asphalts. For many asphalts, the entire group of specimens cracked, while for others the entire group remained uncracked. A slight correlation between tendency to crack, and resistance to stripping will be discussed under "Stripping Tests" in a subsequent portion of this report.

It is believed that visual observation affords the best means of comparing the specimens for surface disintegration. Altho determinations of the loss in weight were made the data were of doubtful value since other losses were included with surface wear. Certain specimens showed a very appreciable loss in material at the point of support. Other specimens lost weight when fragments dropped off adjacent to the irregular cracks which had appeared in them. The following grouping of the various asphalts was made on the basis of surface appearance after testing:

1. N-50, V-50, W-50, G-50 ....Smooth black surface
2. Y-50, O-50, H-50, P-50, D-50.............Smooth but not as black as Group 1
3. E-50, T-50 ....Surface slightly rough
4. R-50, C-50, Q-50...Somewhat rougher than Group 3
5. M-50, S-50 .... Surface definitely rough
6. U-50, X-50 ....Surface very rough and pitted
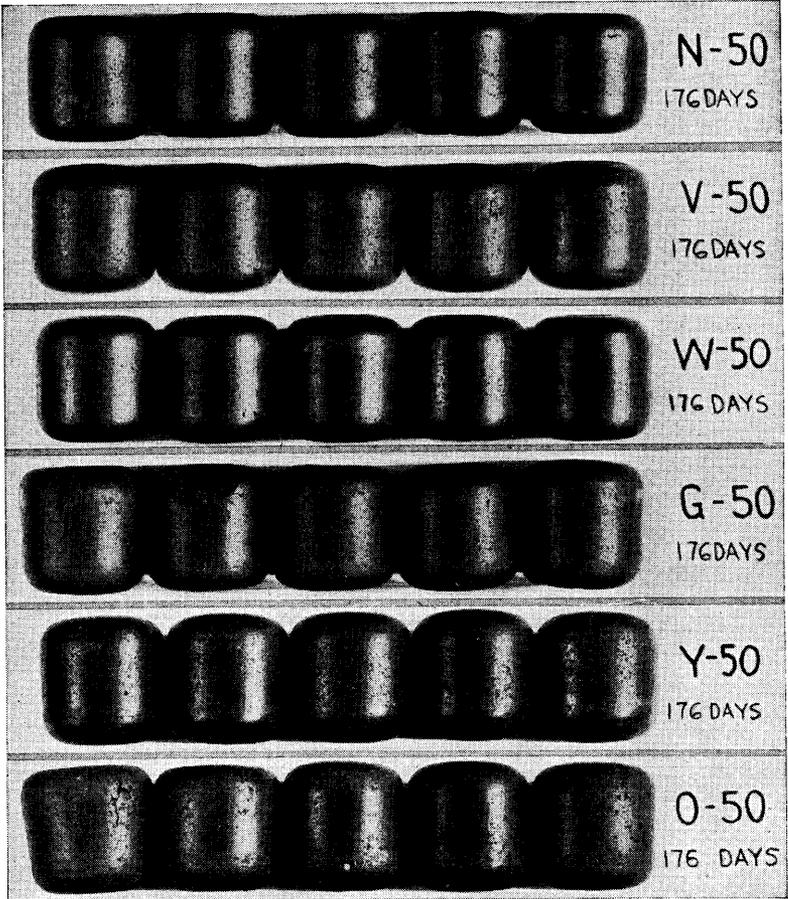
FIGURE 14.   SHEET ASPHALT SPECIMENS AFTER
176 DAYS OF ARTIFICIAL WEATHERING

24
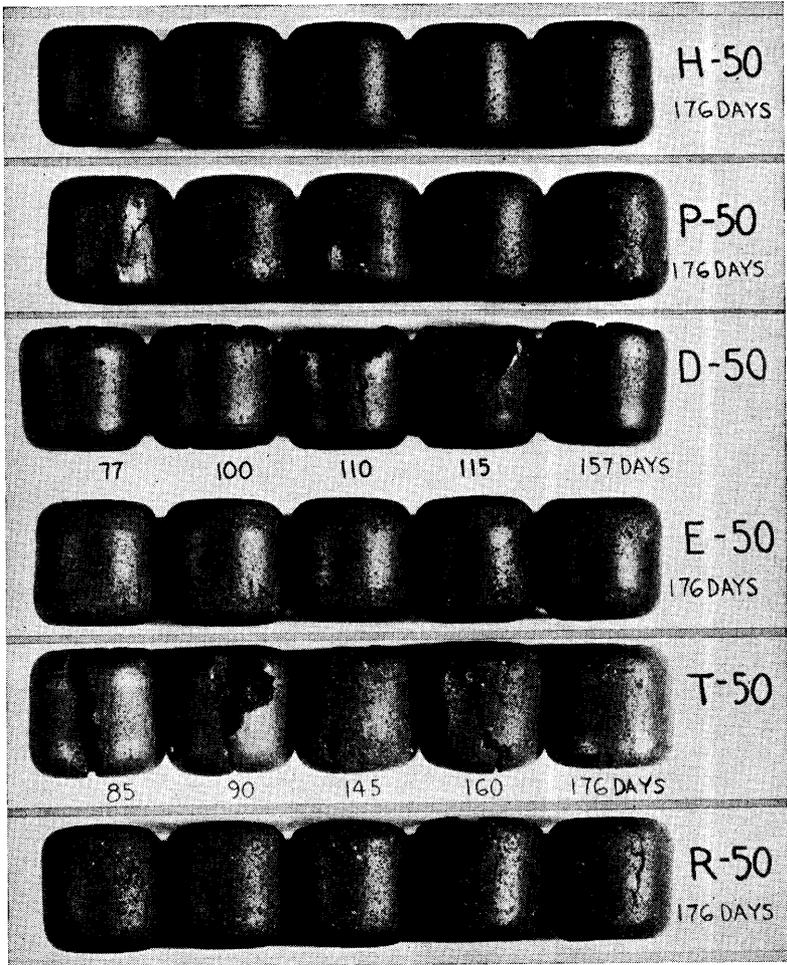
FIGURE 15.   SHEET ASPHALT SPECIMENS AFTER
176 DAYS OF ARTIFICIAL WEATHERING
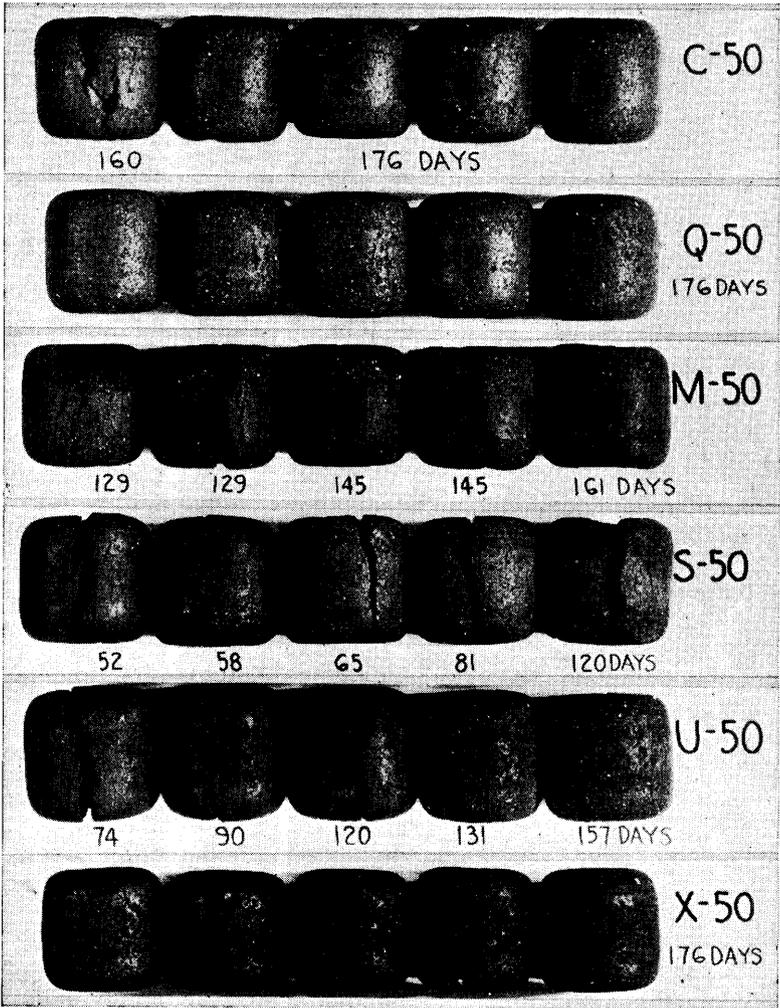
FIGURE 16.   SHEET ASPHALT SPECIMENS AFTER
176 DAYS OF ARTIFICIAL WEATHERING

The loss in weight from specimens V-50, W-50, and X-50 was 0.24 per cent, 0.16 per cent, and 5.88 per cent, respectively. These losses should represent a true picture of surface disintegration, because these specimens showed practically no loss at the point of support.

Asphalt L-50 was omitted from the photographs and from the groupings because the method of proportioning asphalts on a volume basis did not adequately compensate for the lower bitumen content of that asphalt. This resulted in an average film thickness of 4.5 microns. Specimens containing asphalt L-50 were similar in appearance after artificial weathering to those containing asphalt X-50. It should be noted, however, that in all of the previously discussed Ottawa sand mixtures, asphalts L and L-50 were proportioned strictly on a bitumen basis.

It will be observed that the asphalts in Groups 5 and 6 all showed poor resistance to exposure in Ottawa sand tests, but that asphalts W-50, H-50, and P-50 showed better resistance to artificial weathering in sheet asphalt than to exposure in Ottawa sand mixtures.

The hardening of the asphalts in the specimens will be discussed in a subsequent portion of this report.

COEFFICIENT OF THERMAL EXPANSION OF SHEET ASPHALT

Sheet asphalt beams $2\times2\times10$ inches were used for this purpose. The change in length was measured by means of two telescopes equipped with cross hairs and mounted in a vertical position on a movable bar. The telescopes read directly down on glass capillary tube gage points embedded on 8-inch centers in the sheet asphalt beams. The movement of the bar supporting the telescopes was in a horizontal direction and controlled by a screw mechanism. Its position could be determined very accurately by means of a micrometer scale. Readings were always compared to readings on a standard bar. The beams were placed in an alcohol bath whose temperature was maintained by adding bits of solid carbon dioxide. The temperatures were read by means of thermocouples embedded in the beams. The beams were protected from any action of the alcohol bath by a thin coating of a liquid rubber preparation. The coating was too thin to offer any appreciable resistance to volume change.

Two procedures were used in varying the temperature of the beams. In one, the beams were cooled to $-10°$ F. and then allowed to warm up slowly in the bath, readings being taken at intervals. In the other procedure the beams were put through a number of more rapid cycles of temperature change. The temperature was varied from room temperature of 33° F. then to $-20°$ F. and back to 33° F. during one day. The beam was then allowed to warm up to room temperature during the night.

The data for the above measurements are rather cumbersome and are best presented in graphical form. In Figures 17, 18, and 19 unit change in length (unit deformation) has been plotted against tempera-

COEFFICIENT OF THERMAL EXPANSION
OF SHEET ASPHALT

85-100 PENETRATION ASPHALT

ASPHALT "B" K=.0000236

ASPHALT "C" K=.0000232

ASPHALT "D" K=.0000208

ASPHALT "E" K=.0000224

• Single Cycle of slow warming
o Alternating Cycles

.0002

UNIT CHANGE IN LENGTH AS INCHES PER INCH

TEMPERATURE — °F.

80   60   40   20   0   -20

FIGURE 17

28

FIGURE 18

29
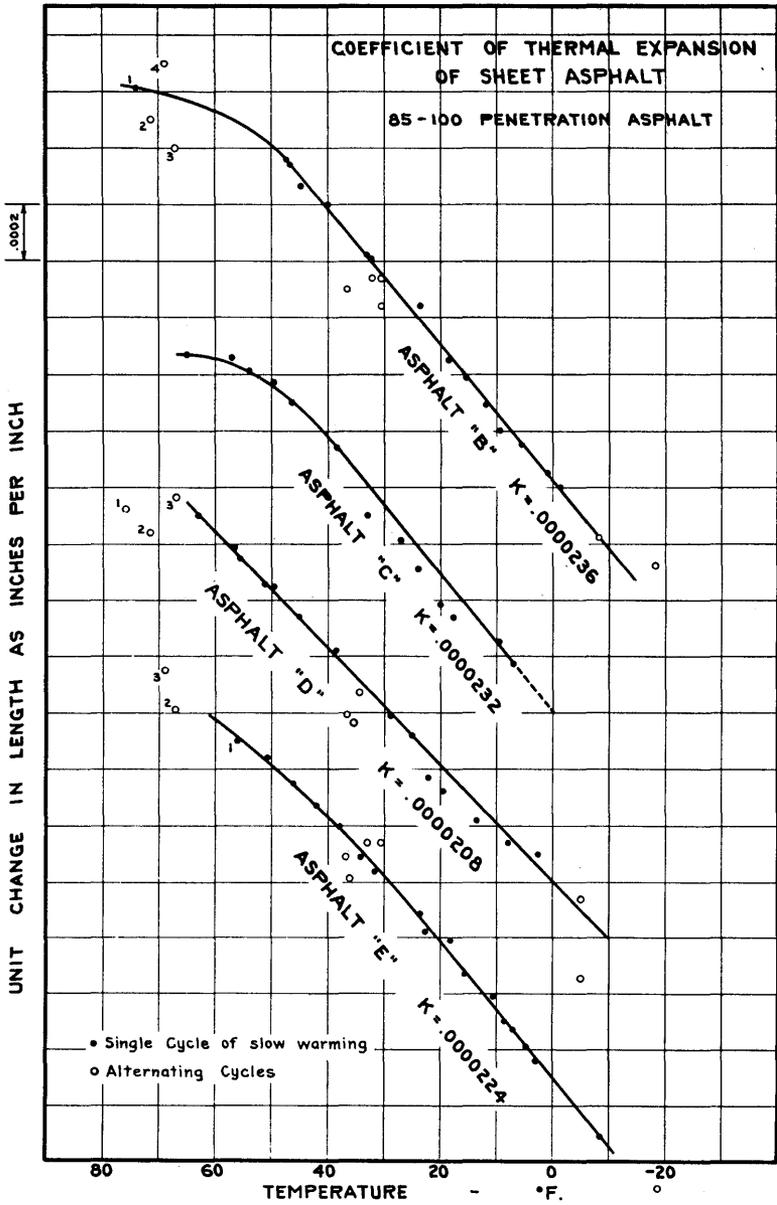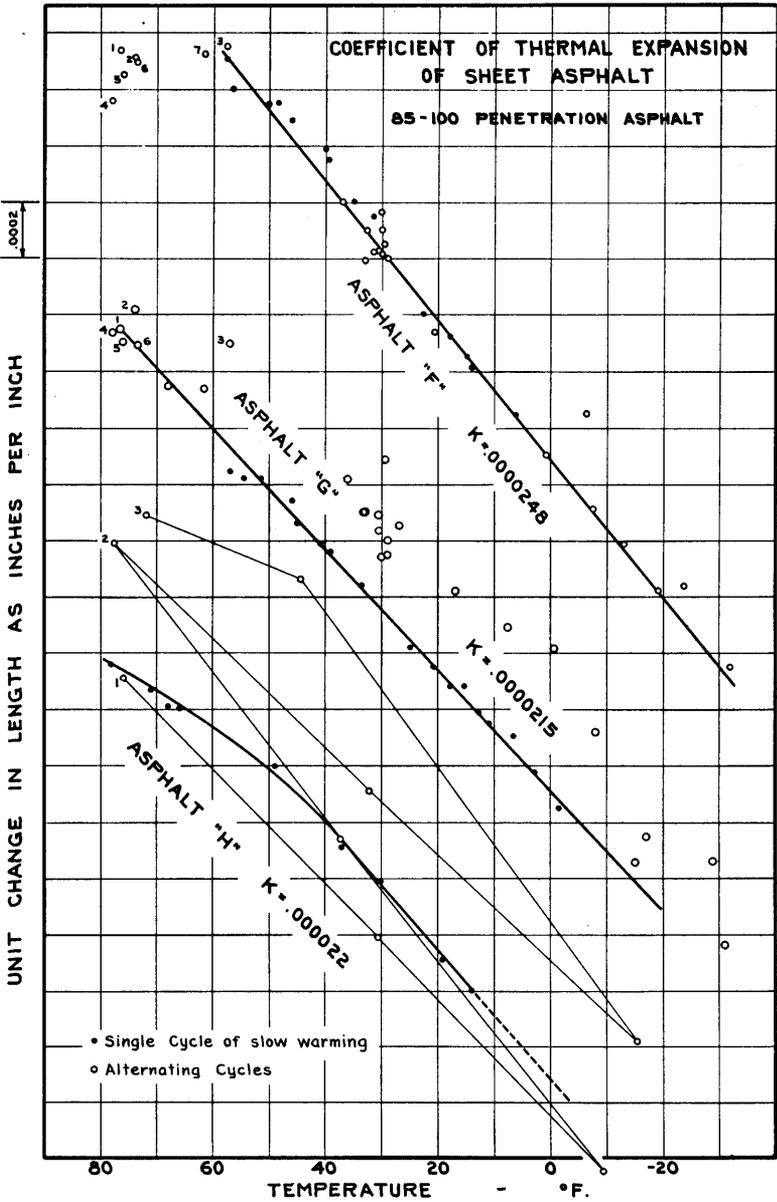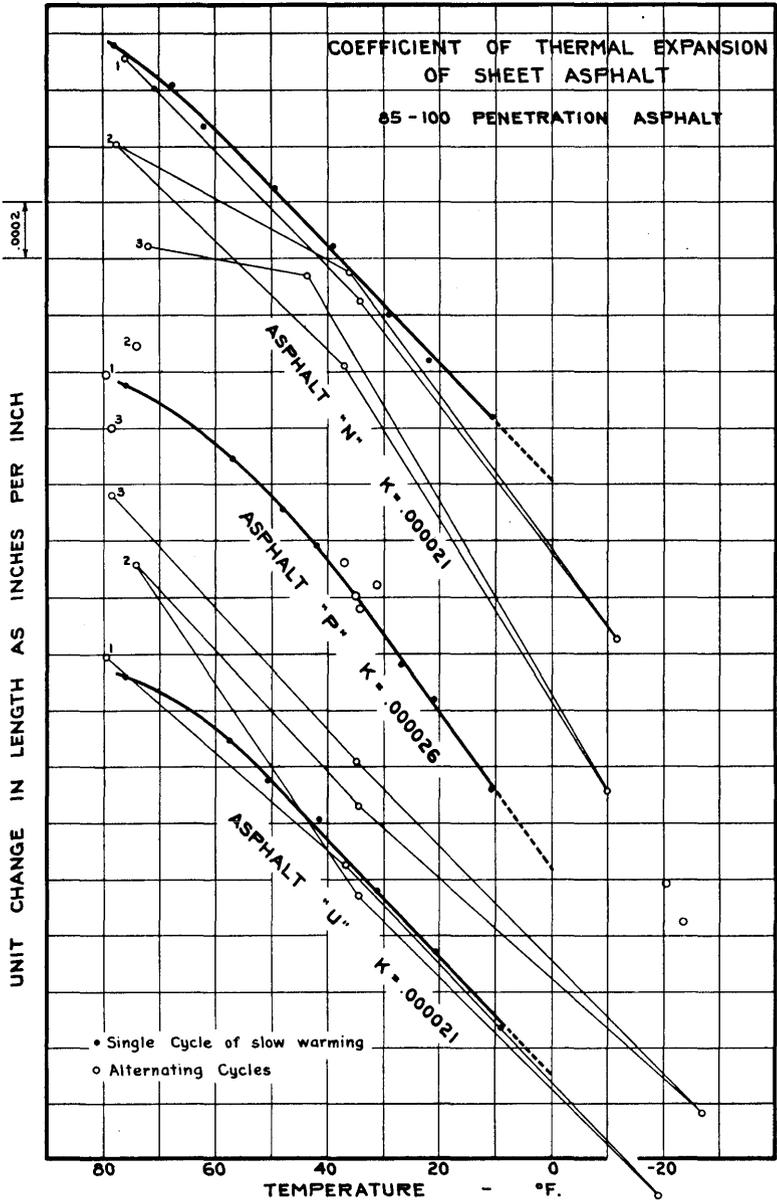
FIGURE 19

ture in degrees F. Solid circles indicate measurements made in the single cycle of slow continuous warming. Hollow circles indicate alternating cycles of temperature change. It will be observed that the beams do not always return to their original length after the rapid cycle of temperature change. Points representing the room temperature end of the rapid cycle are given numbers to indicate the number of the cycle. It will be observed that beams made from asphalts *H, N,* and *U* have apparently undergone a permanent change in length.

It will be observed that in general, the points tend to form a straight line in the region of lower temperatures, but that this line tends to curve downward as the temperature reaches 50° to 60°F. The coefficient of thermal expansion was determined in the straight portion of the curve between 0° and 50° F. Where the points representing the rapid cycle of temperature change showed considerable variation on repeat cycles, the coefficient was based entirely upon the slow warming cycle. Check readings on a given length usually agreed within .0003 inch. The actual change in length of a beam for the 8-inch gage and 50° F. temperature change was approximately .0092 inch indicating a probable error of about 3 per cent.

An average value for the coefficient of thermal expansion of the sheet asphalt used in this investigation was .000023.

PHYSICAL TESTS AT −10° F.

The tensile strengths and elongations of briquettes made from the sheet asphalt mixtures were measured at −10°F. using four 85-100 penetration asphalts which differed widely in test properties. The briquettes were tested in a freezing room with the air temperature at −10° F. The tests were made in a lead shot type of cement testing machine. The load was applied at the rate of 300 pounds per minute. The data are shown in Table IV. Each value represents the average of at least three specimens.

TABLE IV

TENSILE STRENGTH AND ELONGATION OF SHEET ASPHALT AT −10°F.

	Asphalt Designation			
	N	C	P	B
Tensile strength pounds/square inch	1,000	899	657	538
Elongation inches	.0013	.0006	.00025	.0001
Unit strain for 1½-inch gage distance	.0009	.0004	.00017	.00007
Unit strain for ½-inch gage distance	.0026	.0012	.0005	.0002

The distance between the gage centers of the tensile briquettes was 2 inches. Because of the manner of gripping the specimens, only part of this portion is under direct tensile stress. The elongation value would also represent the value of unit strain if the portion of the briquette under tensile stress could be considered as one inch. Table IV shows

values of unit strain for gage distances of ½ inch and 1½ inches, and the true value probably lies between these two. Using a coefficient of thermal expansion of .000023, it will be seen that a drop in temperature of 3 to 10 degrees would exceed the ultimate unit strain of asphalt B at $-10°$ F. It may be seen, however, that asphalts N and C showed considerably more elongation. These data would indicate that the properties of the asphalt cement are an important factor in determining the resistance of a sheet asphalt pavement to temperature contraction forces. However, caution must be exercised in interpreting these results since the deformation was produced at a more rapid rate than would result from temperature contraction.

It may be seen from a comparison of Table IV (page 31) and Table XVI (Appendix) that the relative tensile strengths of asphalts $N, C, P,$ and B in sheet asphalt at $-10°$ F. are substantially reversed from those in Ottawa sand mixtures at 35°F. While penetrations were not obtained at $-10°$ F., penetrations at 0°F. from Table XVIII (Appendix) indicate that the two hardest asphalts, B and $P,$ have the least strength and that the softest asphalt, $N,$ had the greatest strength when tested at $-10°$ F. This tends to confirm a previous statement, that tensile strength tends to increase with consistency up to a certain optimum value. Beyond this optimum value of consistency, increasing brittleness or reduction in binding strength of the asphalt cement may tend to reduce the strength of the mixture.

The beams, which had been used for determination of coefficients of thermal expansion, were tested in flexure at $-10°$ F. The beams were immersed in an alcohol bath maintained at this temperature during the test. They were supported on rollers, using an 8-inch span. The load was applied at the center at the rate of 100 pounds per minute.

In this test, the values represent single determinations. The data should therefore be considered as merely supplemental to other test data in this report. The data are shown in Table V.

TABLE V

FLEXURAL TEST DATA FOR SHEET ASPHALT BEAMS AT $-10°$ F.

Asphalt	Ult. Load Pounds	Ult. Unit Stress Pounds/Sq. In.	Max Deflec. Inches	Ult. Unit Strain	Secant Modulus of Elas. 200- to 400-Pound Load
B	650	970	.0072	.0011	1,130,000
C	645	960	.0288	.0054	146,000
D	695	1,040	.0079	.0015	1,204,000
E	635	930	.0112	.0022	388,000
F	730	1,090	.0141	.0027	400,000
G	630	940	.0046	.0009	1,070,000
H	550	840	.0076	.0014	570,000
N	850	1,310	.0258	.0049	310,000
P	420	630	.0080	.0015	421,000
U	460	690	.0031	.0006	1,330,000

In calculating modulus of elasticity and ultimate unit strain, the usual assumption has been made that deflections caused by shearing deformations are negligible. This is not quite true for beams of this ratio (4) of span to depth. However, since the correction cannot be made without a separate determination of modulus of elasticity in shear, the data must be presented as shown.

It will be seen that the values of ultimate unit strain are from four to ten times as great as the elongation of the tensile briquettes made from corresponding sheet asphalt mixtures and shown in Table IV. The discrepancy may result from: (1) inclusion of deflection caused by shearing stresses in the beam tests; (2) a slower application of load in the beam tests; (3) the fact that larger than normal values of unit strain may occur at the extreme fibers, and (4) errors in measurement inherent in both tests. Of the four asphalts tested in both tension and flexure, it will be observed that asphalts *B* and *P* had the least elongation in tension and the least unit strain in flexure, while asphalt *N,* which had the greatest elongation in tension, had an ultimate strain in flexure slightly less than that for asphalt *C*.

It is believed that ultimate unit deformation is the most significant measure of the ability of a paving mixture to resist cracking under temperature contraction forces. Two materials may have equal modulae of elasticity, but the stronger material will show a greater ultimate unit strain with a correspondingly greater resistance to rupture from temperature contraction. For pavements a combination of low modulus of elasticity with high strength is desirable. Such a material should stretch without cracking.

HARDENING OF ASPHALTS

METHOD USED FOR RECOVERING ASPHALT

In order to measure the hardening of an asphalt during exposure, the asphalt has been extracted with benzene from both exposed and unexposed mixtures. The Rotarex apparatus was used in making the extraction. After the asphalt was recovered by the Abson method (see A-2h Appendix), the penetration was determined. In the case of mixtures prepared from 85-100 penetration asphalts and exposed to heat, air, and ultraviolet light, the per cent of material insoluble in 86° naphtha was also determined. In order to ascertain the effect of the recovery method itself upon the hardening of the asphalts, solutions of asphalt in benzene were prepared and the asphalt immediately recovered. It was found that some of the 85-100 penetration asphalts underwent considerable hardening during the recovery process, indicating that the use of some temperature lower than that specified by Abson (325° F.) might be desirable. The loss in penetration occurring during the recovery of the 85-100 penetration asphalts ranged from 2 to 20 points

with an average of 9.1.   Under similar conditions the loss in penetration
of the 50-60 penetration asphalts ranged from 0 to 8 points with an
average of 4.0.

