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# A LABORATORY STUDY OF RUBBER-ASPHALT MIXTURES FOR PAVEMENTS
(With Supplementary Tests)

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Highway Research Project 46 D-14

Research Laboratory
Testing and Research Division
Report No. 163-a
February 10, 1952

# A LABORATORY STUDY OF RUBBER - ASPHALT MIXTURES FOR PAVEMENTS

Various experimental rubber-asphalt type pavements have been installed in several foreign countries as well as in the United States, but very little laboratory work has been reported along these lines. The present study, therefore, was undertaken to determine the effects of relatively low concentrations of natural rubber, GR-S, and scrap vulcanized rubber on some physical properties of an asphalt cement and an asphalt concrete. The end effects desired were an asphalt concrete with higher stability and resistance to deformation (rutting and shoving), lower temperature susceptibility, and higher elasticity (recovery after deformation).

An attempt was made to correlate physical properties of rubber-asphalt cements with rubber type, rubber concentration, and the temperature at which the rubber and asphalt were mixed. In the study of rubber-asphalt concretes the investigation included variations in rubber type and content and variations in bituminous cement concentration (asphalt or rubber-asphalt), as well as a comparison of methods of incorporating rubber into the asphalt concrete.

The results of the investigation indicated that the addition of GR-S, natural rubber, or scrap rubber to an asphalt cement increased its elasticity and resistance to deformation, and decreased its temperature susceptibility. Furthermore, there were definite indications that the rubber in natural rubber-asphalt cements did, under certain conditions, produce asphalt concretes having increased stability. A significant fact uncovered by the investigation is that stability of asphalt concretes can be maintained with asphalt cement contents somewhat higher than those used in present mix designs by the blending of small amounts of natural rubber with the asphalt prior to mixing the concrete.

Following a brief description of materials and methods, this report comprises two main divisions: the study of rubber-asphalt cements, and the study of rubber-asphalt concretes. Under each subject is included a description of the experimental procedures used, the results of these experiments, and a discussion of the results. A more detailed summary of the most significant results is given at the conclusion of the paper.

## MATERIALS AND METHODS

In addition to using the standard ductility and penetration tests for asphalt cements and the Marshall stability test for asphalt concretes, a torsion test was developed for measuring the resistance of asphalt cements to deformation by twisting, and also for measuring the amount of elastic recovery after twisting a specimen. The torsion test was adapted to this investigation because it was felt that increased resistance to deformation and increased elasticity of asphalt cements would be definite improvements, and so these properties should be measured.

The asphalt used in this investigation was an 85-100 penetration SOA asphalt cement manufactured by the Lion Oil Company. The natural rubber was a powdered latex furnished by the Natural Rubber Bureau in Washington, D. C. The GR-S was a powdered latex furnished by the Goodyear Tire and Rubber Company of Akron, Ohio. The scrap rubber consisted of finely groud treads from scrap automobile tires and comprised about a 50-50 mixture of GR-S and natural rubber stock, according to the Xylos Rubber Company of Akron, Ohio, who furnished the material.

The aggregates used in the asphalt concrete studies were limestone, natural sand, and limestone dust (mineral filler), meeting Michigan State Highway Department specifications, and were all obtained from the Midland Contracting Company at Bay City, Michigan.

## RUBBER-ASPHALT CEMENTS

### Experimental Details

The preparation of the rubber-asphalt cements examined in this investigation, as well as those used in some of the experimental rubber-asphalt concretes, was carried out in the following manner: a weighed amount of asphalt was heated slowly in a No. 10 metal can on a Lindberg electric hot plate. In order to prevent localized overheating, the temperature was kept relatively low until the asphalt reached a liquid state, after which the temperature was gradually increased. This was carried out with almost constant stirring. At no time was the temperature of the hot plate raised higher than was necessary for the asphalt to reach the desired temperature. After the asphalt reached the desired temperature, the powdered rubber material was added as rapidly as possible with constant agitation, and the container immediately removed from the hot plate. In order to prevent settling or floating of the rubber material, the hot mixtures were stirred until the viscosity became too great for movement of the rubber particles. The mixture was then set aside to stand overnight.

In order to isolate the effects of rubber addition from possible heat effects, double controls of straight asphalt cement were tested along with the rubber-asphalt mixtures. One control was heated in the previously described manner, but without the addition of rubber, while the other control was tested, as received, without rubber or heat treatment other than that necessary to melt the sample.

The rubber-asphalt cements thus prepared were tested for hardness, ductility, twisting time, and elasticity. Hardness was determined at 68, 77, and 86° F. with a standard "Precision" penetrometer by measuring the depth of penetration of a needle in five seconds under a load of 100 grams (ASTM Designation: D5). Since it was not possible to use a very broad temperature range and test penetration under identical conditions of load and time, e.g., 100 grams for five seconds, the comparatively narrow range of 68, 77, and 86° F. was used.

Ductility was measured at 77° F. at a speed of five cm. per minute, according to ASTM Designation: D113.

For the twisting and elasticity test a 2- by 2- by 8-inch molded specimen of the cement was suspended vertically in a 68° F. water bath. The lower end of the specimen was capped with a brass cup one inch deep which was rigidly fastened to the framework of the apparatus. The upper end of the specimen was capped with a similar cup, which was rigidly fastened to the axle of a horizontal pulley of 3-inch radius. This pulley axle turned freely in the framework on ball bearings.

A torque was applied to the upper end of the specimen by means of a 100-gram weight attached to a string which passed over a small vertical ball-bearing pulley and around the circumference of the horizontal pulley. The number of seconds necessary to twist the specimen through an angle of 180° was recorded as "twisting time," and regarded as a measure of resistance to deformation. The number of degrees recovery which the specimen made after the weight was removed was computed as percent recovery from the 180° twist, and was regarded as a measure of the elasticity of the material at 68° F. Photographs of the torsion apparatus and a partially twisted specimen are shown in Figure 1.

Test specimens of asphalt, GR-S-asphalt, and scrap rubber-asphalt cements were molded at 150 to 175 degrees F. Molding temperatures for natural rubber-asphalt cements ranged from 150 to 195 degrees F., because of higher viscosities of some of these materials. In each case the molding temperature was the minimum temperature at which the material would pour readily without lumps or entrapped air.

Left, Torsion
test apparatus

Right, Torsion test
specimen twisted
through about a 90°
angle

Figure 1

Rubber-asphalt mixtures were based on 100 parts by weight of asphalt with 0, 2.5, and 5 parts of natural rubber or GR-S. When scrap rubber was used, mixtures up to 10 parts per hundred were included, since the rubber scrap contained only about 50 percent rubber. Mixing temperatures were 250, 300, 350, and 400 degrees F.

