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PROJECT COMPLETION REPORT
OWRT PROJECT NO. A-075-ARIZ

DEVELOPMENT OF A LOW COST ASPHALT-RUBBER MEMBRANE FOR WATER HARVESTING CATCHMENTS AND RESERVOIR SEEPAGE CONTROL

Agreement No. 14-34-0001-7006

Project Dates: July 1976 - June 1977

The University of Arizona
Tucson, Arizona

June, 1977

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DEVELOPMENT OF ECONOMIC WATER HARVEST SYSTEMS FOR INCREASING WATER SUPPLY

PHASE II

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Principal Investigators:

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The University of Arizona
Tucson, Arizona

June, 1977

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ABSTRACT

This project was concerned with the laboratory and field investigation of asphalt-rubber for use in water seepage control applications. Laboratory testing utilized for physical property determination included viscosity, ductility (ASTM D113-74), flow/slope stability, brittleness/impact resistance (ASTM D994-72), water vapor transmission (ASTM E96-72, Procedure BW), water absorption (ASTM 570-72), and permeability. Also, some specialized laboratory equipment was designed and fabricated for the testing.

The results of the testing showed that the asphalt-rubber is relatively impermeable as a membrane, and that the rubber does not effect an otherwise impermeable asphalt film. Physical properties of the base asphalt that are increased with the addition of rubber include water absorption, viscosity, and impact resistance. The tests that exhibited lower physical property values were ductility and slope stability.

Investigations of field applications of asphalt-rubber resulted in preliminary subgrade preparation specifications. Also, the field installations supported the hypothesis that the asphalt-rubber can be effectively used as a water seepage barrier. Preliminary specifications for asphalt-rubber mixing and field application are also included.

LABORATORY TESTING PROGRAM: MATERIALS, TESTS, AND PROCEDURES

Material Identification and Mixing

Two types of asphalt cements were used in this investigation: AR 1000 and AR 4000. The number in each asphalt designation refers to the base viscosity of the asphalt. Complete specifications of these two asphalt cements are shown in Appendix I.

Three types of ground tire rubber, based on the particle size (see Appendix I), were also used. The first type, designated as TP.044*, represents the coarse rubber particle size. The second type of rubber, designated as TP.027, represents the finer particle size. The third type of rubber particle size distribution is designated as TP(.044 + .027). This type of rubber is a blended mixture of coarse and fine rubber. The blend was mixed in proportion by weight of 50 percent coarse rubber and 50 percent fine rubber. The sieve analysis of the three types of rubber are shown in Appendix I.

The mix proportions of the two materials, by weight, were 75 percent asphalt and 25 percent granulated rubber. The designed mixing method was as follows: A specific amount of asphalt was heated in a steel crucible to a temperature of 370 ± 5°F (187.77 ± 2.77°C). At this temperature, a specified amount of rubber, according to the above-mentioned proportion by weight, was added to the hot asphalt. Addition of rubber to asphalt was done very slowly over a period of 5 minutes while continuously mixing the total mix. After all of the rubber was added to the hot asphalt, mixing of the two materials continued for a period of 30 minutes. Mixing temperature was maintained between 350 and 400°F (176.67 and 204.44°C). At the completion of the mixing period, the asphalt-rubber mixture was molded into the required test specimens. Molding and curing of the test specimens varied according to the test under consideration.

Hereafter, reference to the asphalt rubber mixture will be by asphalt type/rubber type, e.g. AR 1000/TP.027.

Viscosity Testing

Due to the relatively high viscosities and granular nature of the asphalt-rubber mix, conventional viscosity determinations could not be used. The falling coaxial viscometer as developed by Traxler and Schweyer (1936) was chosen as a viable viscosity determination method. A detailed theoretical analysis of the viscometer is presented in the thesis by Kalash (1977). The following equipment was used in the viscosity test:

*Manufacturer's identification number.

1. Falling coaxial cylinder viscometer, support and weights as shown in Figure 1.

2. Constant temperature water bath with thermostatic control, stirrer and thermometer.

3. Telescopic sight with vernier scale in cm (cathetometer).

4. Stop watch.

5. Silicone grease lubricant.

The asphalt-rubber mixtures, variables and repetitive tests done on them are shown in Table 1.

Table 1. Viscosity Determinations

Material	Test Temperature		
	59°F	77°F	104°F
AR 1000	2	2	2
AR 1000/TP.027	2	2	2
AR1000/TP.044	2	2	2
AR1000/TP(.044 + .027)	-	2	2
AR4000	-	2	2
AR4000/TP.027	-	2	2
AR4000/TP.044	2	2	2
AR4000/TP(.027 + .044)	-	2	2

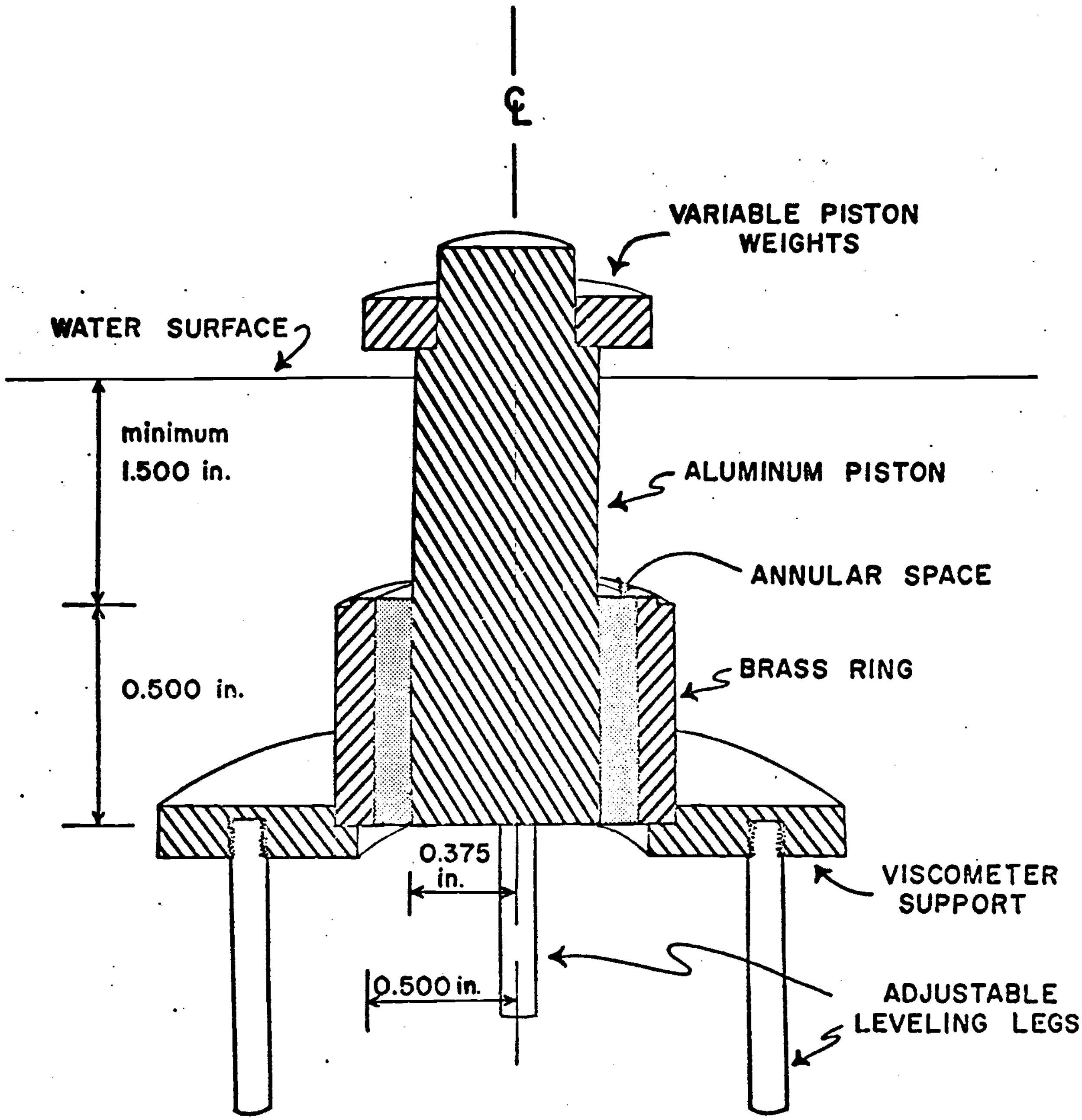
The viscosity determinations were performed by using the viscometer shown in Figure 1. The procedure for running a viscosity test by using the falling coaxial cylinder viscometer involved the following steps:

1. The desired temperature for the water bath was set by thermostatic control and the stirrer speed was set manually.

2. Enough mixture of asphalt-rubber needed for the test was prepared. Mixing procedure is explained at the beginning of this section.

3. A 4x4x1/4 in. (10.16x10.16x.635 cm) glass plate was lightly coated with Dow Corning high vacuum grease. Also, the upper portion of the aluminum piston and the inside of the aluminum centering ring were coated.

4. The viscometer assembly, including the brass ring, the piston inside the ring, and the centering ring on top of the brass ring, was immersed in the asphalt-rubber mixture laid on the glass plate. This immersion should force the asphalt-rubber mixture through the annular space between the piston and the brass ring. The centering



Note: All lines on plan view are circular.
One inch = 2.54 cm.

Figure 1 Falling Coaxial Viscometer

ring was then removed and the annular width was checked to see if enough mixture had filled the space. Because the viscometer designed for this study had a small annular width, this method of molding worked adequately. Excess mixture on top of the brass ring was cleaned out and scraped with a knife. The centering ring was then placed back on the brass ring.

5. The viscometer containing the asphalt-rubber mix was then slipped from the glass plate and set on a new glass plate coated with silicone grease in the same manner as the first one. The viscometer was allowed to cool down and then transferred with the glass plate under it to the constant temperature water bath. The viscometer was left in the water bath for at least one hour before testing.

6. The support was leveled. The centering ring and the glass plate were carefully removed and the viscometer was then placed on the support. The water level should be at least 1.5 in. (3.81 cm) above the asphalt-rubber sample.

7. The telescopic sight was pointed just a small fraction below a well-defined mark on the piston. The stop watch was started when the mark on the piston came down and coincided with the cross hair. Immediately, the telescopic sight was moved down a displacement of 0.1 cm. When the piston mark came down and coincided with the cross hair, the watch was stopped and the time, t, for the piston displacement of 0.1 cm was recorded. The piston was recompressed to its original position and this last step was repeated at least three more times. At least four weights were used to vary the velocity of the piston.

8. For each weight used, the cumulative displacement (H) in cm. vs. cumulative time (t) in seconds was plotted. The velocity in cm/sec was calculated from the straight line portion of H vs. t. The shear rate, S_r, was calculated from the formula

$$S_r = \frac{V}{R-r} \qquad (1)$$

where V = velocity of the piston in cm/sec,
R = the inner radius of the brass ring in cm, and
r = the radius of the piston in cm.

The shear stress was calculated from the equation:

$$S_s = W_{eff} \times \frac{g}{2\pi rL} \qquad (2)$$

where W_{eff} = the effective weight in grams (the total weight minus the buoyant force),
g = 980 cm/sec^2,
r = radius of the piston in cm, and
L = the length of the brass ring in cm.

The buoyant force is given by the formula:

$$\gamma h(\pi r^2) \quad (3)$$

where γ = density of water,
h = distance between water level and bottom of brass ring, and
πr^2 = cross-sectional area of the piston.

A plot of S_r vs. S_s on a log-log scale was drawn. The shear stress at a shear rate of 5×10^{-2} sec^{-1} was found from the graph and the viscosity, η was calculated as follows:

$$\eta = \frac{S_s}{S_r} \text{ (poise)} \quad (4)$$

Graphical results and discussions are provided in the next section.

It is to be noted that the previous procedure applies also to testing raw asphalt with a minor difference in sample preparation. Asphalt cement was usually heated in a small can to a temperature of 250°F (121.1°C). At this temperature, the asphalt was fluid enough and was poured into the annular space between the piston and the brass ring.

Ductility Test

In a paper by Welborn and Babashak (1958), a ductility test study on asphalt-rubber mixtures was done in an attempt to evaluate the effect of rubber on asphalt. Two types of natural rubber latex were used in the investigation. Sulfur in the amounts of 0, 5, 10, 15, and 20 percent of rubber was added to the latex prior to blending with the asphalt. The percent rubber used was 1 to 2 percent of the total mixture. The asphalt rubber blend was tested in accordance with ASTM designation D113-44, except that a rate of pull of 5 cm/min was used at a temperature of 39.2°F (4°C). In the final analysis, it was found that increasing the percent rubber would tend to decrease the ductility in the resulting asphalt-rubber mixture.

The ductility test in this research was done according to ASTM designation D113-74, (1974). The ductility of an asphalt-rubber mixture was measured by the distance to which it will elongate before breaking when the two ends of a briquet specimen of the material were pulled apart at a specified speed and at a specified temperature. The test temperature was maintained at 77°F (25°C), while the test speed was kept at 5 cm/min ± 5 percent.

The following equipment was used in the ductility test:

1. Mold: The full description of the mold used is given in ASTM designation D113-74 (1974).

2. Water bath: the water bath in this test was part of the ductility machine. Its function is to contain water at the test temperature of 77°F (25°C).

3. Ductility machine.

The asphalt-rubber mixtures tested as well as the number of ductility replicates are shown in Table 2.

Table 2. Ductility Test Determinations

Material	Number of Determinations
AR 1000	6
AR 1000/TP.044	6
AR 1000/TP.027	3
AR 1000/TP(.027(.027 + .044)	3
AR 4000	3
AR 4000/TP.027	3
AR 4000/TP.044	3
AR 4000/TP(.027 + .044)	3

The methods of molding and curing for this test were the same as those for the viscosity test. The only difference was that the specimen was molded in a briquette on a brass plate. The rest of the testing procedure was done according to the standard ductility test of bituminous materials specified in ASTM designation D113-74 (1974).

Graphical results and discussion are presented in the following section.

Water Vapor Transmission Test

The purpose of this test is to determine the rate at which water vapor is transmitted through a film of asphalt-rubber when wetted on one surface only. It was done according to the standard test specified in ASTM designation E96-72, Procedure BW (1974). Relative permeability values for the various asphalt-rubber mixtures can also be determined from this test.

The following equipment was used in the water vapor transmission testing:

1. A plexiglass dish having the dimensions shown in Figure 2.

2. A plexiglass retaining ring to fit the plexiglass dish and a 20 mesh galvanized screen (see Figure 2).

3. RC-250 asphalt, distilled water, and a sensitive balance with a graduation of 1/100 of a gram.

4. Vacuum chamber.

The asphalt-rubber mix configurations and application rates used in this test as well as the number of test replicates are shown in Table 3.

Table 3. Water Vapor Transmission Test Replicates

	Application Rate (gal/yd^2)		
Material	0.5	0.75	1.00
AR 1000/TP.044	3	3	3
AR 1000/TP.027	3	3	3
AR 1000/TP(.027 + .044)	3	3	3

An attempt to test AR 1000 asphalt without granulated rubber was unsuccessful. This was due to the fact that the AR 1000 is highly susceptible to flow at the test temperature of 77°F (25°C). The AR 1000 was observed to be flowing out through the retaining screen during testing.

A specific amount of asphalt-rubber mixture was prepared as explained in the beginning of this section. The asphalt-rubber mixture was molded into the required number of specimens by using a method referred to as the forced-molding technique. In this method, samples were molded uniformly both in thickness (application rate) and in diameter. The forced-molding technique utilizes a plexiglass mold and a piston-sleeve arrangement as shown in Figure 3. The molding procedure involved the following steps:

1. Using a ± 0.1 gm graduated balance, the desired amount of hot asphalt-rubber mixture was placed in the plexiglass mold. To prevent the mix from sticking, release paper having the same diameter as the specimen was placed against the interior bottom surface of the mold. The amount of asphalt-rubber mixture placed in the mold depended on the application rate needed.