HARDENING IN OTTAWA SAND MIXTURES

Figure 20 shows the penetration of asphalts recovered from Ottawa
sand mixtures after various periods of exposure to heat and air.   In
general, the asphalts which harden the most on exposure were recovered
from mixtures that developed the greatest abrasion loss (Fig. 2), the
lowest impact resistance (Fig. 3), and the least elongation (Fig. 4).
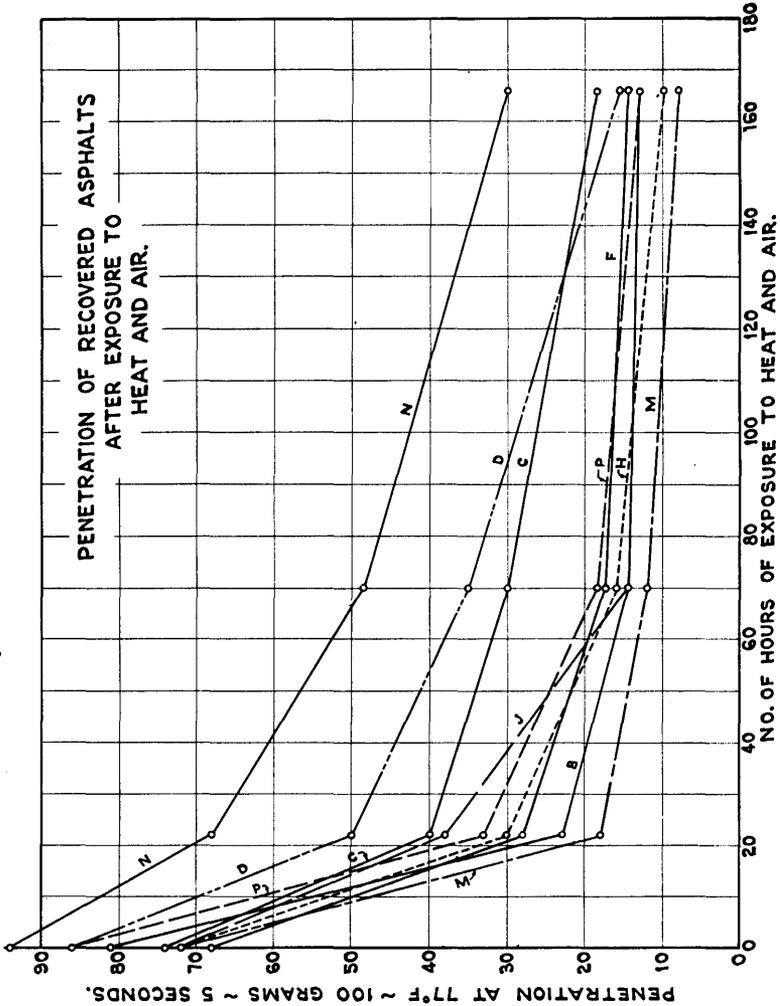
FIGURE 20
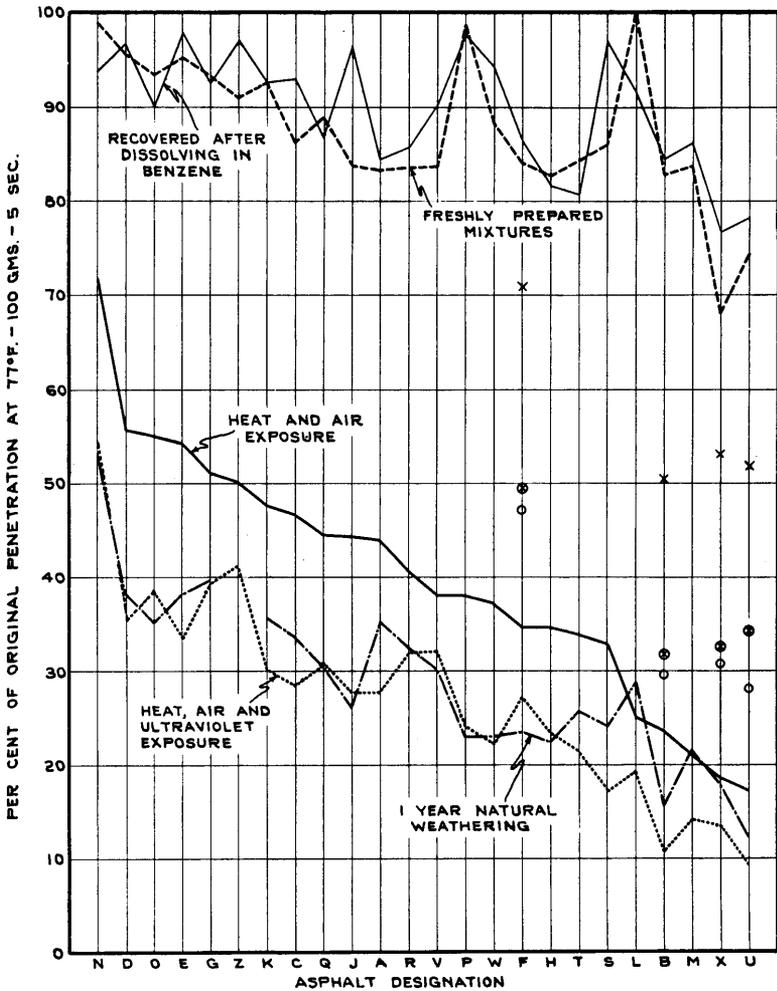
THE HARDENING OF 85-100 PENETRATION ASPHALTS
BY VARIOUS MEANS

O INDICATES OTTAWA SAND MIXTURES STORED 6 MONTHS IN CLOSED CANS.
× INDICATES SHEET ASPHALT SPECIMENS IMMEDIATELY AFTER MOLDING.
⊗ INDICATES SHEET ASPHALT SPECIMENS AFTER 6 MONTHS AT ROOM
      TEMPERATURE.

FIGURE 21

35

EFFECT OF ASPHALT CONSISTENCY UPON PHYSICAL
TESTS OF MIXTURES

o AFTER HEAT AND AIR EXPOSURE
• AFTER HEAT, AIR AND ULTRAVIOLET EXPOSURE

FIGURE 22

36
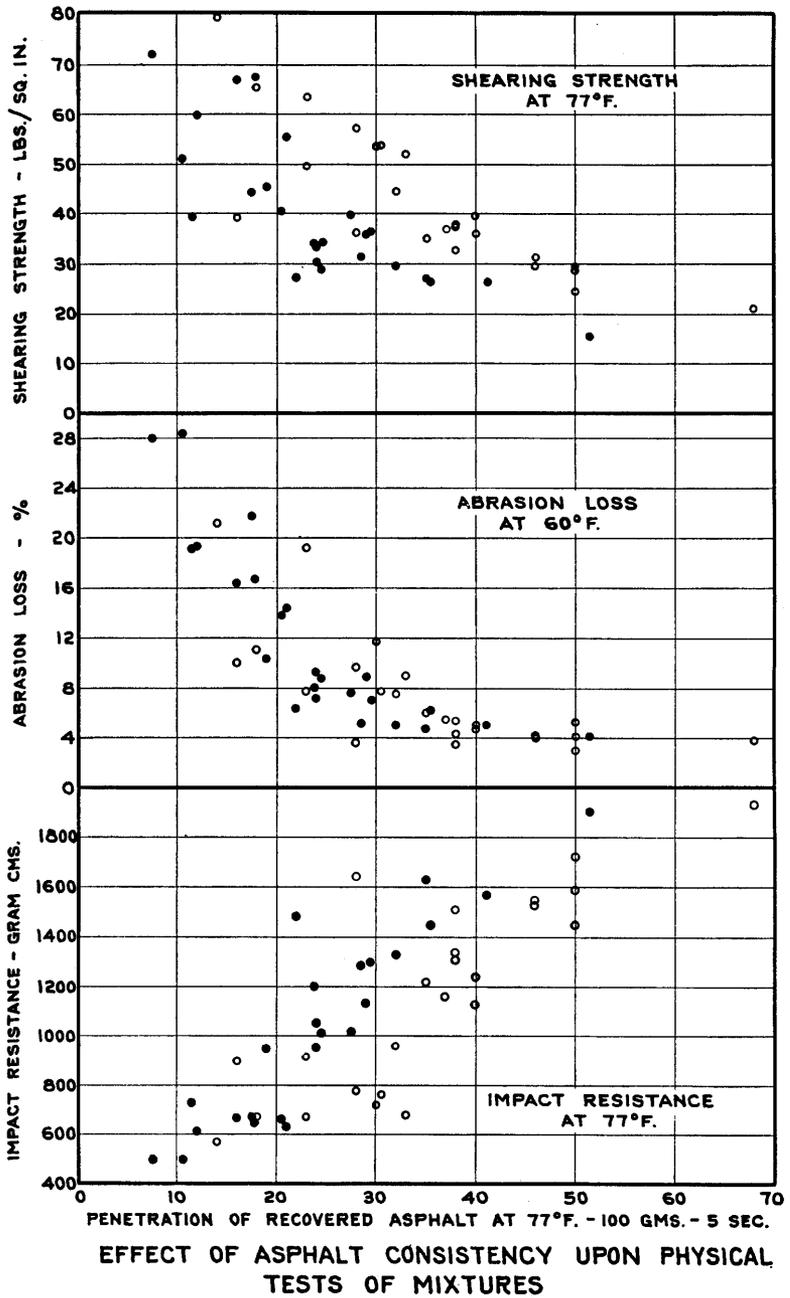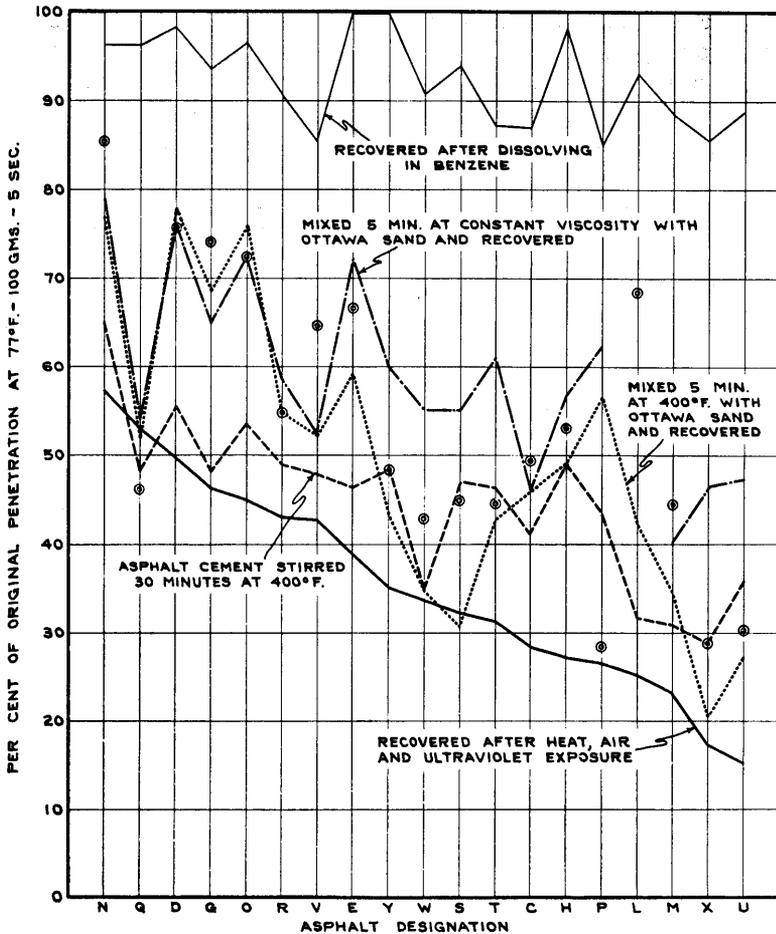
THE HARDENING OF 50-60 PENETRATION ASPHALTS
BY VARIOUS MEANS

⊙ INDICATES SHEET ASPHALT SPECIMENS EXPOSED TO ARTIFICIAL
WEATHERING FOR 6 MONTHS.

FIGURE 23

It will be seen in Figure 20 that asphalt J hardened a great deal between 22 and 70 hours of exposure. After 166 hours of exposure on Ottawa sand, asphalt J became converted into a spongy rubber-like substance during the recovery process. Its lack of fluidity at 325° F. made removal of the last traces of benzene doubtful. Its rough surface and porous interior made a penetration test meaningless. Consequently no value is shown for the penetration of asphalt J for 166 hours of exposure.

Figure 21 shows the hardening of the 85-100 penetration asphalts after various types of exposure. The penetrations are plotted as a per cent of the original penetration. The asphalts are arranged in order of decreasing per cent penetration after exposure to heat and air. To indicate the extent of the hardening which may be attributed to the recovery process, the penetrations (expressed in percentage of original) of asphalts recovered from freshly prepared solutions of asphalt in benzene are shown. As previously stated the average decrease in penetration resulting from the recovery process was 9.1 points. In order to indicate the portion of the hardening which may have taken place during the preparation of the mixtures, the per cent penetrations of asphalts recovered from freshly prepared mixtures are also shown. It will be seen that the hardening which may result during the preparation of the mixtures is largely obscured by the hardening resulting from the recovery process. The average loss in penetration of asphalts recovered from freshly prepared mixtures was 1.8 points greater than the average loss in penetration of asphalts recovered from solutions of asphalt in benzene.

It will be observed that the extent of the hardening produced by natural weathering is very similar to that produced by heat, air, and ultraviolet exposure. It may also be seen that considerable hardening may result without the use of ultraviolet light. An average of the data shown in Figure 21 revealed that 79 per cent of the loss in penetration produced by heat, air, and ultraviolet light was produced by heat and air during an equal length period of exposure.

By observing the identity of the asphalts grouped to the right in Figure 21, it may be seen that these asphalts also showed poor resistance to abrasion, impact, and elongation in Figures 6, 7, and 8. This may indicate: (1) that physical tests are greatly influenced by the consistency of the asphalt, (2) that an asphalt with low resistance to the physical tests is also subject to rapid hardening during exposure or (3) a combination of items (1) and (2). To study the effect of consistency upon some of the physical tests Figure 22 was prepared. The penetration of the recovered asphalt at 77° F. has been plotted against shearing strength at 77° F., abrasion loss at 60° F., and impact resistance at 77° F. These particular tests were selected because they were made at or near the penetration temperature of 77° F. It may be seen that a wide range of test values is possible for a given penetration and a wide range of penetrations for a given test value. The impact tests of unweathered mixtures as shown in Figure 7 indicate a wide range in the impact test for asphalts of similar consistency. It seems evident that altho the physical tests are undoubtedly influenced by the consistency of the asphalt the tests also measure properties other than consistency.

The hardening of 50-60 penetration asphalts is shown in Figure 23. Here the asphalts have been arranged in the order of the per cent of original penetration retained after exposure to heat, air, and ultraviolet

light. The heat and air exposure was not carried out for the 50-60 penetration asphalts.

Since it is known that a paving asphalt undergoes considerable hardening during the mixing process, a test was devised to measure the hardening of an asphalt at a temperature comparable to that used in a paving plant. An oil bath was introduced around the twin-pug mixer shown in Figure 1, and it was maintained at a temperature of 400° F. The Ottawa sand (2,450 grams) was heated to 400° F. and placed in the mixer. Fifty grams of asphalt heated to 300° F. was immediately added, and the materials were then mixed for 5 minutes. The temperature of the mixture was 330° F. at the end of the mixing period. The per cent penetrations of these recovered asphalts are also shown in Figure 23. It will be seen that some asphalts such as *P*-50 show a relatively greater resistance to hardening at the higher temperature. Results are also shown for the hardening during five-minute mixing at temperatures such that all asphalts would have a furol viscosity of 31 seconds.

Mixtures of Ottawa sand and asphalts *B, F, U,* and *X* were prepared and placed loosely in closed metal cans. The cans were then allowed to stand in the laboratory for periods of 3 and 6 months. The penetrations of the asphalts recovered from these mixtures are shown in Table VI and in Figures 21 and 24. It is evident that a very substantial
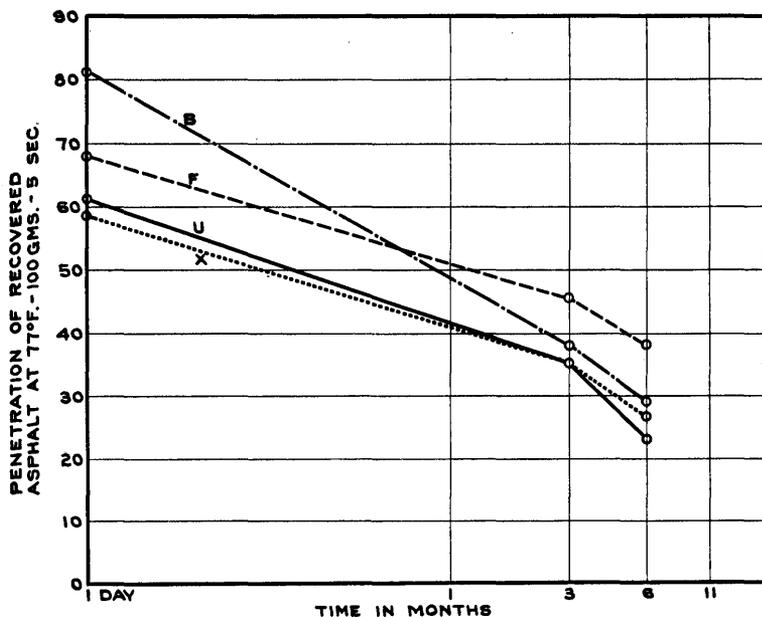
HARDENING OF ASPHALT ON OTTAWA SAND IN CLOSED METAL CONTAINERS

FIGURE 24

hardening of these asphalts has taken place and in the absence of both light and heat. However, considerable air, amounting to probably 20 times the volume of the asphalt, was present.

HARDENING IN SHEET ASPHALT SPECIMENS

In an attempt to determine whether the progressive hardening just discussed would also take place in a densely graded mixture, cylindrical sheet asphalt specimens (2×2 inches) were placed in a closed dark compartment (not airtight) at room temperature for a period of eleven

TABLE VI
THE HARDENING OF ASPHALT ON AGGREGATE AT ROOM TEMPERATURE WITHOUT LIGHT

ASPHALT	ORIG. PENETR. 77° F.	PENETRATION OF RECOVERED ASPHALT AT 77° F.					
		Ottawa Sand Mixtures in Closed Cans—Time			Molded Specimens of Sheet Asphalt—Time		
		1 day	3 mo.	6 mo.	1 day	6 mo	11 mo.
B	98	81	38	29	49.5	31	29
F	81	63	45.5	38	57.5	40	38
U	82	61	35	23	42.5	28	26
X	86	58.5	35	26.5	46	28	24

months. The asphalt was then extracted, recovered, and the penetration determined. In order to allow for hardening occurring during mixing and molding, similar determinations were made on specimens immediately after molding. The data for these tests are shown in Table VI and in Figures 21 and 25. It is apparent that these asphalts are
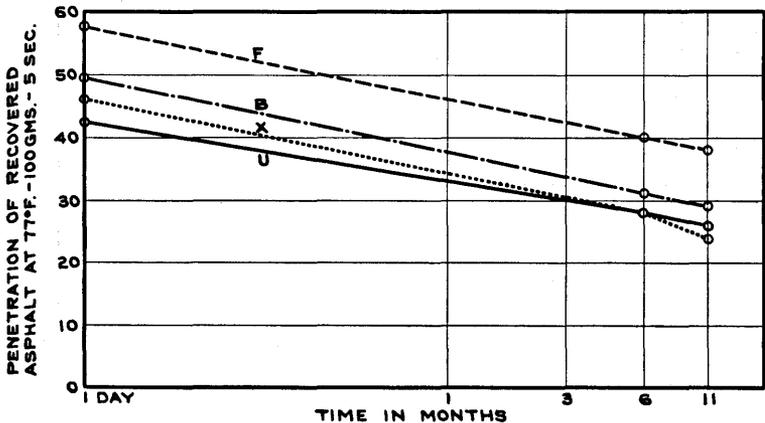
HARDENING OF ASPHALT IN MOLDED SHEET ASPHALT SPECIMENS STORED IN DARK AT ROOM TEMPERATURE

FIGURE 25

undergoing a slow irreversible hardening even in the dense graded sheet asphalt specimens. The air content of the specimens would amount to about one third the volume of the asphalt. Since the specimens were not sealed some percolation of air through them was possible.

It seems apparent from these limited tests that the tendency of an asphalt to harden upon standing in mixtures is a factor that should be given consideration when selecting the kind and penetration of asphalt to be used in pavements. It will be observed that the tendency of asphalts *B, U,* and *X* to harden more than asphalt *F* is in agreement with the hardening during other forms of exposure as shown in Figure 21. It may also be seen that asphalts *B, U,* and *X* hardened more in 6 months in a closed container than did 9 other asphalts during 12 months exposed on a roof to sunlight and much higher temperatures.

The molded sheet asphalt specimens of Figures 14, 15, and 16, which had been subjected to artificial weathering, were extracted with benzene and the asphalt recovered. Because of the small sample available, the penetrations were determined in one-ounce Gill cans instead of the standard three-ounce. The penetrations are shown in Figure 23 as a percentage of the original penetration. It will be observed that a considerable hardening of the asphalt has occurred even in these dense graded sheet asphalt specimens. As a general rule, asphalts which hardened most on Ottawa sand also showed greater hardening in the sheet asphalt specimens. One marked exception was asphalt *L*-50 which had a penetration of 43 when recovered from sheet asphalt specimens and only 14.3 after exposure on Ottawa sand.

ACCELERATED HARDENING TEST
(Using asphalt cement)

An accelerated test performed on the asphalt cement would be advantageous as the recovery of asphalt from Ottawa sand mixtures could then be eliminated.

This test was run for the purpose of making comparisons with the hardening occurring during the five-minute mixing of asphalt and Ottawa sand at 400° F., hence 50-60 penetration asphalts were used. Some investigators have measured the hardening of asphalt during the blowing with air at elevated temperatures. In this test a stirring action was used
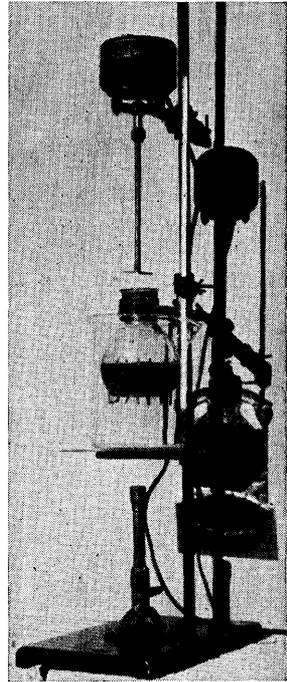
FIGURE 26. STIRRING APPARATUS USED IN ACCELERATED TESTS ON ASPHALT CEMENTS

to agitate the asphalt.   Seventy-five grams of asphalt was placed in a 250 c.c. wide-mouthed flat-bottomed flask.   The flask was then placed in an oil bath maintained at such temperature that the asphalt reached a temperature of 400° F. in 30 minutes.   An electric stirrer was then introduced and the asphalt was stirred (1600 r.p.m.) for 30 minutes (Fig. 26).   During the stirring, the oil bath temperature was maintained at 408° F., so that at the end of the stirring period the asphalt temperature was between 390° and 400° F.   The asphalt was then poured into a three-ounce tin and allowed to cool.   The penetration was then determined in the standard manner at temperatures of 77° F., 115° F., and 32° F.   These values are shown in Table XIX.   Per cent of original penetrations at 77° F. are shown in Figure 23.   Altho a very marked hardening of the asphalts has resulted from this test, it will be seen that the results are not parallel to those in the five-minute mixing of asphalt with Ottawa sand at 400° F.   The stirring test tends to reduce the differences disclosed between the various asphalts in the five-minute mixing.   Apparently the hardening action of asphalt cement in quantity when tested in this manner, is not parallel to hardening in thin films.

DISPLACEMENT OF ASPHALT BY WATER

While most of the emphasis in this investigation has been placed upon weathering of asphalts by means of heat and oxidation, it is recognized that the stripping action of water may be an important factor in the durability of pavements.

STRIPPING TESTS

Tests of stripping were made using crushed stone aggregate and the apparatus proposed by Nicholson.   The detailed procedure is described in part A-3-a of the Appendix.   Table VII shows the data from the stripping tests of the 85-100 penetration asphalts using six kinds of aggregate.   These values must be considered as approximate since the area stripped is only estimated.   The values given are single determinations except in the case of the Feldsite aggregate, in which case the figures represent the average of at least two determinations.   The gravel aggregate consisted entirely of crushed particles of the following composition:

		Per Cent
Limestone	....	32.2
Granite and schists	....	39.4
Traprock	....	26.8
Sandstone	....	.8
Quartzite	....	.8
		100.0

STRIPPING TEST DATA 85-100 PENETR. ASPHALTS TABLE XII

FIGURES INDICATE ESTIMATED % OF AGGREGATE SURFACE STRIPPED OF ASPHALT AFTER VARIOUS PERIODS OF AGITATION

ASPHALT	Granite 15min 75°	15min 75°	15min 100°	15min 120°	Quartzite 15min 75°	15min 75°	15min 100°	15min 120°	Feldsite 15min 75°	15min 75°	15min 100°	15min 120°	Traprock 15min 75°	15min 75°	15min 100°	15min 120°	Limestone 15min 75°	15min 75°	15min 100°	15min 120°	Gravel 15min 75°	15min 75°	15min 100°	15min 120°	Average 15min 75°	15min 75°	15min 100°	15min 120°
A	5	25	50	75	0	15	30	50	0	0	0	35	0	0	0	5	0	0	0	0	0	0	0	0	1	7	13	28
B	15	35	75	80	0	0	10	10	0	0	0	25	0	0	0	15	0	0	0	0	0	0	0	0	2	6	14	22
C	0	5	35	80	0	15	30	60	0	0	0	15	0	0	0	25	0	0	0	0	0	0	6	5	0	3	11	31
D	0	25	80	90	10	30	60	85	0	0	40	75	0	0	0	25	0	0	0	5	0	0	0	0	2	9	30	47
E	0	25	80	90	15	40	75	90	0	0	30	60	0	0	0	40	0	5	5	10	0	0	0	0	2	12	32	48
F	0	15	30	60	0	5	20	25	0	0	0	5	0	0	0	10	0	0	0	5	0	0	0	0	0	3	8	18
G	0	20	60	80	10	15	45	75	0	0	15	65	0	0	0	0	0	0	0	0	0	0	0	0	2	6	20	37
H	0	20	75	90	5	10	30	65	0	0	10	40	0	0	0	0	0	0	0	0	0	0	0	0	1	5	19	32
J	0	5	20	50	0	10	25	50	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	2	8	21
K	0	0	5	5	0	10	25	50	0	0	0	10	0	0	0	0	0	0	0	5	0	0	0	0	0	2	5	12
L	0	5	20	50	0	0	0	25	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	14
M	0	0	30	75	0	0	5	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	6	16
N	0	10	50	75	0	0	20	30	0	0	5	60	0	0	0	20	0	0	10	15	0	0	0	0	0	2	14	33
O	5	15	75	90	10	25	60	90	0	0	10	50	0	0	0	10	0	0	0	5	0	0	0	5	2	7	24	42
P	0	5	35	50	0	15	50	80	0	0	10	45	0	0	0	5	0	0	0	5	0	0	0	0	0	3	16	31
Q	5	15	25	80	0	10	20	40	0	0	5	35	0	0	0	0	0	0	0	0	0	0	0	0	1	4	8	26
R	5	10	20	40	0	5	15	35	0	0	5	30	0	0	0	5	0	0	0	0	0	0	0	0	1	2	7	18
S	0	15	25	75	5	20	40	65	0	0	5	35	0	0	0	5	0	0	0	5	0	0	0	0	1	6	12	31
T	5	15	25	75	0	0	20	60	0	0	15	70	0	0	0	0	0	0	5	10	0	0	0	0	1	2	11	36
U	0	5	20	60	0	0	15	45	0	0	15	45	0	0	0	15	0	0	5	10	0	0	0	0	0	1	9	29
V	0	5	15	50	0	0	5	15	0	0	10	35	0	0	0	15	0	0	5	10	0	0	0	0	0	1	6	21
W	0	5	25	85	0	0	0	10	0	0	5	15	0	0	0	5	0	0	5	10	0	0	0	0	0	1	6	21
X	0	0	0	15	0	0	0	10	0	0	0	10	0	0	0	0	0	0	5	10	0	0	0	0	0	0	1	8
Average	2	12	38	66	2	10	26	47	0	0	8	35	0	0	0	9	0	0	2	5	0	0	0	1	1	4	12	27

Table VII shows marked differences in the stripping properties of aggregates, and some differences between the tendency of the asphalts to strip. Using the averages for all six aggregates it will be seen that the positive spot test asphalts show less stripping. Results of spot test and xylene equivalent tests will be found in Tables XVIII and XIX in the Appendix. The eight asphalts having a xylene equivalent greater than 10 (*B, F, H, L, M, U, W,* and *X*) show an average of 20 per cent of surface area stripped at 120° F.; the remaining fifteen asphalts showing an average of 31 per cent of surface area stripped.