Results and Discussion

The results of the tests on all the rubber-asphalt blends are given in Table I and the graphs in Figures 2, 3, 4, and 5.

The addition of any of the three types of rubber to asphalt decreased penetration, greatly decreased ductility, and increased twisting time and elasticity (percent recovery). Natural rubber increased twisting time and elasticity much more than did equal amounts of GR-S, and was slightly more effective in decreasing penetrations. Scrap rubber increased twisting time and elasticity slightly more than did equal amounts of GR-S. It did not decrease penetration quite as much as did GR-S, however. Scrap rubber was more effective than GR-S when it is considered that the scrap rubber was only 50 percent rubber hydrocarbon. That is, 5.0 parts of scrap rubber should be compared to 2.5 parts of GR-S, etc.

It should be noted here that the controls of straight asphalt which were heated to 250, 300, 350, and 400 degrees F. had physical properties very similar to those of the "as received" control which was tested without any previous heating except for that necessary for the pouring of test specimens. This shows that the physical changes noted above were produced by the addition of the rubber materials, plus heat, rather than by the effect of heat alone on asphalt.

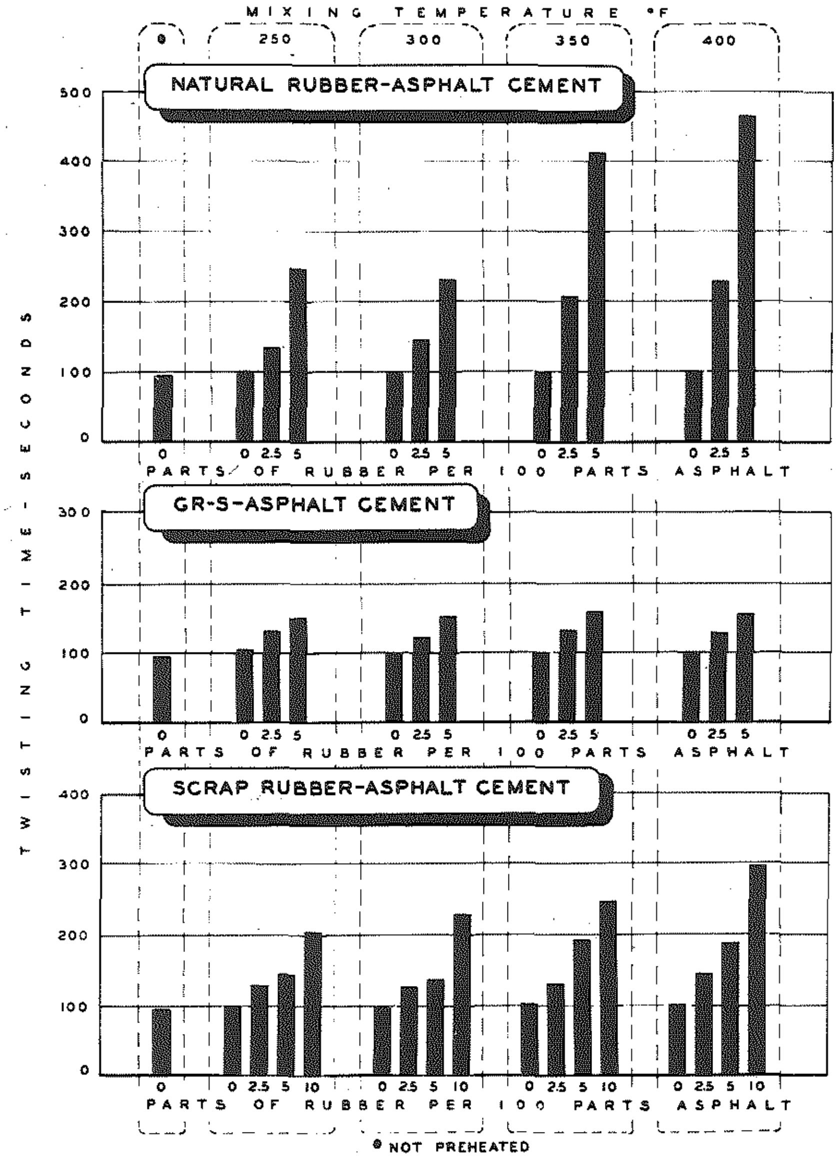
Examination of the penetration data shows that the addition of rubber in all cases appreciably decreased penetration and temperature susceptibility. Natural rubber was the most effective in this respect.

TABLE I

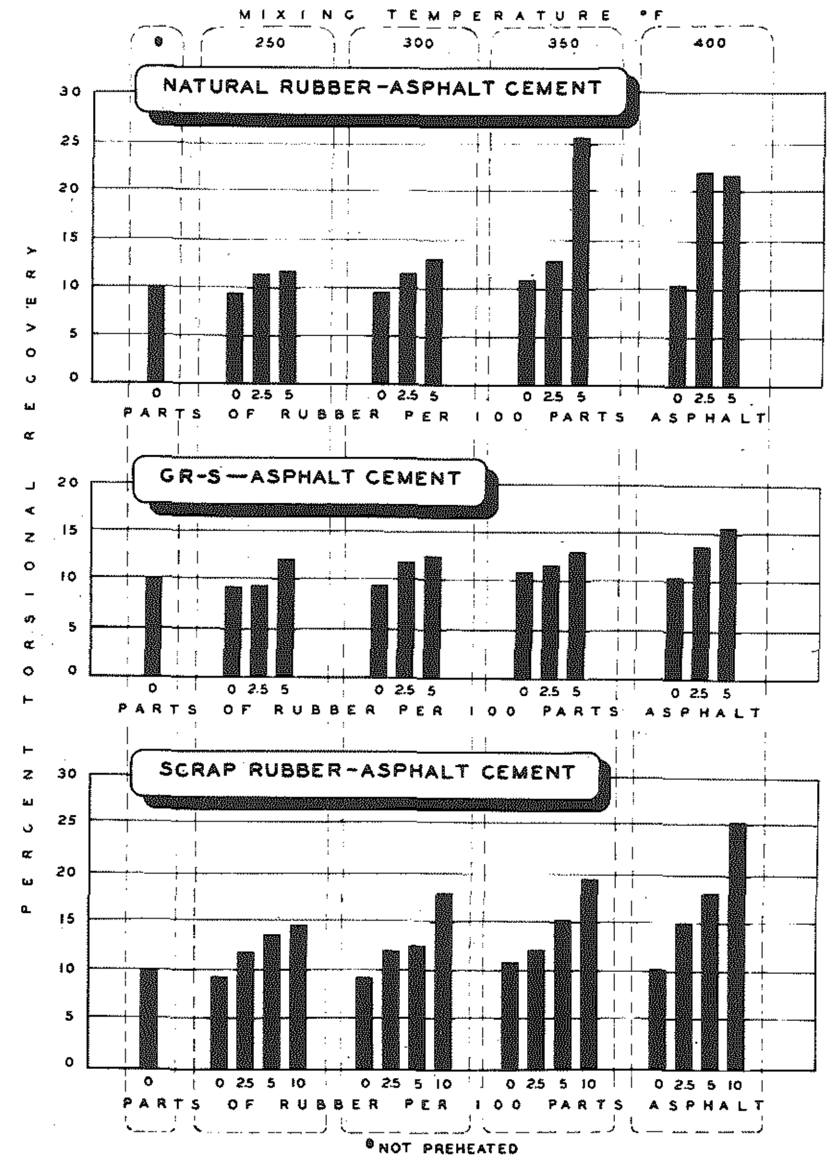
Physical Properties of Various Rubber-Asphalt Cement Blends