2. The mold was removed from the balance and the centering block was placed over the mold.

3. The piston was centered in the centering block and the mixture was compressed to spread evenly across the contained mold diameter, thus producing a uniform specimen size for thin film testing. To prevent the mix from sticking to the piston,

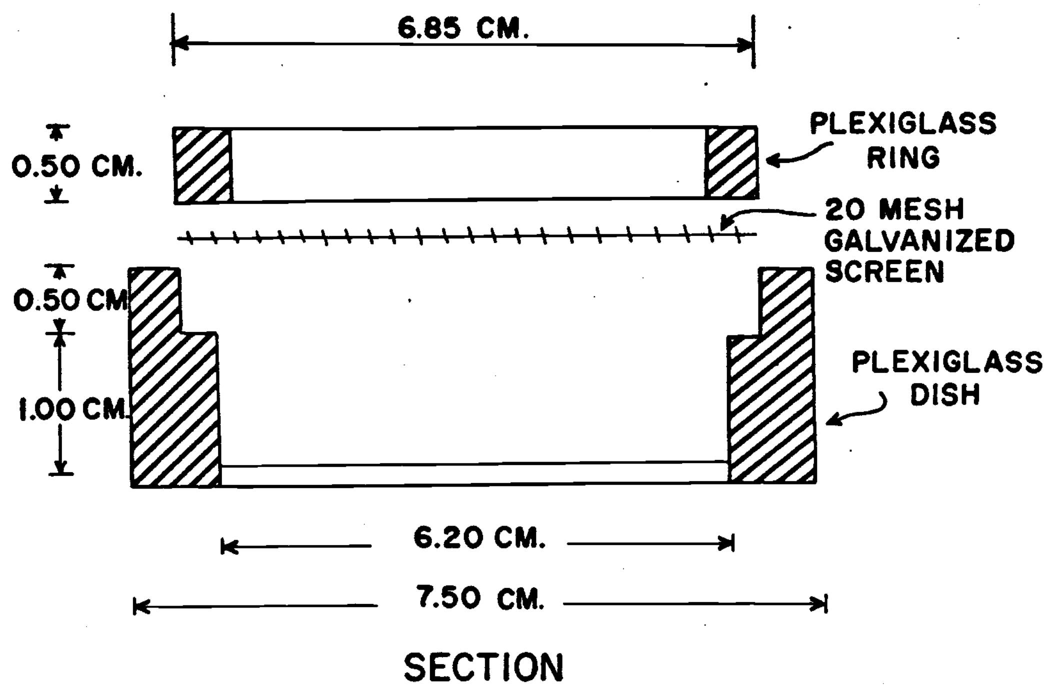


Figure 2. Water Vapor Transmission Test Dish

the contact area of the piston was lightly greased and covered with a release paper having the same diameter as the specimen.

4. The piston and the centering block were removed and the molded specimen was left to cure at room temperature for a period of at least 24 hours before testing.

5. At the end of the curing period, the specimen was removed from the mold, the release papers were peeled off, and then the membrane was ready for testing.

6. The procedure for running the water vapor transmission test (W.V.T.) was the same as that specified in ASTM designation E96-72 (1974), Procedure BW. It is significant, however, to describe the apparatus used and mention the minor changes needed in testing asphalt-rubber mixtures. The apparatus consisted of a small, lightweight dish, restraining ring and a 20 mesh galvanized screen as shown in Figure 2. The dish consisted of an open-mouthed plexiglass cup with a depth of 1 cm and a diameter of 2.44 in. (6.2 cm) (see Figure 2). It was filled with distilled, de-aired water and the sample membrane was placed over the water surface. Care was taken to avoid air entrapment under the specimen. The exposed membrane surface area is 30 cm^2. To hold the membrane in the dish, a wire mesh and a matching, restraining ring were placed over the sample. The function of the wire mesh was to prevent the flow of the asphalt-rubber mixture during testing and was not normally used in the standard ASTM designation E96-72 (1974) test. RC-250 asphalt was used to seal the ring to the dish and specimen, thus preventing edge failure due to leaks. Numerous trials for running the W.V.T. test using a variety of waxes and high vacuum grease as a seal failed. Finally, successful tests were run with RC-250 asphalt as the sealing material.

   The entire test assembly was inverted for wetting one membrane surface and then weighed periodically to determine the weight loss as the water vapor escaped through the test membrane. The successive weight loss vs. elapsed time was plotted on an arithmetic scale and the water vapor transmission rate was calculated from the straight line portion of the curve. When held in a constant temperature humidity room, testing indicated little or no weight loss. To facilitate a more rapid response, the W.V.T. devices were placed in a small vacuum chamber at 10 inches (25.4 cm) of mercury as shown in Figure 4. The temperature inside the vacuum chamber was held at 77 ± 3°F (25 ± 1.67°C). Approximately 50 gm of anhydrous calcium chloride was placed in the vacuum chamber in an attempt to maintain a relatively dry atmosphere. The calcium chloride was changed whenever specimens were removed or added to the chamber. The assemblies were weighed at periodic intervals and subsequent weight losses were recorded. Graphical results and discussion are presented in the following section.

Water Absorption Test

This test was concerned with the determination of the relative rate of water absorption by asphalt-rubber mixtures when submerged. The test has two significant functions. The first is that it acts as a guide to the proportion of water absorbed by the asphalt-rubber mixture while submerged. The second function is to check the uniformity of the molded asphalt-rubber specimens. The standard test specified in ASTM designation D570-72 (1974) was chosen as the best reliable procedure to achieve the desired results.

The equipment used in the water absorption test consists of a water bath maintained at a temperature of 77 ± 2°F (25 ± 1.11°C), and a sensitive balance with a readability to 0.01 gm and precision to 0.005 gm.

The three asphalt-rubber combinations used in this test were the following: AR 1000/TP.044, AR 1000/TP.027, and AR 1000/TP(.044 + .027).

Procedure

The desired amount of asphalt-rubber mixture was prepared using the mixing procedure specified at the beginning of this section. The hot mix was then poured on release paper and spread evenly to form a sample sheet having a thickness of approximately 1/8 in. (0.32 cm). Five specimens were then cut from the cold sample sheet. Each specimen was 3 in. (7.62 cm) long, 1 in. (2.54 cm) wide, and 1/8 in. (0.32 cm) in thickness. The specimens were then allowed to cure at room temperature for a period of at least 24 hours before testing.

At the end of the curing period, the specimens were transferred to the water bath for the water absorption test. At least five specimens of each mix were tested. The percent water absorption of the mix, at the end of any specified period, was then calculated as the average value of the five specimens tested.

A specimen is considered substantially saturated when the increase in weight per two-week period due to water absorption averages less than 1 percent of the total increase in weight, or 5 mg, whichever is greater.

The testing procedure was exactly the same as the long term immersion method specified in ASTM designation D570-72 (1974).

Permeability Test

This test determines the coefficient of permeability of asphalt-rubber by the constant head permeameter method. The method is similar in procedure to the constant head permeability testing of soils and rocks. It gives an indication of the material's permeability when subjected to a constant head pressure.

The apparatus consists of an aluminum base plate fitted with a corundum porous stone, "O" ring and neoprene spacer, and an aluminum top plate which allows water under hydrostatic head to act on the sample placed between the two plates (see Figure 5). A constant head chamber supplies the desired head of water by air pressure on a contained water surface. The amount of water that does flow through a given sample over a specified time period is collected in a burrette graduated in mm. The complete permeameter test set-up is shown in Figure 6.

The asphalt-rubber mixtures, application rates and number of test replicates are shown in Table 4.

Table 4. Permeability Test Replicates

Material	Application Rate (gal/yd^2)		
	0.5	0.75	1.00
AR 1000/TP.044	3	3	3
AR 1000/TP.027	3	3	3
AR 1000/TP(.027 + .044)	3	3	3

Procedure

Asphalt-rubber mixtures were prepared as explained in the beginning of this section. The method of molding used was the forced-molding technique whereby samples can be molded uniformly both in thickness (application rate) and in diameter. This molding method, as well as the dimensions of the specimens used, were the same as for the water vapor transmission test described earlier. A generalized permeability test procedure was as follows: A specimen of asphalt-rubber was placed in the permeameter with a constant hydrostatic head applied to one surface. The flow through the asphalt-rubber membrane was measured as it escaped through the membrane and porous stone. Assuming the asphalt-rubber mixture to be porous, the coefficient of permeability, K, in cm/sec, was then calculated from the following Darcy's equation:

$$K = \frac{Qd}{AH_w t} \qquad (5)$$

where K = coefficient of permeability (cm/sec),
Q = flow through membrane in cm^3,
d = membrane thickness in cm,
A = cross-sectional area of sample in cm^2,
H_w = hydrostatic head (cm of water), and
t = time in seconds

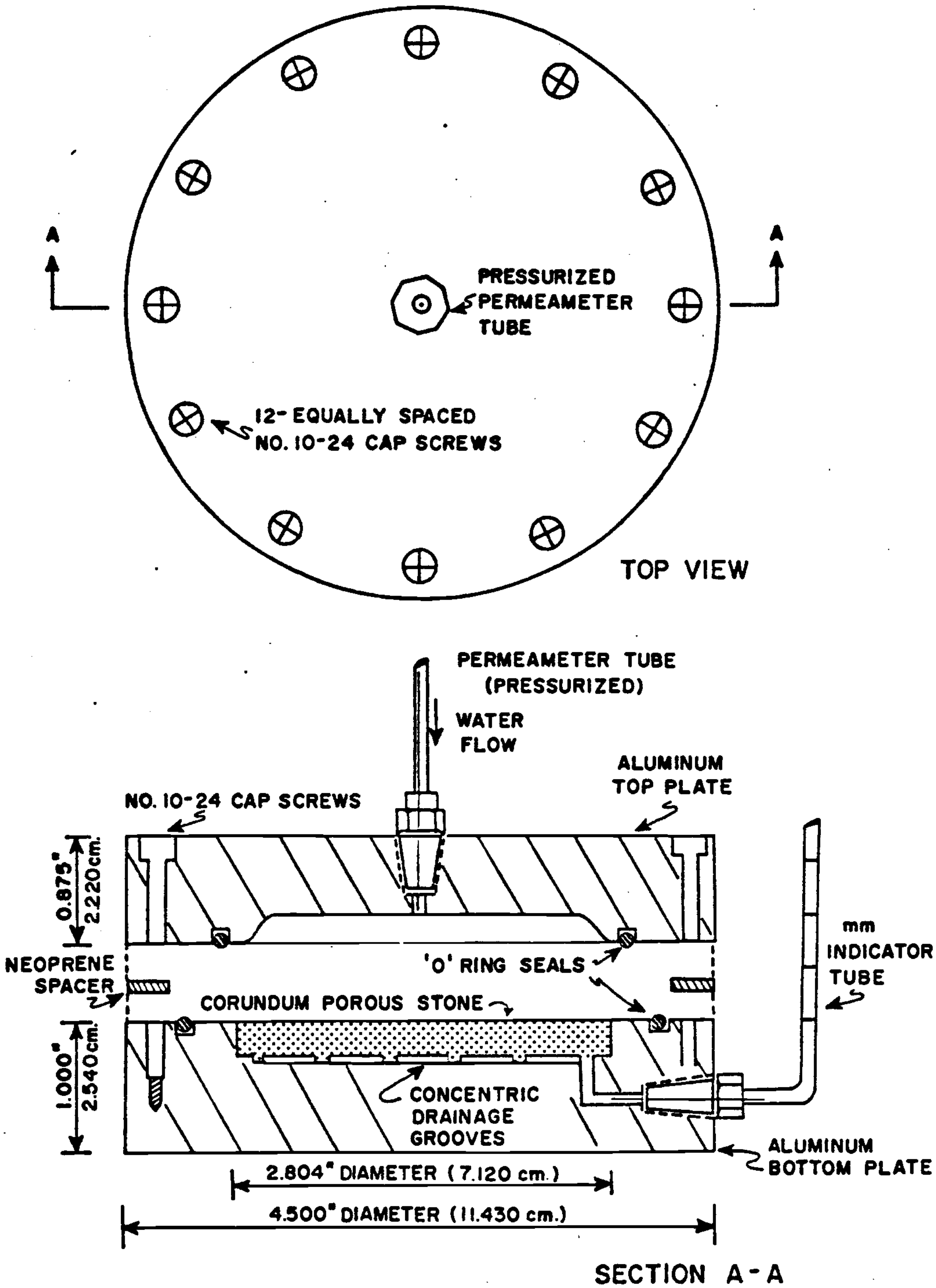


Figure 5. Static Head Permeameter

Brittleness - Impact Resistance

This test was used in an attempt to determine the relative low temperature impact resistance of the asphalt-rubber membrane as compared to the base asphalt cement. It was accomplished in accordance with ASTM designation D994-72 (1974). The test temperatures used were 40°F (4.4°C) and 20°F (-6.6°C). The membrane application rate was 0.75 gal/yd^2 (3.40 l/m^2). Table 5 gives the number of test replicates used for the various asphalt-rubber combinations.

Table 5. Brittleness Test Replicates

Material	Test Temperature	
	40°F	20°F
AR 1000	5	5
AR 1000/TP.027	5	5
AR 1000/TP.044	5	5
AR 1000/TP(.027 + .044)	5	5
AR 4000	5	5
AR 4000/TP.027	5	5
AR 4000/TP.044	5	5
AR 4000/TP(.027 + .044)	5	5

Procedure

The asphalt-rubber mixtures were prepared in accordance with previously defined mixing procedures. The method of molding used was the forced-molding technique in an attempt to achieve uniformity in specimen thickness and diameter. The diameter of the specimens was 3.5 inches (90 mm) and the thickness was 1/8 inch (0.32 cm). A generalized brittleness test procedure was as follows: An asphalt-rubber specimen was placed in chilled water at the prescribed test temperature and held there for two hours. Each specimen was then removed from the water and immediately placed on a wooden block resting on a concrete floor. A 1.0 lb. (0.454 kg) stainless steel ball was dropped on the specimen from a height of 3 feet (.915 m). The ball was allowed to fall freely to the center of the specimen. Failure of a particular mix was determined if one out of the five specimens failed or fractured.

Flow/Slope Stability

An attempt was made at determining the relative flow/slope stability characteristics of asphalt-rubber. In particular, the stiffening properties that the rubber particle size imparts to the asphalt cement were investigated. The modified Barrett Slide test was adopted for use from the Bureau of Reclamation's Test Procedures on filled asphalt cements (Ellsperman and

Becker, 1947). The asphalt-rubber samples were mixed in accordance with previously described mix procedures and immediately placed in the 1/2 inch (12.7 mm) cube molds. The molds were allowed to come to room temperature and then placed in a freezer at 32°F (0°C) for two hours to facilitate ease in specimen removal from the molds. The individual cubes of asphalt-rubber were placed at the top of the copper slides (horizontal position) and allowed to come to room temperature of 77°F (25°C) for a period of not less than two hours. The entire slope assembly was placed in a pre-heated 140°F (60°C) oven for 48 hours at a 1-1/2 to 1 slope. At the end of 48 hours, the displacements along the slope of the various mixes were measured. The tested slope assembly is shown in Figure 7.

LABORATORY TEST RESULTS AND DISCUSSION

The objectives of this study were to determine the properties of asphalt-rubber mixtures that are most useful for seepage control application. The study consisted of devising the testing apparatus, procedures, and determining the relative characteristics of the test results. The testing procedures have been described in the preceding section. The overall evaluation and discussion of the results are described in the following sections.

Viscosity Test

During its application and use, the asphalt-rubber mixture is subjected to heat, changes in temperature, variable shear or loading, and weathering. These factors change the consistency or hardness of the asphalt-rubber mixture and, consequently, influence the performance of the material. The viscosity test has been devised to measure the relative consistency of the material and characterize its physical properties so that, to some extent at least, its flow behavior (rheology) and performance under variable conditions can be controlled and predicted. As a result, the practical uses of the viscosity test are in the preparation and field placement of asphalt-rubber mixtures. In this particular report, the test temperature range reflects the field or in place behavior rather than application. It should be noted that the high viscosities of asphalt-rubber may prohibit spraying through some distributors and that any improvement in viscosity is desirable, e.g. finer rubber particle size distribution.

As noted previously, the variables involved in this test are asphalt type, rubber particle size, and temperature. The effects of each of these variables on the viscosity of asphalt-rubber mixes are shown in the graphs on the following pages.

Figure 8 represents the effect of asphalt type and rubber particle size on the viscosity of the mix at 77°F (25°C). Close inspection of the graph reveals the following results:

1. When rubber is added to asphalt cement, the resulting asphalt-rubber mixture always has a higher viscosity value than the plain asphalt.