Table VIII shows the stripping test data for the 50-60 penetration asphalts. In this case only two types of aggregate were used, but the results represent an average of at least two determinations. Since the

TABLE VIII
STRIPPING TEST DATA 50-60 PENETRATION ASPHALTS[a]

ASPHALT	LIMESTONE				QUARTZITE			
	15 Min. 77° F.	15 Min. 77° F.	15 Min. 100° F.	15 Min. 120° F.	15 Min. 77° F.	15 Min. 77° F.	15 Min. 100° F.	15 Min. 120° F.
C-50	0	0	0	0	0	0	10	15
D-50	0	0	0	1-5	0	5	20	35
E-50	0	0	0	0	0	1-5	10-15	20
G-50	0	0	0	1-5	0	0	10	25
H-50	0	0	0	1-5	0	0	1-5	5
L-50	0	0	0	0	0	0	0	1-5
M-50	0	0	0	0	0	0	5-10	15
N-50	0	0	0	5	0	1-5	10	35
O-50	0	0	0	0	0	5	20	60
P-50	0	0	0	0	0	1-5	15-20	35
Q-50	0	0	0	1-5	0	1-5	10-15	35
R-50	0	0	0	0	0	1-5	10	20-25
S-50	0	0	0	0	0	0	15	35
T-50	0	0	0	0	0	0	15-20	50
U-50	0	0	0	0	0	0	10	30
V-50	0	0	0	0	0	0	5	10
W-50	0	0	0	0	0	1-5	5-10	15
X-50	0	0	0	0	0	0	5-10	10-15
Y-50	0	0	0	1-5	0	0	1-5	10
Average	0	0	0	1	0	1	10	25

[a] Figures indicate estimated per cent of surface area stripped of asphalt after various periods of agitation.

limestone aggregate shows practically no stripping, any comparison between asphalts must be made on the basis of the quartzite aggregate. A study of the molded sheet asphalt specimens of Figures 14, 15, and 16 reveals a slight correlation between the cracking of the specimens and the stripping test results for the corresponding asphalt. The asphalts have been divided into three groups: (1) those having no cracked specimens, (2) those having one to two cracked specimens, and (3) those having five cracked specimens. The average per cent of surface area stripped at 100° and 120° F. has been determined for each group from Table VIII. There are several exceptions in the following group-

ings such as asphalts N-50 and Q-50, each of these having 35 per cent of the area of its aggregate stripped at 120° F.

Sheet Asphalt Specimens	Asphalts 50-60 Penetration	Per Cent of Surface Stripped	
		100° F.	120° F.
None cracked	E,L,N,Q,V,W,X-50	7.5	18.6
1 to 2 cracked	C,G,H,O,P,R,Y-50	10.5	24.6
5 cracked	D,M,S,T,U-50	14.0	33.0

ADSORPTION TESTS

In search of a more exact method of measuring the adhesion of asphalt to aggregate, studies were made of the adsorption of asphalt (85-100 penetration) by powdered aggregate from a benzene solution. The adsorption was measured by the change in the ability of the solution to transmit light as determined by means of a photoelectric cell. The detailed procedure is given in section A-3-b of the Appendix. A summary of the test data is given in Table IX.

The light obscured by the untreated solution is given in the first column. Thus the larger the number the greater is the amount of light absorbed by that solution and the darker the solution appears to the eye. A considerable difference in the untreated solutions of the various asphalts is disclosed.

TABLE IX
ADSORPTION OF ASPHALT BY POWDERED AGGREGATE FROM A BENZENE SOLUTION

ASPHALT	LIGHT OBSCURED BY UNTREATED SOLUTION IN FT. CANDLES	PER CENT DECREASE IN LIGHT ABSORPTION DUE TO ADSORPTION OF ASPHALT BY				
		Limestone	Traprock	Granite	Quartzite	Aver.
A	12.1	40.1	17.3	14.9	11.1	20.8
B	13.1	67.9	52.3	51.1	43.5	53.7
C	12.6	36.9	22.6	6.4	22.2	22.0
D	10.8	30.6	23.1	1.8	7.4	15.7
E	12.7	47.6	38.2	28.3	15.0	32.3
F	14.1	65.2	58.2	38.6	36.9	49.7
G	11.9	43.7	31.1	21.0	18.5	28.6
H	10.8	52.8	40.7	28.7	26.8	37.2
J	12.2	38.1	31.9	23.4	24.6	29.5
K	12.9	53.5	39.5	23.3	18.6	33.7
L	11.0	60.9	42.7	27.7	22.7	33.0
M	13.1	61.1	43.5	25.2	21.8	37.9
N	15.1	44.4	30.1	32.4	29.1	34.0
O	11.5	34.3	27.0	14.3	13.9	22.4
P	8.2	34.8	25.6	8.6	7.3	19.1
Q	14.3	37.8	28.3	16.1	12.3	23.6
R	15.7	42.7	32.8	18.2	21.0	28.7
S	8.9	65.7	40.5	31.5	33.7	42.8
T	9.4	39.4	25.5	14.9	12.8	23.2
U	10.1	53.5	42.6	27.7	30.7	38.6
V	13.1	53.4	45.8	30.9	28.2	39.6
W	10.9	52.3	45.0	26.6	28.4	38.1
X	17.1	42.7	36.8	31.0	33.9	36.1
Average		47.8	35.7	23.6	22.6	32.4

Subsequent columns of Table IX show the per cent decrease in light absorbed by the solution as a result of the adsorption of asphalt by the rock dust. Since it is not known whether or not the adsorption by the rock dust is selective, caution must be used in inferring that the per cent decrease in light absorbed by the solution is proportional to the asphalt adsorbed by the dust.

As evidenced by the difference in light absorbed it appears that the positive spot test asphalts (see Table XVIII) are more readily adsorbed by the aggregate than those asphalts showing a negative spot test. Exceptions to the above statement are asphalts K, N, S, and V, all negative spot test materials.

In an attempt to study the retention of absorbed asphalt by stone dust in the presence of water some additional adsorption tests were made. Four asphalts B, C, D, and X, together with two kinds of dust—limestone and granite—were used. The solution of asphalt in benzene was shaken with rock dust at one-minute intervals for seven minutes as described in the Appendix. Then an equal volume of water was added to the solution and the shaking was repeated. The solution was then centrifuged, most of the water being removed in this way. The light absorbed by the treated solution was then measured as described in the Appendix. It was necessary to add water to the standard solution in order to compensate for the light absorbed by the small amount of water which remained in the benzene after centrifuging. The data for the adsorption tests made in the presence of water are given in Table X.

TABLE X

ADSORPTION OF ASPHALT BY POWDERED AGGREGATE FROM A BENZENE
SOLUTION IN THE PRESENCE OF WATER

| | Per Cent Decrease in Light Absorbed | |
Asphalt	Limestone Dust	Granite Dust
B	63.0	36.4
C	44.6	16.2
D	43.2	24.9
X	42.1	22.7

The addition of water to the benzene solution does not have a marked effect on the relative adsorptions of limestone and granite aggregates. It will be observed that asphalt B again shows the greatest change in light absorbed.

FIELD OBSERVATIONS ON STRIPPING

Some observations were made of the stripping tendency of city pavements. Samples were cut from city streets for purpose of analysis, the results being included in a subsequent portion of this report. In only one case was stripping present in the wearing course. This was a one-course sheet asphalt paving on a natural cement concrete base. The pavement was fifty years old. The surface was badly cracked and ag-

gregate adjacent to cracks was largely uncoated. The lower half inch of the sheet asphalt also showed considerable evidence of stripping.

In several other pavements where the surface was badly cracked, the binder course showed definite evidences of stripping particularly in the vicinity of the cracks. The mixture could be easily pulled apart, and visible water was present. The aggregates included both limestone and trap rock. In one case where the pavement was in excellent condition, there was no evidence of stripping in spite of the fact that granite aggregate was used.

These observations would seem to indicate that if a dense graded hot mixed asphalt paving can successfully withstand temperature contraction and other forces tending to produce cracks, stripping will not be an important factor. On the other hand, pavements forming cracks for the admission of moving water will probably have their disintegration accelerated by stripping action regardless of the type of aggregate used.

PHYSICAL AND CHEMICAL TESTS ON ASPHALT CEMENTS

SPECIFICATION REQUIREMENTS

A summary of the specifications for paving asphalt of the various state highway departments is shown in Table XI. The requirements are for the 50-60 penetration grade unless otherwise noted. In general the specifications are intended for refined petroleum asphalts and should not be applied to natural asphalts. By referring to Table XIX in the Appendix the results of standard tests carried out on the 50-60 penetration asphalts used in this investigation may be seen. The petroleum asphalts which fail to meet the requirements of one or more states will be listed below:

TEST	No. STATES REQUIRING TEST	ASPHALTS FAILING TO MEET REQUIREMENTS
Maximum per cent loss after five hours at 325° F.	40	None fail
Penetration after heating five hours at 325° F. as a percentage of original	41	X-50 (1 state)
Flash point minimum	40	None fail
Ductility 77° F. minimum	39	E-50 (16 states)
Solubility in carbon disulphide	35	D-50, E-50, O-50, X-50 (30 states)
Solubility in CCl₄	9	D-50, E-50, H-50, V-50, X-50 (2 states)
Per cent of bitumen soluble in CCl₄	20	None fail
Softening point minimum	8	None fail
Oliensis spot test	15	E-50, H-50, R-50, U-50, W-50, X-50 (15 states)
Specific gravity minimum	23	D-50, N-50, Y-50 (12 states) E-50, P-50, V-50 (2 states)
Specific gravity maximum	1	C-50, U-50, X-50 (1 state)
Insoluble in 86° naphtha	2	P-50 (1 state)
Ductility 39.2° F. 5 cm./min.	1	All 50-60 penetration (1 state)
Fluidity factor	1	All except C-50 and O-50 (1 state)

SPECIFICATIONS FOR PAVING ASPHALT
OF THE VARIOUS STATE HIGHWAY DEPARTMENTS

TABLE XI

STATE	% LOSS 325°F 5.HRS. MAX.	PENETRATION % OF ORIG. MIN.	FLASH POINT °F. MIN.	DUCTILITY CMS 77°F. MIN.	SOLUBILITY IN CS₂ % MIN.	ORGANIC MATTER INSOLUBLE IN CS₂ % MAX	% OF BITUMEN SOLUBLE MIN.	SOLUBILITY IN CCl₄ % MIN.	SOFTENING POINT RING & BALL °F.	OLIENSIS SPOT TEST	SPEC. GRAV.	MISCELLANEOUS
.ALABAMA	1	60	400	100	–	–	99.5	–	–	NEG.	1.02 +	DUCTILITY 39.2°F ¼ CM. PER MINUTE = ⅒ OF PENETR. AT 77°F.
ARIZONA	–	–	–	–	–	–	–	–	–	–	–	(1)
ARKANSAS	2	60	347	60	99.5	.2	–	–	–	NEG.	–	
CALIFORNIA	2	60	400	100	99.5	–	–	98.0	–	–	–	NOT OVER 23.0% INSOL. IN 80-82° NAPHTHA
COLORADO	1	50	347	30	99.5	–	99.0	–	–	–	1.01+	
CONNECTICUT	1	60	347	60	99.5	–	–	–	–	–	–	
DELAWARE	1	60	347	30	99.0	–	–	–	–	–	–	85 -100 PENETRATION
FLORIDA	1	60	347	100	99.5	–	–	99.0	–	–	–	
GEORGIA	1	60	392	100	99.5	–	–	–	120 +	–	1.02 +	SOFT. POINT 115+ FOR 85-100 PEN.
IDAHO	1	60	347	40	99.5	–	–	99.0	–	–	–	MINIMUM SPEC. GRAV. FOR 85-100 PEN. = 1.01
ILLINOIS	1	60	350	100	99.5	–	–	–	–	NEG.	–	
INDIANA	1	60	347	50-60	–	–	–	99.0	–	NEG.	1.00 +	
IOWA	1	75	347	30	99.5	–	99.0	–	–	–	–	85-100 PENETR. ONLY
KANSAS	1	60	370	60	99.5	–	–	–	150–	–	.95+	SOFT. POINT 104-140 FOR 85-100 PEN.
KENTUCKY	1	60	350	30	99.5	–	99.0	–	105-140	–	1.01 +	SOFT. POINT. 95-130 FOR 85-100 PENETR. (2)
LOUISIANA	–	60	347	–	99.5	.2	–	–	–	NEG.	1.01 +	150 -200 PENETR.
MAINE	1	60	347	60	99.5	–	–	–	–	–	1.00 +	
MARYLAND	1	70	392	100	99.5	–	99.0	–	–	NEG.	–	
MASSACHUSETTS	1	60	347	60	99.5	–	–	–	–	–	1.00 +	
MICHIGAN	1	60	347	100	99.5	–	99.0	–	113-149	NEG.	1.01 +	(2) (3) SOFT. POINT NOT REQD. FOR 85-100 PEN.
MINNESOTA	1	60	347	100	99.5	–	99.0	–	–	NEG.	1.00 +	
MISSISSIPPI	1	60	350	100	99.5	–	–	99.0	104-149	NEG.	1.01 +	(2)
MISSOURI	1	60	446	50	99.5	–	99.5	–	113-149	NEG.	–	INSOL. IN 86°NAPHTHA 15-29% FOR 50-60 PENETRATION (4)
MONTANA	1	60	347	–	99.5	–	99.0	–	–	–	1.01 +	60 -70 PENETRATION
NEBRASKA	–	–	–	–	–	–	–	–	–	–	–	(1.)
NEVADA	1	60	350	30	99.5	–	99.0	–	–	–	–	
NEW HAMPSHIRE	1	60	347	60	99.5	–	–	–	–	–	1.00+	
NEW JERSEY	1	30 PEN.	437	100	–	–	99.0	–	–	–	1.00 +	SOL. IN BENZENE 99.8%, IN ETHER 75%, PEN. 115°F. 300 –.DUCTILITY 18 ON 94 PEN.
NEW MEXICO	–	–	–	–	–	–	–	–	–	–	–	(1.)
NEW YORK	1	60	347	60	99.5	–	–	–	–	–	1.00-1.04	PEN. AT 39.2°F NOT LESS THAN 30% OF THAT AT 77°F.
NORTH CAROLINA	1	60	347	30	99.5	–	–	99.0	–	–	1.00 +	DUCTILITY 77°-100 CMS. 1939
NORTH DAKOTA	–	–	–	–	–	–	–	–	–	–	–	(1.)
OHIO	1	60	392	100	99.5	–	99.0	–	–	NEG	–	
OKLAHOMA	1	60	347	50	99.5	–	99.0	–	–	NEG.	1.01+	
OREGON	2	60	400	30	99.0	–	99.65	–	–	–	–	
PENNSYLVANIA	1	60	345	30	99.5	–	99.0	–	–	–	–	DUCTILITY AT 77°F FOR 85-100 PENETR. = 50 +
RHODE ISLAND	1	60	347	75	99.5	–	99.0	–	–	–	1.01 +	(2)
SOUTH CAROLINA	–	–	–	–	–	–	–	–	–	–	–	(1.)
SOUTH DAKOTA	–	–	–	–	–	–	–	–	–	–	–	(1.)
TENNESSEE	1	60	347	100	–	–	–	99.0	–	NEG.	–	
TEXAS	.75	30 PEN.	450	100	–	–	–	99.5	113-140	–	–	MATERIAL SHALL NOT BE CRACKED
UTAH	1	50	347	100	99.5	–	99.5	–	104-140	–	1.00+	
VERMONT	1	60	347	30	99.0	–	–	–	–	–	1.00+	DUCTILITY 77°F. FOR 85-100 PENETR. = 75 +
VIRGINIA	1	60	–	50	–	–	–	99.5	104-140	–	1.01 +	100 CMS. DUCTILITY 77°F. AND 100+ SPEC. GRAV. FOR 85-100 PENETR.
WASHINGTON	1	60	450	100	99.5	–	99.65	–	–	NEG.	1.01+	
WEST VIRGINIA	3	60	340	30	95.0	–	99.0	–	–	–	–	
WISCONSIN	1	60	345	100	99.5	–	99.0	–	–	NEG.	–	FLUIDITY FACTOR 160. DUCTILITY 39.2°F .5 CM./MIN. = ⅒ PEN. 77°F. = 1
WYOMING	–	–	–	–	–	–	–	–	–	–	–	(1)

NOTES
(1.) PENETRATION ASPHALTS NOT USED
(2.) MINIMUM SPEC.GRAV. 85-100 PENETR. =1.00
(3.) SAMPLE RECOVERED FROM PAVEMENT MUST HAVE 40 CM. DUCTILITY AT 77°F. AND 50% OF ORIG. PENETR.

ABOVE DATA ARE FOR 50-60 PENETRATION
ASPHALTS UNLESS OTHERWISE NOTED
(4) SOFTENING POINT 104-140 FOR 85-100 PENETRATION

The results of standard tests on the asphalt cements will be discussed in more detail before commenting on the merits of the various specification requirements. References to the standard method of test will be found in part A-1 of the Appendix. Results in tabular form will be found in Table XVIII and XIX in the Appendix.

CONSISTENCY TESTS

Figure 27 shows the results of consistency tests on the 85-100 penetration asphalts at eight different temperatures. The asphalts are arranged in the order of their penetration at 77° F. with the softest
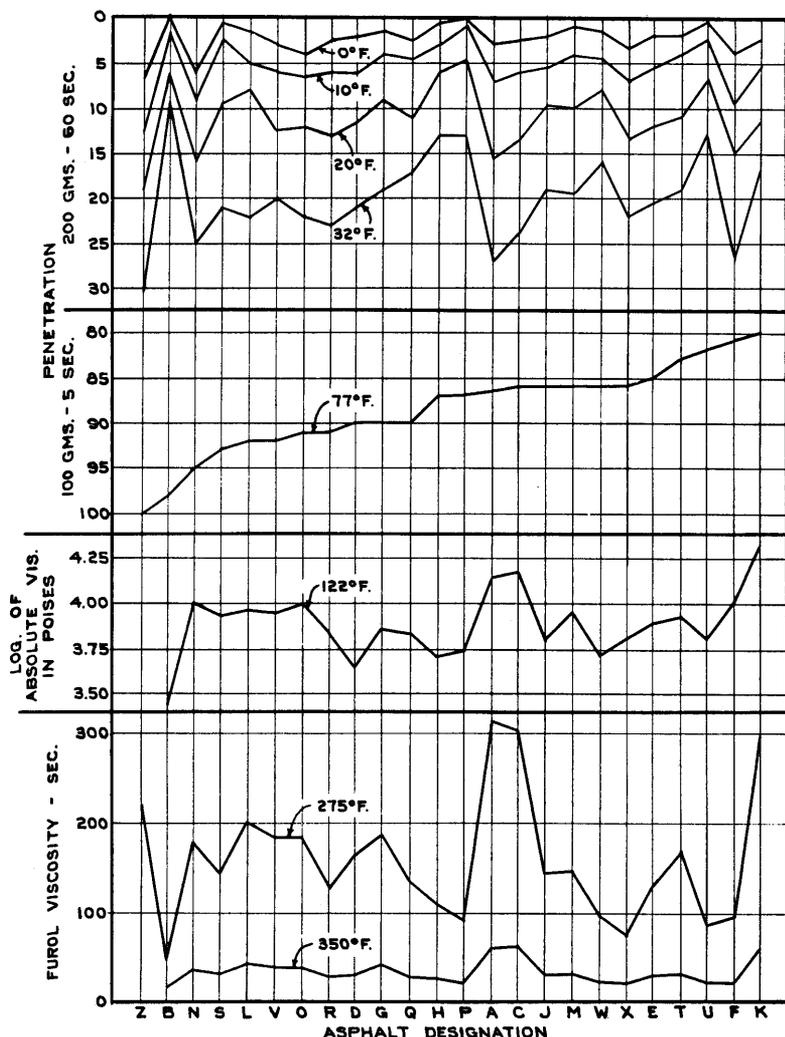
FIGURE 27. CONSISTENCY TESTS OF ASPHALTS—85-100 PENETRATION
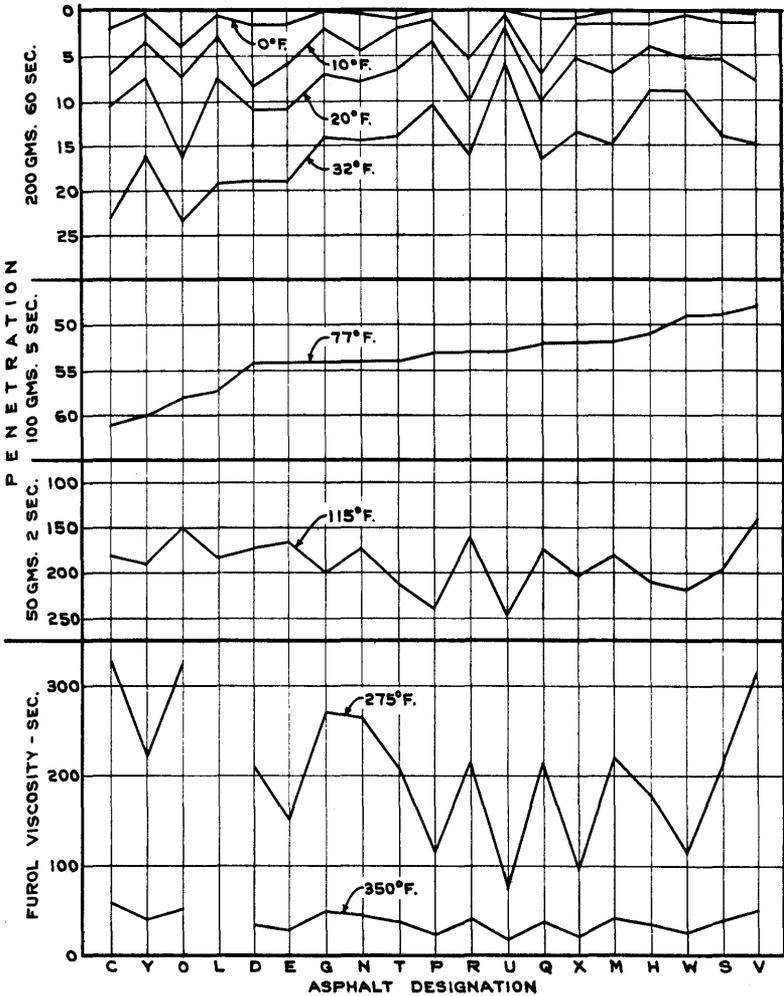
FIGURE 28. CONSISTENCY TESTS OF ASPHALTS—50-60 PENETRATION

material to the left. The scales are so arranged that the higher points indicate a more viscous material. The capillary tube type of viscosimeter was used in the determination of the absolute viscosity of 122° F. The test method will be found in section A-2-e of the Appendix.

Figure 28 shows similar data for the 50-60 penetration asphalts except that penetration at 115° F. is given in place of log of absolute viscosity at 122° F.

Figures 29 and 30 show the variations in furol viscosity with temperature. These data indicate need for adjusting the mixing temperature at the paving plant to the viscosity of the asphalts. If the mixing temperature for all the asphalts was as high as that needed for as-
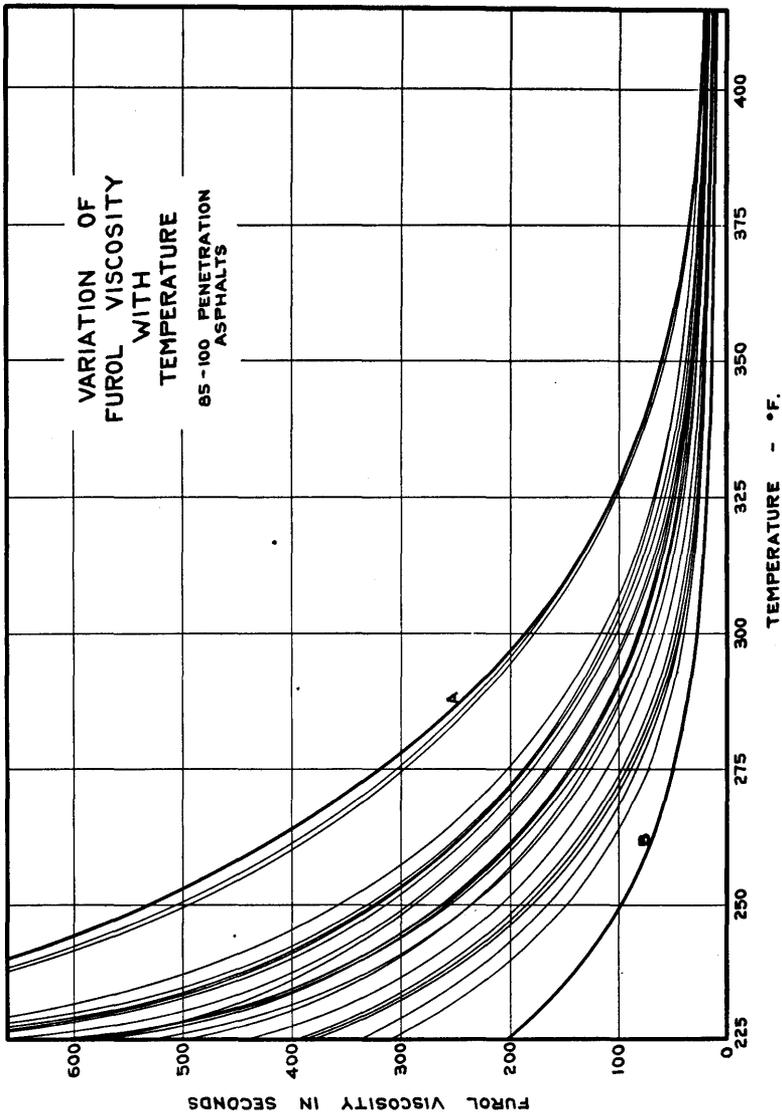
FIGURE 29

phalt *C*-50, then some of the asphalts such as *U*-50 would probably flush to the surface in dense mixtures or drain to the bottom in open mixtures during transit. This would give the mixture the appearance of being overly rich and might erroneously result in a reduction of the asphalt content. In addition to avoiding separation of the asphalt from the aggregate a lower mixing temperature would avoid unnecessary hardening of the asphalt.