| Mixing Temp. °F. | Rubber Content, pph. | Type of Rubber* | Twisting Time, Sec. | Recovery, Percent | Penetration 100 g., 5 sec. 68° F. | 77° F. | 86° F. | Ductility, 77° F. Cm. |
|---|---|---|---|---|---|---|---|---|
| *** | 0 | --- | 97 | 10.0 | 53 | 88 | 142 | 145+ |
| 250 | 0 | --- | 102 | 9.2 | 53 | 86 | 139 | 145+ |
| | 2.5 | N | 138 | 11.1 | 45 | 77 | 126 | 51 |
| | | G | 132 | 9.4 | 47 | 77 | 116 | 34 |
| | | S | 134 | 11.7 | 48 | 77 | 124 | 34 |
| | 5.0 | N | 255 | 11.4 | 43 | 64 | 97 | 20 |
| | | G | 156 | 11.9 | 45 | 73 | 109 | 30 |
| | | S | 156 | 13.3 | 47 | 74 | 126 | 22 |
| | 10.0 | S | 215 | 14.4 | 52 | 78 | 125 | 19 |
| 300 | 0 | --- | 98 | 9.4 | 53 | 88 | 146 | 145+ |
| | 2.5 | N | 150 | 11.1 | 46 | 71 | 117 | 43 |
| | | G | 123 | 11.7 | 48 | 79 | 128 | 40 |
| | | S | 126 | 11.9 | 46 | 78 | 127 | 31 |
| | 5.0 | N | 229 | 12.8 | 42 | 65 | 98 | 24 |
| | | G | 162 | 12.4 | 42 | 69 | 111 | 28 |
| | | S | 142 | 12.2 | 46 | 77 | 124 | 25 |
| | 10.0 | S | 232 | 17.8 | 40 | 65 | 105 | 14 |
| 350 | 0 | --- | 101 | 10.8 | 52 | 86 | 142 | 145+ |
| | 2.5 | N | 209 | 12.8 | 46 | 72 | 112 | 20 |
| | | G | 127 | 11.4 | 50 | 80 | 127 | 39 |
| | | S | 132 | 11.9 | 49 | 80 | 132 | 33 |
| | 5.0 | N | 420 | 24.7 | 38 | 62 | 93 | 20 |
| | | G | 172 | 12.8 | 47 | 72 | 117 | 27 |
| | | S | 192 | 14.2 | 42 | 70 | 118 | 19 |
| | 10.0 | S | 251 | 18.9 | 42 | 66 | 101 | 18 |
| 400 | 0 | --- | 101 | 10.3 | 53 | 85 | 144 | 145+ |
| | 2.5 | N | 210 | 21.7 | 41 | 69 | 115 | 40 |
| | | G | 133 | 13.3 | 49 | 80 | 128 | 32 |
| | | S | 148 | 15.0 | 49 | 77 | 122 | 23 |
| | 5.0 | N | 462 | 21.4 | 42 | 66 | 99 | 46 |
| | | G | 170 | 15.3 | 45 | 73 | 111 | 24 |
| | | S | 187 | 17.8 | 47 | 76 | 119 | 18 |
| | 10.0 | S | 295 | 25.6 | 46 | 67 | 104 | 19 |

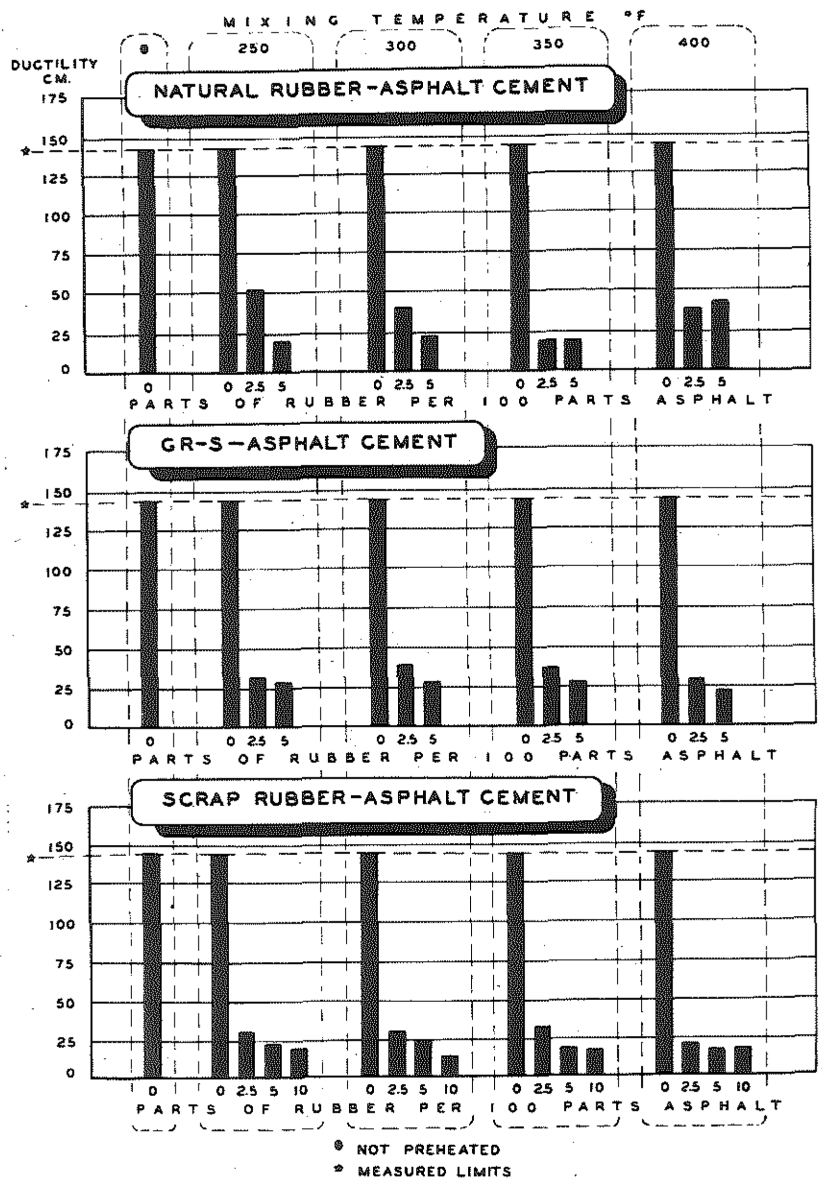
* N- natural rubber G- GR-S S- scrap rubber
** Heated only to molding temperature