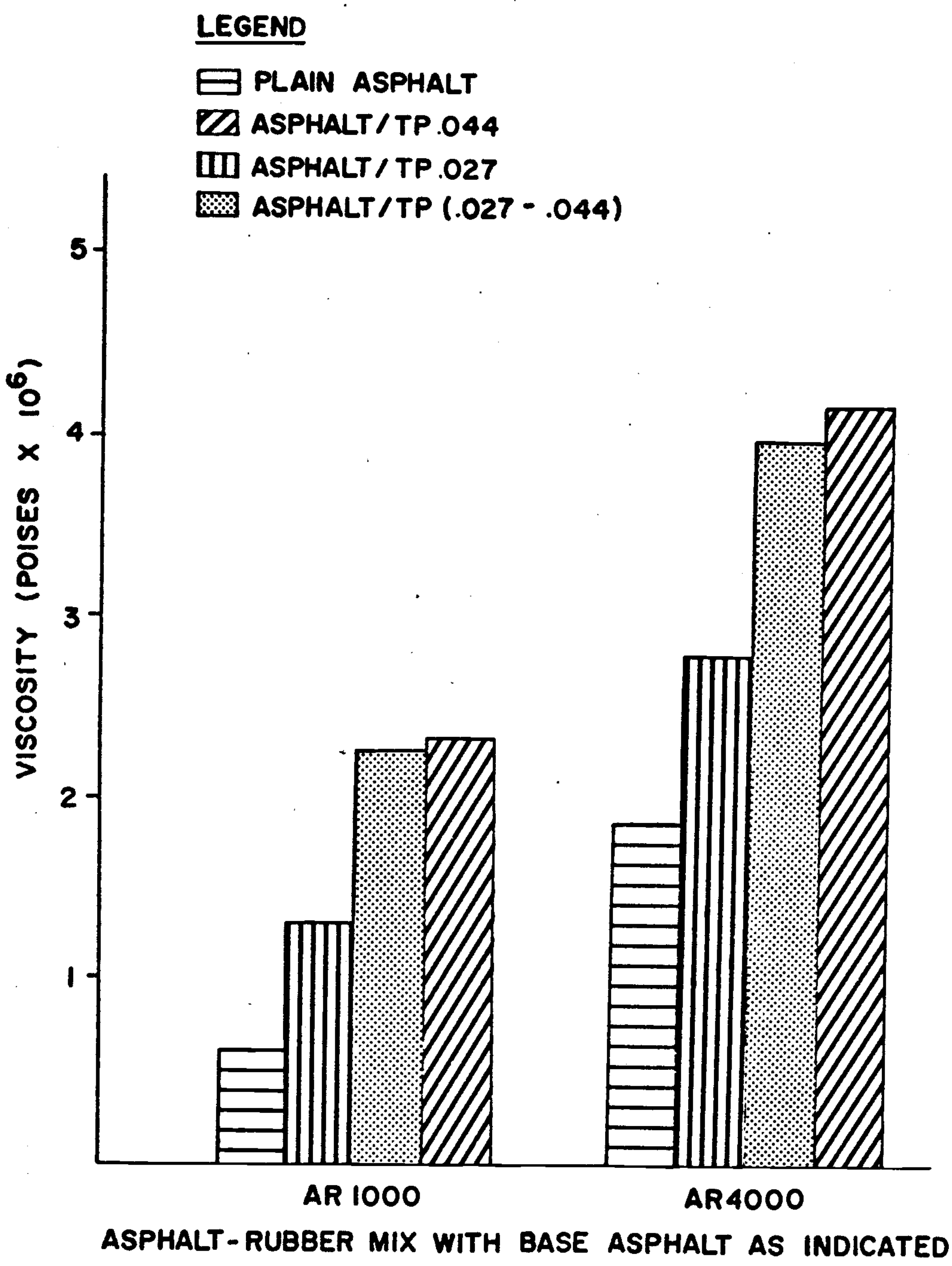


Figure 8. Relative Viscosities of Asphalt-Rubber Mixes at 77°F (25°C)

2. Addition of variable rubber particle sizes results in variable viscosity values for asphalt-rubber. Also, the larger the rubber particle size used in the mixture, the higher the viscosity value obtained.

These findings are logically acceptable. The mixing of rubber, which is a solid material, with the fluid asphalt should obviously result in a mixture with a lower potential for flow than plain asphalt. This lower potential for flow reflects a higher consistency measure of the asphalt-rubber mixture and, consequently, a higher viscosity value than plain asphalt. Furthermore, the coarser the rubber used with a specific type of asphalt, the greater its effect in reducing the flow potential of asphalt-rubber. As a result, a higher viscosity value is expected. The effect of the asphalt hardness on the viscosity of the asphalt-rubber mixture is significant. It is a proven fact in asphalt technology that harder asphalt has a higher viscosity than the softer one at the same temperature. This fact is reflected in the viscosity results of asphalt-rubber combinations that have the same rubber size but different grade asphalt cement.

Figure 9 also explains the effect of asphalt grades and rubber sizes on the viscosity of asphalt-rubber mixtures. The only difference in this case is that the test temperature is 104°F (40°C). The characterizing results of this graph are the same as those for Figure 8. It is to be noted, however, that the viscosity values obtained in Figure 9 are lower than the values obtained in Figure 8. This difference is due to the temperature change effect. Detailed analysis of the temperature effect on the viscosities of the different asphalt-rubber combinations is presented in Figure 10.

As for asphalt, the asphalt-rubber mixture is a thermo-plastic material; that is, the material changes its consistency with changes in temperature. The variation in consistency with temperature is important because, in the application of the asphalt-rubber mixture in the field, the actual consistency at different temperatures must be noted to carry out proper design and construction. A common technique to study the change in viscosity with the change in temperature (temperature susceptibility) is to specify the slope of the temperature vs. viscosity relationship of the asphalt-rubber mixture when the viscosity is plotted in absolute units (poises). A straight line relationship is assumed when the log-log viscosity vs. log-absolute temperature is plotted graphically. Figure 10 illustrates the method of plotting and comparison of temperature vs. viscosity characteristics for AR 1000 and three different asphalt-rubber combinations.

As noted previously, viscosity values are determined at a constant shear rate of $5 \times 10^{-2} sec^{-1}$. Comparison was made on the basis of the numerical value of the slope of each line in the graph of Figure 10. The steeper the slope, the more temperature susceptible the material. Close inspection of this figure reveals the following:

1. When rubber was added to an AR 1000 asphalt, the resulting asphalt-rubber mixture had a lower temperature susceptibility than the asphalt.

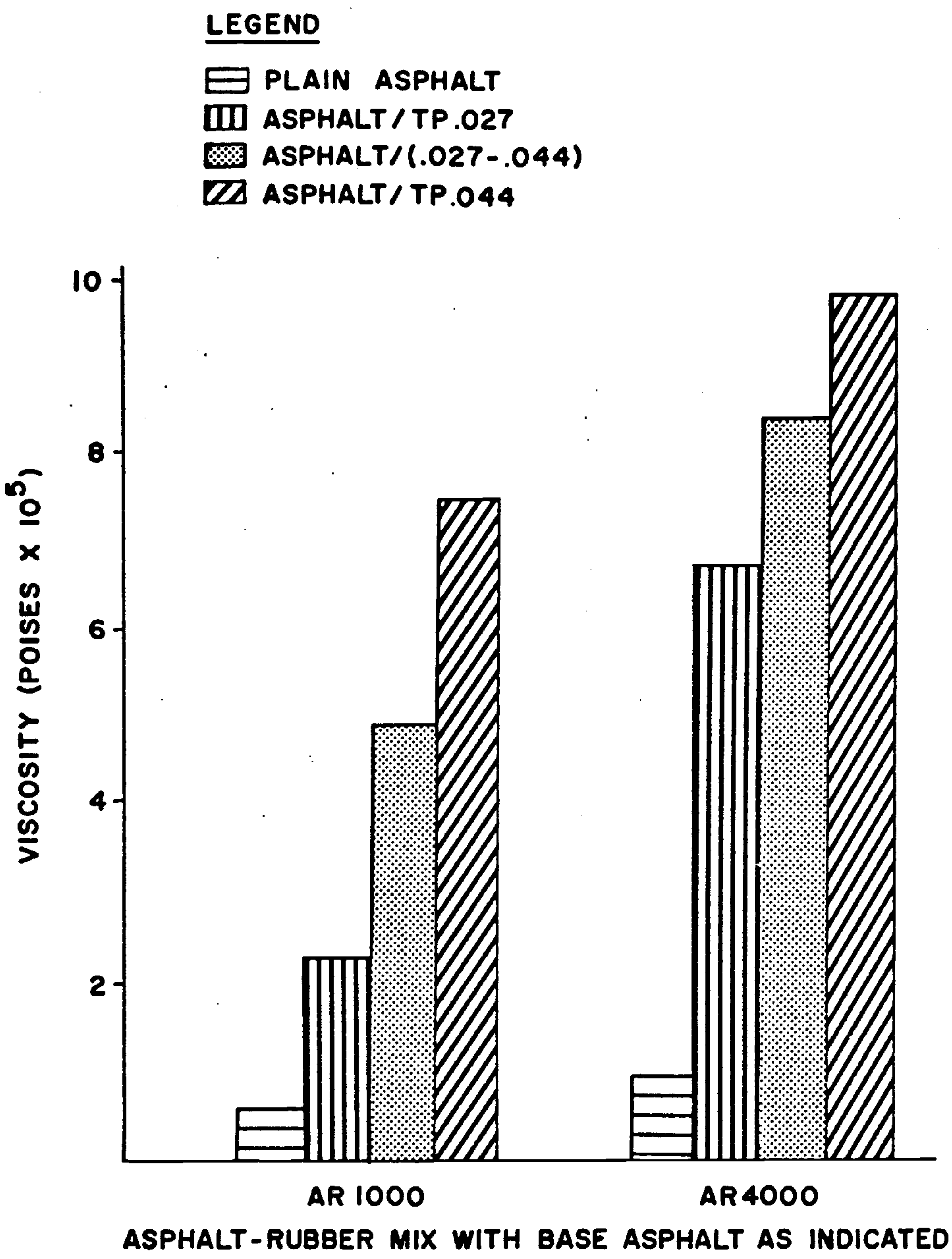


Figure 9. Relative Viscosities of Asphalt-Rubber Mixes at 104°F (60°C)

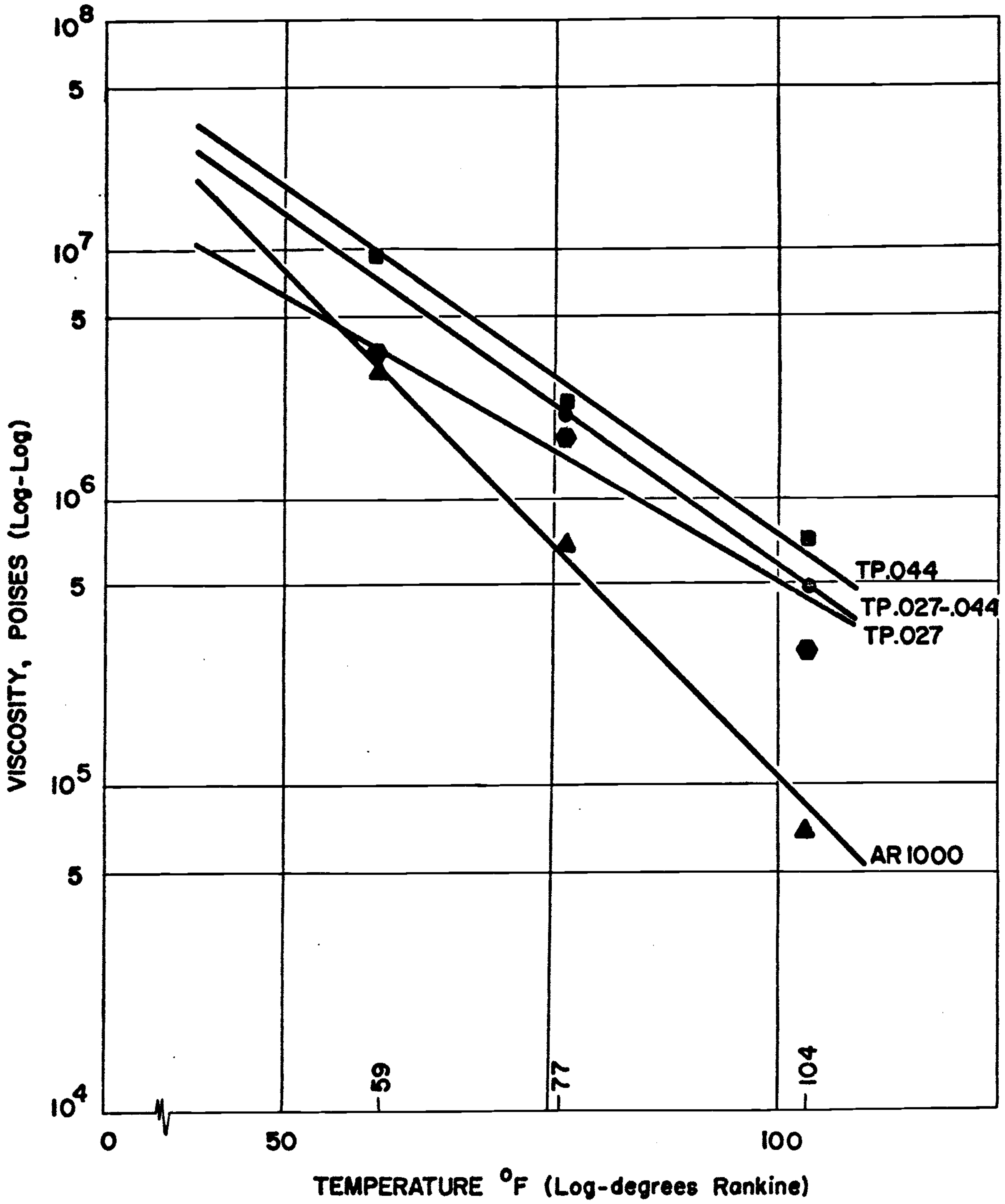


Figure 10. Effect of Temperature on the Viscosity of Asphalt and Asphalt-Rubber Mixtures

2. Addition of different rubber particle sizes results in a different temperature susceptibility of the mixture. Also, the greater the rubber particle size used in the mixture, the lower the temperature susceptibility obtained.

Ductility Test

Figure 11 shows the ductility values for asphalts and for asphalt-rubber mixtures tested at 77°F (25°C). The following results are derived directly from the graph:

1. The addition of rubber to asphalt results in a mixture with a considerably lower ductility value than the plain asphalt.

2. For a specific asphalt grade, the larger the rubber particle size, the lower the ductility value of the resulting mixture.

3. The degree of asphalt hardness has unpredictable effects on the ductility of the asphalt-rubber mixture at 77°F (25°C). When fine rubber (TP.027) was used, the harder asphalt gave a lower ductility value. On the other hand, when coarser rubber (TP.044) was used, the harder asphalt gave a higher ductility value than the soft one. This may change with variability in temperature.

4. Finally, no difference was observed when TP(.027 + .044) was mixed separately with both AR 1000 and AR 4000. The resulting two mixtures seemed to have the same ductility value.

It is assumed, for the purposes of this report, that rubber behaves very similar to aggregate when mixed with asphalt. Ground tire rubber, having a smooth particle surface texture, results in poor adhesion when mixed with asphalt. This poor adhesive property reflects a lower capacity for stretching in the asphalt-rubber mixture as compared to the original asphalt. Consequently, a lower ductility value is expected for the asphalt-rubber mixture.

The exact amount of rubber that goes into solution with asphalt when the two materials are mixed has not yet been determined (McDonald, 1969). It is apparent, however, that more fine rubber dissolves in asphalt than the coarse do primarily to a greater reactive rubber surface area. This extra portion of dissolved fine rubber reflects a higher elasticity in the resulting asphalt-rubber mixture. As a result, the mixture of fine rubber and asphalt will have a higher ductility value than that of coarse rubber and asphalt.

When using a different grade asphalt, the above analysis also applies. However, different ductility values were obtained for the resulting asphalt-rubber mixtures. This difference could be due to the variation in the rheologic properties of different asphalt grades as well as to the complex, undetermined behavior of the asphalt-rubber mixture.