VARIATION OF
FUROL VISCOSITY
WITH
TEMPERATURE

50-60 PENETRATION
ASPHALTS

FIGURE 30

52
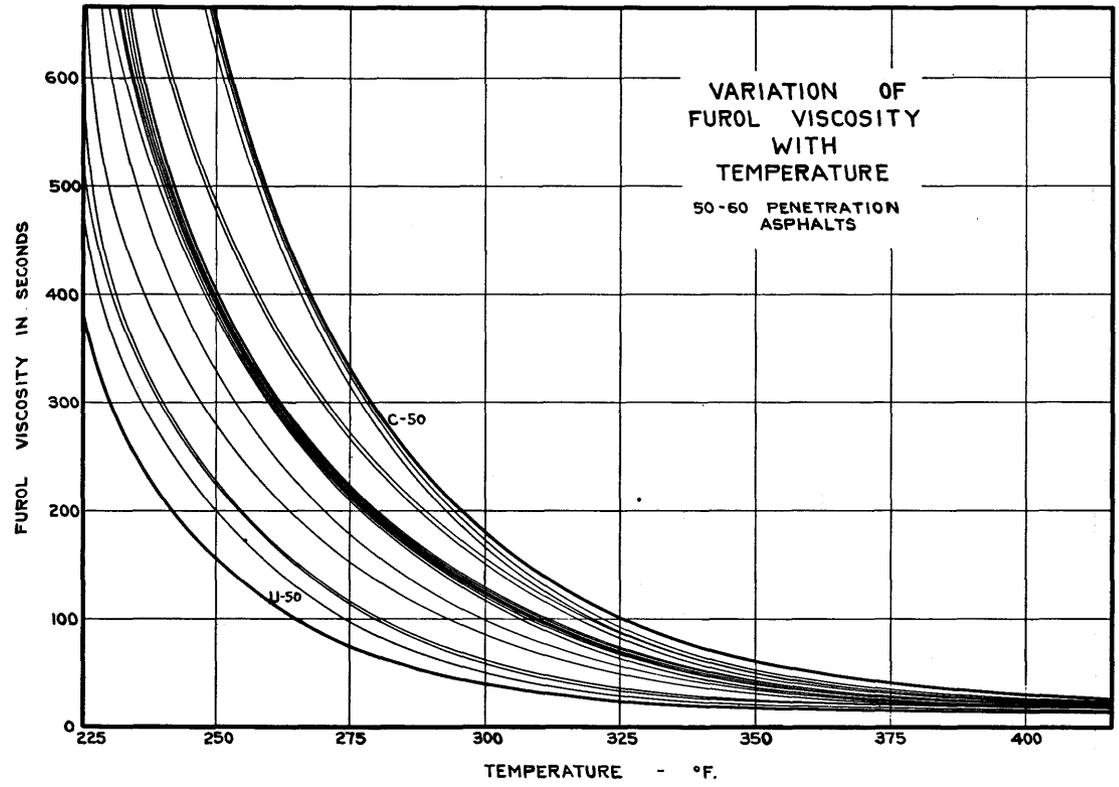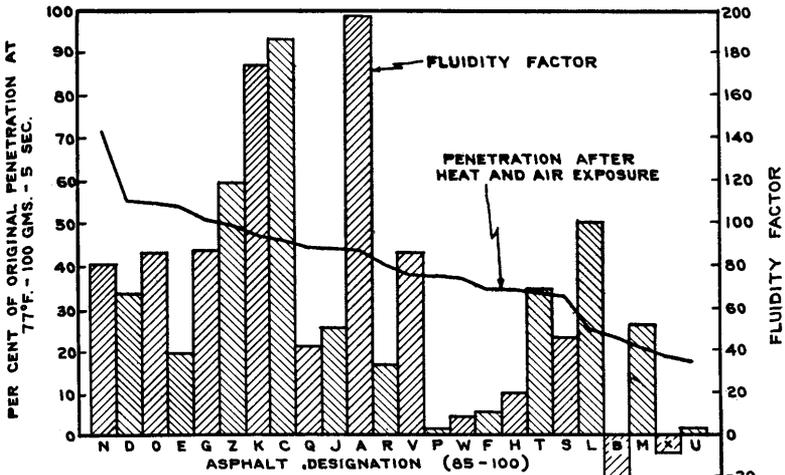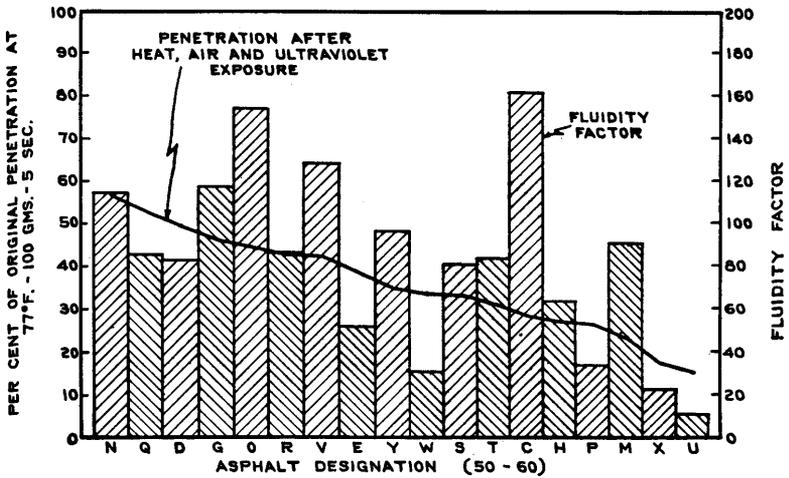
RELATION BETWEEN FLUIDITY FACTOR AND
HARDENING OF ASPHALTS DURING EXPOSURE

FIGURE 31

53

Fluidity factor, sometimes used in specifications, is intended to indicate the temperature susceptibility of an asphalt.

$$\text{Fluidity factor} = \frac{(\text{Furol vis. at } 275° \text{ F.} - \text{pen. } 77° \text{ F.})}{100} \text{ pen. } 77° \text{ F.}$$

Fluidity factors have been plotted in Figure 31 with the asphalts arranged in order of per cent of original penetration retained after exposure on Ottawa sand. It will be seen that there is little if any relationship between fluidity factor and hardening during exposure.

DUCTILITY TESTS

Figures 32 and 33 show the results of ductility tests. The asphalts are arranged in order of decreasing ductility at 39.2° F. at a speed of ¼ centimeter per minute. It will be seen that in ductility tests at 39.2° F.
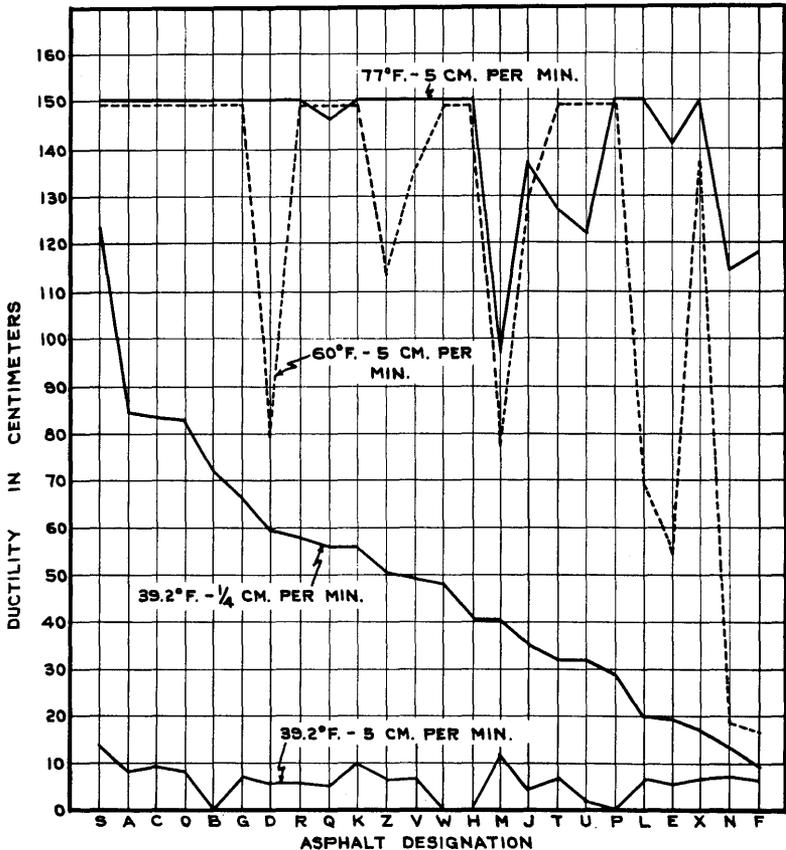
FIGURE 32. DUCTILITY TESTS OF ASPHALTS—85-100 PENETRATION
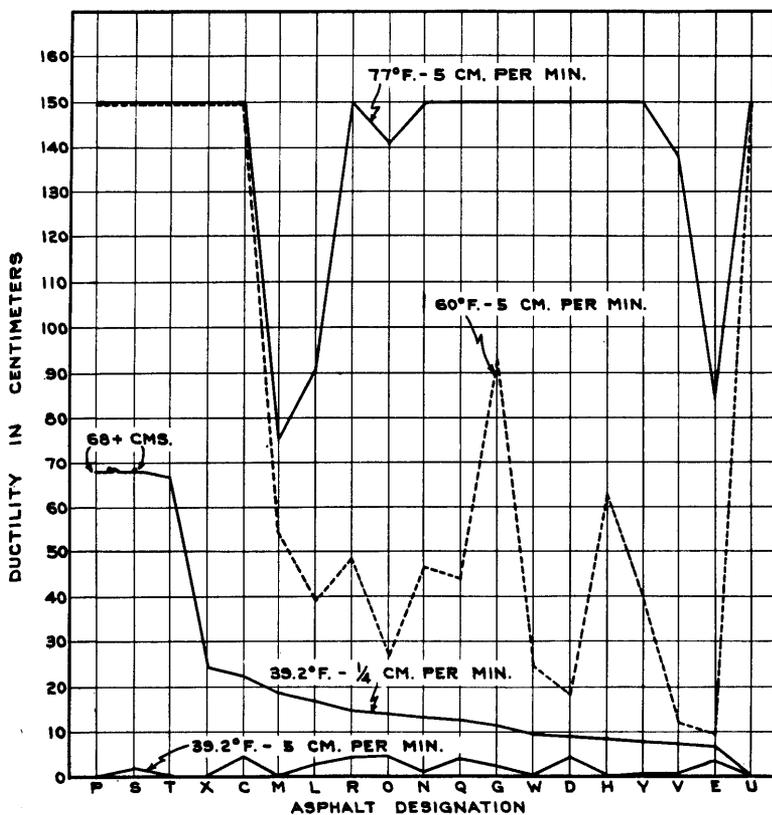
FIGURE 33. DUCTILITY TESTS OF ASPHALTS—50-60 PENETRATION

there is no relation between results obtained at $\frac{1}{4}$ centimeter per minute and those obtained at 5 centimeters per minute. By studying the arrangement of the asphalts it will be seen that ductility is quite unrelated to resistance to exposure as measured in this investigation.

FLASH POINT AND EFFECT OF HEATING TO 325° F.

In Figures 34 and 35 the asphalts are arranged in order of decreasing flash points. Loss in weight during heating at 325° F., ductility of the residue, and the penetration of the residue in per cent of the original are shown. Heating at 325° F. for 5 hours was carried out according to the standard method. Heating for 24 hours was carried out in the same manner. The 85-100 penetration asphalts were also heated at 325° F. in $\frac{1}{8}$-inch films for 25 hours using a 50-ml. sample and a pan $5\frac{1}{2}$ inches in diameter. It will be seen that asphalts with low flash points show the greatest loss in weight and usually retain a smaller percentage of their original penetration. It will be observed that many of
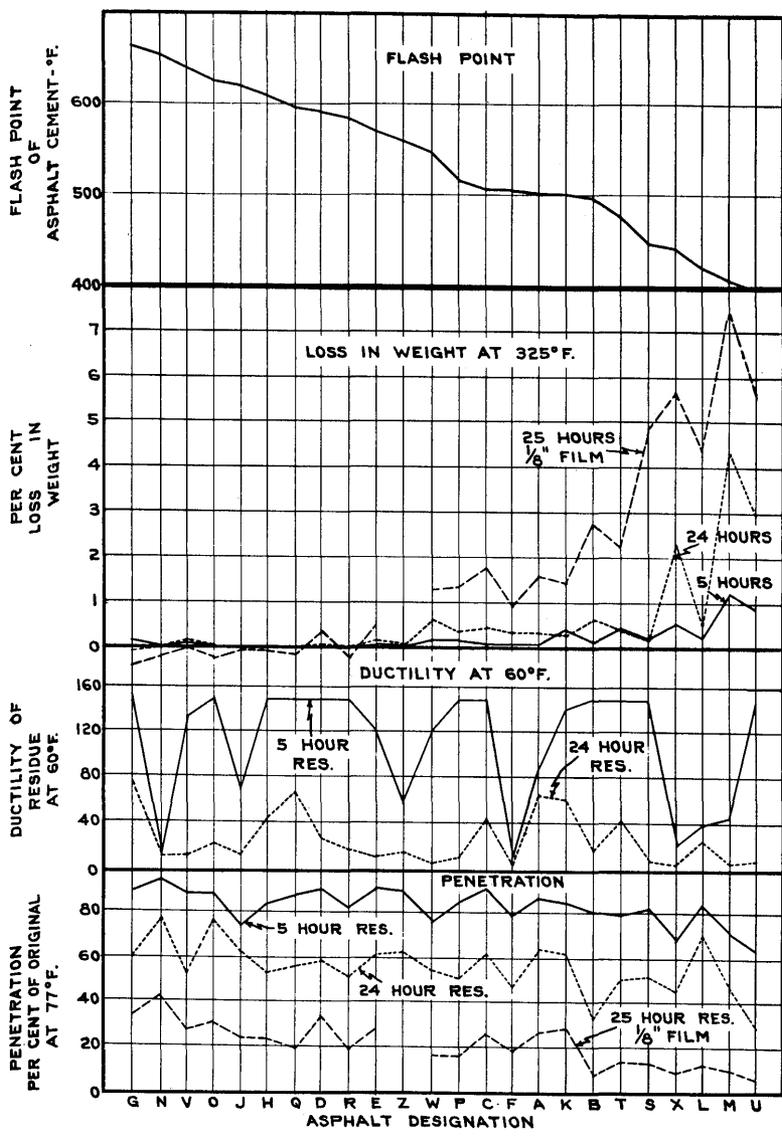
FLASH POINT AND EFFECT OF HEATING
ASPHALT CEMENTS TO 325°F.
85-100 PENETRATION

FIGÜRE 34

56
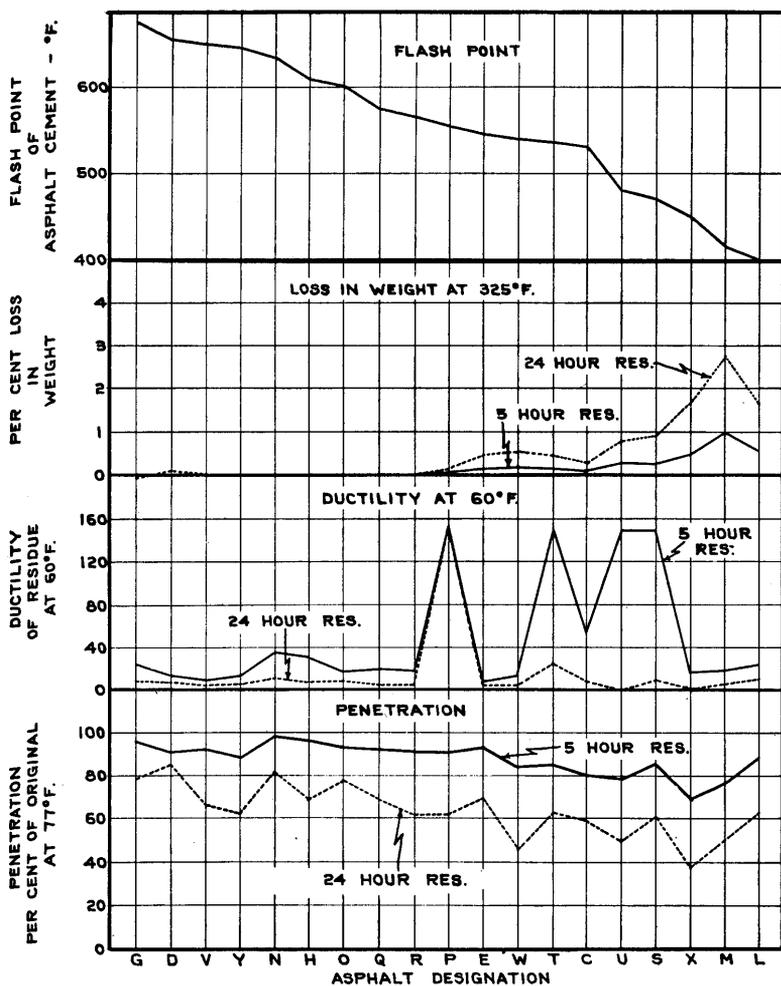
FLASH POINT AND EFFECT OF HEATING
ASPHALT CEMENTS TO 325°F.
50 - 60 PENETRATION

FIGURE 35

the asphalts at the extreme right in Figures 34 and 35 are also located
at the right in Figures 21 and 23.   Thus asphalts with low flash points
showed poor resistance to exposure on Ottawa sand altho asphalts of
high flash point did not in all cases show good resistance, as for example,
asphalt *H*.

It is interesting to observe the very marked increase in severity of
the test produced by spreading the sample in a ⅛-inch film as con-

trasted with the standard sample about .9 inch deep.   In spite of the marked differences in resistance to exposure on Ottawa sand exhibited by the various asphalts used in this investigation, all of the petroleum asphalts met the commonly accepted requirements for loss on heating and penetration of the residue.   It is believed that serious consideration should be given to the substitution of some test to include heating in thin films in place of the present test.

SPECIAL TESTS

A number of special tests of the asphalt cement were made.   These are not ordinarily included in paving asphalt specifications.   An attempt will be made to study what relation, if any, exists between results of these tests and the tests made on Ottawa sand mixtures after exposure.

Xylene equivalent.—This test has been proposed as a quantitative measure of the heterogeneity disclosed by the spot test.   The procedure will be found in section A-2-b of the Appendix.   The results of the test are contained in Tables XVIII and XIX.   A study of Figures 6, 7, 8, 21, and 23 reveals that asphalts with a xylene equivalent greater than 10 usually have poor resistance to exposure in the Ottawa sand mixtures used.   Exceptions to the above statement are asphalts *F*, and *E-50.*   It will also be observed that asphalts *P, S,* and *T,* negative spot test materials, show low resistance in the tests used.   Thus it will be seen that the spot test or the determination of xylene equivalent is not always sufficient to predict the degree of resistance of an asphalt to the exposures used in this investigation.

Separation of asphalt into asphaltenes, oils, and resins.—The 85-100 penetration asphalts were separated into asphaltenes, oils, and resins by a modification of Marcusson's procedure.   The detailed procedure used will be found in section A-3-c of the Appendix.   The results are shown in Table XVIII and they include determination of the density, viscosity, molecular weight, and refractive index of the oil fraction and the sintering point of the asphaltenes.   Some of the data are plotted in Figure 36 where the asphalts are arranged in decreasing order of the molecular weights of the oil fractions which were determined by measuring the depressions in the freezing point of benzene caused by known amounts of dissolved oils.   It will be observed that as a general rule asphalts, whose oils had low molecular weights, showed relatively poor resistance to exposure.   It is interesting to observe the reciprocal relation shown between density of the oils and molecular weights.   Altho the relative amounts of asphaltenes, oils, and resins differed considerably among the various asphalts, the composition of the asphalts as defined in this manner did not appear to be related to the results of physical tests on mixtures either before or after exposure.

Attempts to measure the molecular weight of the asphaltene samples by the method used for the oils were not successful, as the asphaltenes
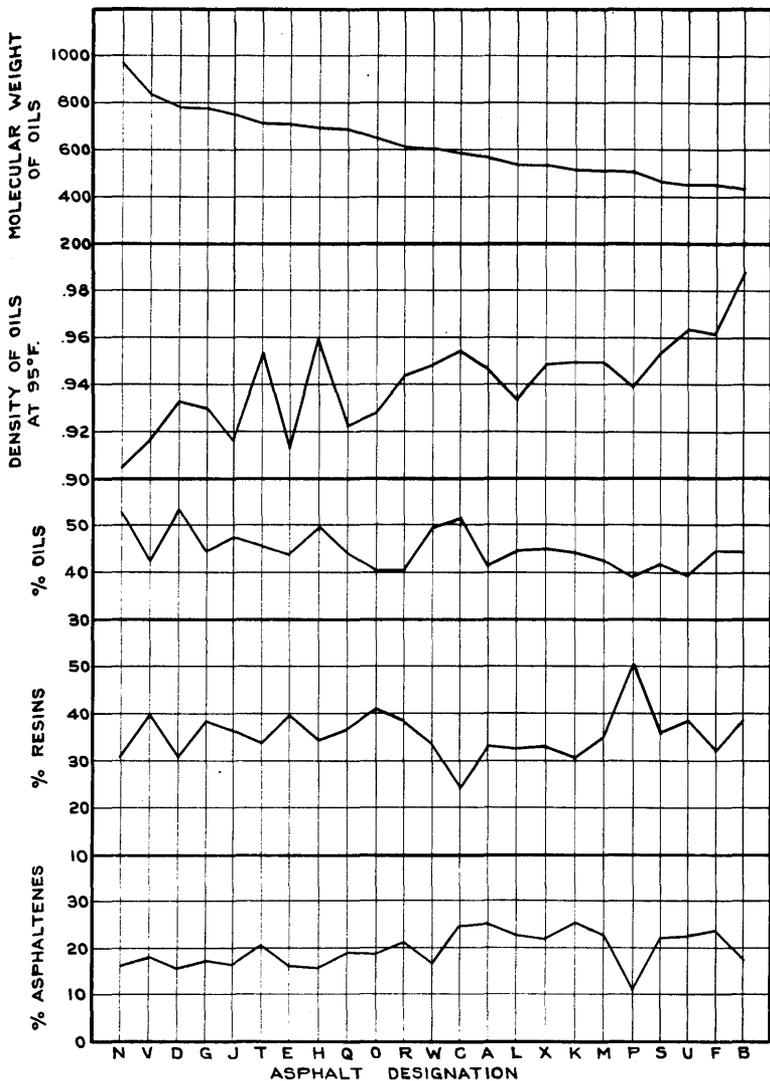
FIGURE 36. MOLECULAR WEIGHTS AND DENSITIES OF OIL FRACTIONS FROM
85-100 PENETRATION ASPHALTS AND PROPORTIONS OF
ASPHALTENES, OILS, AND RESINS

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did not remain in true solution in the benzene. Determinations of the average molecular weight of the asphalt were made for a few materials. The values are given in Table XII together with the molecular weights of the corresponding oil.

TABLE XII
MOLECULAR WEIGHTS OF ASPHALTS AND EXTRACTED OILS

ASPHALT DESIGNATION	MOLECULAR WEIGHT OF ASPHALT	MOLECULAR WEIGHT OF OILS	PER CENT OILS
A	977	576	41.5
B	595	442	44.1
N	1,525	964	52.8
P	935	513	38.9

Determination of saponifiable matter.—The per cent of saponifiable matter in the 85-100 penetration asphalts is shown in Table XVIII. The method used may be found in section A-2-c of the Appendix. It will be observed that the amount of saponifiable matter is small and apparently unrelated to other properties of an asphalt.

Sulfur.—The sulfur contents of the 85-100 penetration asphalts have been determined. The method used may be found in section A-2-d of the Appendix. All determinations were made in duplicate, and the maximum difference between any pair of samples was .06 per cent of sulfur. Sulfur contents are shown in Table XVIII. A study of the data fails to reveal a correlation between sulfur content and other tests included in this investigation. On the basis of these data a sulfur content requirement in a specification must be considered as an identification test.

Nitrogen.—Nitrogen has been determined by the Kjeldahl and the combustion methods. The values are shown in Table XVIII. It will be seen that Kjeldahl nitrogen is not necessarily the same as total nitrogen. No correlation has been found between the nitrogen content of an asphalt and any other property.

Absolute viscosity.—The absolute viscosities of the 85-100 penetration asphalts have been measured in poises at temperatures of 33°, 60°, and 77° F. by means of the falling coaxial cylinder viscosimeter. The values are presented in Table XVIII. The detailed procedure may be found in section A-3-e of the Appendix. Measurements of absolute viscosity at 122° F. were made by means of the capillary tube type of viscosimeter (see section A-2-e of the Appendix). Additional measurements were made by this method for asphalts *B, C, D, F, N,* and *P* at temperatures of 144.5°, 167°, 189.5°, and 212° F. Figure 37 shows the variation of log viscosity with temperature between 33° and 275° F. Furol seconds were converted to absolute viscosity by the formula:[1]

$$\text{Viscosity in poises} = .0216 \text{ furol seconds} \times \text{density}$$

[1] *International Critical Tables,* Vol. 1, pp. 32-33. 1926.
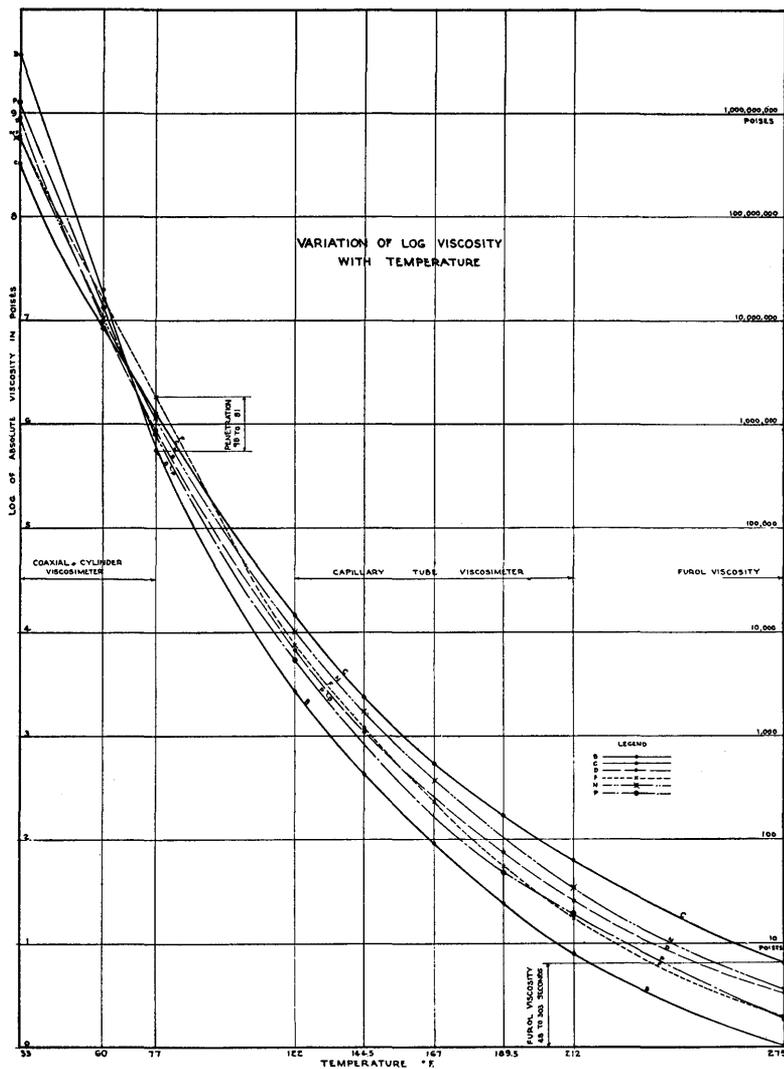
FIGURE 37. VARIATION OF LOG VISCOSITY WITH TEMPERATURE

Viscosity index.—A viscosity index, representing the change in log viscosity for a corresponding change in log of absolute temperature, has been calculated from the values of absolute viscosity at 33° and 77° F. The values are presented in Table XVIII.

$$\text{Viscosity index} = \frac{\text{Log viscosity at 33° F.} - \text{Log viscosity at 77° F.}}{\text{Log } T_{77} - \text{Log } T_{33}}$$

where T_{77} and T_{33} are the absolute temperatures corresponding to 77° and 33° F., respectively.

The absolute viscosities of the oil fractions were determined at 95° and 125° F. and a viscosity index similar to that used for the asphalts was calculated. The data are shown in Table XVIII.