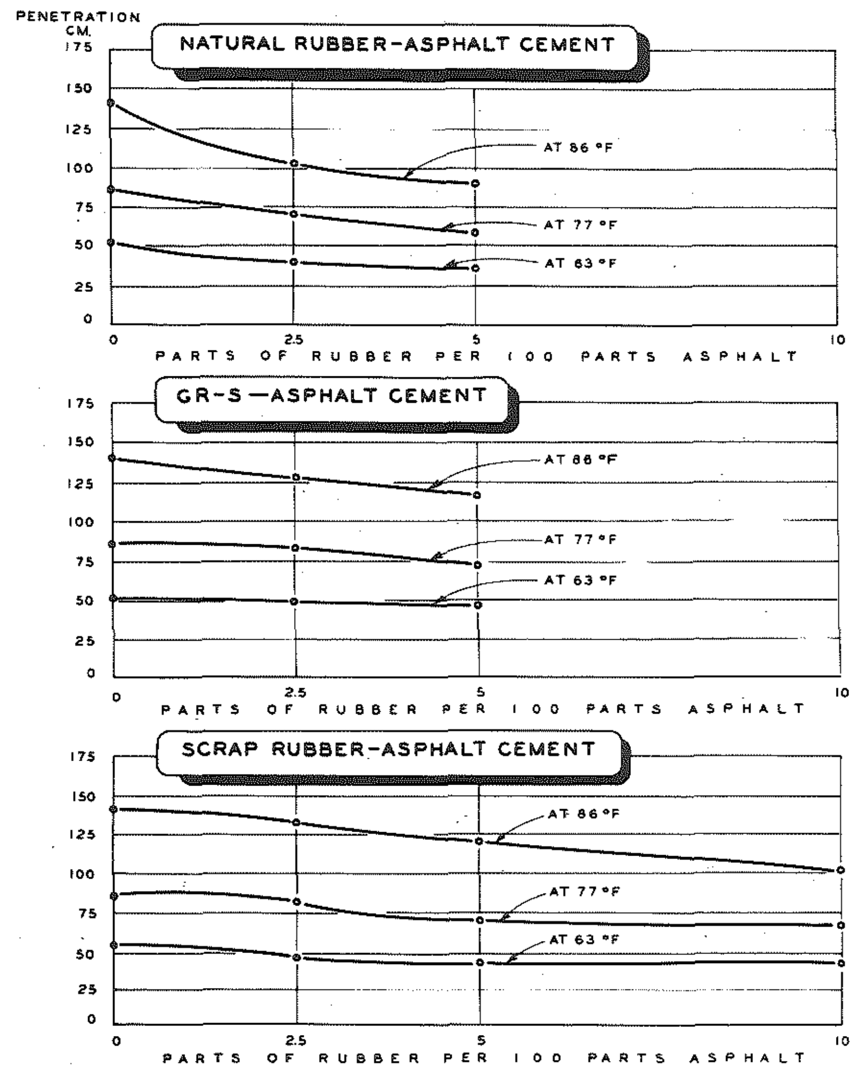

TWISTING TIME OF RUBBER-ASPHALT BLENDS IN TORSION TEST
FIGURE 2




RECOVERY OF RUBBER-ASPHALT BLENDS IN TORSION TEST
FIGURE 3




DUCTILITY OF RUBBER-ASPHALT BLENDS
FIGURE 4




PENETRATION OF RUBBER-ASPHALT BLENDS
FIGURE 5

The increases in twisting time and elasticity, and the decreases in temperature susceptibility noted above are considered improvements. It is to be expected that an asphalt cement with a high resistance to deformation (high twisting time) will produce an asphalt concrete with high resistance to deformation. Likewise, an asphalt concrete made from an asphalt cement having a high elasticity will be more prone to come back to its original shape after being deformed. Furthermore, an asphalt cement with low temperature susceptibility should produce an asphalt concrete that would be less likely to be brittle in winter, or tend to flow in summer.

The rubber-asphalt blends studied were definitely mixtures rather than solutions. Even in mixtures prepared at 400° F., discrete rubber particles were discernible when smears were examined under a microscope (Figure 6). During the ductility test the presence of these rubber particles caused premature breakage of the thread that was formed. The asphalt phase of the mixture between the particles stretched out very thin before breakage, indicating a high ductility. Thus, it was the heterogeneity of the cements that caused their low ductility, rather than any change in the asphalt.

In all cases where physical properties were influenced by the temperature at which the rubbers were added, only slight additional changes were obtained above 350° F. In view of this fact, and the fact that the rubber-asphalt cements would receive further heating when in contact with hot (360° F.) aggregate, it was decided to use 350° F. as the mixing temperature of rubber-asphalt cements for use in the studies of rubber-asphalt concretes described below.