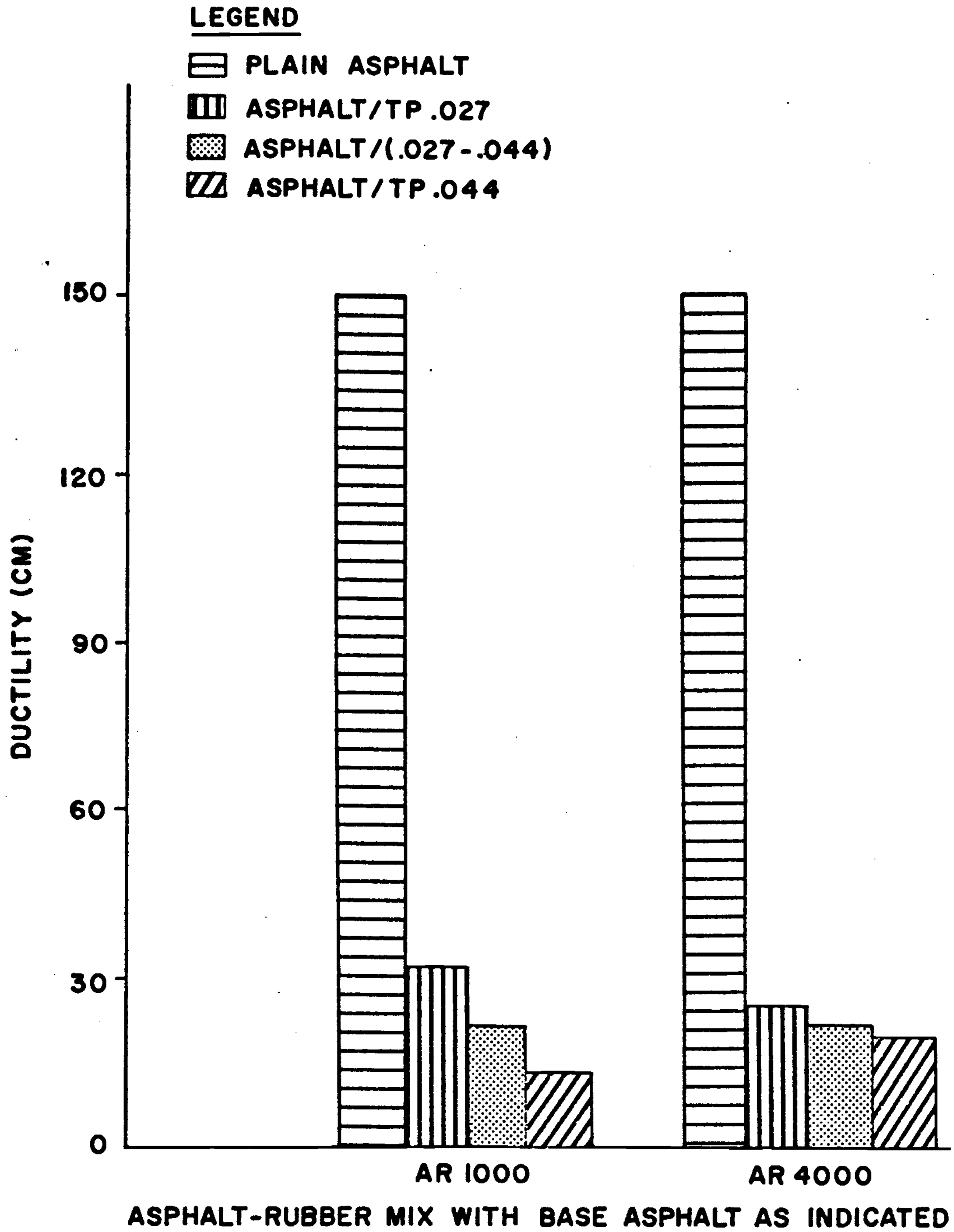


Figure 11. Ductility Values for Asphalt and Asphalt-Rubber Tested at 77°F (25°C).

Water Vapor Transmission Test

This test attempted to measure the relative water vapor transmission (W.V.T.) rate and subsequent permeability constant (K) for asphalt-rubber mixtures. The permeability constant, K (in cm/sec), is obtained by direct application of Darcy's equation:

$$K = \frac{Qd}{AH_w t} \tag{5}$$

Figure 12 shows the water vapor transmission rates for three asphalt-rubber mixtures tested at the three application rates: 0.5, 0.75, and 1 gal/yd^2 (2.26, 3.40, 4.53 l/m^3). The following two observations summarize the graphical representation:

1. Among the three mixtures tested, AR 1000/TP(.044 + .027) is found to give the lowest water vapor transmission rate. This value is obtained at an application rate of 1 gal/yd^2 (4.53 l/m^3). Consequently, it is the most impermeable mixture of those tested.

2. For a particular mixture, increasing the application rate apparently reduces the water vapor transmission rate.

As for any other material, the permeability or perviousness of an asphalt-rubber mixture is concerned with the ease with which air as well as water may pass into or through the mixture. The void content is an indication of the susceptibility of the asphalt-rubber mixture to the passage of air, water, or water vapor. More significant, however, is the interconnection of voids and their access to surface water. AR 1000/TP(.027 + .044), being a blended mixture of coarse and fine rubber mixed with asphalt, obviously will result in a lower void content (close packing ratio) than the other two asphalt-rubber mixtures. Consequently a lower water vapor transmission rate would be expected. This is seen in the graph of Figure 12 at the two application rates of 0.5 gal/yd^2 (2.26 l/m^2) and 1 gal/yd^2 (4.53 l/m^2). At 0.75 gal/yd^2 (3.40 l/m^2) application rate, AR 1000/TP(.027 + .044) apparently has a higher water vapor transmission rate than the other two mixtures.

AR 1000/TP.044, having a larger particle size rubber than AR 1000/TP.027, will provide a higher void ratio within the mix. This would result in higher WVT rates (see Figure 12).

The significance of this test lies in the fact that it gives essential information about the relative waterproofing properties of asphalt-rubber mixtures. These properties are important for determining the material performance in the field. Table 6 summarizes the WVT rates and some corresponding permeability constants that are in common usage in the literature. Depending on membrane thickness and mix, K varies from a low of 2.14×10^{-12} cm/sec to a high of 3.73×10^{-12} cm/sec. These values, for all practical purposes, can be considered as impermeable. A typical oxidized asphalt possesses a permeability of 0.0171 - 0.0330 perms (Hoiberg, 1965)

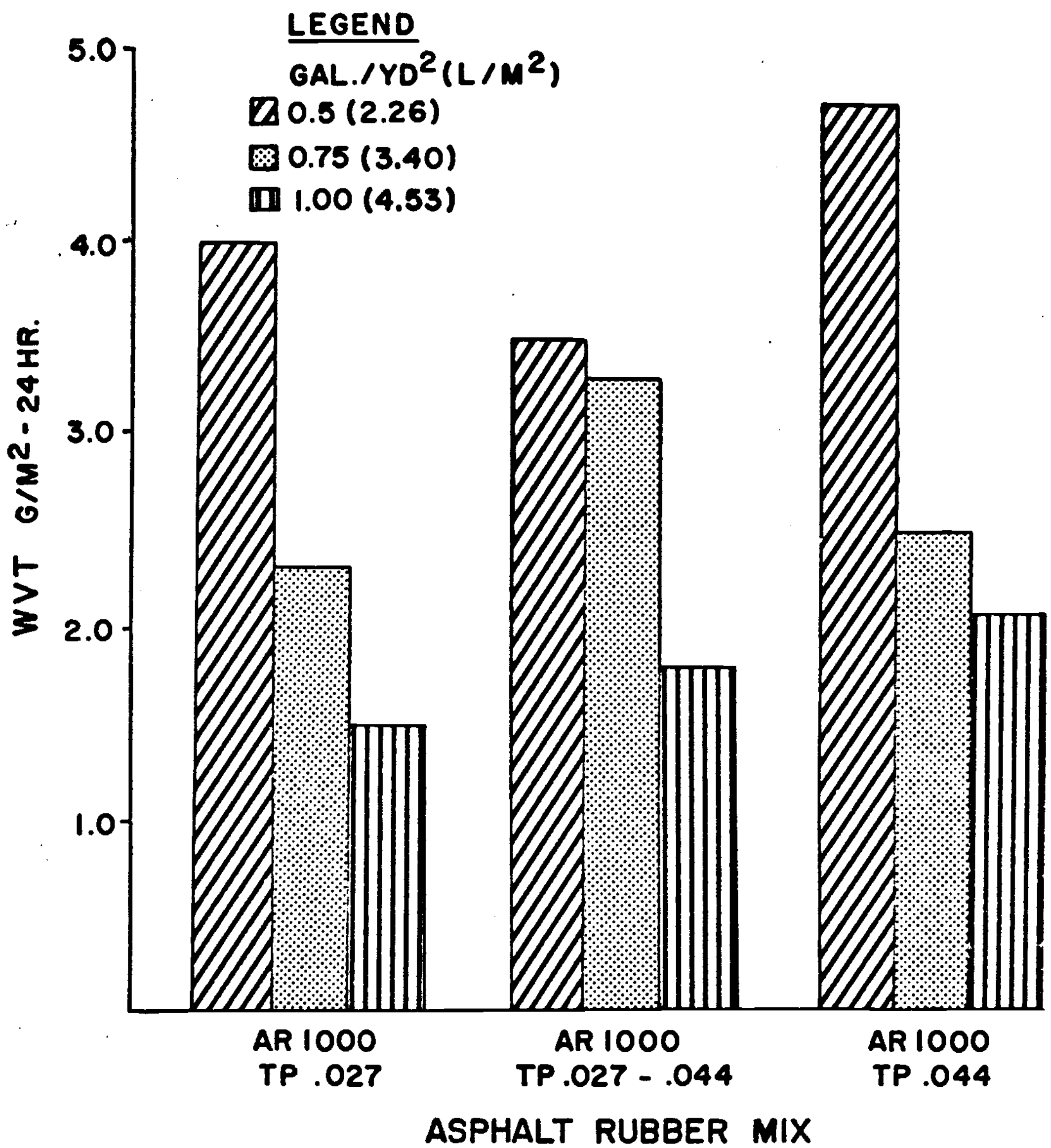


Figure 12. Relative WVT Rates for Various Asphalt-Rubber Mixes

Table 6. Water Vapor Transmission Test Results

AR MIX	APPLICATION RATE [Gal/yd^2 (l/m^2)]	WVT (gm/m^2-24 hr)	K (cm/sec)	PERMEABILITY CONSTANT (gm/cm^2-hr-mm Hg.)	PERMS (grains/ft^2-hr-in Hg.)
AR1000/TP.027	0.50 (2.26)	4.04	3.07×10^{-12}	1.52×10^{-8}	.024
	0.75 (3.40)	2.27	2.56×10^{-12}	1.27×10^{-8}	.013
	1.00 (4.53)	1.44	2.14×10^{-12}	1.06×10^{-8}	.008
AR1000/TP.027-.044	0.50 (2.26)	3.50	2.66×10^{-12}	1.32×10^{-8}	.021
	0.75 (3.40)	3.32	3.73×10^{-12}	1.85×10^{-8}	.020
	1.00 (4.53)	1.81	2.69×10^{-12}	1.34×10^{-8}	.011
AR1000/TP.044	0.50 (2.26)	4.71	3.58×10^{-12}	1.77×10^{-8}	.028
	0.75 (3.40)	2.53	2.84×10^{-12}	1.41×10^{-8}	.015
	1.00 (4.53)	2.11	3.14×10^{-12}	1.56×10^{-8}	.013

which is slightly higher than the range of laboratory values for the asphalt-rubber (0.008 - 0.028 perms) as shown in Table 6. This indicates that the rubber aggregate has no appreciable detrimental effect on the overall permeability of a plain asphalt membrane.

Water Absorption Tests

The water absorbed by the asphalt-rubber is of little significance in most asphalt-rubber applications. That is, the function performed by the asphalt-rubber is not directly dependent on this property but rather on changes it might cause in other physical properties. For asphalts these changes are usually very minor in nature (Hoiberg, 1965).

Accurate dimensions of the specimens could not be obtained due to the plastic nature of the A-R membrane material. Many specimens deformed slightly upon handling during intermittent weighings and therefore could not be accurately measured for dimensional change during testing. It was also difficult to completely surface dry all specimens before periodic weighings due to surface irregularities of the A-R. Some human error, therefore, in the weighing procedures may be present.

The test specimens were cut from a molded membrane sample in the form of rectangular sections 3 in. (76.2 mm) long, 1 in. (25.4 mm) wide and 1/8 in. (3.2 mm) in thickness. A minimum of five specimens for each sample were placed in a container of distilled water at a temperature of 77°F (25°C). Due to the relatively little water absorption after 24 hours, long-term immersion testing was used to determine the water absorption with time. Graphical results of water absorption vs. time are presented in Figure 13. The lowest water absorption rate occurred with the AR 1000/TP(.027 + .044) mix. The maximum 28 day total absorption of 0.67%, however, was approximately the same as for the AR 1000/TP.027 which was 0.80%. This higher absorption, although small, may be attributable to the fine particle size of rubber and thus greater absorptive surface area. It should be noted that in a separate test on the plain crumb rubber, the total water absorbed by the rubber alone was exactly 1.0%. Although the asphalt cement by itself does not absorb a measurable amount of water, obviously the rubber phase in the A-R does.

It is apparent that the maximum absorption for the A-R occurs within 14 to 21 days with little increase in weight after 28 days. This may only be a surface absorption phenomenon over a relatively short time span. Water immersion testing over months or years may yield slightly higher water absorption values. For the purposes of this study, it is safe to say that the maximum water absorption is in the range of 0.6 to 0.8 percent by weight of the dry membrane. Although additional testing may be needed, it is not felt there is any appreciable deterioration in the physical properties of asphalt-rubber when totally immersed in water.

Permeability Test

Actual test results indicated that asphalt-rubber mixtures have a very low coefficient of permeability, ranging from 2.0×10^{-6} to 9.62×10^{-7} cm/sec.