It was previously pointed out that asphalts having low flash points had poor resistance to exposure on Ottawa sand, but that a few asphalts with relatively high flash points also had poor resistance. Examples of the latter are asphalts *H* and *B* whose flash points are considerably above those of adjacent asphalts in Figures 6, 7, 8, and 21. It will be observed that asphalts *H* and *B* have viscosity indices among the three highest in Table XVIII.

Solubility in naphtha.—The solubility in 86° naphtha of the 85-100 penetration asphalts was obtained after recovery from mixtures exposed to heat, air, and ultraviolet light. The data are shown in Table XVI. The actual amount of insoluble material after exposure does not appear to be as significant as the increase in insoluble material during exposure.

The per cent insoluble in naphtha was also determined for the 85-100 penetration asphalts after heating in ⅛-inch films for 25 hours at 325° F. The loss in weight for these samples was previously shown in Figure 34. In calculating the increase in material insoluble in naphtha during exposure, the increase which would result from a simple concentration of insoluble material through volatilization as previously determined, is not included in the increase. The loss in weight and the increase in insoluble material after exposure in ⅛-inch films is shown in Figure 38. The asphalts are arranged in order of decreasing per cent of original penetration after heating. The corresponding per cent of original penetration after heat and air exposure on Ottawa sand is also shown. Asphalts *J, H, Q,* and *R,* which are materials of comparatively high flash point, showed no loss in weight but rather a gain in Figure 38. Thus the very appreciable hardening occuring in these asphalts did not result from volatilization. Figure 38 shows that these asphalts had an increase in material insoluble in naphtha greater than the average.

It seems apparent that the hardening of an asphalt is a function of two properties, which might tentatively be considered as volatility and chemical change. Flash point and loss in weight during heating may be considered as approximate measures of volatility. None of the tests in present specifications are believed to be measures of chemical change. The chemical change which occurs is probably due to oxidation. It will be seen that eight of the asphalts in Figure 38 showed a gain in weight which suggests oxidation. It will be recalled that exposure to nitrogen at 180° F. in thin films produced little change in the asphalts tested. Some work, not yet completed, in which asphalts are blown with air or carbon dioxide at 400° F. indicates that the increase in insoluble material in naphtha when air is used is almost twice as great as·the increase when carbon dioxide is used. It would appear that some standard oxidation test is needed. A test employing thin films at compara-
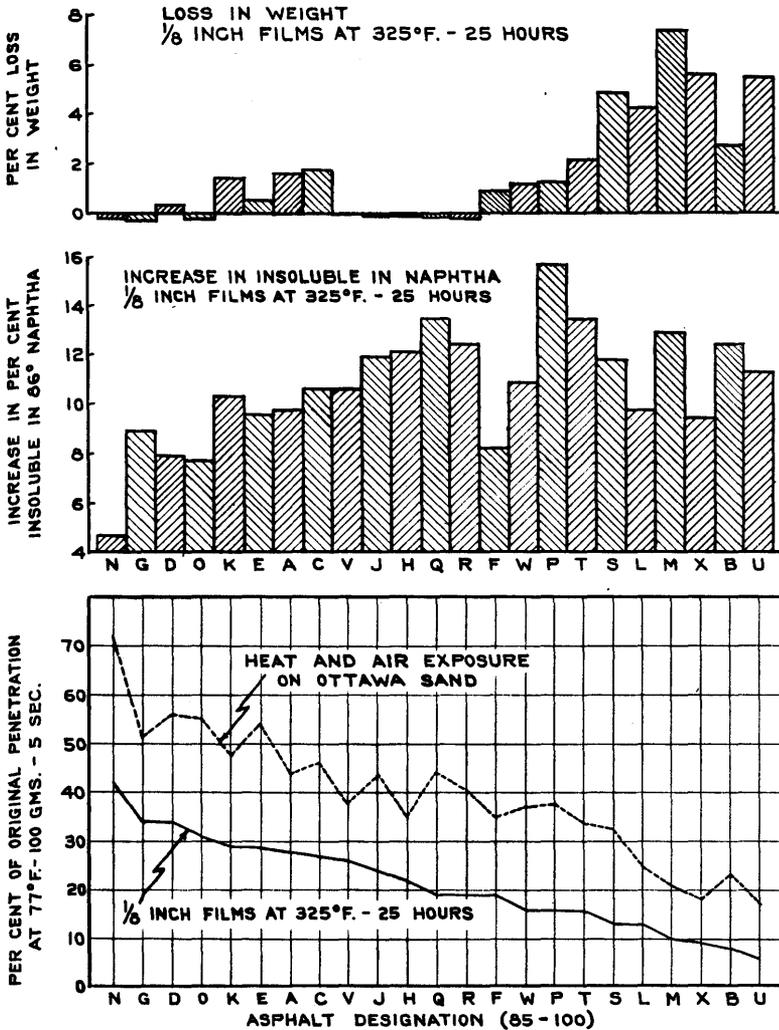
FIGURE 38. HARDENING AS RELATED TO LOSS IN WEIGHT AND INCREASE IN PORTION INSOLUBLE IN NAPHTHA

tively low temperatures is suggested since volatilization must be reduced in order to avoid the obscuring of the oxidation effect.

Ductility tension.—The ductility tensions of the 85-100 penetration asphalts were measured at 60° F. Determinations at 77° F. were abandoned when the asphalts proved to be too soft for reliable measurement. The apparatus as developed by Pullar was used. See section A-2-f of the Appendix for procedure. Only typical examples of the curves of tension versus ductility, which are drawn by the apparatus,
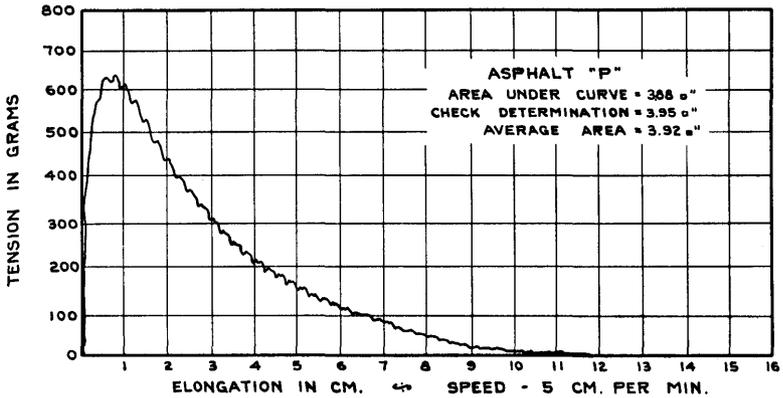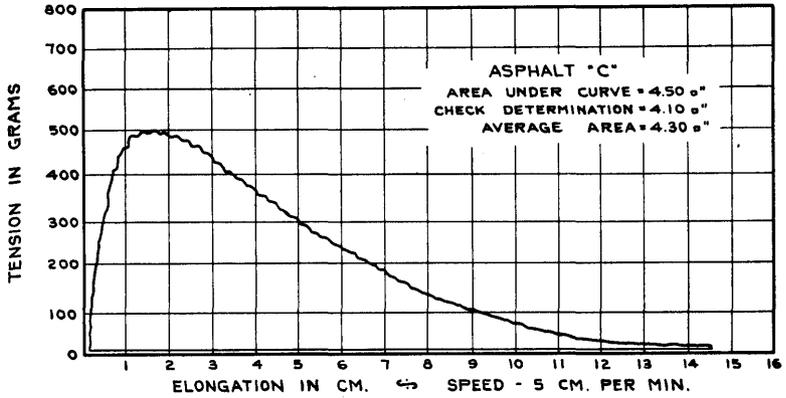
FIGURE 39. DUCTILITY TENSION CHARTS—TEMPERATURE, 60° F.

are reproduced here.   As a general rule it was found that the asphalts which were most susceptible to temperature changes tended to form curves which were pointed at the maximum tensile strength and concave in the descending portion of the curve (Fig. 39), while asphalts less susceptible to temperature change formed curves with a more rounded maximum and a more convex descending portion.   There were, however, exceptions to the above statements.   Values of maximum tension and total work done are presented in Table XIII.   It will be noted that the asphalts are arranged in order of maximum strengths, and that the order of their work areas is very nearly the same.   An attempt was made to correlate some other test property of the asphalts with the order of the asphalts thus established.   Absolute viscosity at 60° F. was the only test property which showed a correlation.   In Figure 40, log of absolute viscosity at 60° F. has been plotted against maximum ductility

FIGURE 40

65
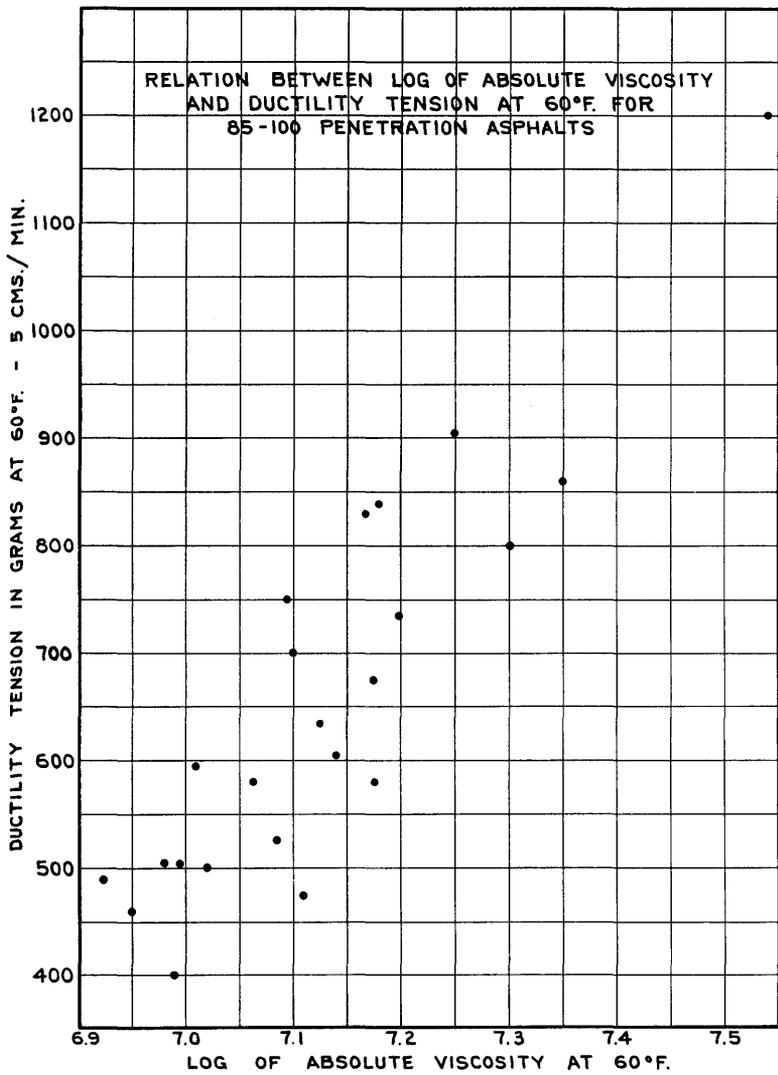
TABLE XIII

DUCTILITY TENSION AT 60° F., 5 CENTIMETERS PER MINUTE SHOWING
MAXIMUM STRENGTH AND TOTAL WORK DONE FOR
TWENTY-THREE 85-100 PENETRATION ASPHALTS

ASPHALT	AVERAGE AREA. SQ. IN.	MAXIMUM STRENGTH, GRAMS	WORK IN GM. CMS.,659-8 × AREA SQ. IN.
D	3.36	400	2,217
A	4.26	460	2,811
M	3.52	475	2,322
C	4.30	490	2,837
N	3.25	500	2,144
O	4.14	505	2,732
S	3.96	505	2,613
Q	3.92	525	2,586
Ǩ	4.30	580	2,837
R	4.62	580	3,048
X	4.56	595	3,009
G	4.99	605	3,292
P	3.92	635	2,586
E	5.92	675	3,906
L	4.57	700	3,015
F	4.69	735	3,094
T	5.61	750	3,702
B	5.33	800	3,517
V	5.54	830	3,655
U	6.22	840	4,104
J	2.14[a]	860	4,187
W	7.24	905	4,777
H	2.68[a]	1,200	5.447

[a] Multiplying factor 2,032 (weights No. 3 C).

tension at 60° F. It is apparent from these tests that the maximum ductility tension is greatly influenced by the viscosity of the asphalt.

Microscopic studies.—These studies were carried out in the hope of obtaining a quantitative measure of the heterogeneity disclosed by the spot test. The detailed observations and procedure are given in section A-3-f of the Appendix. It was found that the standard solution of asphalt in naphtha used in the spot test was too concentrated for observation in a blood count chamber. Two per cent solutions of asphalt in naphtha were then used, but it was found that the coagulation was much too irregular and continuous to permit a count. A classification of the asphalts on the basis of visual observations is given in the Appendix. All of the asphalts except *D, G, N,* and *O* showed some coagulation. Photomicrographs of the solutions are shown in Figure 41. With the exception of asphalts *G* and *P* they are in agreement with the visual observations. It will be observed that the asphalts showing the least coagulation, *D, N, O, E,* and *G* all showed a high resistance to exposure on Ottawa sand.

A film test for coagulation (A-2-g, Appendix) was performed by J. R. Benson on the 85-100 penetration asphalts. Samples were exposed in a .001-inch film at 325° F. for 80 hours. Other samples were

exposed at 180° F. 1½ inches from a cold quartz ultraviolet lamp for 68 hours. The coagulation of the films was observed by means of a microscope. The same four asphalts out of the twenty-three tested showed coagulation under both methods of exposure. The number of hours within which coagulation occurred are listed below:

Asphalt	180° F.	325° F.
B	20-45	20-36
F	15-20	5-13
W	15-20	1-5
X	30-38	1-5

The results did not correlate very well with exposure on Ottawa sand. Altho asphalts *B* and *X* showed poor resistance to exposure on Ottawa sand, asphalts *W* and *F* showed better resistance to exposure than did *H, T, S, L, M,* and *U.*

A count of particles insoluble in nitrobenzene was also carried out as a part of this study. The data from three separate counts are shown in Table XIV. The material insoluble in nitrobenzene represents a very small portion of the asphalt and must include dirt and foreign matter present. However, the particle count appears to be a definite property of an asphalt. For example, asphalts *A, C,* and *K* represent similar asphalts as may be seen by data in Table XVIII, yet each sample was obtained individually. It will be seen that in each count these asphalts all have relatively high particle counts. There is a tendency for asphalts of low viscosity index to have a high particle count.

TABLE XIV

MILLIONS OF PARTICLES INSOLUBLE IN NITROBENZENE
PER CUBIC MILLIMETER OF ASPHALTS

Asphalt	N1	N2	N3
A	9.35	19.2	22.4
B	0.237	0.581	1.41
C	16.8	20.3	24.2
D	0.561	0.53	1.61
E	0.448	0.863	.90
F	1.83	3.44	3.46
G	1.61	1.79	....
H	0.785	1.16	1.27
J	0.382	0.836	1.39
K	16.8	17.0	18.6
N	3.84	4.61	3.53
O	14.6	11.5	16.4
P	0.755	1.23	1.52
Q	3.01	3.44	4.16
R	2.00	0.742	2.00
S	3.22	3.30	3.98
T	0.427	0.942	1.27
U	0.386	0.550	0.866
V	9.98	8.58	6.06
W	0.855	1.71	2.81
X	0.534	0.807	1.21

PHOTOMICROGRAPHS OF 2% SOLUTIONS OF 85-100 PENETRATION ASPHALTS IN NAPHTHA
100 TIMES ACTUAL SIZE
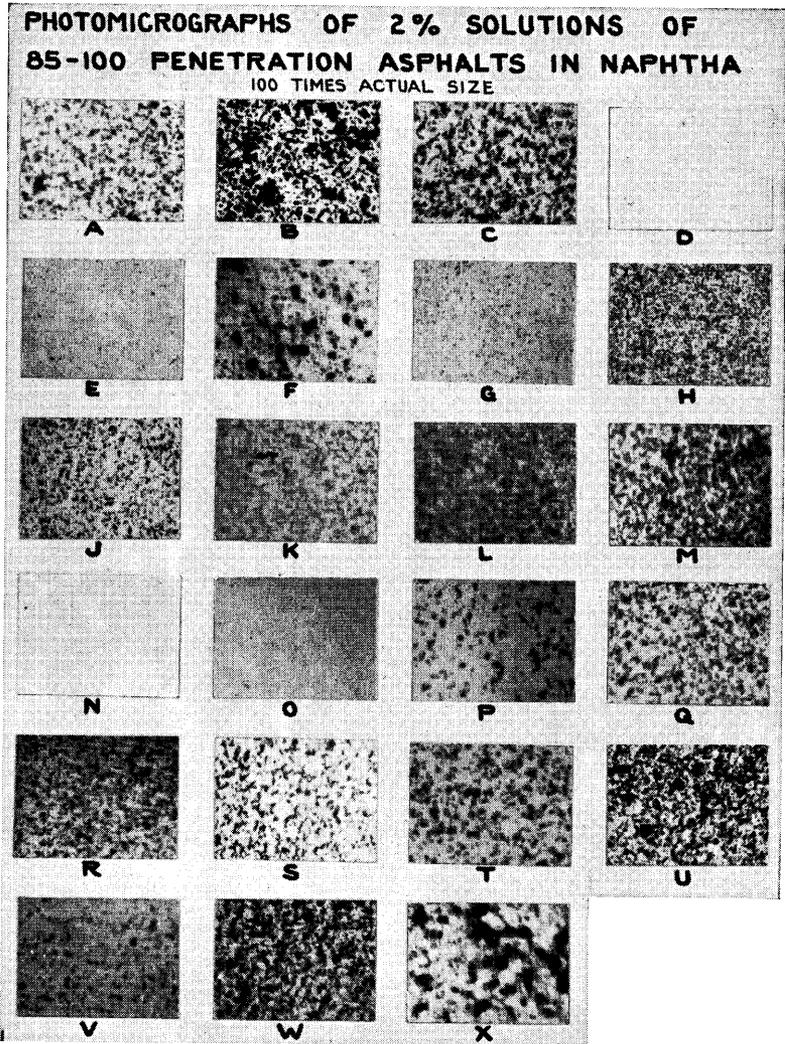
FIGURE 41

STUDIES OF EXISTING PAVEMENTS

Samples have been cut from city pavements at eight different locations. The asphalts have been extracted with benzene and recovered by the Abson method. The proportions of asphalt and aggregate and the gradations of the aggregates have been determined. The original test data on the asphalts used have been obtained as completely as they were available.

The pavement sample was broken up and digested in hot benzene over a water bath. The benzene was then extracted in the Rotarex apparatus. Both the recovered asphalt and the aggregate were weighed in determining the proportions. A loss in weight between 1 and $1\frac{1}{2}$ per cent was usually found. This loss represented moisture, loss in aggregate, and loss in asphalt. The determination of asphalt content on samples of known composition indicates that the asphalt determinations are slightly low, and a correction of 0.3 could be added to the amount shown in Table XV. Corrections for the ash contents have been made.

SURFACE CONDITION

In the description of the pavement condition, each sample has been given a number by which it may be identified in the discussion to follow:

1. This street was paved in 1919, and has been subjected to heavy traffic. It is free from local cracks and distortion. Transverse cracks extending across the street are present at intervals of 50 to 60 feet. The street may be seen in Figure 42.

2. This street was paved in 1935 and carries very heavy traffic. Sheet asphalt was used only for completing irregular sections adjacent to old paving and it is from this portion that the sample was obtained. The pavement is free from local cracking and distortions. The major portion of the pavement (asphaltic concrete)
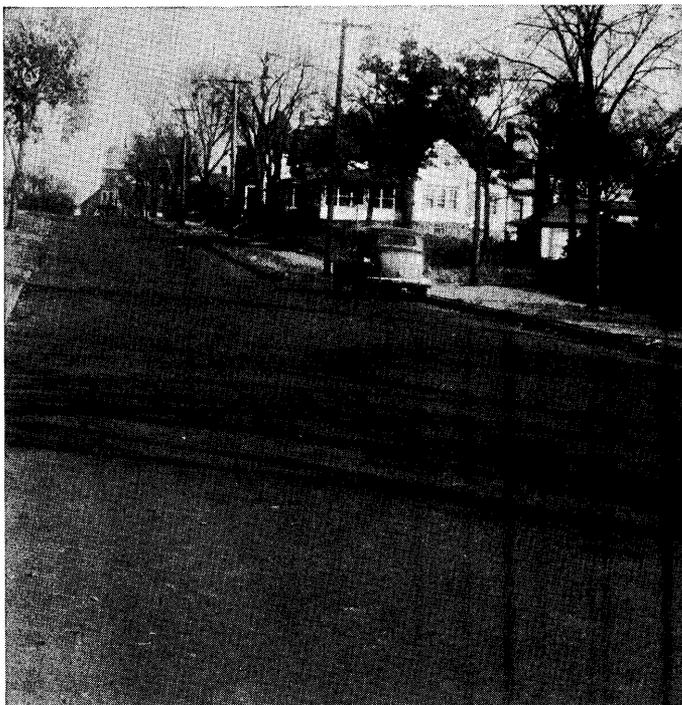
FIGURE 42. PAVEMENT NO. 1

is free from local cracks, but has continuous transverse cracks at intervals of about 50 feet.

3. This street was paved in 1925 as a part of an experimental pavement. A 2-inch sheet asphalt wearing course was laid on a 5-inch asphaltic concrete base. Traffic is moderate at the present time but has been heavy in the past. The street is almost free from patching and shows no displacement, but local cracks are present at intervals of 1 to 10 feet. Cracks tend to be concentrated in certain spots, possibly indicating the overheating of some loads. This is also evidenced by variations in the penetration of the asphalts recovered from three different locations.

4. This street was paved in 1932. Traffic is very heavy. Altho free from patching, local cracks are present in checkerboard fashion at intervals of about 3 feet.

5. This street was paved in 1923. Traffic is heavy. Extensive local cracking is in evidence at intervals of 1 to 3 feet. Considerable patching is in evidence.

6. This street was paved in 1923. Its condition is very similar to that of location No. 5. Traffic is moderate.

7. This pavement, which was laid in 1888, consisted of a sheet asphalt wearing course (without binder) over a natural cement, concrete base. Traffic is light. Surface cracks are present at intervals of 1 to 3 feet. After taking up the sample additional hidden cracks were found in the bottom of the sample at intervals of about 3 inches. Because of extensive patching only about 10 per cent of the original surface is left.

8. This street was paved in 1926 (Fig. 43). The surface is cracked in all directions. The cracks are at intervals of about one foot. The cracks have been sealed and no patching has been required as yet. Traffic is light.
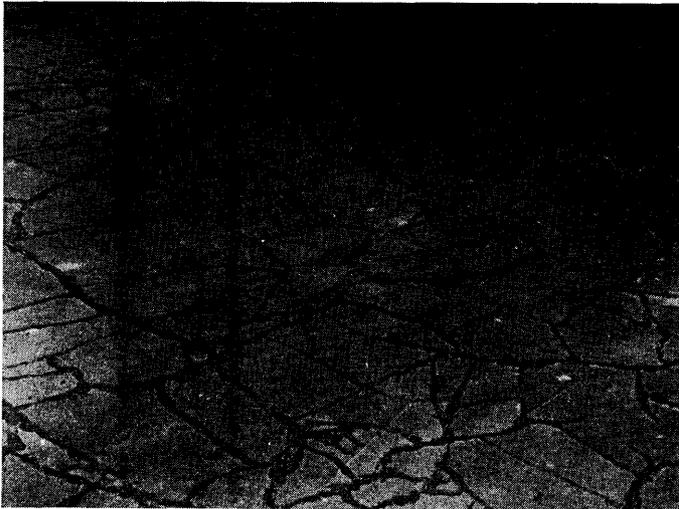
FIGURE 43.   PAVEMENT NO. 8

COMPOSITION

Data resulting from analysis of pavement samples are given in Table XV. It will be seen that a high filler content cannot be blamed for the cracking in the pavements studied. Pavements No. 7 and No. 8 showed the most extensive cracking and yet they have the lowest percentage

passing the 200-mesh sieve among the sheet asphalt samples. Likewise sample No. 8 had the highest average film thickness, 7.85 microns, indicating that the cracking was probably associated with some property of the asphalt. Sample No. 7 had the poorest sand gradation with 68 per cent of the sand having a size between the 40- and 80-mesh sieves. Sample No. 1 had a gradation following closest to the Richardson grading for heavy traffic, while sample No. 2 had a similar but somewhat finer grading.

PROPERTIES OF THE ASPHALT CEMENT

The penetration of the asphalts recovered from pavement samples is shown in Table XV. It seems strikingly significant that the asphalt from sample No. 1 should still have a penetration of 50 after nineteen

TABLE XV
ANALYSIS OF PAVEMENT SAMPLES

Sample Number	1[a]	2	3	4	5	6	7	8[b]
Age in years	19	3	13	6	15	15	50	12
Original penetration	55-58	50-57	50	47-55	40-45	35	?	?
Wearing Course								
Recovered penetration	50	34	a-21 b-24 c-28	20	20	12	20	12
Per cent asphalt	11.3	9.3	10.3	9.4	7.9	7.5	8.8	11.6
Film thickness—microns	7.5	5.5	5.7	6.1	6.2	6.1	6.5	7.85
Per cent passing								
¾ inch	100	100	100	100	100	100	100	100
⅜ inch	100	100	100	100	97.2	88.5	100	100
No. 4	100	100	100	100	83.7	78.9	100	100
No. 10	97.2	98.7	99.6	95.4	73.6	70.6	100	98.3
No. 20	89.8	90.6	97.5	88.3	67.4	66.5	99.0	92.4
No. 40	74.4	77.6	89.5	78.8	60.4	58.0	91.6	77.8
No. 80	40.9	45.5	55.0	44.2	34.6	35.5	23.4	41.7
No. 100	28.2	34.4	38.6	30.5	24.8	24.6	19.5	29.3
No. 200	14.5	17.4	15.9	12.2	11.6	9.8	8.1	11.7
Binder Course								
Recovered penetration	52	22	a-11 b-27 c-35	20	12	14	......	7½
Per cent asphalt	6.8	5.0	4.0	5.0	4.7	6.0	......	4.8
Film thickness—microns	7.4	7.2	5.5	5.6	5.1	6.3	......	7.7
Per cent passing								
¾ inch	96.4	79.6	82.6	84.2	81.6	95	......	79.2
⅜ inch	75.4	58.0	51.5	60.8	52.7	64.1	......	42.9
No. 4	60.4	45.0	41.1	50.9	46.6	53.4	......	37.4
No. 10	53.1	38.1	36.4	47.3	44.0	47.5	......	35.7
No. 20	46.1	35.3	34.5	43.0	40.4	45.1	......	34.4
No. 40	37.6	29.3	30.8	38.1	35.4	40.9	......	30.9
No. 80	22.7	20.0	18.4	22.2	23.1	27.5	......	14.8
No. 100	17.2	13.3	13.7	16.1	16.7	20.0	......	10.7
No. 200	9.5	5.3	6.0	8.2	9.9	7.9	......	4.0

[a] Figure 42.   [b] Figure 43.

years of service. Apparently this asphalt has some particular property which provides this resistance to hardening. This asphalt was a domestic asphalt of 63 to 65 penetration to which was added not over 5 per cent of Trinidad asphalt for hardening. The resulting mixture had a penetration of 55 to 58. The test properties of the domestic asphalt, which constitutes 95 per cent of the mixture, are given below.

TESTS OF ASPHALT—STREET SAMPLE NO. 1

Original Tests

Penetration 77° F.	65
Penetration 32° F., 200 grams, 60 seconds	33
Penetration 115° F., 50 grams, 5 seconds	210
Softening point (ring and ball) ° F.	133
Ductility 77° F.	52

Recovered Asphalt

Penetration 77° F.	50
Penetration 32° F., 200 grams, 60 seconds	29
Ductility 77° F.	14

This is obviously an oxidized asphalt. Because of its low ductility it would fail to pass the paving asphalt specifications of a majority of the states. As a contrast to this, asphalt *B* would comply with most specifications not requiring a spot test. Asphalt *B,* which had a ductility of 250+ at 50° F., had the least elongation in Ottawa sand briquettes at 35° F. and the least elongation in sheet asphalt briquettes at −10° F. Also asphalt *B* hardened rapidly in thin films both when exposed and when kept in a closed container.