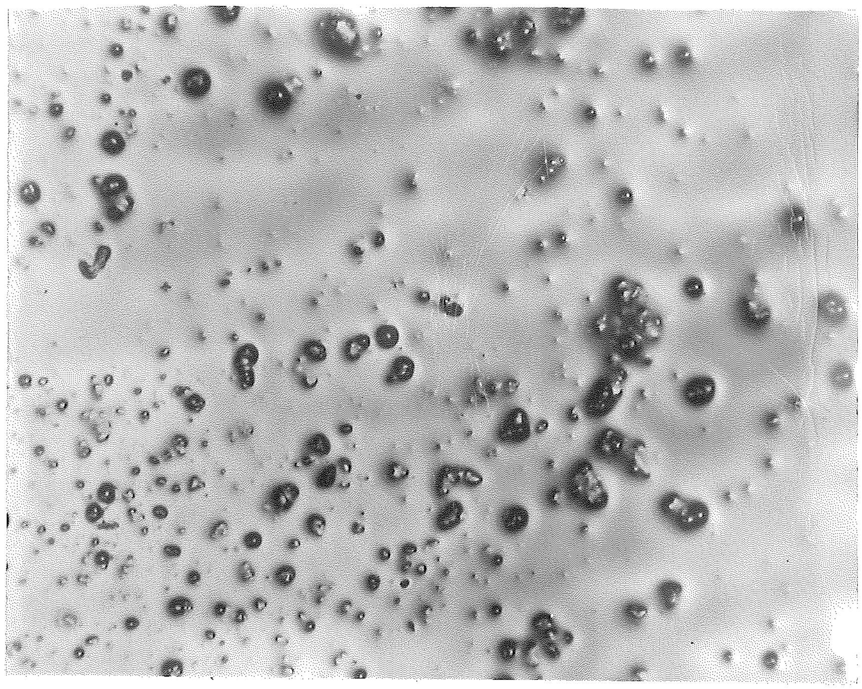


Figure 6

Showing Rubber Particles in a GR-S-Asphalt Cement Mixed at 400°F (24X).

## RUBBER-ASPHALT CONCRETES

### Experimental Details

Rubber-asphalt cements containing 0, 1, 2, 3, 4, and 5 percent natural rubber were prepared and used in quantities of 3, 4, 5, and 6 percent in rubber-asphalt concrete mixes. The direct mix rubber-asphalt concretes contained 0, 3, 5, 7, and 10 parts by weight of natural rubber or GR-S per 100 parts of asphalt cement. When scrap rubber was used, the quantities were 0, 6, 10, 14, and 20 parts per hundred, since the scrap rubber contained only about 50 percent rubber hydrocarbon. All of the direct mixed batches contained 5.5 percent asphalt cement.

The base recipe for the rubber-asphalt concretes studied in this project was as follows:

| | | Parts by Weight |
|---|---|---|
| **Stone** | | |
| Pass 5/8" mesh, retained on 1/2" mesh | | 2.9 |
| " 1/2" " " " 3/8" " | | 23.9 |
| " 3/8" " " " #4 " | | 23.9 |
| " #4 " " " #10 " | | 4.3 |
| **Sand** | | |
| Pass #10 mesh, retained on #200 mesh | | 34.0 |
| **Filler (Limestone Dust)** | | |
| Pass #200 mesh | | 5.5 |
| Asphalt (or rubber-asphalt) cement | | variable |
| | Total | variable |

The stone as originally received was separated into the various fractions by sieving, and these fractions put back together according to the above proportions. Each batch of sand was tested for its dust content (passing #200 mesh) and corresponding adjustments made in the amount of sand and filler used.

Mixing and compaction of Marshall test specimens were carried out, with a few minor exceptions that are detailed below, according to the standard Marshall method for the design and control of bituminous paving mixtures. Mixing was accomplished in a Model A-200 Hobart mixer equipped with a 12-qt. bowl and a wire beater whip. After weighing the aggregate and bituminous cement into the mixing bowl, the batch was mechanically mixed for 50 seconds, hand mixed for 10 seconds, mechanically mixed for 50 seconds more, and finally mixed 10 seconds more by hand. This is a total of two minutes' mixing time.

In the cases where the rubber was added directly to the batch (direct mix method) rather than in the form of a rubber-asphalt cement, the pre-weighed powdered rubber was added to the hot aggregate in the mixing bowl and mechanically mixed for 10 seconds. After this preliminary mix the asphalt cement was weighed in and the normal mixing procedure followed.

The aggregates and compaction molds were pre-heated to 360° F. and the bituminous cements to 250° F. Compacted specimens were carefully removed from the molds while still hot and allowed to come to room temperature before handling. The test specimens were placed in a 140° constant temperature water bath for 45-50 minutes before testing.

In the Marshall stability test, the test head was raised at a rate of about 0.3 inches per minute instead of the 2 in. specified in the standard Marshall test. This lower speed was found to be the practical maximum for hand operation in testing specimens of high stability.

Results and Discussion

Results of the tests on rubber-asphalt concretes are given in Tables II through IV, and graphically in Figures 7, 8, and 9.

TABLE II

Effect of Rubber Content of Natural Rubber-Asphalt Cement Blends on the Physical Properties of Bituminous Concrete

| Physical Property Measured | Rubber Content of Cement, Percent | Value of Property for Bituminous Mixtures Having Cement Content (Percent) of: 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Specific Gravity | 0 | 2.396 | 2.450 | 2.459 | 2.439 |
| | 1 | 2.401 | 2.435 | 2.454 | 2.428 |
| | 2 | 2.388 | 2.441 | 2.458 | 2.426 |
| | 3 | 2.391 | 2.432 | 2.451 | 2.430 |
| | 4 | 2.392 | 2.439 | 2.450 | 2.450 |
| | 5 | 2.377 | 2.415 | 2.437 | 2.446 |
| Voids, Percent | 0 | 8.8 | 5.2 | 3.3 | 2.6 |
| | 1 | 8.6 | 5.7 | 3.5 | 2.9 |
| | 2 | 9.0 | 5.5 | 3.3 | 3.0 |
| | 3 | 8.9 | 5.8 | 3.6 | 2.9 |
| | 4 | 8.9 | 5.6 | 3.6 | 2.6 |
| | 5 | 9.4 | 6.5 | 3.6 | 2.4 |
| Marshall Flow, $10^{-2}$ in. | 0 | 8.3 | 7.9 | 13.5 | 18.1 |
| | 1 | 7.5 | 7.2 | 9.2 | 14.3 |
| | 2 | 8.2 | 7.9 | 10.1 | 17.8 |
| | 3 | 8.8 | 8.4 | 9.7 | 15.4 |
| | 4 | 8.2 | 7.1 | 10.6 | 17.6 |
| | 5 | 10.3 | 10.0 | 9.6 | 15.0 |
| Marshall Stability, Lb. | 0 | 1150 | 1025 | 800 | 550 |
| | 1 | 1200 | 1175 | 900 | 575 |
| | 2 | 1175 | 1150 | 950 | 575 |
| | 3 | 1150 | 1100 | 1000 | 600 |
| | 4 | 1275 | 1250 | 1250 | 750 |
| | 5 | 1250 | 1250 | 1450 | 1075 |