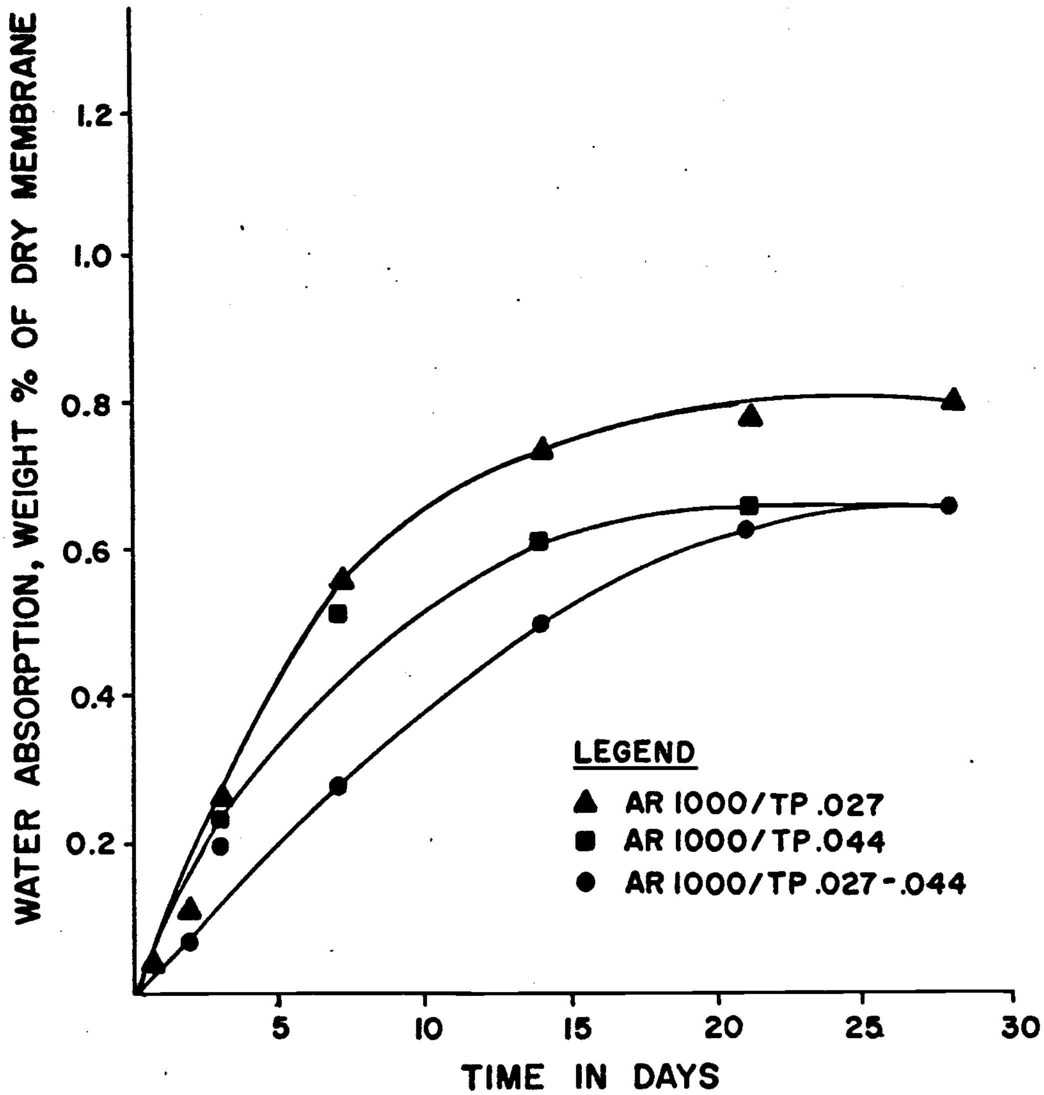


Figure 13. Relative Water Absorption Rates for Various Asphalt-Rubber Mixes

However, these results were felt to be unreliable for several reasons. A close inspection of test specimens indicated that most of the failures occurred at the porous stone/aluminum base plate interface. Several attempts for sealing the interface failed. When hard wax was used as a seal, several specimens did not show any visible flow rate. This difficulty in obtaining adequate edge seal, as well as the fact that the liquid phase (as opposed to water vapor phase) is very difficult to measure with respect to flow rate through asphalt-rubber, led to the conclusion that the permeability data was unreliable. When testing plain AR 1000 asphalt, no measurable water passed through the asphalt film. It is to be noted, however, that after 48 hours the plain asphalt flowed through the porous corundum stone and into the permeameter tubing. This occurred under 5 psi (.35 kg/cm^2) hydrostatic pressure. On the other hand, the asphalt-rubber mixtures did not penetrate the stone even after 72 hours of testing under as much as 15 psi (1.06 kg/cm^2). This reinforces the hypothesis that when rubber is added to asphalt the resulting mixture develops a higher resistance to deformation than the original asphalt.

Brittleness - Impact Resistance

This test attempted to determine the relative impact resistance of the asphalt-rubber membrane. Plain asphalt cement failed (shattered) at both test temperatures of 20°F (-6.6°C) and 40°F (4.4°C). Results of impact resistance testing are shown in Table 7.

Table 7. Brittleness Test Results

Material	Test Temperature 40°F	20°F
AR 1000	F*	F
AR 1000/TP.027	NF	NF
AR 1000/TP.044	NF	F
AR 1000/TP(.027 + .044)	NF	F
AR 4000	F	F
AR 4000/TP.027	NF	F
AR 4000/TP.044	NF	F
AR 4000/TP(.027 + .044)	NF	F

*F = Failure NF = No Failure

The asphalt-rubber specimens that did not fail exhibited only minor radial cracks that penetrated the surface only slightly. Those that failed fractured from the center radially outward and cracked the full thickness of the specimen. None of the asphalt-rubber specimens shattered as was the case with plain asphalt cement. It should be noted that the softer asphalt

(AR 1000) in combination with TP.027 rubber resisted fracture at 20°F (-6.6°C) and was the only mix to do so.

Generally, the rubber aggregate, when added to asphalt cement, greatly increases the flexibility and elasticity of the total mix at 40°F (4.4°C). This results in greatly improved impact resistance. At temperatures below freezing (in this case 20°F), the asphalt rubber mix is susceptible to fracture. The only mix that may not fracture at relatively lower temperatures is AR 1000/TP.027 due primarily to the softer asphalt grade and smaller rubber particle size which results in greater flexibility, elasticity, and toughness.

Flow/Slope Stability

The asphalt-rubber did not behave as anticipated in that the total test cube remained intact at the top of the slope. It was anticipated that the asphalt-rubber would react similarly to a filled asphalt cement and flow as a homogeneous mix. The cubes, however, did exhibit asphalt separation and subsequent asphalt flow down slope. Figure 14 shows the relative slope movements of the asphalt contained in the asphalt-rubber mixes. Slides 1 and 2 contain plain asphalt cement (AR 1000) which flowed the entire slide length within six hours from start of testing. Slides 3 and 4 contain AR 1000/TP.027 which exhibits only slight asphalt separation whereas slides 7 and 8 (AR 1000/TP.044) exhibit a greater degree of separation. This is an indication that the greater amount of crumb rubber aggregate surface area (smaller particle size), the more homogeneous the mix becomes due to increased surface interaction. This results in less asphalt separation and better slope stability for the finer rubber aggregate mix. The efficiency of various aggregate rubber sizes used as stiffening agents will vary with the type, source, particle size gradation and subsequent surface area of the crumb rubber.

Field Installations

Experimental field installations of asphalt-rubber treatments on prepared subgrades were made in an attempt to provide additional information on water proofing characteristics, subgrade preparation, and physical degradation. Also, a 100,000 gallon (3785 m^3) water storage reservoir was lined with asphalt rubber to test its effectiveness in site application and actual service.

Three asphalt-rubber field plots were installed at the outdoor exposure laboratory located at the Water Resources Research Center Field Laboratory, Tucson, Arizona. The outdoor exposure laboratory contains 21 experimental plots of various lining materials that are continuously monitored. Each plot measures 8 ft (2.44 m) by 16 ft (4.88 m) and is contained by a 4 inch (101.6 mm) high concrete curbing. The slope of all plots is 5 percent and all accumulated runoff is collected and measured to evaluate the effectiveness of each type of membrane. The plots used for the asphalt-rubber application were as follows:

Plot No. 13: Subgrade - Silty sand type SM

A-R application - AR 1000/TP(.027 + .044) applied at a rate of 0.5 gal/yd^2 (2.26 l/m^2)
Cover material - 3/8 inch (9.5 mm) washed stone applied at a rate of 25 lb/yd^2 (13.56 kg/m^2)

Plot No. 14: Subgrade - Silty sand type SM

A-R application - AR 1000/TP(.027 + .044) applied at a rate of 0.5 gal/yd^2 (2.26 l/m^2)
Cover material - Sand applied at a rate of 15 lb/yd^2 (8.14 kg/m^2)

Plot No. 16: Subgrade - Silty clay type CH

A-R application - AR 1000/TP(.027 + .044) applied at a rate of 0.5 gal/yd^2 (2.26 l/m^2)
Cover material - none

All field plots were monitored for rainfall-runoff data and any visual weathering or physical deterioration. After approximately one year of exposure, the following observations on the asphalt-rubber plots were made: Plots 13 and 14 exhibited outstanding waterproofing characteristics in that they both indicated rainfall-runoff efficiencies in excess of 95%. There were no signs of any physical deterioration of the membrane material. However, most of the sand cover on plot 14 has eroded and has accumulated at the base of the plot. The 3/8 inch (9.5 mm) stone cover material has not deteriorated and is providing an excellent protective cover. The asphalt-rubber membrane has deteriorated slightly on plot 16 due to the highly expansive clay subgrade and exposed condition. The expansive clay has caused the asphalt-rubber to crack with the subgrade. It should be noted that the cracks tend to reheal themselves with increase in surface temperature. Also, some atmospheric degradation has been noted because of the lack of cover material. Due to the cracking, the rainfall-runoff efficiency was less than 40%.

Reservoir Installation

An existing 100,000 gallon (3785 m^3) capacity reservoir was prepared and lined with asphalt-rubber. This particular structure was previously lined with polyethylene which had failed. A representative drawing of the reservoir shape and size is shown in Figure 15. The excavated reservoir had a finished subgrade generally consisting of a silty sand type SM. Side slopes and bottom were cleared and smoothed. All loose aggregate or foreign matter was removed. The excessive 1:1 side slopes prohibited complete smoothness due to sloughing of the embankment material. The bottom was smoothed and compacted with a vibratory flat plate compactor to insure that the subgrade would support a workman without causing excessive depressions or irregularities in the subgrade.

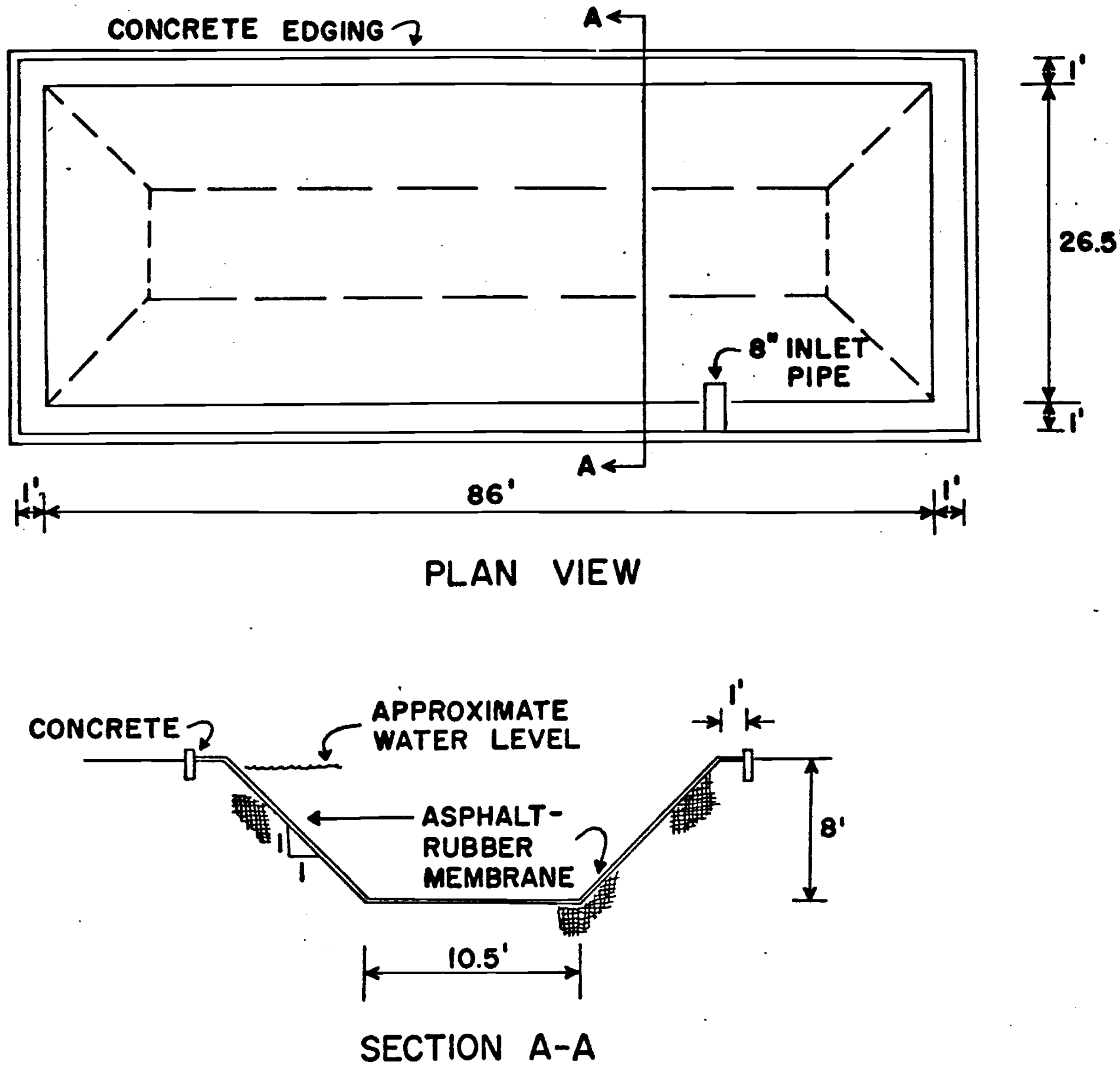


Figure 15. Reservoir Used for Asphalt-Rubber Membrane Lining

The entire subgrade was primed with SS-1h cationic emulsion at an application rate of approximately 0.2 gal/yd^2 (0.9 l/m^2). This was used to establish a penetrating tack coat for the asphalt-rubber, expecially for the relatively unstable side slope embankment material. The asphalt emulsion was allowed to cure for approximately 12 hours before asphalt-rubber application. Due to the short cure time, the tack coat was observed to pull easily from the subgrade when walked on causing an undesirable subgrade condition. A longer cure time (in excess of 24 hours) and less tack coat quantity would be recommended for future installations. In addition to the tack coat on the excessively steep side slope, unwoven fiberglass (10 mil thickness) was placed before asphalt-rubber application to help compensate for the irregular subgrade. Also, the fiberglass was used to help prevent excessive downslope movement.

The asphalt-rubber was applied at a rate of 1.0 gal/yd^2 (4.53 l/m^2) and consisted of the AR 1000/TP(.027 + .044) mix. The asphalt was heated to 370°F (187.77°C) in a 200 gal (0.757 m^3) portable distributor tank. The rubber was added in the proportion of 1 part rubber to 3 parts asphalt and mixed for a period of approximately 30 minutes (the distributor tank was specially equipped with an interval mixing device). The asphalt-rubber was applied by a hand spray applicator (single nozzle) as shown in Figure 16. Coating of the sides was from top to bottom in a sweeping side to side motion. The mix sprayed easily and evenly and formed a continuous, smooth membrane with no puddling or separation of asphalt. Only slight down slope movement was detected immediately after the asphalt-rubber application due to initially high temperatures and low viscosity. To prevent additional movement of the membrane on the very steep slopes, the asphalt rubber was lightly coated with white acrylic roofing paint which effectively reduced summer surface temperatures by reflecting the sun's energy. The finished reservoir without the white acrylic paint is shown in Figure 16.

After filling the reservoir to capacity, it was monitored for any noticeable seepage losses, taking into account evaporation losses, minimal seepage was detected. Total cost of the lining installation was $464.00 or $1.27/yd^2 including labor and materials. For larger lining installation, this cost would be cut considerably due to mechanization (distributor trucks) and larger material quantities.

Subgrade and application specifications were formulated based upon the above field work and previously described laboratory work. These specifications can be found in Appendix II.

CONCLUSIONS

This investigation was initiated with the goal of determining several engineering characteristics of asphalt-rubber used as a water seepage barrier and to develop preliminary specifications for its use. The physical characteristics investigated for this report were viscosity, ductility, water vapor transmission, water absorption, permeability, flow/slope stability and brittleness/impact resistance. Also, field installations provided additional information on mix design and application procedure.

The viscosity test results indicate that the addition of rubber to asphalt cement AR 1000 or AR 4000 results in a mixture with a higher viscosity value than the original asphalt. This increase is considerably greater at higher temperatures than at lower ones. AR 1000/TP.044, for example, is more than ten times as viscous as the AR 1000 at 104°F (60°C). At 77°F, (25°C), the viscosity of AR 1000/TP.044 is approximately four times greater than that of AR 1000. Test results also show that the addition or rubber greatly reduces the temperature susceptibility of the material under consideration. This reduction was greater when using coarse rubber than when using the finer rubber particle size. These findings should be given special consideration when choosing the appropriate asphalt distributor equipment (e.g., nozzle size) for field application. Also, site characteristics such as slope stability should be considered when looking at viscosity/temperature results. A slope of 2 horizontal to 1 vertical should be considered maximum for application unless reinforcement is incorporated within the membrane.

The ductility of asphalt is greatly reduced when rubber is added to it. Asphalt-rubber was found to have a ductility value of about one-fifth that of plain asphalt. This is a further indication of the toughness and resistance to flow when rubber is added to asphalt. It should be noted that the coarser the rubber aggregate, the lower the ductility.

The water vapor transmission rate and subsequent permeability values for asphalt-rubber were found to be very low. Therefore, one can conclude that the combination of asphalt and rubber aggregate results in a relatively impermeable membrane and that the rubber does not significantly effect the otherwise impermeable asphalt cement membrane.