Complete test data of the original asphalts were available only in the case of the samples 2 and 3. These were domestic asphalts.

	Sample 2	Sample 3
Penetration 77° F.	50- 55	50
Penetration 32° F., 200 grams, 60 seconds	14- 20	
Ductility at 77° F.	100+	100+
Flash point ° F.	555- 620	570- 585
Loss after 5 hours at 325° F., per cent	.028-.152	.020-.058
Penetration of residue, per cent of original	46- 52	48

Samples from pavement No. 3 show considerable variation in the penetration of the recovered asphalt. This may be an indication of non-uniform mixing temperatures. The samples are listed in the order of progress during construction. They grow progressively softer, indicating that control of temperatures at the plant improved with operation, an observation commonly found to be true.

Mexican asphalts were used in pavements 4, 5, and 6. The indications are that too hard an asphalt was used in pavements 5 and 6. The asphalt used in pavement No. 4 had a ductility of 6.8 to 9.0 cm. at 32° F. and ¼ cm. per minute.

The asphalt used in sample No. 8 was a domestic asphalt. It is believed that it had a penetration of approximately 50.

Asphalt recovered from pavement sample No. 1 was mixed with Ottawa sand and exposed to heat, air, and ultraviolet light in the laboratory pugmill for 22 hours. The exposed mixture had an abrasion loss of 4.9 per cent, an impact resistance of 1,500 gram centimeters, and an elongation of .0194 inch. The penetration of the recovered asphalt was 32. Thus this material exceeded the best values found in Table XVII for each of the tests mentioned.

The asphalt recovered from sample No. 7 was mixed with Ottawa sand and tested without further exposure. The mixture had an abrasion loss of 17.3 per cent, an impact resistance of 820, and an elongation of .0041 inch. A study of Table XVII reveals that of the asphalts exposed to heat, air, and ultraviolet light, only 32 per cent of them had a greater abrasion loss while 53 per cent had less impact resistance and less elongation.

The indications are that an asphalt which is giving good service in the pavement also proves durable in the accelerated tests. While the converse of this statement cannot be proved by existing data, it is at least implied by this and other data presented in this report.

SUMMARY

A method has been developed for the testing of asphalts in mixtures. These tests show definite reproducible differences between asphalts which are not indicated by ordinary tests on the asphalt cement.

A method of exposing asphalt in thin films on standard Ottawa sand to heat, air, and ultraviolet light has also been developed. The accelerated weathering thus produced has been at least partly correlated to the effects of nature by means of weathering of specimens on the laboratory roof and by means of examination and tests of existing pavements.

Striking differences have been disclosed in the resistance of different asphalts to hardening when exposed in thin films to heat, air, and ultraviolet light. Some asphalts were found to harden in thin films at a rapid rate when Ottawa sand asphalt mixtures were stored in closed containers. These asphalts also hardened in densely graded sheet asphalt specimens.

The tests ordinarily used in standard specifications for asphalt cements do not adequately distinguish between asphalts having low and high resistance to the exposure conditions of this investigation, altho flash point and per cent penetration of residue after heating are partially successful in this respect.

Asphalts which were found positive in the Oliensis spot test usually had poor resistance to exposure altho some exceptions were noted. Some negative spot test materials also had poor resistance to exposure.

No correlation was found between the fluidity factor of an asphalt and its resistance to exposure.

The per cent of asphaltenes, resins, oils, saponifiable matter, sulfur, and nitrogen have been determined and found unrelated to the resistance of the asphalts to exposure.

The microscopic studies have revealed a marked difference in the resistance of the various asphalts to coagulation in dilute naphtha solutions. As a general thing asphalts showing little or no coagulation had the greatest resistance to exposure on Ottawa sand.

In general positive spot test asphalts showed greater resistance to stripping than did negative spot test asphalts.

Tensile briquettes and beams prepared from sheet asphalt mixtures were tested at $-10°$ F. The asphalts used in these specimens had not been exposed to any accelerating tests. The tests showed marked differences in the ability of the various asphalts to permit deformations at this low temperature.

The ductility tension of an asphalt has been found to be largely a function of viscosity.

The temperatures at which hot paving mixtures are to be prepared in commercial plants should be kept as low as practicable. The proper viscosity of the asphalt at the mixing and placing temperatures should be used as the basis for the selection of the temperature.

During recent years much emphasis has been placed upon the use of soft asphalts (at $77°$ F.) and upon the use of a sufficient quantity of asphalt. It is believed that emphasis should also be placed upon obtaining paving mixtures which will be resistant to exposure and which have sufficient softness at low temperatures to resist cracking.

The lack of correlation between ductility and tests on mixtures suggests that possibly the emphasis that is ordinarily placed on ductility requirements is not warranted.

APPENDIX

A-1. STANDARD TEST METHODS USED IN TESTING ASPHALT CEMENTS

The following test designations refer to the methods of the American Association of State Highway Officials.

Specific gravity	A.A.S.H.O.	T-43
Flash point	A.A.S.H.O.	T-48
Penetration	A.A.S.H.O.	T-49
Penetration, 5-hour residue	A.A.S.H.O.	T-47
Penetration, 24-hour residue	A.A.S.H.O.	T-47
Furol viscosity	A.A.S.H.O.	T-72
Ductility	A.A.S.H.O.	T-51
Loss on heating 325° F.	A.A.S.H.O.	T-47
Softening point	A.A.S.H.O.	T-53
Solubility in carbon disulphide	A.A.S.H.O.	T-44
Solubility in carbon tetrachloride	A.A.S.H.O.	T-45
Per cent insoluble in 86° naphtha	A.A.S.H.O.	T-46

A-2. REFERENCES FOR SPECIAL TESTS FOR ASPHALT CEMENTS

a. Oliensis spot test — A.S.T.M., *Technical Papers*, pp. 506-507. 1936.

b. Xylene equivalent — A.S.T.M., *Technical Papers*, p. 503. 1936.

c. Determination of saponifiable matter — M. Katz, "The Composition of Blown Alberta Bitumen." *Can. J. Research* 10:435-51. 1934.

d. Determination of sulfur content — A.S.T.M., D129-34, "Sulfur in Petroleum Oils by Bomb Method."

e. Viscosity by the capillary tube type of viscosimeter — Rhodes, Volkmann, and Barker, "New Viscosimeter Has Extended Range." *Engineering News-Record,* November 21, 1935.

f. Ductility tension — J. R. Grant and H. B. Pullar, "A Study of the Relation between Ductility and Tensile Strength When Measured Simultaneously." *Assoc. of Asphalt Paving Technologists,* p. 124. January 23, 1936.

g. Benson film test — *Proceedings Highway Research Board,* 17:368-83. 1937.

h. Abson method for recovery of asphalt — Gene Abson, "Method and Apparatus for Recovery of Asphalt," A.S.T.M. *Technical Papers,* pp. 704-14. 1933.

A-3. DETAILED TEST PROCEDURE

A-3a. STRIPPING TESTS

The aggregate consisted of 100 per cent crushed particles graded from a ⅜-inch sieve to a No. 6. Fifty-gram samples of mixture were used, each containing 5 per cent of asphalt by weight. This produced a very heavy film. The samples were placed in 250 c.c. Erlenmeyer flasks with 175 c.c. of distilled water. They were then rotated at 44 r.p.m. for two fifteen-minute periods at 75° F. and for additional

15-minute periods at 100° and 120° F. At the end of each fifteen-minute period the samples were examined and the estimated per cent of the surface area of the aggregate which had been stripped of asphalt was recorded.

A-3b. ADSORPTION TESTS

The solution of asphalt in benzene was freshly prepared using 500 c.c. of benzene and one gram of asphalt. Fifty c.c. of solution was placed in an Erlenmeyer flask to which was then added five grams of rock dust passing the 270-mesh sieve, retained on the 325. The solution was then shaken at one-minute intervals for a period of seven minutes, after which it was transferred to glass centrifuge cups. The centrifuge was started after a total elapsed time of ten minutes during which the dust had been in contact with the solution. The solution was centrifuged five minutes, transferred to new cups, and centrifuged for a second five-minute period. Thirty-five c.c. of solution was then decanted off the top and from this exactly 30 c.c. was transferred by means of a pipette to a straight-walled crystallizing dish 10 cm. in diameter by 5 cm. in height. An enclosed box was used for making the photometric measurements. The light intensity was adjusted by means of a rheostat so that a reading of 30-foot candles was obtained when the light passed through an empty dish.

A reading was then taken at once on the treated solution. A similar reading on a solution which had not been treated with rock dust was taken, but which had been centrifuged. Note that the untreated solution was centrifuged so that it would have the same evaporation during the centrifuging process with a consequent slight increase in concentration.

An occasional reading on 30 c.c. of clean benzene was also taken. The following readings and calculations may help to illustrate the method:

Light transmitted by clean benzene	28.9-foot candles
Light transmitted by untreated solution of asphalt in benzene	16.2-foot candles
Light absorbed by asphalt in solution	12.7-foot candles
Light transmitted by solution of asphalt in benzene after adsorption by rock dust	22.0-foot candles
Light transmitted by untreated solution of asphalt in benzene	16.2-foot candles
Light absorbed by portion of asphalt removed by rock dust	5.8-foot candles
Per cent decrease in light absorbed resulting from adsorption of asphalt by rock dust	$\dfrac{5.8}{12.7} = 45.6$ per cent

A-3c. SEPARATION OF ASPHALT INTO ASPHALTENES, OILS, AND RESINS

The 85-100 penetration asphalts have been separated into their asphaltene, oil, and resin fractions by a modification of Marcusson's procedure.[1] At the beginning of this study a quantity of naphtha boiling below 50° C. was prepared which was to be used in the precipitation of asphaltenes. Difficulty was encountered in obtaining good check results and it was felt that variations in the naphtha used were partially responsible. Therefore, after eight asphalts had been run it was decided to use a naphtha with a sharply defined boiling range. Skellysolve "A" with a boiling range at 28°-38° C. was adopted and used for the entire series of twenty-three asphalts. The asphaltenes determined with each solvent are listed in Table XVIII. Skellysolve "A," which had the narrower boiling range, yielded the higher percentage of asphaltenes in all cases. The difference was about 3 per cent.

[1] J. Marcusson, "Der Chemische Aufbau der Naturasphalte," *Angew Chem.* 29:346. 1916.

A five-gram sample of asphalt was weighed into a tared 250 c.c. beaker. About 100 c.c. of Skellysolve "A" was added and the beaker allowed to stand for several hours to assist in the solution of the asphalt (i.e., of the oils plus resins fraction). The asphaltenes were contained in the beaker as a sludge.

A paper extraction thimble (C. S. and S.) 25 mm. in diameter by 70 mm. in height was placed in a weighing bottle 40 mm. in diameter by 80 mm. in height. The uncapped weighing bottle plus thimble was placed in an oven at 100° C. for one hour, after which it was removed, capped, and air-cooled. The weighing bottle plus thimble was then weighed. The thimble was placed in a Soxhlet extractor and the weighing bottle set aside pending further use.

The solution of asphalt in Skellysolve "A" (i.e., dissolved oils plus resins) and the sludge of impure asphaltenes was then transferred by means of a funnel to the above paper thimble in the Soxhlet apparatus. The dissolved oils plus resin solution was first decanted from the sludge after which the sludge was washed into the thimble with fresh Skellysolve "A."

The small amount of asphaltenes adhering to the funnel, stirring rod, and beaker was washed into a weighing bottle with carbon tetrachloride. The weighing bottle was oven-dried at 100° C. to remove the carbon tetrachloride.

The solvent which had filtered through the paper thimble was quite concentrated with oils and resins. Since heat might alter the composition of the oils and resins, the solution was poured directly on about 100 grams of fuller's earth. About 75 c.c. of fresh Skellysolve "A" was added to the reflux flask and the impure asphaltenes were refluxed until the extract was colorless. This required about three days of continuous refluxing.

The extract obtained after the complete extraction of the asphaltenes was added to the same fuller's earth mentioned above. A small amount of gummy material was removed from the flask with 1-2 c.c. of benzene followed by a washing with fresh naphtha. The gummy material was also added to the fuller's earth.

The thimble plus asphaltenes was removed from the extractor and placed in the weighing bottle containing the small amount of asphaltenes which had adhered to the funnel, stirring rod, and beaker. This was air-dried until there was no further odor of naphtha and then oven-dried at 100° C. for about one hour. The weighing bottle plus thimble, plus asphaltenes was then removed from the oven, capped, and air-cooled. It was then weighed. All determinations were made in duplicate and the maximum deviation allowed between duplicate results was 3 per cent. The average values are shown in Table XVIII.

Separation of Oils

For the oil extraction, Soxhlet extractors were used which contained paper thimbles 43 mm. in diameter and 123 mm. in height. These thimbles held approximately 100 grams of fuller's earth. With this quantity of earth, the oil extract had a light straw-yellow color.

The extract from the aspheltene determination was poured on the fuller's earth. The small amount of gummy material, which formed in the extraction flask in many instances, was dissolved in a few c.c. of benzene and added to the extract on the fuller's earth.

The naphtha was allowed to evaporate in the air, the beaker holding the fuller's earth plus extract being placed in the dark to avoid decomposition by light. The dry fuller's earth was then placed in an extraction thimble and extracted in the Soxhlet apparatus using Skellysolve "F" (30°-60° C.).

In a few cases, 100 grams of fuller's earth was not sufficient for decolorizing the extract to a pale straw-yellow color. When this occurred the extract was added to fresh fuller's earth and this earth was extracted with Skellysolve "F."

The extraction of oils was carried out until the solvent in the extractor was water white. Test samples showed that thirty hours of continuous extraction was sufficient for the complete recovery of the oils.

The extract was then poured through filter paper to remove the small amounts of fuller's earth which had come through the thimble or splashed out during extraction.

The removal of naphtha from the oil and naphtha solution presented many difficulties. An attempt was made to remove the naphtha by heating in a vacuum dessicator. A resistance heater was built into a dessicator for this purpose. It was found that if the samples still contained enough naphtha to remain fluid, the sample always boiled over, even in the absence of applied heat. Some samples were allowed to stand in the room until sufficient naphtha had evaporated to leave a viscous residue. These "air-dried" samples, when placed in the vacuum dessicator at 50° C., foamed badly, throwing oil droplets on the top and sides of the dessicator.

The aforementioned "air-dried" samples were placed in a vacuum dessicator without heat. High losses were still found. In view of these difficulties, the use of a vacuum to remove the last trace of naphtha was abandoned.

Marcusson[2] suggests "drying" the oil extract at 100° C. until the odor of naphtha is no longer discernible. The oils, however, had a pronounced odor, and this odor completely masked the odor of the naphtha.

Other workers heat the oil extract at 100° C. to constant weight. An attempt was made to employ this method. The bulk of the naphtha was allowed to evaporate at room temperature in a dark place. If this evaporation took place in the light a dark oil would result. An attempt was made to accelerate the removal of naphtha by heating. The oils tended to creep over the rim of the retaining beaker or flask with such ease that the use of heat for this purpose was hazardous and impractical. Most of the naphtha will evaporate from the oils after standing over night.

This "air-dried" oil was then heated at 100° C. to constant weight. Consistent results could not be obtained with this procedure. The yellow oils always darkened to black nonflowing products. Furthermore, the majority of samples, when removed from the oven at 100° C. showed a marked tendency to fume. It was hoped that a short interval of heating might be established which would give substantially constant results, but the losses were so great that this could not be realized.

The darkening of the oils to black gummy residues at 100° C. was probably the result of oxidation. The use of either lower temperatures or an inert atmosphere appeared to be the only solution. Fortunately, consistent results were readily obtained by using lower temperatures. Whereas the oils still lost appreciable weight on further heating after thirty-six hours at 100° C., "air-dried" samples attained constant weight in less than an hour at a temperature of 60 to 75° C. The oils darkened perceptibly at 75° C. but were unaffected at 65° C. The procedure of heating the "air-dried" oils at 60-65° C. to constant weight was consequently adopted.

[2] Abraham, *Asphalts and Allied Substances.* Third edition, pages 755-58. New York: D. Van Nostrand Company. 1929.

All determinations were performed in duplicate and the maximum discrepancy between any duplicate results used was 2 per cent. Table XVIII shows the average values.

Recovery of Resins

Extraction methods for the recovery of resins were tried. Dark-colored extracts, obtained from the oil-free fuller's earth with chloroform, gave reddish brown to black gummy residues upon evaporation of the chloroform. The resins could be dried to constant weight at 100° C. with none of the difficulties experienced in the case of the oils.

However, the recovery of resins was incomplete. Thus, resins by difference might be 33 per cent, whereas resins by recovery would be 23 per cent. Thus a 30 per cent loss of resins was not uncommon. Continuous chloroform extractions have been run as long as seven days and still discrepancies of the aforementioned magnitude were found. Resins are reported by difference in Table XVIII.

A-3d. SINTERING POINTS OF ASPHALTENES

In an attempt to classify the asphaltenes, sintering points were determined. No definite melting point exists for asphaltenes, but the mass first undergoes perceptible shrinkage. Finally it fuses to a viscous tarry mass of brilliant black color. Sintering points were determined using cylindrical brass plates 2½ inches in diameter and ⅞ inch thick. The sintering point must be defined somewhat arbitrarily. The determination must be made shortly after the material contacts the brass plate since the sintering point changes considerably as the time of contact with the plate increases.

Asphaltenes are reported in the literature as having no definite melting point, but fusing with the liberation of fumes or distillation of an oil. When the asphaltenes on the brass plate were heated to 650° F. in no case was the distillation of an oil or the liberation of fumes observed. Possibly, the presence of oils and resins in asphaltenes determined by other methods results in distillable impurities. However, the fumes might result from the destruction of complex molecules by heat. At least the absence of fumes indicates a high degree of "purity" of our product.

A-3e. VISCOSITY BY THE FALLING COAXIAL CYLINDER VISCOSIMETER

The absolute viscosity in poises was determined for the 85-100 penetration asphalts at temperatures of 33°, 60°, and 77° F. A falling coaxial cylinder viscosimeter of the type described by Traxler[3] was used for these measurements. The inner cylinder was one inch in diameter and one inch high. The outer cylinder had an inside diameter of one and one-half inches and was one inch high.

The asphalt was heated just enough to permit pouring. The specimens were cooled twenty minutes in air and forty minutes in the water bath at the selected temperature. In making viscosity measurements at 77° F. an applied load of one pound was used. The inner cylinder was allowed to move 0.2 inch between reversals of loading. The time interval for the calculation of viscosity was measured for the central 0.1 inch of movement. For determination of viscosity at 60° F. a load of two pounds and a timed movement of .03 inch was used. At 33° F. a load of ten pounds and a timed movement of .005 inch was used. The values obtained are shown in Table XVIII. Each value shown represents the

[3] R. N. Traxler and H. E. Schweyer, "Measurements of High Viscosity—A Rapid Method," *A.S.T.M.*, Part II, pages 518-29. 1936.

average of at least two specimens, a number of determinations being made on each specimen.

The selection of the above loads and movements was simply for convenience in testing. It is known that few if any of the asphalts are truly viscous materials at 33° F., and that the selection of other loads and other movements would yield somewhat different values for the viscosity.

A-3f.   MICROSCOPIC STUDY

The microscopic study was undertaken in the hope that some important information could be obtained concerning the heterogeneity of various types of asphalts. The standard method of testing for heterogeneity is the Oliensis spot test. The spot test is carried out with two grams of asphalt and 10.2 c.c. of naphtha. The solution is thus very concentrated. Because of the high concentration of asphalt the oils from the same may alter the properties of the solvent a great deal. Asphalts can be considered to be made up of asphaltene particles of colloid size stabilized by adsorbed resins and dispersed in a medium consisting of an oil solution of resins. In order to show a spot test some of the asphaltene particles must be coagulated. The coagulation of the asphaltenes will depend on the following:

On the Stability of the Dispersed Phase in Itself

This stability will be influenced by:
1. The degree of dispersion.
2. The extent to which the asphaltene particles are stabilized by adsorbed resins and how strongly these adsorbed resins are retained by the asphaltene particles.

On the Specific Solvent Action of the Naphtha

Certain types of resins are probably more soluble than others in naphtha. Thus, the extent to which the resins which stabilize the asphaltene particles are dissolved by the naphtha will vary with different asphalts.

On the Surface Tension of the Dispersing Phase

This phase will be a rather concentrated solution of oils and resins in naphtha and so its surface tension will depend on both the type and quantity of the oils and resins in the asphalt. The lower the surface tension, the greater will be the tendency for the asphaltenes to coagulate.

An outline of the work covered in this study follows:
1. Microscopic examination of dilute naptha solutions of twenty-three 85-100 penetration asphalts, before and after exposure to heat, air, and ultraviolet light.
2. A study of the leaching of twenty-three asphalts with the following solvents:
   (a) Skellysolve "S," (b) Ethyl ether.
3. The particle count of the asphalts in nitrobenzene solution.

MICROSCOPIC EXAMINATION OF SOLUTIONS OF ASPHALTS IN NAPHTHA

A solution of asphalt in naphtha meeting the requirements of the Oliensis spot test and prepared according to the standard procedure, was examined under the microscope. The sample was contained in a blood cell count chamber. The solution of .1 mm. thickness thus provided proved to be too opaque so it was diluted to one tenth its original concentration. All solutions thereafter were pre-

pared directly as 2 per cent solutions. The solvent employed was Skellysolve "S" and the solution procedure was exactly as per spot test procedure except that only one tenth as much asphalt was used.

Nearly all of the asphalts when made up into a naphtha solution of 2 per cent concentration showed some coagulation when examined under the microscope. As a supplementary test, a drop of this dilute solution was placed on filter paper and the resulting spot examined. This spot test appeared to be very sensitive. A slight spot could be seen even when the quantity of material precipitated was very small.

It was originally hoped that a quantitative measure of the amount of coagulation could be made. The coagulated particles were of such irregular shape and size that it was impossible to make a particle count which would serve as a quantitative measure of the degree of precipitation.

A qualitative survey was therefore made of the amount and character of the precipitation observed in each solution. To assist in this classification photomicrographs of the solutions of unweathered asphalts were taken, and these are shown in Figure 41.

The twenty-three asphalts were put into solution in naphtha in the manner described above. They were then allowed to stand for 24 hours after which they were examined under the microscope and photographed. A drop of solution was at the same time placed on a sheet of filter paper and the spot observed.

Great variations were noted in the amount and character of the coagulation. The spot test followed the amount of coagulation very closely. Two fundamentally different kinds of particles were observed.

The first type of particle was very irregular in shape and size and appeared to be made up of a large number of exceedingly fine particles adhering together. The appearance of this type of particle was not the same for all asphalts. This was probably due to a difference in the size of the smaller units which go to build up the particle. The second type of particle had a granular appearance. It was fairly large and was roughly rectangular in shape with well-rounded corners. Altho the particles had the appearance of rounded pebbles under the microscope, they were actually very thin. This type of particle was observed only in the more heterogeneous asphalts. Later developments indicated that this second type of particle was largely the result of the solution process.

As a result of these microscopic observations and examinations of the photomicrographs (Fig. 41) the asphalts have been grouped into eight classes as follows:

CLASS   RESULT

1. No coagulation observed. Solution gives no spot on filter paper.
    Asphalts *D, G, N, O.*

2. Very little coagulation observed. Solution gives very slight spot on filter paper.
    Asphalts *E, P.*

3. Greater density of coagulated particles observed. Solution gives a stronger spot than in 2.
    Asphalts *V, J.*

4. Fair density of the first type of particle observed. Solution gives a fair spot on filter paper.
    Asphalts *A, C, H, K, Q.*

5. Quite a bit of coagulation observed. Precipitate is of the first type and appears to be made up of smaller particles than is the case in other asphalts. Solution shows a good spot on filter paper.
    Asphalts *L, M, W.*

6. Some coagulation of first type observed. These particles, however, seem to be built of larger units than is normal. The solution shows a fair spot on filter paper.
    Asphalts *S, T.*

7. Much coagulation observed. No large particles of the second type present. Solution shows a very good spot test.
    Asphalt *R.*

8. Shows an exceedingly dense coagulation with many large particles of the second type. The solution on filter paper gives an exceedingly dense spot.
    Asphalts *B, F, U, X.*

Most of the asphalts that show a positive spot in the standard Oliensis test fall into Classes 5, 7, and 8. The only exceptions are asphalts *E* and *H*. These asphalts, however, have a very low xylene equivalent. The more heterogeneous asphalts, having a high xylene equivalent (greater than 45), all fall in Class 8. It is believed the presence of the granular type particle in these asphalts is related to the solution process. This will be discussed in detail later.

The asphalts of Class 1 all stand up well in the accelerated weathering tests. Their oils have high molecular weights. Asphalts *S* and *T* representing Class 6 show up poorly in the accelerated weathering tests.

EXAMINATION OF RECOVERED ASPHALTS AFTER EXPOSURE TO HEAT, AIR, AND ULTRAVIOLET LIGHT

Solutions were prepared from twenty-one asphalts recovered from exposed mixtures. They were then examined as previously described. Asphalts *L* and *M* contain mineral matter. Special samples of these asphalts, from which the mineral matter had ben centrifuged out, were available for the study of unweathered asphalts. No such samples of exposed asphalts were made, so no observations were made on asphalts *L* and *M* after weathering.

In general, the amount of coagulation was more after exposure. The large particles of granular appearance observed only in the more heterogeneous asphalts before weathering were found in many of the asphalts after exposure. These large particles were particularly marked in *S* and *T* asphalts. It is interesting to note that altho *S* and *T* showed little coagulation before exposure the precipitated material was of peculiar character, in that the particles appeared to be built from larger units than normal. It seems likely that in the case of these asphalts the asphaltenes are present in a much coarser state of subdivision than in other asphalts. Many of the exposed asphalts, particularly those which showed very little coagulation before exposure, had an appearance closely resembling that of *L* and *M* before exposure.

LEACHING ACTION OF SKELLYSOLVE "S"

This experiment was performed as follows:

A small amount of asphalt was deposited on a microscope slide and brought into the field of the microscope. A magnification of 100 was employed. The asphalt was then covered with a drop of solvent which attacked the asphalt until it (the solvent) was removed by evaporation.

Most asphalts when treated with Skellysolve "S" in the manner described above were completely broken up and spread over the surface of the slide. In the case of the more heterogeneous asphalts (*B, F, U, X*) the action was different. Here apparently the solvent was capable of taking out a large part of the oils without breaking up the asphalt. The heterogeneous asphalt when first treated with Skellysolve swelled. Upon successive applications of the solvent more and more oil was leached out until the asphalt finally cracked up upon evaporation of the solvent. These experiments lend added support to the suggestion made before, namely, that the large granular type particles which appear only in the more heterogeneous asphalts are a direct result of the solution process. The naphtha leaches the oils from the asphalt leaving a residue which is not easily dispersed.

Similar tests were made using ethyl ether as a solvent instead of Skellysolve "S." The ether does not have as great solvent action as naphtha. Furthermore, since it has a higher volatility it will not remain in contact with the asphalt for as long a time.

A classification of the action of ether on the asphalt follows:

CLASS   RESULT

1. Asphalt swells, oils are leached out. After a few leachings only a black residue remains which cracks up.
   Asphalts *A, B, C, F, K, R, U, X.*

2. Asphalt swells and spreads. On further leaching black residue remains which is thinner than in Class A. This residue likewise cracks.
   Asphalts *W, T, L, M, H, O.*

3. Asphalt swells and spreads. A thin black residue remains, but some black particles are also precipitated by the solvent on evaporation.
   Asphalts *E, O, V, N, J, S.*

4. Asphalt completely taken up by the solvent. Some precipitation occurs when the solvent evaporates.
   Asphalts *P, D.*

It is interesting to note that *P* and *D* are the lowest in asphaltenes. All asphalts in Class 1 are heterogeneous except *A, C,* and *K,* and they are the highest in asphaltenes.