## TABLE III

Effect of Rubber Additions on the Physical Properties of Bituminous Concrete#
(Direct Mix Method)

| Type of Rubber | Rubber Content, pph.* of Asphalt Cement | Specific Gravity | Voids, Percent | Marshall Flow, $10^{-2}$ in. | Marshall Stability, Lb. |
|---|---|---|---|---|---|
| Natural Rubber | 0 | 2.450 | 2.9 | 14.0 | 750 |
| | 3 | 2.442 | 2.9 | 14.0 | 650 |
| | 5 | 2.438 | 2.9 | 12.4 | 775 |
| | 7 | 2.440 | 2.6 | 15.5 | 850 |
| | 10 | 2.435 | 2.5 | 15.1 | 800 |
| GR-S | 0 | 2.450 | 2.9 | 14.0 | 750 |
| | 3 | 2.448 | 2.6 | 14.1 | 800 |
| | 5 | 2.443 | 2.7 | 14.6 | 825 |
| | 7 | 2.445 | 2.6 | 14.4 | 850 |
| | 10 | 2.445 | 2.2 | 14.3 | 875 |
| Scrap Rubber | 0 | 2.450 | 2.9 | 14.0 | 750 |
| | 6 | 2.433 | 3.2 | 12.5 | 800 |
| | 10 | 2.434 | 2.9 | 12.8 | 800 |
| | 14 | 2.436 | 3.0 | 13.0 | 750 |
| | 20 | 2.420 | 2.9 | 12.9 | 750 |

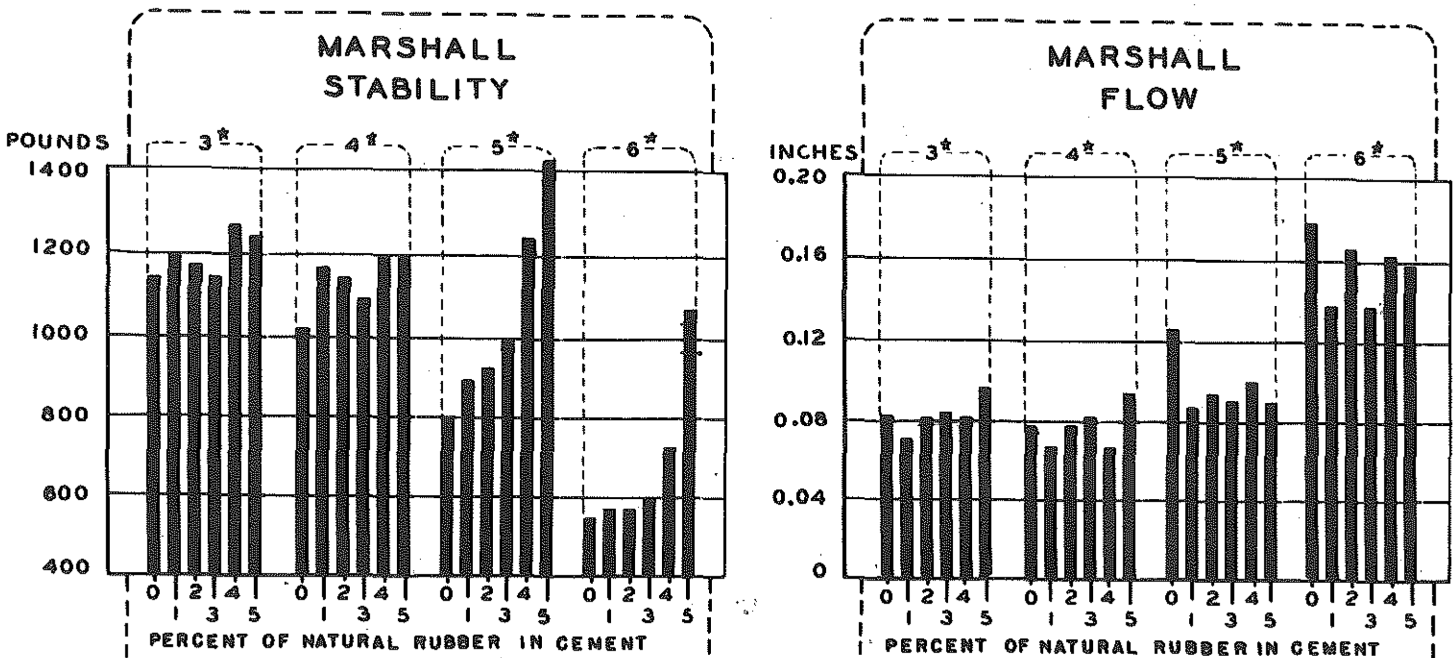
# All mixes contained 5.5 percent of asphalt cement exclusive of rubber

* pph. - parts per hundred

TABLE IV

Effect of Natural Aging on Physical Properties of Bituminous Concrete Containing Various Rubber Additives (Direct Mix Method)

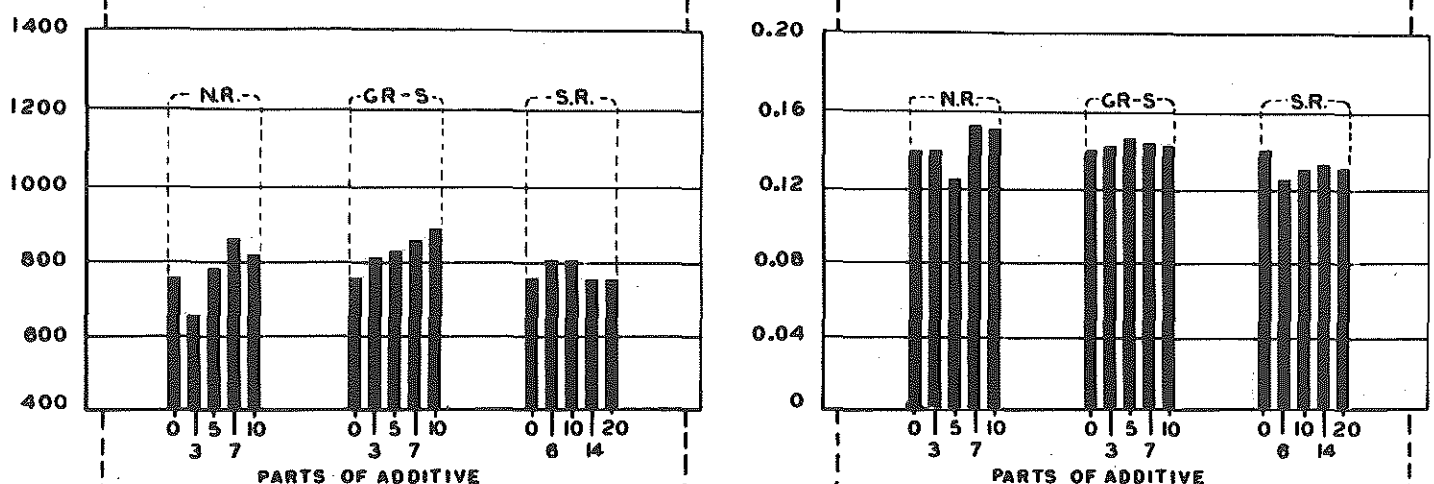
| Aging Period | 0 | 1 day | 3 days | 7 days | 1 mo. | 3 mo. | 1 yr. |
|---|---|---|---|---|---|---|---|
| Control - No Rubber | | | | | | | |
| Specific Gravity | 2.450 | 2.454 | 2.456 | 2.452 | 2.444 | 2.446 | 2.480 |
| Percent Voids | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.8 |
| Marshall Flow, $10^{-2}$ in. | 14.0 | 14.0 | 14.1 | 13.3 | 15.8 | 14.6 | 17.0 |
| Marshall Stability, lb. | 750 | 900 | 875 | 875 | 750 | 875 | 1000 |
| Natural Rubber | | | | | | | |
| Specific Gravity | 2.438 | 2.434 | 2.440 | 2.436 | 2.430 | 2.444 | 2.460 |
| Percent Voids | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |
| Marshall Flow, $10^{-2}$ in. | 12.8 | 17.1 | 15.7 | 16.8 | 18.0 | 15.1 | 17.5 |
| Marshall Stability, lb. | 775 | 625 | 700 | 675 | 675 | 800 | 825 |
| GR-S | | | | | | | |
| Specific Gravity | 2.445 | 2.442 | 2.441 | 2.445 | 2.441 | 2.435 | 2.464 |
| Percent Voids | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.7 |
| Marshall Flow, $10^{-2}$ in. | 14.4 | 15.3 | 15.4 | 14.3 | 14.8 | 17.4 | 16.7 |
| Marshall Stability, lb. | 875 | 850 | 775 | 750 | 800 | 725 | 925 |
| Scrap Rubber | | | | | | | |
| Specific Gravity | 2.433 | 2.443 | 2.434 | 2.439 | 2.433 | 2.434 | 2.462 |
| Percent Voids | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| Marshall Flow, $10^{-2}$ in. | 12.5 | 15.2 | 13.9 | 11.6 | 14.5 | 16.9 | 17.6 |
| Marshall Stability, lb. | 800 | 850 | 725 | 700 | 750 | 675 | 975 |