The water absorption test indicates a higher percent absorption obtained when rubber is added to asphalt. When substantially saturated, asphalt rubber is found to have a percent absorption value of at least 0.65% as compared to plain asphalt whose maximum percent absorption is 0.01%. This increase in percent absorption is due to the surface water absorption tendency present in the granular tire rubber. This small amount of water absorption is not considered detrimental to asphalt-rubber physical properties.

As rubber aggregate is added to asphalt, the resulting mix greatly reduces flow or downslope movement over that of asphalt cement. As the rubber particle size decreases, more asphalt apparently goes into solution with the rubber (more rubber surface area) and subsequently reduces the amount of asphalt that can separate from the total A-R mix. A coarser particle size in the A-R mix will result in more asphalt separation if placed on a relatively steep slope.

The brittleness or impact resistance of asphalt cement is increased significantly with the addition of rubber aggregate especially at a relatively low temperature of 40°F (4.4°C). The softer asphalt cement (AR 1000) and fine rubber gradation should be used if impact resistance is a consideration below 32°F (0°C).

Field installations indicate that the asphalt-rubber as a membrane material exhibits excellent waterproofing properties. It is imperative that adequate subgrade preparation be provided for an effective asphalt-rubber membrane. If a smooth, compacted subgrade cannot be attained, the field installations have shown the advantage of using the woven fiberglass to

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APPENDIX I

LABORATORY MATERIAL SPECIFICATIONS

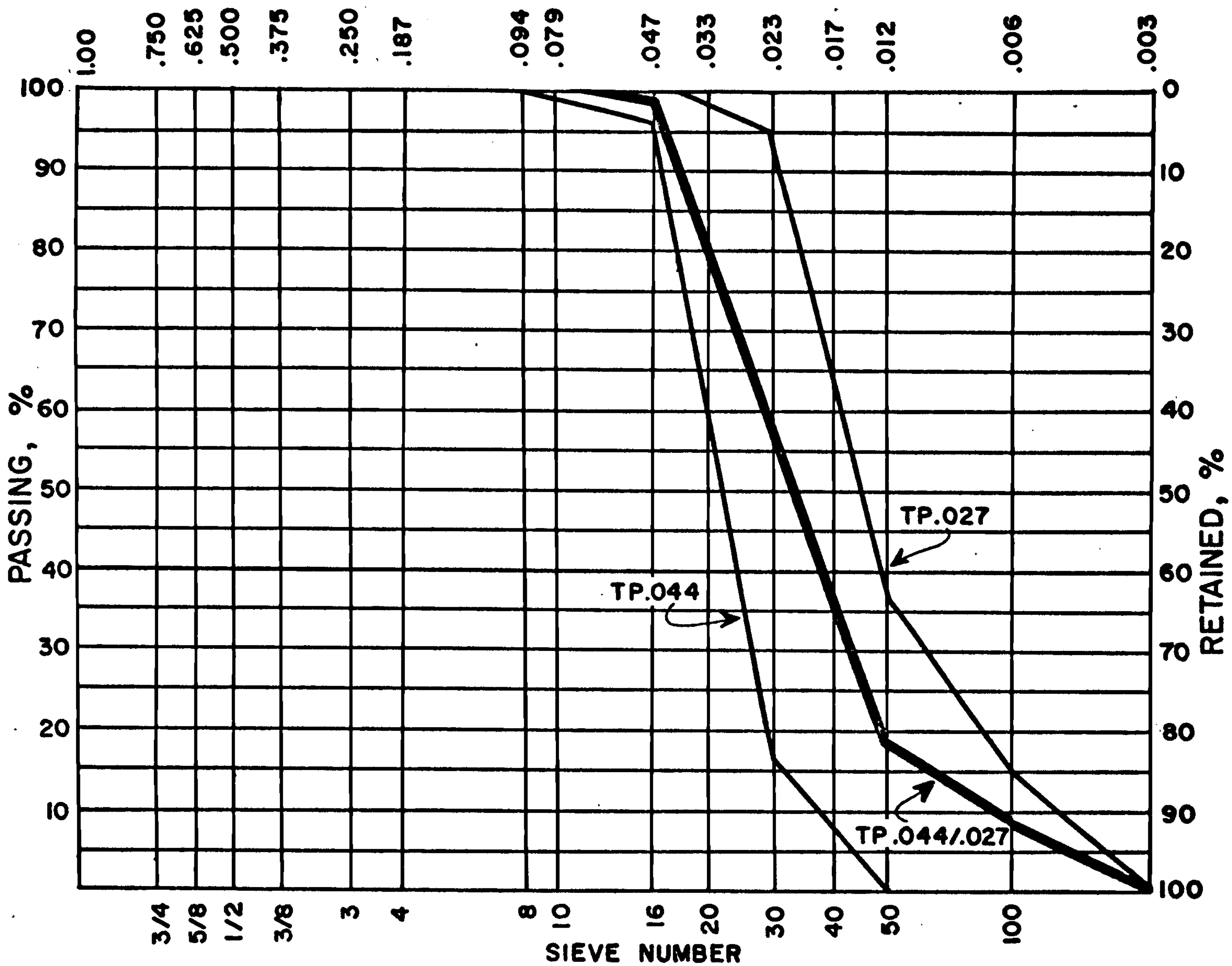

Figure I - 1. Particle Size Disribution of Crumb Rubber Used in the Asphalt-Rubber Testing.

Table I-1. Standard Specifications for Asphalt Cement Used in this Research.

Tests on Residue from AASHTO T240	AASHTO Test Method	Viscosity Grade	
		AR 1000	AR 4000
Viscosity, 140°F, poises	T202	750-1250	3000-5000
Viscosity, 275°F, minimum	T201	140	275
Penetration, 77°F, 100 gm, 5 sec, minimum	T49	65	25
Percent of original penetration, 77°F, minimum	-[a]	-	45
Ductility, 77°F, cm, minimum	T51	100[b]	75
Tests on Original Asphalt			
Flash point, Pensky-Marten closed tester, °F, minimum	T73	400	440
Solubility in trichloroethylene, %, minimum	T44	99	99

[a]Penetration of original asphalt as well as penetration of asphalt after the RTFC test will be determined in accordance with the requirements of AASHTO T49.

[b]If the ductility is less than 100, material will be accepted if the ductility at 60°F is more than 100.

APPENDIX II

GENERAL SPECIFICATIONS FOR SUBGRADE PREPARATION AND MATERIAL DISTRIBUTION FOR ASPHALT-RUBBER MEMBRANE INSTALLATIONS

GENERAL SUBGRADE SPECIFICATIONS FOR ASPHALT-RUBBER MEMBRANE LININGS USED IN RESERVOIR AND WATER HARVESTING INSTALLATIONS

1. General

1.1 This work involves the preparation of the subgrade surface before application of the asphalt-rubber membrane. These specifications apply to an unprepared soil subgrade and are not needed if an asphalt concrete or equivalent hard surface is provided for the lining. Also included are general specifications for the cover material.

2. Subgrade Preparation

2.1 The subgrade shall be firm enough to support the men or equipment to be used during the membrane installation. Adequate structural bearing shall be provided. In particular, determine the optimum moisture content which gives the greatest degree of compaction (maximum density) in accordance with ASTM designation D 698 or AASHO designation T 99. The subgrade soil in place in the field shall be compacted to a density of 95% of the maximum obtained in the laboratory. Moisture content shall not vary more than 2% above or below optimum. This section need not apply to water harvesting catchment installations.

2.2 All large clods, brush, roots, rocks, sod, or other foreign material, shall be eliminated from the area to be lined. All backfilled depressions, including areas where large rocks have been removed, are particularly subject to abnormal, localized settling and shall be compacted with care. Maximum surface particle size shall not exceed 1/2 inch before roller-compaction. Roller compaction is not needed for water harvesting membrane installations but is essential for reservoir installations. A roller may be needed to obtain a relatively smooth subgrade for some water harvesting applications.

2.3 For reservoir lining, inspect exposed subgrade soil for zones of coarse gravel, sand lenses, etc. All such zones should be over-excavated one foot and backfilled with suitable compactible material composed of stockpiled sandy clay soils, type SM or finer (as defined in ASTM designation D 2487).

2.4 Subgrade shall be graded and dressed to relatively uniform gradients and shall be rolled with steel wheel rollers to achieve the desired density and/or surface smoothness. Rollers shall not weigh less than 50 pounds per linear inch or drum width. At least two coverages by the roller shall be required for reservoirs. There shall be no sharp bends, ruts or sudden changes in the subgrade.

2.5 Fill or loose subgrade material that is to be compacted but is inaccessible to rollers should be compacted with pneumatic, vibrating, or other approved hand-tamping equipment. (Reservoir installation only).

2.6 If isolated areas in the subgrade are still coarse-textured and open after preparing and compacting, a light two-inch cushion layer of filter grade soil, type SW or finer (as defined in ASTM designation D 2487) should be applied and compacted. (Reservoir installation only).

2.7 If weed growth is considered to be a problem, a high quality, non-selective soil sterilant should be applied after preparation of the subgrade and before application of the tack coat. The asphalt-rubber membrane should not be applied over penetrating type plants unless they are completely removed. If liquid soil sterilants are to be used, their application can be done before rolling to provide the required moisture for compaction.

2.8 Excavations within reservoir bottoms shall not have slopes steeper than 1 vertical to 3 horizontal. Steeper slopes through channeled areas shall be terraced to prevent sloughing of the lining or cover material. The mean slope of the terraced section shall not be steeper than 1 vertical to 2 horizontal.

2.9 The contractor shall plan his operations so that all asphalt-rubber membrane material placed in a single working day shall be covered the same working day with the specified select cover material. A 3-foot strip along the edge of the membrane shall be left uncovered for the next pass of the distributor truck. Vehicles and/or construction equipment shall not operate directly on the uncovered asphalt-rubber membrane.

3. Select Fill Over Asphalt-Rubber Membrane

3.1 For reservoir construction, all asphalt-rubber membrane lining material shall be covered with a minimum of 12 inches of select material composed of stockpiled soil excavated from the reservoir area if acceptable. The bottom 3 to 6 inches of soil cover next to the membrane shall not be coarser than silty sand, type SM. The remaining cover material should pass a 1-inch square mesh screen and shall contain a minimum of 30% passing a Number 8 screen.

3.2 For water harvesting catchment construction, a cover material composed of 3/8 inch (9.5 mm) washed stone applied at a rate of 25 lb/yd^2 (13.56 Kg/m^2) shall be applied to the asphalt-rubber immediately after spray application. Stone distribution shall be by mechanized spreader immediately following the asphalt distributor truck.

3.3 Placing of cover material shall be conducted in such a manner that the lining will not be damaged by equipment or overburden. Care must be taken in the placement of the cover material when temperatures are over 100°F (38°C) as the puncture resistance of the asphalt-rubber membrane diminishes with increasing temperature.

3.4 The cover material shall be sufficiently stable to minimize wind erosion and/or liquid scouring on sloping sides of a reservoir as the water level fluctuates.

GENERAL SPECIFICATION FOR HOT ASPHALT-VULCANIZED CRUMB RUBBER MEMBRANE WATERPROOFING FOR RESERVOIR AND WATER HARVESTING APPLICATIONS

1. General

1.1 This work involves the placing of a hot asphalt-vulcanized crumb rubber waterproof membrane liner on prepared surfaces in accordance with the following specifications.

2. Materials

2.1 The asphalt cement membrane lining shall conform, prior to the addition of rubber, to the specifications for viscosity, grading AR 1000 or AR 4000 as specified by the Pacific Coast User's Conference.

2.2 The vulcanized crumb rubber shall meet the following requirements:

2.2.1 The total rubber aggregate phase of the asphalt-rubber mix shall consist of equal parts by weight of two rubber particle sizes supplied by the manufacturer as follows:

Particle Size No. 1 - Not less than 95% shall pass the No. 16 sieve and not more than 10% shall pass the No. 25 sieve (TP.044 ATLOS).

Particle Size No. 2 - Not less than 95% shall pass the No. 25 sieve and not more than 30% shall pass the No. 50 sieve (TP.027 ATLOS).

Sieves shall comply with ASTM Designation E-11 or AASHO Designation M-92. Sample size shall be 150-200 grams.

2.2.2 The granulated crumb rubber, irrespective of diameter shall be less than 1/8 inches in length and shall be free from fabric, wire, or other contaminating material.

2.2.3 The specific gravity of the crumb rubber shall be 1.15 ±.02 and shall be fully vulcanized. The crumb rubber shall be protected from atmospheric moisture or any adverse weather conditions. Up to 4% of a granulated, anhydrous compound such as calcium carbonate may be included to prevent the rubber particles from sticking together.

2.3 Tack Coat: A tack coat comprised of CSS-1 or CSS-1h emulsified asphalt, mixed with equal parts water shall be applied to the compacted base at a rate of approximately 0.10 gal/yd^2. The asphalt material shall meet the requirements of ASTM designation D 2397 or AASHO designation M 208.

3. General Specification for Mixing and Application of Asphalt-Rubber

3.1 Equipment

3.1.1 A self-powered pressure distributor equipped with a separate power unit, distributing pump capable of pumping the specified material at the specified rate through the distributor tips, and equipment for heating the bituminous material. The distribution bar on the distributor shall be fully circulating with nipples and valves so constructed that they are in such intimate contact with the circulating asphalt that the nipples will not become partially plugged with congealed asphalt upon standing, thereby causing preliminary streaked or irregular distribution of the asphalt. Any distributor that produces a streaked or irregular distribution of the material shall be promptly removed from the project. Distributor equipment shall include a tachometer, pressure gauges, volume measuring devices, mixing equipment inside distributor tank capable of being run off either separate power unit or power take off, and a thermometer for reading the temperature of the tank contents. The spray bars on the distributor shall be controlled by a bootman riding at the rear of the distributor in such a position that operation of all sprays is in full view and accessible to him for controlling overall spread widths and individual fan widths.

3.1.2 The method and equipment for combining the rubber and asphalt shall be so designed and accessible that the engineer can readily determine the percentages, by weight, of each of the rubber gradations added to the mixture. If the crumb rubber is packaged in bags, alternate sieve sizes (by bag) shall be placed in the distributor tank until the total rubber quantity is incorporated into the mix.

3.2 Mixing

3.2.1 The crumb rubber shall be added to the preheated asphalt as rapidly as possible for such a time and at such a temperature that the consistency of the mix approaches that of a semifluid material. The temperature of the asphalt before mixing shall be between 350° and 400° F. The engineer shall be the sole judge of when the material has reached application consistency. After all rubber has been added and the mix has reached proper consistency, application shall proceed immediately; and in no case shall the mixture be held at temperatures over 325°F for more than two hours after reaching that point.

3.2.2 The proportions of the mix shall be as follows: 33-1/3% of the asphalt, by weight, shall be vulcanized crumb rubber consisting of equal parts of the two rubber particle sizes as specified in 2.2.1.

3.2.3 No kerosene diluent shall be used in the asphalt-rubber mix.

3.3 Membrane Application

3.3.1 Prior to the asphalt-rubber membrane application, the surface to be sealed shall be prepared as specified under subgrade preparation.

3.3.2 The tack coat shall be applied a minimum of 24 hours prior to the application of the asphalt-rubber membrane. There shall be no "puddling" of the emulsified asphalt and all areas shall be relatively dry before applying the asphalt-rubber. The rate of application of the tack coat shall be ±0.10 gal/yd^2. It is desirable that the distributor trucks not "pick up" the tack coating with their tires when dispensing the asphalt-rubber. Application of asphalt-rubber should be made at relatively cool air and surface temperatures when possible. In lieu of an asphalt emulsion tack coat, a light spray of water may be desirable for certain climatic and soil conditions.

3.3.3 The application rate of the hot asphalt-rubber mixture shall be determined by water harvesting catchment subgrade and reservoir design parameters. Application shall produce a continuous membrane without holidays, streaking or "skips" at overlaps and shall be made in one pass of the distributor truck.

3.3.4 All overlaps shall be a minimum of one foot and shall be clean of any debris or adjacent cover material. Overlapping joints shall be continuous and an integral part of the membrane.

3.3.5 Areas that are inaccessible by distributor truck shall be covered by a hand hose applicator in such a manner as to produce the desired application rate.