PARTICLE COUNT OF THE ASPHALTS IN NITROBENZENE SOLUTION

Nellensteyn[4] has developed a method for making a count of the particles in tars. He claims that the microscopic count is a direct measure of the quality of tars for paving purposes. The count is more difficult to make in the case of asphalts. The number of particles are fewer and they are more difficult to see than in the case of tar. Several solvents were tried but nitrobenzene was the only one which was at all suitable.

The procedure used in making the count was as follows:

About 0.01 gm. of asphalt was weighed out on a microscope cover glass slide. It was then transferred to a small sample bottle and 1 c.c. of nitrobenzene was added. After the asphalt was completely dissolved a drop of solution was removed by means of a stirring rod and placed on the blood count chamber. The cover glass was then slipped on and the chamber examined under the microscope. A count was then made of the average number of particles per square. Where the density of the particles was low, it was necessary to count more squares to get a representative count. The size of the particles appeared to be in an inverse ratio to their number so that the quantity of material represented by the particles was more or less the same with all asphalts. The quantity of material represented by the particle seems to correspond roughly to the benzene insoluble fraction (about .3 per cent).

A particle count was made first on the solutions shortly after they were pre- pared. This count was checked about one week later. The solutions were then diluted to one half their original concentration and a third count was made. The count did not change in any regular way when the solutions were diluted. Most of the asphalts showing low counts had more particles after dilution.

The number of particles per cu. mm. of the original asphalt is given by the following expression:

$$N = p \times 4000 \times \frac{1}{w} \times d$$

where *p* is the average number of particles per square (0.05 mm. square and .1 mm. deep), *w* is the weight of the asphalt sample, *d* is the density of the asphalt.

Table XIV shows the data taken on the particle count. The first count was made on the freshly prepared solution. The second count is that made after the solutions had stood for one week. The third count was made after dilution.

[4] J. J. Nellensteyn "Microscopic Researches on Coal Tar Solutions." *Gas World*, 92:54. 1930.

TABLE XVI

SUMMARY OF TEST DATA ON ASPHALT AND OTTAWA SAND MIXTURES
85-100 PENETRATION ASPHALTS

NOTE.—Duplicate tests shown represent separate mixtures each weathered independently.

	ABRASION PER CENT LOSS AT 60° F.								
ASPHALT	Unweathered Mixtures		22 Hrs., 180° F. Nitrogen	22 Hrs., 180° F. Air		22 Hrs., 180° F. Ultraviolet Light		1 Yr. Natural Weathering	
	Dup.	Aver.		Dup.	Aver.	Dup.	Aver.	Dup.	Aver.
A	2.7 2.4	2.6	2.1	3.9 4.8	4.4	8.8 9.8	9.3	21.4 19.6	20.5
B	11.8 11.7	11.7	14.3	16.0 22.5	19.2	28.8 28.0	28.4	36.4 33.1	34.8
C	2.5 2.8	2.6	2.1	3.9 5.5	4.7	9.9 7.6	8.8	19.5 24.5	22.0
D	2.5 2.7	2.6	2.5	3.2 5.0	4.1	5.7 4.2	4.9	15.5 15.6	15.6
E	2.9 3.2	3.1	2.4	3.6 4.4	4.0	4.9 5.5	5.2	17.5 16.4	17.0
F	2.6 2.7	2.7	3.2	2.8 4.5	3.6	6.9 6.0	6.4	17.2 14.8	16.0
G	2.8 2.8	2.8	2.1	3.9 4.6	4.2	5.6 6.8	6.2	17.7 17.5	17.6
H	8.2 8.4	8.3	7.4	9.2 14.3	11.7	11.7 16.0	13.8	28.5 25.1	26.8
J	3.5 3.6	3.6	3.4	4.9 5.9	5.4	7.8 8.1	8.0	18.1 18.5	18.3
K	2.7 2.4	2.6	2.5	3.2 3.8	3.5	7.6 6.9	7.2	19.0 17.0	18.0
L	3.2 3.0	3.1	4.2	8.4 7.3	7.8	19.8 23.8	21.8	15.8 16.6	16.2
M	5.6 5.6	5.6	4.1	10.0 12.2	11.1	20.1 18.8	19.4	26.0 22.7	24.4
N	1.7 1.9	1.8	1.5	3.7 3.8	3.8	3.6 4.6	4.1	12.7 12.2	12.4
O	3.4 4.4	3.9	1.8	2.6 3.2	2.9	5.0 4.6	4.8	14.2 12.4	13.3
P	6.4 7.0	6.7	6.8	7.7 10.2	9.0	11.9 16.9	14.4	29.6	29.6
Q	4.9 5.6	5.3	4.2	5.0 5.0	5.0	6.2 9.1	7.6	19.0 18.7	18.8
R	5.3 6.3	5.8	3.1	5.3 5.7	5.5	7.6 10.2	8.9	18.4 21.5	20.0
S	6.3 6.4	6.4	4.0	7.0 8.6	7.8	17.1 15.6	16.4	23.6 22.5	23.1
T	9.1 8.3	8.7	7.7	8.9 10.2	9.6	17.4 16.1	16.8	24.1 25.2	24.6
U	10.9 9.5	10.2	11.0	19.5 22.9	21.2	28.6 27.4	28.0	34.3 32.0	33.2
V	4.3 3.8	4.0	3.5	4.7 7.1	5.9	5.2 8.8	7.0	14.1 17.9	16.0
W	5.5 5.4	5.4	6.4	6.6 8.3	7.5	8.6 12.2	10.4	19.5 25.1	22.3
X	4.2 4.3	4.3	3.4	8.5 11.4	10.0	19.6 18.7	19.2	21.4 22.6	22.0
Z	3.8 3.4	3.6	....	4.9 5.7	5.3	5.2 4.7	5.0	....	....

TABLE XVI—*Continued*

SUMMARY OF TEST DATA ON ASPHALT AND OTTAWA SAND MIXTURES
85-100 PENETRATION ASPHALTS

NOTE.—Duplicate tests shown represent separate mixtures each weathered independently.

	IMPACT RESISTANCE GRAM CMS. AT 77° F.								
ASPHALT	Unweathered Mixtures		22 Hrs., 180° F. Nitrogen	22 Hrs., 180° F. Air		22 Hrs., 180° F. Ultraviolet Light		1 Yr. Natural Weathering	
	Dup.	Aver.		Dup.	Aver.	Dup.	Aver.	Dup.	Aver.
A	2060 2100	2080	1860	1560 1460	1510	960 940	950	680	680
B	780 780	780	700	700 640	670	460 540	500	520 500	510
C	1800 1880	1840	1700	1180 1300	1240	980 1040	1010	640 725	682
D	2080 1920	2000	1700	1540 1360	1450	1340 1320	1330	900 1100	1000
E	1780 1780	1780	1620	1680 1420	1550	1340 1240	1290	760 820	790
F	1560 1560	1560	1620	1640 1640	1640	1480 1480	1480	900 940	920
G	1800 1700	1750	1840	1560 1500	1530	1480 1420	1450	940 840	890
H	1140 1160	1150	1000	680 760'	720	640 680	660	640 580	610
J	1740 1680	1710	1800	1260 1420	1340	1120 1275	1198	780 780	780
K	1820 1880	1850	1860	1260 1360	1310	1060 1040	1050	680 750	715
L	1520 1480	1500	1520	850 980	915	680 660	670	820 720	770
M	1160 1060	1110	1000	640 700	670	600 620	610	540 500	520
N	1760 1780	1770	1740	1900 1960	1930	1880 1920	1900	1220 1260	1240
O	1820 1780	1800	1860	1500 1680	1590	1600 1660	1630	1020 920	970
P	980 980	980	720	640 720	680	640 620	630	460 500	480
Q	1700 1640	1670	1260	1160 1100	1130	960 1080	1020	780 775	778
R	1700 1740	1720	1580	1140 1180	1160	1020 1240	1130	800 840	820
S	1280 1260	1270	1000	780 740	760	600 740	670	540 660	600
T	1320 1320	1320	1180	740 820	780	580 720	650	460 520	490
U	1000 1040	1020	680	560 580	570	480 520	500	420 340	380
V	2060 2000	2030	1280	1220 1220	1220	1240 1360	1300	960 720	840
W	1600 1660	1630	1220	840 1080	960	960 940	950	740 600	670
X	1800 1880	1840	1700	860 940	900	700 760	730	600 700	650
Z	1840 1880	1860	....	1640 1800	1720	1640 1500	1570	....	....

TABLE XVI—*Continued*

SUMMARY OF TEST DATA ON ASPHALT AND OTTAWA SAND MIXTURES
85-100 PENETRATION ASPHALTS

NOTE.—Duplicate tests shown represent separate mixtures each weathered independently.

ASPHALT	Unweathered Mixtures		22 Hrs., 180° F. Nitrogen	22 Hrs., 180° F. Air		22 Hrs., 180° F. Ultraviolet Light		1 Yr. Natural Weathering	
	Dup.	Aver.		Dup.	Aver.	Dup.	Aver.	Dup.	Aver.
A	.0398 .0426	.0412	.0314	.0210 .0252	.0231	.0100 .0144	.0122	.0133 .0179	.0156
B	.0049 .0025	.0037	.0016	.0004 .0009	.0007	.0005 .0004	.0004	.0005 .0003	.0004
C	.0379 .0372	.0376	.0359	.0164 .0227	.0196	.0096 .0091	.0094	.0118 .0142	.0130
D	.0359 .0340	.0350	.0326	.0234 .0296	.0265	.0254 .0209	.0232	.0128 .0155	.0142
E	.0332 .0292	.0312	.0301	.0242 .0249	.0246	.0157 .0162	.0160	.0122 .0157	.0140
F	.0272 .0291	.0282	.0110	.0110 .0100	.0105	.0062 .0040	.0051	.0049 .0041	.0045
G	.0352 .0389	.0370	.0344	.0211 .0252	.0232	.0212 .0231	.0222	.0038 .0085	.0062
H	.0191 .0256	.0224	.0067	.0015 .0015	.0015	.0014 .0015	.0014	.0010 .0006	.0008
J	.0323 .0364	.0344	.0164	.0126 .0178	.0152	.0089 .0070	.0080	.0036 .0061	.0048
K	.0373 .0394	.0384	.0275	.0178 .0201	.0190	.0130 .0140	.0135	.0127 .0098	.0112
L	.0304 .0264	.0284	.0166	.0064 .0074	.0069	.0019 .0020	.0020	.0050 .0086	.0068
M	.0202 .0289	.0246	.0152	.0017 .0017	.0017	.0009 .0009	.0009	.0009 .0023	.0016
N	.0325 .0339	.0332	.0365	.0328 .0289	.0308	.0259 .0309	.0284	.0267 .0199	.0233
O	.0360 .0362	.0361	.0371	.0295 .0292	.0294	.0280 .0255	.0268	.0120 .0144	.0132
P	.0099 .0089	.0094	.0117	.0013 .0021	.0017	.0012 .0011	.0012	.0009 .0008	.0008
Q	.0320 .0357	.0338	.0248	.0168 .0214	.0191	.0120 .0121	.0120	.0134	.0134
R	.0309 .0374	.0342	.0266	.0152 .0213	.0182	.0109 .0125	.0117	.0128 .0140	.0134
S	.0321 .0403	.0362	.0295	.0044 .0031	.0038	.0019 .0022	.0020	.0033 .0047	.0040
T	.0289 .0255	.0272	.0231	.0041 .0033	.0037	.0012 .0014	.0013	.0015 .0014	.0014
U	.0027 .0047	.0037	.0009	.0002 .0003	.0003	.0004 .0003	.0004	.0003 .0003	.0003
V	.0344 .0349	.0346	.0232	.0180 .0238	.0209	.0209 .0189	.0199	.0167 .0149	.0158
W	.0230 .0283	.0256	.0154	.0062 .0072	.0067	.0086 .0060	.0073	.0034 .0017	.0026
X	.0223 .0249	.0236	.0147	.0015 .0013	.0014	.0009 .0011	.0010	.0033 .0026	.0030
Z	.0472 .0445	.0458	....	.0266 .0267	.0267	.0224 .0287	.0256	....	....

TABLE XVI—*Continued*

SUMMARY OF TEST DATA ON ASPHALT AND OTTAWA SAND MIXTURES
85-100 PENETRATION ASPHALTS

NOTE.—Duplicate tests shown represent separate mixtures each weathered independently.

ASPHALT	TENSION POUNDS PER SQUARE INCH AT 35° F								
	Unweathered Mixtures		22 Hrs., 180° F. Nitrogen	22 Hrs., 180° F. Air		22 Hrs., 180° F. Ultraviolet Light		1 Yr. Natural Weathering	
	Dup.	Aver.		Dup.	Aver.	Dup.	Aver.	Dup.	Aver.
A	76.2 80.4	78.3	103.4	111.4 114.8	113.1	110.5 100.5	105.5	80.0 86.0	83.0
B	98.0 97.5	97.8	107.0	78.5 85.3	81.9	76.9 81.2	79.0	53.6 49.6	51.6
C	89.0 76.1	82.6	87.3	126.9 121.3	124.1	110.0 108.9	109.4	78.4 80.6	79.5
D	86.7 76.9	81.8	82.7	112.1 106.8	109.5	107.6 116.1	111.9	77.9 82.2	80.1
E	95.7 87.4	91.6	92.0	117.9 117.5	117.7	111.0 119.1	115.0	76.9 71.1	74.0
F	64.1 60.3	62.2	72.5	82.9 71.2	77.1	62.4 67.2	64.8	48.4 42.7	45.6
G	96.2 97.8	97.0	89.4	120.7 129.8	125.3	121.0 111.6	116.3	66.6 74.6	70.6
H	124.6 128.6	126.6	129.6	98.6 111.4	105.0	89.1 91.0	90.0	70.3 59.6	65.0
J	96.9 92.0	94.4	123.4	130.1 128.5	129.3	127.0 122.0	124.5	66.0 92.0	79.0
K	78.4 69.8	74.1	96.6	117.0 109.4	113.2	109.5 100.1	104.8	79.2 75.9	77.6
L	79.7 83.3	81.5	103.0	118.8 124.5	121.7	95.4 96.8	96.1	76.7 82.3	79.5
M	97.3 101.3	99.3	125.9	113.7 116.8	115.3	86.2 84.8	85.5	52.3 63.3	57.8
N	60.7 59.3	60.0	72.6	77.6 75.4	76.5	68.8 76.9	72.8	60.1 52.6	56.4
O	68.6 72.3	70.4	93.7	108.9 100.2	104.6	99.7 116.4	108.0	65.9 64.3	65.1
P	139.1 124.3	131.7	146.7	119.1 120.8	120.0	97.7 105.0	101.4	45.5 54.6	50.0
Q·	111.4 98.5	105.0	113.4	130.6 130.6	130.6	124.6 125.1	124.8	90.9	90.9
R	98.6 78.0	88.3	104.2	123.6 120.6	122.1	114.0 120.7	117.3	80.0 78.4	79.2
S	116.3 108.2	112.2	132.9	108.6 119.6	114.1	99.7 106.5	103.1	79.9 84.2	82.0
T	112.2 117.9	115.0	118.2	138.2 120.8	129.5	95.4 106.9	101.2	55.8 63.9	59.8
U	100.2 115.2	107.7	96.0	66.4 63.2	64.8	74.6 67.0	70.8	46.4 49.7	48.0
V	76.8 93.9	85.4	114.7	137.7 123.2	130.5	119.0 140.0	129.5	87.4 87.9	87.7
W	117.0 117.6	117.3	130.4	109.6 130.6	120.1	123.1 133.4	128.2	93.0 59.4	76.2
X	79.5 79.2	79.4	85.0	75.4 74.0	74.7	58.8 70.6	64.7	49.2 62.7	56.0
Z	54.7 54.3	54.5	....	86.7 84.9	85.8	86.0 83.4	84.7	....	....

TABLE XVI—*Continued*

SUMMARY OF TEST DATA ON ASPHALT AND OTTAWA SAND MIXTURES
85-100 PENETRATION ASPHALTS

NOTE.—Duplicate tests shown represent separate mixtures each weathered independently.

| | SHEAR POUNDS PER SQUARE INCH 35° F. | | | | | | | SHEAR POUNDS PER SQUARE INCH 77° F. | | | | |
| | Unweathered Mixtures | | 22 Hrs. 180° F. Nitrogen | 22 Hrs. 180° F. Air | | 22 Hrs. 180° F. Ultra-violet Light | | Un-weathered Mixtures | 22 Hrs. 180° F. Air | | 22 Hrs. 180° F. Ultra-violet Light | |
ASPHALT	Dup.	Aver.		Dup.	Aver.	Dup.	Aver.		Dup.	Aver.	Dup.	Aver.
A	69.0 68.5	68.8	93.9	102.6 107.0	104.8	94.1 90.2	92.2	15.7	36.6 28.7	32.7	30.6 29.8	30.2
B	99.2 101.0	100.1	128.3	96.0 105.7	100.9	68.7 67.2	68.0	27.1	62.6 64.3	63.5	49.9 52.4	51.2
C	70.2 68.6	69.4	92.8	100.0 113.4	106.7	82.7 95.5	89.1	17.6	41.7 37.8	39.8	33.7 34.4	34.0
D	67.2 65.6	66.4	91.2	95.5 108.3	101.9	88.1 107.8	98.0	13.2	33.2 25.8	29.5	29.2 29.8	29.5
E	70.6 76.5	73.6	92.8	96.5 116.5	106.5	90.9 104.7	97.8	12.9	32.7 26.6	29.7	28.6 34.3	31.4
F	60.6 60.6	60.6	67.4	71.5 76.5	74.0	60.1 60.5	60.3	14.1	37.9 34.8	36.4	26.5 27.9	27.2
G	78.8 93.2	86.0	75.7	104.7 116.5	110.6	104.4 97.7	101.0	15.2	34.1 27.1	30.6	27.5 25.8	26.6
H	116.0 113.8	114.9	134.0	138.7 157.2	148.0	120.0 119.8	119.9	23.6	55.2 52.6	53.9	44.4 37.0	40.7
J	86.0 77.3	81.6	103.0	114.8 123.5	119.2	110.9 94.8	102.8	23.8	38.7 36.3	37.5	34.7 33.5	34.1
K	60.4 65.3	62.8	92.2	97.1 115.2	106.2	101.6 86.2	93.9	20.6	39.1 36.8	38.0	36.0 30.8	33.4
L	68.1 67.5	67.8	96.5	89.4 115.2	102.3	81.2 85.2	83.2	12.4	45.1 54.4	49.8	49.8 39.2	44.5
M	89.0 82.2	85.6	106.6	124.5 131.6	128.1	97.0 73.2	85.1	18.9	59.4 71.3	65.4	68.5 51.3	59.9
N	58.0 59.0	58.5	69.9	64.5 75.1	69.8	70.6 72.6	71.6	11.3	24.8 17.8	21.3	16.9 14.1	15.5
O	67.1 67.5	67.3	86.0	85.8 107.4	96.6	85.6 106.9	96.2	12.6	28.0 29.3	28.7	26.3 27.7	27.0
P	133.6 118.0	125.8	129.2	167.8 132.0 138.2	146.0	121.6 126.0	123.8	24.8	53.8 50.2	52.0	57.5 53.6	55.6
Q	88.9 95.6	92.2	93.0	112.2 116.3	114.3	107.0 116.0	111.5	18.9	40.6 31.4	36.0	43.5 36.0	39.8
R	86.6 71.1	78.8	91.8	105.2 110.5	107.9	107.5 112.0	109.8	20.4	39.4 34.0	36.7	37.9 34.2	36.0
S	107.1 91.5	99.3	108.6	140.0 129.3 159.1	134.7	138.2 112.4	125.3	23.6	53.9 54.0	54.0	75.7 58.4	67.0
T	101.0 93.6	97.3	105.5	121.2 137.9	139.4	118.0 118.1	118.0	25.1	54.6 59.8	57.2	65.8 69.7	67.8
U	105.0 106.0	105.5	104.7	68.6 79.2	73.9	58.0 73.6	65.8	34.1	61.8 96.5	79.2	64.0 80.2	72.1
V	74.4 78.2	76.3	87.2	95.8 108.3	102.1	97.9 127.0	112.4	18.1	36.0 34.0	35.0	34.0 39.4	36.7
W	98.5 95.8	97.2	100.0	107.8 129.6	118.7	110.2 128.0	119.1	23.6	44.2 45.0	44.6	41.1 50.1	45.6
X	72.7 69.4	71.0	81.9	63.5 70.4	67.0	59.6 66.9	63.3	24.3	40.9 37.6	39.3	40.7 38.1	39.4
Z	63.4 62.9	63.2	....	87.2 82.5	84.9	87.3 88.7	88.0	12.6	25.9 23.0	24.5	26.2 27.0	26.6

TABLE XVI—*Continued*

SUMMARY OF TEST DATA ON ASPHALT AND OTTAWA SAND MIXTURES
85-100 PENETRATION ASPHALTS

NOTE.—Duplicate tests shown represent separate mixtures each weathered independently.

Asphalt	Density 1—Air Voids		Penetration at 77° F. 100 Grams 5 Seconds (Recovered by Abson Method)								Per Cent Insol. in Naphata Recovered After 22 Hrs. 180° F. + Ultraviolet Light	
	Unweathered	22 Hrs. 180° F. Ultraviolet Light	Original	Fluxed with Benzene	Mixed at 250° F. 5 Min.	After 22 Hrs. 180° F.	After 22 hrs. At 180° F. + Ultraviolet Light Dup.	Aver.	After 1 Yr. Natural Weathering Dup.	Aver.	Dup.	Aver.
A	63.51	65.22	86.5	73	72	38	24 / 24	24	32 / 29	30.5	38.1 / 38.5	38.3
B	62.49	64.69	98	83	81	23	10.5 / 10.5	10.5	15 / 15.5	15.3	36.6 / 36.4	36.5
C	63.55	65.60	86	80	74	40	25 / 24	24.5	29 / 29	29	38.5 / 38.3	38.4
D	63.48	66.57	90	87	86	50	30 / 34	32	34 / 35	34.5	25.9 / 25.8	25.8
E	63.31	66.19	85	83	81	46	27 / 30	28.5	30 / 35	32.5	27.5 / 27.4	27.4
F	63.23	64.66	81	70	68	28	24 / 20	22	20 / 18	19	36.3 / 36.5	36.4
G	63.68	66.47	90	83	84	46	34 / 37	35.5	39 / 32	35.5	29.5 / 28.7	29.1
H	63.08	65.87	87	71	72	30	21 / 20	20.5	20 / 19	19.5	30.9 / 31.5	31.2
J	63.24	65.92	86	83	72	38	24 / 23.5	23.8	22 / 23	22.5	30.7 / 30.2	30.4
K	63.72	65.36	80	74	74	38	24 / 24	24	33 / 24	28.5	37.8 / 37.8	37.8
L	63.56	63.88	92	84	92	23	18 / 17	17.5	28 / 25	26.5	48.1 / 47.7	47.9
M	63.69	64.53	86	74	72	18	12 / 12	12	20 / 17	18.5	38.4 / 38.7	38.6
N	63.72	65.92	95	89	94	68	52 / 51	51.5	49 / 52	50.5	24.3 / 24.5	24.4
O	63.36	66.06	91	82	85	50	35 / 35	35	30 / 34	32	29.7 / 30.0	29.8
P	63.67	66.36	87	85	86	33	21 / 21	21	19 / 21	20	23.4 / 23.3	23.4
Q	63.62	65.60	90	78	80	40	27 / 28	27.5	26 / 29	27.5	32.7 / 32.7	**32.7**
R	63.61	65.39	91	78	76	37	29 / 29	29	30 / 29	29.5	35.3 / 35.0	35.2
S	63.82	65.48	93	90	80	30.5	18 / 14	16	22 / 23	22.5	37.0 / 37.0	37.0
T	63.47	65.48	83	67	70	28	21 / 14.5	17.8	19.5 / 23	21.2	36.0 / 35.8	35.9
U	63.37	64.93	82	64	61	14	9 / 6	7.5	9 / 11	10	40.7 / 40.9	40.8
V	63.58	65.74	92	83	77	35	31 / 28	29.5	30.5 / 25	27.8	....	32.4
W	63.24	65.01	86	81	76	32	19 / 19	19	23.5 / 16	19.8	....	32.3
X	62.81	63.44	86	66	58.5	16	14 / 9	11.5	16 / 15	15.5	40.2 / 41.1	40.6
Z	....	....	100	97	91	50	40 / 42.5	41.2	....	....	....	....

TABLE XVII

SUMMARY OF TEST DATA ON ASPHALT AND OTTAWA SAND MIXTURES
50-60 PENETRATION

NOTE.—Duplicate tests shown represent separate mixtures each weathered independently

ASPHALT	ABRASION PER CENT LOSS 60° F.				IMPACT RESISTANCE GRAM CMS. 35° F.			
	Unweathered Mixtures		22 Hrs. 180° F. Ultraviolet Light		Unweathered Mixtures		22 Hrs. 180° F. Ultraviolet Light	
	Dup.	Aver.	Dup.	Aver.	Dup.	Aver.	Dup.	Aver.
C-50	5.8 8.4	7.1	10.8 12.6	11.7	1220 1260	1240	720 760	740
D-50	6.6 5.1	5.9	4.9 5.1	5.0	1720 1640	1680	1160 1140	1150
E-50	3.9 5.2	4.6	7.8 9.0	8.4	1560 1640	1600	1140 1200	1170
G-50	5.6 7.5	6.6	7.6 6.8	7.2	1420 1260	1340	960 1000	980
H-50	13.1 16.6	14.9	15.5 20.0	17.8	880 900	890	660 620	640
L-50	6.5 5.9	6.2	24.4 26.2	25.3	1200 1220	1210	600 540	570
M-50	10.0 12.2	11.1	18.3 21.1	19.7	1040 1020	1030	500 600	550
N-50	7.1 8.4	7.8	9.3 7.8	8.6	1120 1180	1150	820 860	840
O-50	3.9 4.9	4.4	6.1 4.0	5.1	1780 1780	1780	1160 1230	1195
P-50	9.9 13.1	11.5	13.8 16.0	14.9	740 820	780	620 560	590
Q-50	5.6 5.5	5.6	13.3 10.0	11.7	1400 1780	1590	860 980	920
R-50	6.4 7.8	7.1	13.5 9.5	11.5	1560 1380	1470	920 880	900
S-50	6.6 7.0	6.8	17.9 18.1	18.0	800 960	880	640 720	680
T-50	11.0 10.9	11.0	15.0 16.2	15.6	800 880	840	560 700	630
U-50	20.6 26.6	23.6	28.4 33.0	30.7	540 600	570	575 660	617
V-50	6.3 6.1	6.2	7.3 11.5	9.4	1360 1540	1450	940 1040	990
W-50	11.0 11.0	11.0	14.8 19.0	16.9	1120 960	1040	720 760	740
X-50	9.1 8.3	8.7	27.4 27.8	27.6	1100 1040	1070	600 580	590
Y-50	8.0 6.2	7.1	10.1 12.4	11.3	1300 1240	1270	1000 980	990

TABLE XVII—*Continued*

SUMMARY OF TEST DATA ON ASPHALT AND OTTAWA SAND MIXTURES
50-60 PENETRATION

NOTE.—Duplicate tests shown represent separate mixtures each weathered independently.