*PERCENT NATURAL RUBBER-ASPHALT CEMENT IN MIX

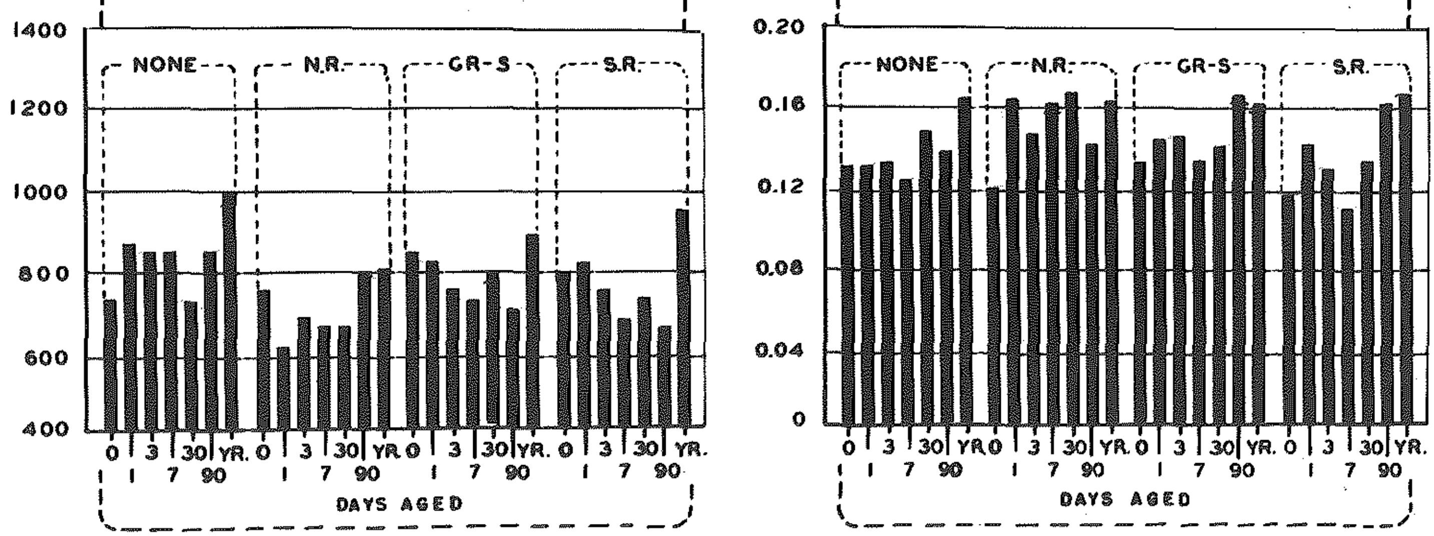
ASPHALT CONCRETES CONTAINING PRE-BLENDED NATURAL RUBBER-ASPHALT CEMENTS

FIGURE 7




ASPHALT CONCRETES CONTAINING VARIOUS TYPES
AND AMOUNTS OF RUBBER ADDED SEPARATELY TO THE MIX

FIGURE 8




EFFECT OF AGE ON ASPHALT CONCRETES CONTAINING VARIOUS TYPES
OF RUBBER ADDED SEPARATELY TO THE MIX

FIGURE 9

Each value presented in the data in Table II (rubber-asphalt concretes prepared from pre-blended rubber-asphalt cement), was obtained from an average of four tests, representing two batches of mix. Each value in Tables III and IV (rubber-asphalt concretes prepared by the direct mix method) was obtained from an average of eight tests, representing four mixes.

From comparison of the data in Table II with that in Table III, it is obvious that natural rubber has more effect on the properties of asphalt concrete when it is incorporated as part of a rubber-asphalt cement than when added separately to the mix. It is to be expected that GR-S and scrap rubber would also be more effective when pre-blended with the asphalt, even though such mixes were not tested.

When natural rubber-asphalt cement was used in high concentrations (5 or 6 percent) the Marshall stability value definitely increased as the rubber content of the rubber-asphalt cement increased. This was true to a much lesser degree with lower concentrations of natural rubber-asphalt cement. The data obtained for Marshall flow value showed no correlation with rubber content, but the flow increased as the asphalt content increased.

The explanation of the effectiveness of the rubber-asphalt blend method of mixing might be in the fact that the rubber has more opportunity to absorb and swell in the asphaltic oils. In order to determine whether the rubber would eventually swell more thoroughly in the asphalt and have more effect on the properties of the asphalt concrete, extra specimens of some of the direct mix batches were laid away for natural aging. They were placed on unpainted wood shelves with enough space between specimens for air circulation and were tested after periods of 0, 1, 3, and 7 days, and 1 month, 3 months, and 1 year.