3.3.6 For reservoir application, select cover material shall be placed over the asphalt-rubber membrane only after it has cooled and shall be placed with rubber-tired vehicles only. At no time shall vehicles or construction equipment be allowed on the exposed membrane without sufficient cover material in place.

3.3.7 For water harvesting catchment construction, the select cover stone shall be placed immediately after spray application of the asphalt-rubber.

LIST OF PUBLICATIONS

Frobel, R. K., C. B. Cluff and R. A. Jimenez, "Development of an Asphalt-Crumb Rubber Membrane for Water Harvesting Catchments and Reservoir Seepage Control," Office of Water Research and Technology Completion Report A-075-ARIZ, Water Resources Research Center, University of Arizona, Tucson, Arizona, 1977.

Frobel, R. K., R. A. Jimenez, C. B. Cluff and G. R. Morris, "Asphalt-Crumb Rubber Waterproofing Membrane," Journal of the Irrigation and Drainage Division, ASCE, Article Pending, 1977.

Kalash, R., "Asphalt-Rubber Mixtures for Seepage Control," M. S. Thesis, Dept. of Civil Engineering, University of Arizona, Tucson, Arizona, 1977.

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PROJECT COMPLETION REPORT
OWRT PROJECT NO. A-075-ARIZ

DEVELOPMENT OF A LOW COST ASPHALT-RUBBER MEMBRANE FOR WATER HARVESTING CATCHMENTS AND RESERVOIR SEEPAGE CONTROL

Agreement No. 14-34-0001-7006

Project Dates: July 1976 - June 1977

The University of Arizona
Tucson, Arizona

June, 1977

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PROJECT COMPLETION REPORT
OWRR PROJECT NO. B-015-ARIZ

DEVELOPMENT OF ECONOMIC WATER HARVEST SYSTEMS FOR INCREASING WATER SUPPLY

PHASE II

Agreement No. 14-01-0001-1425

Project Dates: June, 1970 - December, 1971

The University of Arizona
Tucson, Arizona
July, 1972

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Principal Investigators:

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R. M. Kalash - Civil Engineering

The University of Arizona
Tucson, Arizona

June, 1977

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ABSTRACT

This project was concerned with the laboratory and field investigation of asphalt-rubber for use in water seepage control applications. Laboratory testing utilized for physical property determination included viscosity, ductility (ASTM D113-74), flow/slope stability, brittleness/impact resistance (ASTM D994-72), water vapor transmission (ASTM E96-72, Procedure BW), water absorption (ASTM 570-72), and permeability. Also, some specialized laboratory equipment was designed and fabricated for the testing.

The results of the testing showed that the asphalt-rubber is relatively impermeable as a membrane, and that the rubber does not effect an otherwise impermeable asphalt film. Physical properties of the base asphalt that are increased with the addition of rubber include water absorption, viscosity, and impact resistance. The tests that exhibited lower physical property values were ductility and slope stability.

Investigations of field applications of asphalt-rubber resulted in preliminary subgrade preparation specifications. Also, the field installations supported the hypothesis that the asphalt-rubber can be effectively used as a water seepage barrier. Preliminary specifications for asphalt-rubber mixing and field application are also included.

LABORATORY TESTING PROGRAM: MATERIALS, TESTS, AND PROCEDURES

Material Identification and Mixing

Two types of asphalt cements were used in this investigation: AR 1000 and AR 4000. The number in each asphalt designation refers to the base viscosity of the asphalt. Complete specifications of these two asphalt cements are shown in Appendix I.

Three types of ground tire rubber, based on the particle size (see Appendix I), were also used. The first type, designated as TP.044*, represents the coarse rubber particle size. The second type of rubber, designated as TP.027, represents the finer particle size. The third type of rubber particle size distribution is designated as TP(.044 + .027). This type of rubber is a blended mixture of coarse and fine rubber. The blend was mixed in proportion by weight of 50 percent coarse rubber and 50 percent fine rubber. The sieve analysis of the three types of rubber are shown in Appendix I.

The mix proportions of the two materials, by weight, were 75 percent asphalt and 25 percent granulated rubber. The designed mixing method was as follows: A specific amount of asphalt was heated in a steel crucible to a temperature of 370 ± 5°F (187.77 ± 2.77°C). At this temperature, a specified amount of rubber, according to the above-mentioned proportion by weight, was added to the hot asphalt. Addition of rubber to asphalt was done very slowly over a period of 5 minutes while continuously mixing the total mix. After all of the rubber was added to the hot asphalt, mixing of the two materials continued for a period of 30 minutes. Mixing temperature was maintained between 350 and 400°F (176.67 and 204.44°C). At the completion of the mixing period, the asphalt-rubber mixture was molded into the required test specimens. Molding and curing of the test specimens varied according to the test under consideration.

Hereafter, reference to the asphalt rubber mixture will be by asphalt type/rubber type, e.g. AR 1000/TP.027.

Viscosity Testing

Due to the relatively high viscosities and granular nature of the asphalt-rubber mix, conventional viscosity determinations could not be used. The falling coaxial viscometer as developed by Traxler and Schweyer (1936) was chosen as a viable viscosity determination method. A detailed theoretical analysis of the viscometer is presented in the thesis by Kalash (1977). The following equipment was used in the viscosity test:

*Manufacturer's identification number.

1. Falling coaxial cylinder viscometer, support and weights as shown in Figure 1.
2. Constant temperature water bath with thermostatic control, stirrer and thermometer.
3. Telescopic sight with vernier scale in cm (cathetometer).
4. Stop watch.
5. Silicone grease lubricant.

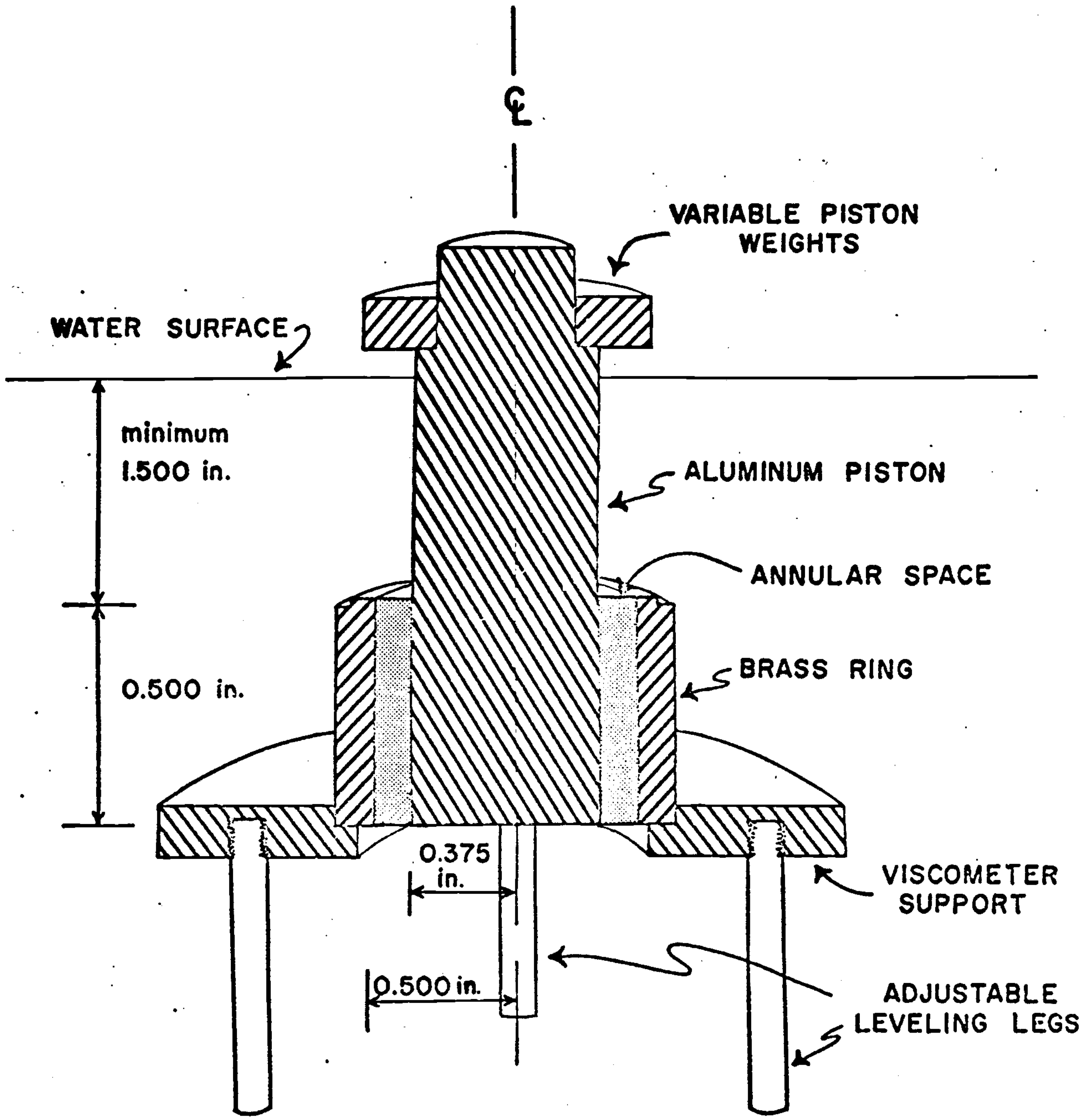
The asphalt-rubber mixtures, variables and repetitive tests done on them are shown in Table 1.

Table 1. Viscosity Determinations

Material	Test Temperature		
	59°F	77°F	104°F
AR 1000	2	2	2
AR 1000/TP.027	2	2	2
AR1000/TP.044	2	2	2
AR1000/TP(.044 + .027)	-	2	2
AR4000	-	2	2
AR4000/TP.027	-	2	2
AR4000/TP.044	2	2	2
AR4000/TP(.027 + .044)	-	2	2

The viscosity determinations were performed by using the viscometer shown in Figure 1. The procedure for running a viscosity test by using the falling coaxial cylinder viscometer involved the following steps:

1. The desired temperature for the water bath was set by thermostatic control and the stirrer speed was set manually.
2. Enough mixture of asphalt-rubber needed for the test was prepared. Mixing procedure is explained at the beginning of this section.
3. A 4x4x1/4 in. (10.16x10.16x.635 cm) glass plate was lightly coated with Dow Corning high vacuum grease. Also, the upper portion of the aluminum piston and the inside of the aluminum centering ring were coated.
4. The viscometer assembly, including the brass ring, the piston inside the ring, and the centering ring on top of the brass ring, was immersed in the asphalt-rubber mixture laid on the glass plate. This immersion should force the asphalt-rubber mixture through the annular space between the piston and the brass ring. The centering



Note: All lines on plan view are circular.
One inch = 2.54 cm.

Figure 1 Falling Coaxial Viscometer

ring was then removed and the annular width was checked to see if enough mixture had filled the space. Because the viscometer designed for this study had a small annular width, this method of molding worked adequately. Excess mixture on top of the brass ring was cleaned out and scraped with a knife. The centering ring was then placed back on the brass ring.

5. The viscometer containing the asphalt-rubber mix was then slipped from the glass plate and set on a new glass plate coated with silicone grease in the same manner as the first one. The viscometer was allowed to cool down and then transferred with the glass plate under it to the constant temperature water bath. The viscometer was left in the water bath for at least one hour before testing.

6. The support was leveled. The centering ring and the glass plate were carefully removed and the viscometer was then placed on the support. The water level should be at least 1.5 in. (3.81 cm) above the asphalt-rubber sample.

7. The telescopic sight was pointed just a small fraction below a well-defined mark on the piston. The stop watch was started when the mark on the piston came down and coincided with the cross hair. Immediately, the telescopic sight was moved down a displacement of 0.1 cm. When the piston mark came down and coincided with the cross hair, the watch was stopped and the time, t, for the piston displacement of 0.1 cm was recorded. The piston was recompressed to its original position and this last step was repeated at least three more times. At least four weights were used to vary the velocity of the piston.

8. For each weight used, the cumulative displacement (H) in cm. vs. cumulative time (t) in seconds was plotted. The velocity in cm/sec was calculated from the straight line portion of H vs. t. The shear rate, S_r, was calculated from the formula

$$S_r = \frac{V}{R-r} \tag{1}$$

where V = velocity of the piston in cm/sec,
R = the inner radius of the brass ring in cm, and
r = the radius of the piston in cm.

The shear stress was calculated from the equation:

$$S_s = W_{eff} \times \frac{g}{2\pi rL} \tag{2}$$

where W_{eff} = the effective weight in grams (the total weight minus the buoyant force),
g = 980 cm/sec^2,
r = radius of the piston in cm, and
L = the length of the brass ring in cm.

The buoyant force is given by the formula:

$$\gamma h(\pi r^2) \tag{3}$$

where γ = density of water,
h = distance between water level and bottom of brass ring, and
πr^2 = cross-sectional area of the piston.

A plot of S_r vs. S_s on a log-log scale was drawn. The shear stress at a shear rate of 5×10^{-2} sec^{-1} was found from the graph and the viscosity, η was calculated as follows:

$$\eta = \frac{S_s}{S_r} \text{ (poise)} \tag{4}$$

Graphical results and discussions are provided in the next section.

It is to be noted that the previous procedure applies also to testing raw asphalt with a minor difference in sample preparation. Asphalt cement was usually heated in a small can to a temperature of 250°F (121.1°C). At this temperature, the asphalt was fluid enough and was poured into the annular space between the piston and the brass ring.

Ductility Test

In a paper by Welborn and Babashak (1958), a ductility test study on asphalt-rubber mixtures was done in an attempt to evaluate the effect of rubber on asphalt. Two types of natural rubber latex were used in the investigation. Sulfur in the amounts of 0, 5, 10, 15, and 20 percent of rubber was added to the latex prior to blending with the asphalt. The percent rubber used was 1 to 2 percent of the total mixture. The asphalt rubber blend was tested in accordance with ASTM designation D113-44, except that a rate of pull of 5 cm/min was used at a temperature of 39.2°F (4°C). In the final analysis, it was found that increasing the percent rubber would tend to decrease the ductility in the resulting asphalt-rubber mixture.

The ductility test in this research was done according to ASTM designation D113-74, (1974). The ductility of an asphalt-rubber mixture was measured by the distance to which it will elongate before breaking when the two ends of a briquet specimen of the material were pulled apart at a specified speed and at a specified temperature. The test temperature was maintained at 77°F (25°C), while the test speed was kept at 5 cm/min ± 5 percent.

The following equipment was used in the ductility test:

1. Mold: The full description of the mold used is given in ASTM designation D113-74 (1974).

2. Water bath: the water bath in this test was part of the ductility machine. Its function is to contain water at the test temperature of 77°F (25°C).

3. Ductility machine.

The asphalt-rubber mixtures tested as well as the number of ductility replicates are shown in Table 2.

Table 2. Ductility Test Determinations

Material	Number of Determinations
AR 1000	6
AR 1000/TP.044	6
AR 1000/TP.027	3
AR 1000/TP(.027(.027 + .044)	3
AR 4000	3
AR 4000/TP.027	3
AR 4000/TP.044	3
AR 4000/TP(.027 + .044)	3

The methods of molding and curing for this test were the same as those for the viscosity test. The only difference was that the specimen was molded in a briquette on a brass plate. The rest of the testing procedure was done according to the standard ductility test of bituminous materials specified in ASTM designation D113-74 (1974).

Graphical results and discussion are presented in the following section.

Water Vapor Transmission Test

The purpose of this test is to determine the rate at which water vapor is transmitted through a film of asphalt-rubber when wetted on one surface only. It was done according to the standard test specified in ASTM designation E96-72, Procedure BW (1974). Relative permeability values for the various asphalt-rubber mixtures can also be determined from this test.

The following equipment was used in the water vapor transmission testing:

1. A plexiglass dish having the dimensions shown in Figure 2.

2. A plexiglass retaining ring to fit the plexiglass dish and a 20 mesh galvanized screen (see Figure 2).

3. RC-250 asphalt, distilled water, and a sensitive balance with a graduation of 1/100 of a gram.

4. Vacuum chamber.

The asphalt-rubber mix configurations and application rates used in this test as well as the number of test replicates are shown in Table 3.