ASPHALT	ELONGATION INCHES 35° F.				TENSION LBS./SQ. IN. 35° F.				SHEAR LBS./SQ. IN. 35° F.			
	Unweathered Mixtures		22 Hrs. 180° F. Ultra-violet Light		Unweathered Mixtures		22 Hrs. 180° F. Ultra-violet Light		Unweathered Mixtures		22 Hrs. 180° F. Ultra-violet Light	
	Dup.	Aver.	Dup.	Aver.	Dup.	Aver.	Dup.	Aver.	Dup.	Aver.	Dup.	Aver.
C-50	.0285 .0291	.0288	.0038 .0049	.0044	101.5 100.1	100.8	97.0 112.0	104.5	105.8 88.6	97.2	102.8 81.4	92.1
D-50	.0332 .0292	.0312	.0146 .0124	.0135	88.0 92.3	90.2	118.1 109.6	113.9	83.4 83.5	83.5	95.4 119.0	107.2
E-50	.0269 .0259	.0264	.0083 .0085	.0084	82.3 86.5	84.4	90.7 96.6	93.6	91.1 77.8	84.5	98.5 98.0	98.3
G-50	.0233 .0230	.0232	.0061 .0089	.0075	122.3 109.6	115.9	138.8 129.6	134.2	115.0 110.2	112.6	123.6 134.3	129.0
H-50	.0015 .0012	.0014	.0008 .0008	.0008	88.9 78.4	82.2	83.3 80.0	81.7	134.3 129.2	131.8	93.0 84.2	88.6
L-50	.0196 .0181	.0189	.0007 .0009	.0008	90.6 86.3	88.5	70.7 74.7	72.7	70.8 83.7	77.3	60.0 62.7	61.4
M-50	.0223 .0234	.0229	.0005 .0003	.0004	112.4 107.1	109.8	78.6 63.2	70.9	100.0 96.3	98.2	61.5 66.5	64.0
N-50	.0349 .0321	.0335	.0131 .0127	0.129	117.6 100.9	109.3	140.2 119.8	130.0	101.0 96.6	98.8	125.0 105.3	115.2
O-50	.0417 .0384	.0400	.0154 .0172	.0163	71.1* 68.2	69.7	90.9 90.1	90.5	64.9 66.0	65.5	90.6 84.1	87.4
P-50	.0026 .0023	.0025	.0005 .0005	.0005	111.0 96.7	103.9	86.0 80.7	83.4	148.7 131.2	140.0	98.5 93.2	95.9
Q-50	.0381 .0340	.0361	.0040 .0031	.0036	96.3 94.9	95.6	109.8 88.1	98.9	90.0 91.2	90.6	109.2 108.6	108.9
R-50	.0289 .0252	.0271	.0057 .0037	.0047	·93.2 102.8	98.0	96.2 93.7	94.9	91.8 100.1	96.0	97.4 104.6	101.0
S-50	.0168 .0148	.0158	.0007 .0005	.0006	136.1 137.0	136.6	82.9 78.3	80.6	127.0 117.5	122.3	106.0 105.0	105.5
T-50	.0188 .0184	.0186	.0007 .0009	.0008	135.8 135.1	135.5	88.4 91.8	90.1	120.0 128.0	124.0	92.0 123.7	107.9
U-50	.0003 .0006	.0005	.0002 .0002	.0002	71.8 69.1	70.5	60.9 64.2	62.6	125.0 122.0	123.5	52.7 62.6	57.7
V-50	.0287 .0257	.0272	.0059 .0045	.0052	100.7 107.5	104.1	122.5 109.4	115.9	94.7 86.7	90.7	113.3 107.1	110.2
W-50	.0122 .0102	.0112	.0010 .0011	.0011	134.0 135.7	134.9	87.3 77.3	82.3	122.3 125.0	123.7	103.3 111.6	107.5
X-50	.0088 .0087	.0088	.0006 .0003	.0005	97.7 90.9	94.3	59.3 53.3	56.3	91.3 104.3	97.8	41.7 45.4	43.6
Y-50	.0258 .0242	.0250	.0070 .0044	.0057	119.6 113.6	116.6	140.8 123.3	132.1	100.4 111.7	106.1	154.5 134.4	144.5

TABLE XVII—*Continued*

SUMMARY OF TEST DATA ON ASPHALT AND OTTAWA SAND MIXTURES
50-60 PENETRATION

NOTE.—Duplicate tests shown represent separate mixtures each weathered independently.

ASPHALT	Shear Lbs./Sq. In. 77° F.				Penetration at 77°F. 100 Grams 5 Seconds					
	Unweathered Mixtures		22 Hrs. 180° F. Ultra-violet Light		(Recovered by Abson Method)					
					Original	From a Solution in Benzene	Mixed at 400° F. 5 Minutes	Mixed at Temp. for 31 Sec. Furol Vis. 5 Min.	22 Hrs. 180° F. Ultra-violet Light	
	Dup.	Aver.	Dup.	Aver.					Dup.	Aver.
C-50	27.6 23.6	25.6	52.7 45.0	48.9	61	53	28	28	15.5 19	17.3
D-50	22.2 22.4	22.3	39.9 48.3	44.1	54	53	42	41	28 25.5	26.8
E-50	22.1 20.1	21.1	42.6 41.2	41.9	54	54	32	39	20 22	21
G-50	21.6 26.5	24.1	49.5 49.1	49.3	54	50.5	37	35	24.5 25.5	25
H-50	35.9 38.8	37.4	77.0 77.7	77.4	51	50	25	29	14.5 13	13.8
L-50	16.2 22.7	19.5	47.5 62.7	55.1	57	53	24		14 14.5	14.3
M-50	23.2 22.7	23.0	84.1 94.3	89.2	52	46	18	21	12 12	12
N-50	23.3 20.0	21.7	38.5 39.4	39.0	54	52	41.5	42.5	30.5 31	30.8
O-52	17.2 15.7	16.5	33.9 34.4	34.2	58	56	44	42	25 27	26
P-50	40.0 31.3	35.7	86.2 87.4	86.8	53	45	30	33	14.5 13.5	14
Q-50	22.1 27.6	24.9	49.1 53.3	51.2	52	50	27	28	28 27	27.5
R-50	24.5 29.3	26.9	50.5 52.6	51.6	53	48	29	31	24 21.5	22.8
S-50	37.2 32.2	34.7	85.2 88.9	87.1	49	46	15	27	17 14.5	15.8
T-50	30.5 37.3	33.9	68.4 74.2	71.3	54	47	23	33	18 15.5	16.8
U-50	41.7 51.7	46.7	103.6 99.0	101.3	53	47	14.5	25	9 7	8
V-50	25.7 23.2	24.5	44.0 52.4	48.2	48	41	25	25	21 20	20.5
W-50	35.0 46.1	40.6	52.9 62.0	57.5	49	44.5	17	27	17 16	16.5
X-50	35.7 31.8	33.8	52.1 45.8	49.0	52	44.5	10.5	24	10 8	9
Y-50	27.7 24.5	26.1	49.3 55.0	52.2	60	61	26	36	20.5 21.5	21

TABLE XVIII
TESTS ON ORIGINAL ASPHALTS
85-100 PENETRATION

Asphalt	Specific Gravity 77°/77°	Spot Test Original	Spot Test 24 Hr. Res.	Xylene Equiv. (Original)	Flash Point °F.	200 Gms., 1 Min. 0° F.	10° F.	20° F.	32° F.	100 Gms., 5 Sec. 77° F.	50 Gms., 2 Sec. 115° F.	5 Hr. Res. 77° F.	Per Cent of Orig.	24 Hr. Res. 77° F.	Per Cent of Orig.	25 Hr. Res. ⅛" Films 77° F.	Per Cent of Orig.
A	1.038	Neg.	Neg.		500	3	7	15.5	27	86.5	240	75	87	56	65	24	28
B	1.081	Pos.	Pos.	95-100	495	0	1.5	6	9	98	325+	79	81	32	33	8	8
C	1.036	Neg.	Neg.		505	2.5	6	13.5	24	86	260	78	91	53	62	23	27
D	1.010	Neg.	Neg.		590	2	6	11.5	21	90	305	82	91	52	58	30	33
E	1.015	Sl. Pos.	Sl. Pos.	0- 5	570	2	5.5	12	20.5	85	303	77	91	52	61	25	29
F	1.043	Pos.	Pos.	45- 50	505	4	9.5	15	27	81	288	64	79	37	46	15	19
G	1.021	Neg.	Neg.		665	1.5	4	9	19	90	310	80	89	54	60	31	34
H	1.024	Pos.	Pos.	10- 15	610	0.5	3	6	13	87	340	73	84	46	53	19	22
J	1.009	Neg.	Neg.		620	2	5.5	9.5	19	86	323	64	74	54	63	21	24
K	1.037	Neg.	Neg.		500	2.5	5.5	11.5	17	80	215	68	85	49	61	23	29
L	1.174	Pos.[a]	Pos.	20- 25[a]	420	1.5	5	8	22	92	324	78	85	64	70	12	13
M	1.044	Pos.[a]	Pos.	10- 15[a]	405	1	4	10	19.5	86	320	61	71	40	46	9	10
N	.985	Neg.	Neg.		655	6	9	16	25	95	308	90	95	74	78	40	42
O	1.022	Neg.	Neg.		620	4	6.5	12	22	91	283	80	88	70	77	28	31
P	1.008	Neg	Neg.		515	0	1	4.5	13	87	345	74	85	44	51	14	16
Q	1.033	Neg.	Sl. Pos		595	2.5	4.5	11	17	90	335	79	88	50	56	17	19
R	1.038	Pos.	Pos.	5- 10	585	2.5	6	13	23	91	415	75	82	46	51	17	19
S	1.030	Neg.	Neg.		445	0.5	2.5	9.5	21	93	330	76	82	48	52	12	13
T	1.039	Neg.	Neg.		475	2	4	11	19	83	280	66	79	42	51	13	16
U	1.072	Pos.	Pos.	70- 75	395	0.5	2.5	7	13	82	328	52	63	24	29	5	6
V	1.007	Neg.	Neg.		640	3	6	12 5	20	92	310	81	88	48	52	24	26
W	1.039	Pos.	Pos.	25- 30	545	1.5	4.5	8	16	86	405	65	76	46	54	14	16
X	1.044	Pos.	Pos.	0- 85	440	3.5	7	13.5	22	86	320	58	67	39	45	8	9
Z	1.023	Neg.	Neg.		560	6.5	12.5	19	30.5	100	304	89	89	63	63		

[a] Asphalt dissolved in benzol, centrifuged and recovered.

TABLE XVIII—*Continued*

TESTS ON ORIGINAL ASPHALTS
85-100 Penetration

Asphalt	Furol Viscosity (Sec.) 225° F.[b]	275° F.	350° F.[b]	450° F.[b]	Fluidity Factor[c]	Log Absolute Viscosity in Poises 33° F.	60° F.	77° F.	122° F.[d]	Viscosity Index 33°-77° F.[e]	¼ Cm. per Min. 39.2° F.	5 Cm. per Min. 39.2° F.	60° F.	77° F.	5 Hr. Res. 60° F.	77° F.	24 Hr. Res. 60° F.	77° F.	Loss 325° F. 5 Hr. Per Cent	24 Hr. Per Cent	25 Hr. ⅛" Films Per Cent
A	1336	315	60.1	16.4	197	8.504	6.949	6.105	4.142	64.5	84.5	8.5	150+	150+	89	150+	66.5	101.5	.10	.35	1.60
B	201	48	16	9.8	−49	9.562	7.301	5.749	3.444	102.5	72	0	150+	150+	150+	150+	15	150+	.122	.66	2.74
C	1386	303	62.7	16.3	186	8.518	6.923	6.105	4.167	64.8	83.5	9.5	150+	150+	150+	150+	44	70	.109	.48	1.74
D	580	164	30.6	13.3	67	8.862	6.986	5.941	3.654	78.5	59.7	6	79	150+	150+	150+	27	150+	.061	.12	.37
E	492	131	30.5	13	39	8.952	7.175	6.002	3.876	79.3	19.5	5.5	55	141	119.5	110	13	150+	.095	.22	.51
F	386	95	20.7	11.9	11	8.756	7.198	6.257	4.012	67.2	9.2	6	16.8	118	9	49	4.5	6	.09	.36	.92
G	798	187	43.2	14.1	87	9.109	7.141	5.969	3.855	84.5	66.5	7.5	150+	150+	150+	150+	76	150	.20	*.079*	*.37*
H	440	110	25.4	12.4	20	9.478	7.538	6.058	3.707	92.0	40.2	0	150+	150+	150+	150+	45	150+	.037	.025	.09
J	586	145	30.3	13.1	51	9.350	7.354	5.999	3.796	90.2	35	4.2	129	137	68	134	12.8	150+	.083	.029	*.08*
K	1558	298	61.3	17.2	174	8.669	7.176	6.262	4.318	64.9	56.2	10	150+	150+	142	150+	61	129.5	.430	.308	1.39
L	805	201	42	16.6	100	8.761	7.100	5.987	3.960	74.5	20	7	69	150+	40	150+	25	60.5	.269	.525	4.27
M	605	146	32.4	14.1	52	8.713	7.109	5.999	3.951	72.9	40.2	12	77	97	43.5	101	4.8	16.8	1.259	4.33	7.41
N	837	180	36.3	14.8	81	8.755	7.020	6.070	4.003	72.2	13.5	7.2	18.5	114	10.5	100	9.5	39	.022	*.006*	*.22*
O	884	185	38.1	15	86	8.558	6.980	6.001	3.991	68.9	83	8.1	150+	150+	150+	150+	22.5	150+	.056	*.033*	*.28*
P	378	91	20.7	11.5	3	9.109	7.125	5.913	3.740	86.1	29.2	0	150+	150+	150+	150+	9.5	80	.183	.398	1.31
Q	610	137	27.6	13.3	42	8.829	7.085	5.979	3.827	76.6	56.3	5.2	150+	146	150+	150+	68	150+	.004	.009	*.19*
R	526	127	27.9	13.6	33	8.787	7.062	5.911	3.827	77.5	58	6	150+	150+	150+	150+	20.5	150+	.001	.011	*.27*
S	590	143	31.8	12.2	46	8.813	6.995	6.004	3.927	75.6	123.2	14	150+	150+	150+	150+	8.5	150+	.215	.187	4.84
T	674	166	32.5	14.2	69	8.976	7.095	5.977	3.932	80.6	32.2	7	150+	127	150+	150+	44	150+	.477	.425	2.18
U	336	86	19.6	12.3	3	9.253	7.181	5.991	3.811	87.6	32.2	2	150+	122	150+	150+	7	150+	.844	2.95	5.52
V	740	185	38.9	14.6	86	9.128	7.167	6.065	3.944	82.3	49	7	135	150+	135	150+	12.5	120	.138	.223	*.02*
W	390	97	21.6	12.5	9	9.368	7.248	5.932	3.720	92.4	48.2	0	150+	150+	122	150+	4.8	9.2	.219	.646	1.26
X	308	76	20.2	11.4	−9	8.891	7.009	6.018	3.807	77.2	17.2	6.8	137	150+	20	150+	4	7.8	.581	2.32	5.66
Z		219			119	8.640		6.000		71.0	50.3	6.8	113	150+	57	150+	18.3	97.8	.002	*.019*	......

Note.—Italicized figures represent gain.

[b] Values obtained by Federal Aid student.

[c] Fluidity factor $= \left(\dfrac{\text{Vis. } 275° \text{ F.} - \text{Pen. } 77° \text{ F.}}{100} \right) \left(\text{Pen. } 77° \text{ F.} \right)$

[d] From U. S. Bureau of Public Roads.

[e] Viscosity index $= \dfrac{\text{Log Vis. @ } T_1 - \text{Log Vis. @ } T_2}{\text{Log } T_2 - \text{Log } T_1}$ when $T =$ absolute temperature

TABLE XVIII—*Continued*

TESTS ON ORIGINAL ASPHALTS
85-100 PENETRATION

As-phalt	Soft. Point Ring and Ball, °F.	CS₂	CCl₄	Benzene	Insoluble in 86° Naphtha	Naphtha B.P.<50° C. Asphaltenes	Asphaltenes	Oils	Resins	Saponifiable Matter	Sulfur	Kjeldahl Nitrogen	Dumas Nitrogen	Sintering Pt. Naphtha B.P.<50° C.	Sintering Pt. Skelly Solve "A"	Density of Oils, 95° F.	Viscosity 95° F.	Viscosity 125° F.	Viscosity Index	Refractive Index	Molecular Weight Oil
A	122	99.76	99.90	99.89	26.52	22.51	25.18	41.52	33.30	0.38	6.10	0.503	0.93	499	472	.9473	29.37	6.857	27.6	1.5328	576
B	112	99.82	99.75	99.10	21.01	14.66	17.21	44.06	38.73	0.31	2.36	0.546	0 53	552	530	.9884	36.34	3.990	41.9	1.5697	442
C	122	99.84	99.93	99.97	24.79	20.91	24.40	51.55	24.05	0.51	5.95	0.543	1.33	506	478	.9555	20.25	5.305	25.4	1.5364	590
D	114	99.48	99.31	99.60	16.73	12.26	15.49	53.53	30.98	0.38	2.92	0.466	1.33	528	488	.9334	37.07	8.543	27.9	1.5253	783
E	114	99.51	99.36	99.40	17.06	13.83	16.18	43.92	39.90	0.34	2.71	0.423	1.56	540	482	.9133	29.04	7.529	25.6	1.5222	712
F	119	99.84	99.62	99.78	25.55	20.31	23.34	44.73	31.93	0.31	3.03	0.235	0.99	583	536	.9618	10.84	2.944	24.7	1.5484	457
G	115	99.80	99.84	99.87	16.51	13.44	17.28	44.17	38.55	0.10	3.93	0.280	1.77	539	489	.9295	45.64	8.653	31.5	1.5226	781
H	114	99.82	99.81	99.49	14.73	12.48	15.87	49.83	34.30	Trace	3.41	0.476	2.64	552	488	.9599	44.37	9.559	29.2	1.5370	699
J	113	99.83	99.78	99.70	15.91	....	16.21	47.29	36.50	0.07	2.44	0.497	1.58	....	503	.9160	18.94	7.294	18.1	1.5220	757
K	123	99.91	99.88	99.92	23.81	....	25.32	44.25	30.43	0.25	6.02	0.402	2.16	....	460	.9502	17.59	3.409	31.0	1.5335	520
L	118	77.56	72.90	81.55	37.88	....	22.78ᶠ	44.58ᶠ	32.64ᶠ	2.14ᶠ	3.67	0.522	1.59	....		.9346	19.40	4.801	26.5	1.5246	546
M	117	97.83	97.12	97.87	24.08	....	22.68ᶠ	42.37ᶠ	34.95ᶠ	1.64ᶠ	4.05	0.741	2.90	....	472	.9502	6.02	2.747	14.9	1.5336	516
N	119	99.86	99.81	99.75	17.14	....	16.16	52.80	31.04	0.16	0.58	0.534	1.88	....	590	.9049	20.47	5.632	24.5	1.5043	964
O	114	99.86	99.97	99.83	18.74	....	18.75	40.39	40.86	0.25	3.64	0.381	0.60	....	510	.9287	24.13	12.03	13.2	1.5267	651
P	114	99.98	99.99	99.91	8.82	....	10.31	38.92	50.77	0.37	1.39	0.847	4.57	....	447	.9392	133.8	8.750	51.7	1.5253	513
Q	114	99.99	99.99	99.60	20.95	....	19.14	44.29	36.57	0.07	4.37	0.647	0.83	....	509	.9229	265.2	10.84	60.6	1.5245	692
R	113	99.99	99.90	99.65	21.79	....	21.06	40.50	38.44	0.19	4.34	0.626	0.63	....	496	.9436	309.29	25.59	47.2	1.5335	614
S	113	99.99	99.98	99.99	21.61	....	22.13	41.92	35.95	0.77	4.87	0.862	0.63	....	425	.9545	20.55	13.62	7.8	1.5356	466
T	115	100.00	100.00	99.99	20.20	....	20.53	45.67	33.80	0.17	5.30	0.515	0.58	....	485	.9539	78.90	17.18	28.9	1.5408	713
U	113	99.99	99.93	99.92	24.20	....	22.19	39.23	38.58	0.11	3.52	0.516	0.28	....	476	.9636	14.53	3.800	25.4	1.5668	460
V	116	99.77	99.61	99.37	18.33	....	17.97	42.14	39.89	0.09	0.93	0.468	1.69	....	552	.9171	211.3	20.62	44.1	1.5162	835
W	112	99.76	99.69	99.52	18.47	....	16.52	49.82	33.66	0.08	0.97	0.533	1.72	....	539	.9481	115.4	20.49	32.8	1.5448	607
X	113	99.87	99.88	99.80	25.40	....	21.91	44.96	33.13	0.26	0.47	0.449	1.58	....	592	.9490	26.92	9.823	19.1	1.5446	545
Z	117	99.68	99.60	99.19	27.08	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

ᵉ Viscosity index $= \dfrac{\text{Log Vis. @ } T_1 - \text{Log Vis. @ } T_2}{\text{Log } T_2 - \text{Log } T_1}$ when T = absolute temperature.

ᶠ Based on part soluble in CS₂.

ᵍ By Department of Organic Chemistry, University of Minnesota.

TESTS ON ORIGINAL ASPHALTS
50 - 60 PENETRATION

TABLE XIX

ASPHALT	SPECIFIC GRAVITY 77°/77°	SPOT TEST ORIGINAL	SPOT TEST 24 HR. RES.	XYLENE EQUIV. (ORIGINAL)	FLASH POINT °F.	PEN 200 GMS 1 MIN 0°F.	10°F.	20°F.	32°F.	PEN 100 GMS 5 SEC 77°F.	PEN 50 GMS 2 SEC 115°F.	PEN 5 HR. RES. 77°F.	%of brig	PEN 24 HR. RES. 77°F.	%of brig	FUROL VISC 225°F.	275°F.	350°F.	450°F.	FLUIDITY FACTOR	DUCT % CM PER MIN 39.2°F.	5 CM PER MIN 39.2°F.	60°F.	77°F.	5 HR. RES. 60°F.	77°F.	24 HR. RES. 60°F.	77°F.	LOSS 325°F 5 HR. %	24 HR. %	SOFT POINT RING&BALL °F.	SOLUB CS₂	CCl₄	BENZENE	INSOL IN 86° NAPTHA	PEN AFTER STIRRING 200 GMS 1 MIN 32°F.	100 GMS 5 SEC 77°F.	50 GMS 2 SEC 115°F.
C-50	1.043	NEG.	NEG.		530	2	7	10.5	23	61	181	49.	80	36	59	1713	327	60.1	17.0	162	22.0	4.6	150+	150+	54.8	150+	9.3	102.7	.103	.281	129	99.67	99.61	99.72	27.31	16	25	
D-50	1.008	NEG.	NEG.		655	1.5	8.5	11	19	54	172	49	91	46	85	943	209	36.4	14.3	83	8.9	4.1	18.0	150+	14.4	150+	8.5	150+	.045	.105	127	99.41	99.38	99.38	19.66	17	30	57
E-50	1.019	POS.	POS.	10-15	545	1.5	6	11	19	54	166	50	93	38	70	766	151	30.2	13.5	52	6.6	3.5	9.3	84	8.0	63	4.6	12.0	.143	.445	127	99.26	99.36	99.36	22.06	15	25	45
G-50	1.024	NEG.	NEG.		675	0	2	7	14	54	200	52	96	42	78	1341	271	48.8	16.0	118	11.4	2.1	93.1	150+	24.3	150+	9.5	150+	.012 (GAIN)	.078 (GAIN)	122	99.73	99.65	99.72	19.02	10	26	68
H-50	1.033	POS.	POS.	10-15	610	0	1.5	4	9	51	210	49	96	35	69	921	177	33.9	13.8	64	8.3	0	62.6	150+	32.9	150+	7.8	150+	.026	.020	122	99.54	99.41	99.48	18.81	7	25	75
L-50	1.203				400	0.5	3	7.5	19	57	183	50	88	36	63						16.8	2.6	39.0	91	23.9	72	10.5	51.8	.525	1.650	122	73.56	73.19	72.67	43.82	7	18	54
M-50	1.054				415	0	1.5	7	15	52	182	40	77	26	50	1173	220.	42.0	14.7	91	18.6	0.1	54.3	75	19.5	63	6.3	18.1	.998	2.765	122	96.70	96.24	96.34	26.29	6	16	24
N-50	1.001	NEG.	NEG.		685	0.5	4.5	8	14.5	54	173	53	98	44	82	1351	265	46.2	15.2	115	13.1	0.6	46.5	150+	37.3	150+	15.8	150+	.018	.014	130	99.53	99.60	99.70	18.23	17	35	94
O-50	1.021	NEG.	NEG.		600	4	7.5	16.5	23.5	56	150	54	93	45	78	1687	325	53.5	17.0	155	13.8	4.5	26.5	141	18.4	150+	8.8	86.7	.018	.002 (GAIN)	129	99.38	99.50	99.64	23.93	19	31·	60
P-50	1.014	NEG.	NEG.		555	0	1	3.5	10.5	53	238	48	91	33	62	577	116	24.5	12.3	34	68+	0.1	150+	150+	150+	150+	150+	150+	.063	.184	120	99.68	99.73	99.75	11.79	8	23	101
Q-50	1.032	NEG.	NEG.		575	1	7	10	16.5	52	172	48	92	36	69	1202	216	38.5	14.6	86	12.4	3.8	43.7	150+	20.1	150+	6.5	62.6	.010	.013 (GAIN)	127	99.69	99.64	99.45	25.17	12	25	49
R-50	1.034	POS.	POS.	5-10	565	0	5.5	10	16	53	160	48	91	33	62	1110	217	40.2	14.5	87	14.4	4.5	48.6	150+	18.1	150+	5.3	39.4	.004	.030 (GAIN)	126	99.69	99.68	99.55	25.77	13	26	58
S-50	1.036	NEG.	NEG.		470	0	1.5	5.5	14	49	196	42	86	30	61	1073	214	38.2	14.3	81	68+	1.9	150+	150+	150+	150+	10.5	150+	.247	.900	120	99.73	99.57	99.76	23.26	6	23	77
T-50	1.039	NEG.	NEG.		535	1	2	6.5	14	54	211	46	85	34	63	1154	210	38.8	14.7	84	66.8	0.3	150+	150+	150+	150+	24.9	150+	.158	.437	124	99.71	99.67	99.79	20.76	8	25	70
U-50	1.079	POS.	POS.	55-60	480	0	0.5	2	6	53	244	42	79	26	49	383	74	18.3	11.0	11	0	0.1	150+	150+	150+	150+	0'	150+	.283	.797	122	99.67	99.74	99.77	20.15	4	19	82
V-50	1.011	NEG.	NEG.		650	0.5	1.5	8	15	48	139	44	92	32	67	1658	315	49.5	16.3	129	7.3	0.3	12.0	138	10.3	74	4.5	13.0	.031	.013	120	99.56	99.47	99.36	21.21	9	23	45
W-50	1.026	POS.	POS.	50-55	540	0	0.5	5.5	9	49	218	41	84	22	45	515	112	23.9	12.9	31	9.5	0.1	24.3	150+	13.9	150+	4.3	13.8	.182	.508	123	99.56	99.55	99.43	19.62	7	17	39
X-50	1.061	POS.	POS.	90-95	450	1	1.5	5.5	13.5	52	203	36	65	19	37	474	96	20.1	11.3	23	24.0	0	150+	150+	17.8	150+	0.5	9.6	.495	1.625	127	99.32	98.82	98.08	26.01	8	15	33
Y-50	1.007	NEG.	NEG.		645	0.5	3.5	7.5	16	60	189	53	88	38	63	1074	221	42.2	15.3	97	7.9	0.3	39.6	150+	13.8	150+	6.1	.30.9	.023 (GAIN)	.032 (GAIN)	120	99.56	99.56	99.57	17.69	14	29	59

*Fluidity Factor = $\dfrac{\text{Vis.275°F.} - \text{Pen.77°F.}}{100}$ (Pen.77°F.)