The results of the aging tests are given in Table IV, and show that age up to one year had no significantly beneficial effect on the direct-mix batches.

SUPPLEMENTARY TESTS ON RUBBER-ASPHALT CEMENTS

In order to compare rubber-asphalt and straight asphalt cements of equal consistency, a blend of 6 parts of 88 penetration brand A asphalt cement, as was used in the previous work, and 26 parts of 56 penetration asphalt cement of the same brand were blended at 250°F. This mixture had a penetration of 62 as did a rubber-asphalt cement prepared by adding 5 parts of natural rubber to 100 parts of the 85-100 penetration asphalt cement at 350°F. The blend and the rubber-asphalt cement were each subjected to the torsion test to determine twisting time and recovery.

The results in Table V indicate that, in spite of equal penetrations, rubber-asphalt cement had a much higher twisting time and recovery than did the asphalt cement blend of similar penetration but containing no rubber.

For the high temperature storage test, 18 pounds of natural rubber-asphalt cement were prepared by the same method. A portion of this cement was tested for ductility, twisting time and recovery, and penetration. The remainder was loosely covered and placed in a 270°F oven for a period of 7 days. Each day during this period a portion of the cement was removed and subjected to the above tests.

It was found, Table VI, that the only significant chenges occurring during 275°F storage of the asphalt-rubber cement were a slight increase in penetration after one day of aging and a large increase in ductility after the third day. The increase in penetration was very slight and the increase in ductility was considered extremely desirable.

To compare the effect of rubber on asphalts of various chemical compositions, rubber asphalt cements were prepared from brands B, C, and D, 85-100 penetration asphalt cement by the methods used in the preceding experiments and tested for twisting time, recovery and penetration.

Examination of the data in Table VII will bring out the fact that the presence of rubber increased the twisting time and recovery and decreased the penetration and temperature susceptibility of each of brand B, C, and D asphalts as it did with brand A asphalt. The properties of brand A asphalt cement and the rubber-asphalt cement prepared from the brand A material, which are included in Table III for comparison, were taken from Table I. There were slight variations in the degree of changes in physical properties caused by the addition of rubber to the various asphalts but the changes were all in the same direction.

TABLE V

COMPARISON OF THE PHYSICAL PROPERTIES OF A 60 PENETRATION RUBBER-ASPHALT CEMENT AND A 60 PENETRATION ASPHALT CEMENT

| | Penetration, 100g, 5 sec., 77°F | Twisting Time at 68°F | Percent Recovery at 68°F |
|---|---|---|---|
| Rubber-Asphalt Cement | 62 | 456 | 13.9 |
| Asphalt Cement Blend | 62 | 208 | 10.8 |

TABLE VI

EFFECT OF STORAGE AT 275°F ON PHYSICAL PROPERTIES OF RUBBER-ASPHALT CEMENT

| Storage Days | Ductility at 77°F. | Twisting Time at 68°F. | Percent Recovery at 68°F. | Penetration, 100g, 5 sec. 68°F. | 77°F | 86°F |
|---|---|---|---|---|---|---|
| 0 | 15 | 390 | 15.4 | 34 | 54 | 84 |
| 1 | 60 | 560 | 15.0 | 40 | 60 | 90 |
| 2 | 90 | 396 | 13.6 | 41 | 60 | 102 |
| 3 | 150+ | 409 | 16.7 | 40 | 66 | 116 |
| 4 | 150+ | 394 | 15.8 | 42 | 61 | 111 |
| 5 | 150+ | 426 | 12.2 | 40 | 62 | 96 |
| 6 | 150+ | 385 | 12.0 | 40 | 60 | 90 |
| 7 | 150+ | 419 | 16.1 | 40 | 62 | 100 |
| 0 without rubber | 150+ | 97 | 10.0 | 53 | 88 | 142 |

TABLE VII

COMPARISON OF PHYSICAL PROPERTIES OF RUBBER-ASPHALT CEMENTS CONTAINING VARIOUS BRANDS OF ASPHALT

| Brand of Asphalt Cement | A | B | C | D |
|---|---|---|---|---|
| Twisting Time at 68°F | | | | |
| without rubber | 97 | 113 | 96 | 133 |
| with rubber | 420 | 948 | 830 | 1210 |
| Percent Recovery, 68°F | | | | |
| without rubber | 10.0 | 11 | 11.7 | 20 |
| with rubber | 24.7 | 31.6 | 20.6 | 28.3 |
| Penetration | | | | |
| at 68°F without rubber | 53 | 54 | 53 | 56 |
| at 68°F with rubber | 38 | 40 | 42 | 45 |
| at 77°F without rubber | 88 | 85 | 88 | 85 |
| at 77°F with rubber | 62 | 56 | 63 | 63 |
| at 86°F without rubber | 142 | 142 | 146 | 127 |
| at 86°F with rubber | 93 | 87 | 100 | 85 |
| Temperature Susceptibility Index | | | | |
| without rubber | 4.3 | 4.3 | 4.3 | 3.5 |
| with rubber | 3.8 | 3.3 | 3.7 | 2.7 |

## SUMMARY OF RESULTS

Rubber-Asphalt Cements

1. GR-S, natural rubber, and valcanized scrap rubber were all effective in increasing twisting time and elasticity of asphalt cements.
2. GR-S, natural rubber, and vulcanized scrap rubber all decreased penetration and temperature susceptibility of asphalt cements.
3. GR-S, natural rubber, and vulcanized scrap rubber greatly decreased the ductility of asphalt cements.

Natural rubber was more effective than either GR-S or scrap rubber in effecting these changes in physical properties.

Rubber-Asphalt Concretes

1. When rubber-asphalt concretes were prepared from natural rubber-asphalt blends, the presence of rubber increased stability and allowed a relatively high asphalt content to be used without sacrificing stability.
2. When rubber-asphalt concretes were prepared by adding GR-S, natural rubber or vulcanized scrap rubber in powdered form directly to the dry aggregate, without first blending with the asphalt, the rubber had no apparent influence on stability.

Supplementary Tests on Natural Rubber-Asphalt Cements

1. A natural-rubber-asphalt cement showed higher twisting time and more recovery than did a straight asphalt cement having the same penetration.
2. The enhanced physical properties produced by the presence of natural rubber in rubber-asphalt cements were not harmed by storage at 270°F for a period of seven days.
3. The effects of the presence of natural rubber on the physical properties of rubber-asphalt cements were similar in several different brands of asphalt.