Table 3. Water Vapor Transmission Test Replicates

	Application Rate (gal/yd^2)		
Material	0.5	0.75	1.00
AR 1000/TP.044	3	3	3
AR 1000/TP.027	3	3	3
AR 1000/TP(.027 + .044)	3	3	3

An attempt to test AR 1000 asphalt without granulated rubber was unsuccessful. This was due to the fact that the AR 1000 is highly susceptible to flow at the test temperature of 77°F (25°C). The AR 1000 was observed to be flowing out through the retaining screen during testing.

A specific amount of asphalt-rubber mixture was prepared as explained in the beginning of this section. The asphalt-rubber mixture was molded into the required number of specimens by using a method referred to as the forced-molding technique. In this method, samples were molded uniformly both in thickness (application rate) and in diameter. The forced-molding technique utilizes a plexiglass mold and a piston-sleeve arrangement as shown in Figure 3. The molding procedure involved the following steps:

1. Using a ± 0.1 gm graduated balance, the desired amount of hot asphalt-rubber mixture was placed in the plexiglass mold. To prevent the mix from sticking, release paper having the same diameter as the specimen was placed against the interior bottom surface of the mold. The amount of asphalt-rubber mixture placed in the mold depended on the application rate needed.

2. The mold was removed from the balance and the centering block was placed over the mold.

3. The piston was centered in the centering block and the mixture was compressed to spread evenly across the contained mold diameter, thus producing a uniform specimen size for thin film testing. To prevent the mix from sticking to the piston,

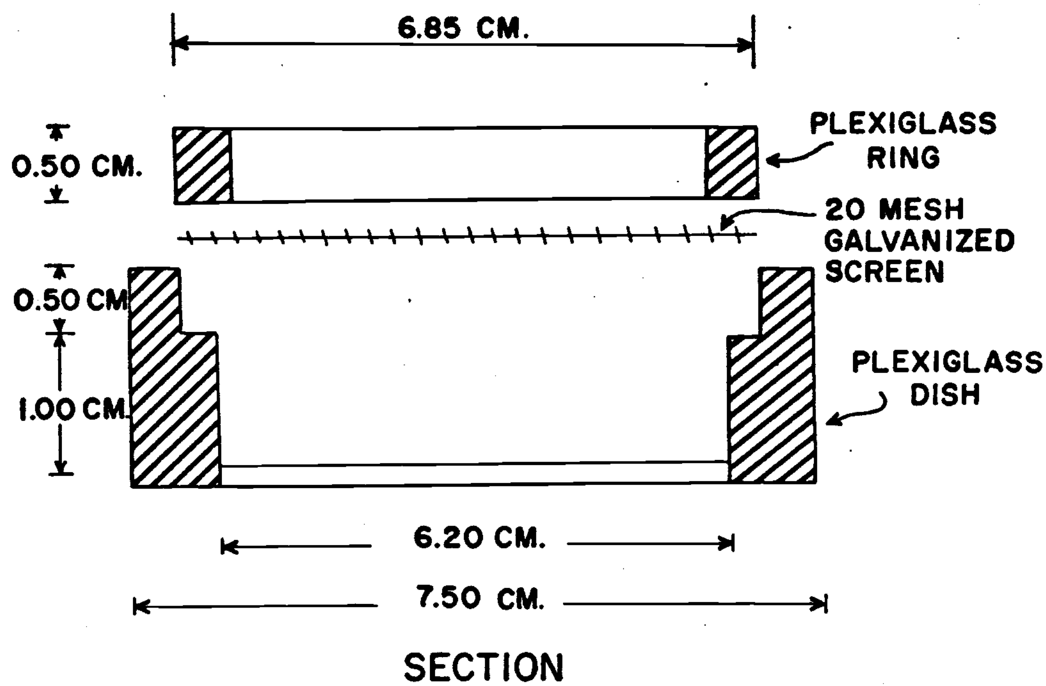


Figure 2. Water Vapor Transmission Test Dish

the contact area of the piston was lightly greased and covered with a release paper having the same diameter as the specimen.

4. The piston and the centering block were removed and the molded specimen was left to cure at room temperature for a period of at least 24 hours before testing.

5. At the end of the curing period, the specimen was removed from the mold, the release papers were peeled off, and then the membrane was ready for testing.

6. The procedure for running the water vapor transmission test (W.V.T.) was the same as that specified in ASTM designation E96-72 (1974), Procedure BW. It is significant, however, to describe the apparatus used and mention the minor changes needed in testing asphalt-rubber mixtures. The apparatus consisted of a small, lightweight dish, restraining ring and a 20 mesh galvanized screen as shown in Figure 2. The dish consisted of an open-mouthed plexiglass cup with a depth of 1 cm and a diameter of 2.44 in. (6.2 cm) (see Figure 2). It was filled with distilled, de-aired water and the sample membrane was placed over the water surface. Care was taken to avoid air entrapment under the specimen. The exposed membrane surface area is 30 cm^2. To hold the membrane in the dish, a wire mesh and a matching, restraining ring were placed over the sample. The function of the wire mesh was to prevent the flow of the asphalt-rubber mixture during testing and was not normally used in the standard ASTM designation E96-72 (1974) test. RC-250 asphalt was used to seal the ring to the dish and specimen, thus preventing edge failure due to leaks. Numerous trials for running the W.V.T. test using a variety of waxes and high vacuum grease as a seal failed. Finally, successful tests were run with RC-250 asphalt as the sealing material.

   The entire test assembly was inverted for wetting one membrane surface and then weighed periodically to determine the weight loss as the water vapor escaped through the test membrane. The successive weight loss vs. elapsed time was plotted on an arithmetic scale and the water vapor transmission rate was calculated from the straight line portion of the curve. When held in a constant temperature humidity room, testing indicated little or no weight loss. To facilitate a more rapid response, the W.V.T. devices were placed in a small vacuum chamber at 10 inches (25.4 cm) of mercury as shown in Figure 4. The temperature inside the vacuum chamber was held at 77 ± 3°F (25 ± 1.67°C). Approximately 50 gm of anhydrous calcium chloride was placed in the vacuum chamber in an attempt to maintain a relatively dry atmosphere. The calcium chloride was changed whenever specimens were removed or added to the chamber. The assemblies were weighed at periodic intervals and subsequent weight losses were recorded. Graphical results and discussion are presented in the following section.

Water Absorption Test

This test was concerned with the determination of the relative rate of water absorption by asphalt-rubber mixtures when submerged. The test has two significant functions. The first is that it acts as a guide to the proportion of water absorbed by the asphalt-rubber mixture while submerged. The second function is to check the uniformity of the molded asphalt-rubber specimens. The standard test specified in ASTM designation D570-72 (1974) was chosen as the best reliable procedure to achieve the desired results.

The equipment used in the water absorption test consists of a water bath maintained at a temperature of 77 ± 2°F (25 ± 1.11°C), and a sensitive balance with a readability to 0.01 gm and precision to 0.005 gm.

The three asphalt-rubber combinations used in this test were the following: AR 1000/TP.044, AR 1000/TP.027, and AR 1000/TP(.044 + .027).

Procedure

The desired amount of asphalt-rubber mixture was prepared using the mixing procedure specified at the beginning of this section. The hot mix was then poured on release paper and spread evenly to form a sample sheet having a thickness of approximately 1/8 in. (0.32 cm). Five specimens were then cut from the cold sample sheet. Each specimen was 3 in. (7.62 cm) long, 1 in. (2.54 cm) wide, and 1/8 in. (0.32 cm) in thickness. The specimens were then allowed to cure at room temperature for a period of at least 24 hours before testing.

At the end of the curing period, the specimens were transferred to the water bath for the water absorption test. At least five specimens of each mix were tested. The percent water absorption of the mix, at the end of any specified period, was then calculated as the average value of the five specimens tested.

A specimen is considered substantially saturated when the increase in weight per two-week period due to water absorption averages less than 1 percent of the total increase in weight, or 5 mg, whichever is greater.

The testing procedure was exactly the same as the long term immersion method specified in ASTM designation D570-72 (1974).

Permeability Test

This test determines the coefficient of permeability of asphalt-rubber by the constant head permeameter method. The method is similar in procedure to the constant head permeability testing of soils and rocks. It gives an indication of the material's permeability when subjected to a constant head pressure.

The apparatus consists of an aluminum base plate fitted with a corundum porous stone, "O" ring and neoprene spacer, and an aluminum top plate which allows water under hydrostatic head to act on the sample placed between the two plates (see Figure 5). A constant head chamber supplies the desired head of water by air pressure on a contained water surface. The amount of water that does flow through a given sample over a specified time period is collected in a burrette graduated in mm. The complete permeameter test set-up is shown in Figure 6.

The asphalt-rubber mixtures, application rates and number of test replicates are shown in Table 4.

Table 4. Permeability Test Replicates

Material	Application Rate (gal/yd^2)		
	0.5	0.75	1.00
AR 1000/TP.044	3	3	3
AR 1000/TP.027	3	3	3
AR 1000/TP(.027 + .044)	3	3	3

Procedure

Asphalt-rubber mixtures were prepared as explained in the beginning of this section. The method of molding used was the forced-molding technique whereby samples can be molded uniformly both in thickness (application rate) and in diameter. This molding method, as well as the dimensions of the specimens used, were the same as for the water vapor transmission test described earlier. A generalized permeability test procedure was as follows: A specimen of asphalt-rubber was placed in the permeameter with a constant hydrostatic head applied to one surface. The flow through the asphalt-rubber membrane was measured as it escaped through the membrane and porous stone. Assuming the asphalt-rubber mixture to be porous, the coefficient of permeability, K, in cm/sec, was then calculated from the following Darcy's equation:

$$K = \frac{Qd}{AH_w t} \tag{5}$$

where K = coefficient of permeability (cm/sec),
Q = flow through membrane in cm^3,
d = membrane thickness in cm,
A = cross-sectional area of sample in cm^2,
H_w = hydrostatic head (cm of water), and
t = time in seconds

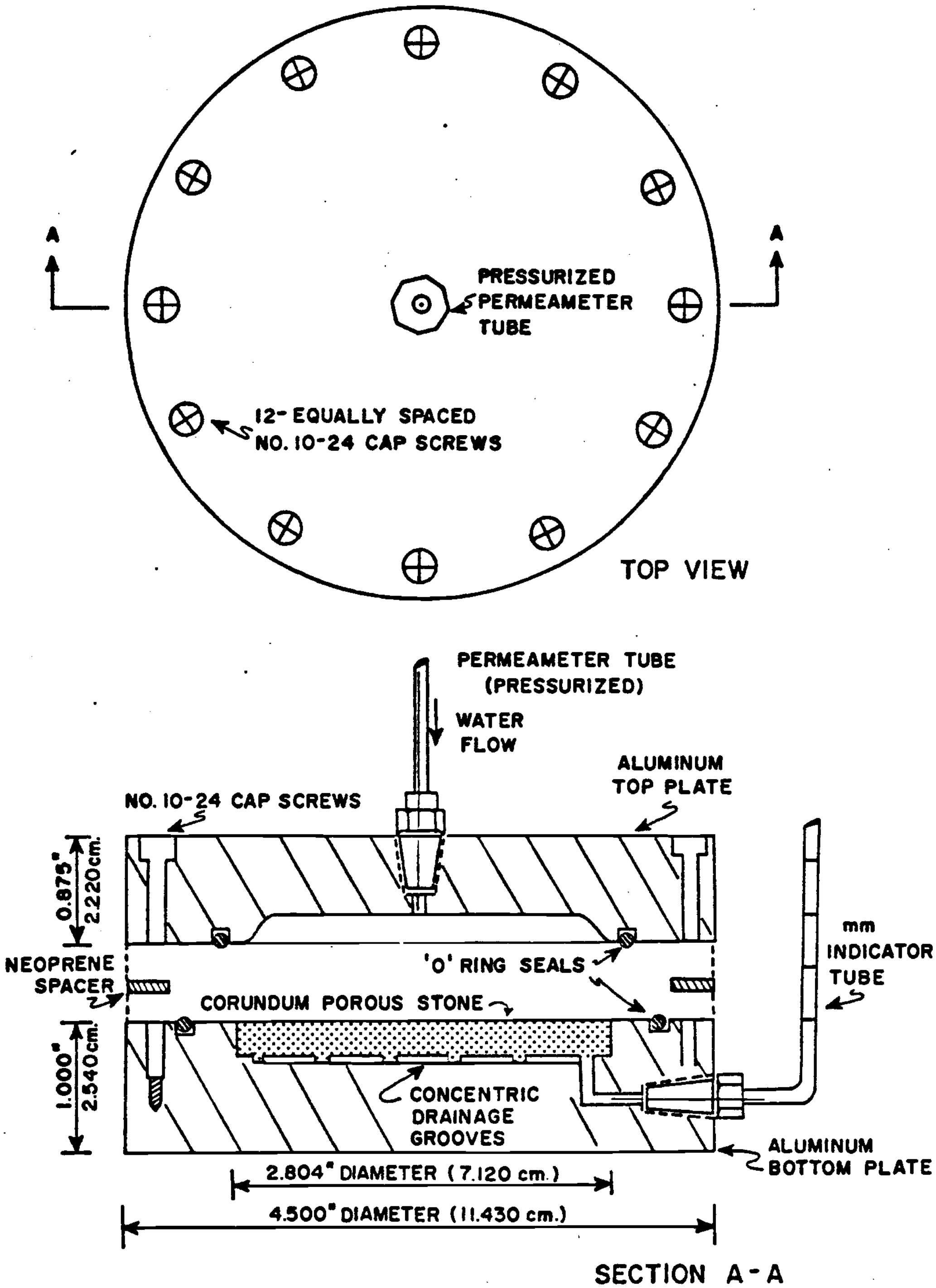


Figure 5. Static Head Permeameter

Brittleness - Impact Resistance

This test was used in an attempt to determine the relative low temperature impact resistance of the asphalt-rubber membrane as compared to the base asphalt cement. It was accomplished in accordance with ASTM designation D994-72 (1974). The test temperatures used were 40°F (4.4°C) and 20°F (-6.6°C). The membrane application rate was 0.75 gal/yd^2 (3.40 l/m^2). Table 5 gives the number of test replicates used for the various asphalt-rubber combinations.

Table 5. Brittleness Test Replicates

Material	Test Temperature	
	40°F	20°F
AR 1000	5	5
AR 1000/TP.027	5	5
AR 1000/TP.044	5	5
AR 1000/TP(.027 + .044)	5	5
AR 4000	5	5
AR 4000/TP.027	5	5
AR 4000/TP.044	5	5
AR 4000/TP(.027 + .044)	5	5

Procedure

The asphalt-rubber mixtures were prepared in accordance with previously defined mixing procedures. The method of molding used was the forced-molding technique in an attempt to achieve uniformity in specimen thickness and diameter. The diameter of the specimens was 3.5 inches (90 mm) and the thickness was 1/8 inch (0.32 cm). A generalized brittleness test procedure was as follows: An asphalt-rubber specimen was placed in chilled water at the prescribed test temperature and held there for two hours. Each specimen was then removed from the water and immediately placed on a wooden block resting on a concrete floor. A 1.0 lb. (0.454 kg) stainless steel ball was dropped on the specimen from a height of 3 feet (.915 m). The ball was allowed to fall freely to the center of the specimen. Failure of a particular mix was determined if one out of the five specimens failed or fractured.

Flow/Slope Stability

An attempt was made at determining the relative flow/slope stability characteristics of asphalt-rubber. In particular, the stiffening properties that the rubber particle size imparts to the asphalt cement were investigated. The modified Barrett Slide test was adopted for use from the Bureau of Reclamation's Test Procedures on filled asphalt cements (Ellsperman and

Becker, 1947). The asphalt-rubber samples were mixed in accordance with previously described mix procedures and immediately placed in the 1/2 inch (12.7 mm) cube molds. The molds were allowed to come to room temperature and then placed in a freezer at 32°F (0°C) for two hours to facilitate ease in specimen removal from the molds. The individual cubes of asphalt-rubber were placed at the top of the copper slides (horizontal position) and allowed to come to room temperature of 77°F (25°C) for a period of not less than two hours. The entire slope assembly was placed in a pre-heated 140°F (60°C) oven for 48 hours at a 1-1/2 to 1 slope. At the end of 48 hours, the displacements along the slope of the various mixes were measured. The tested slope assembly is shown in Figure 7.

LABORATORY TEST RESULTS AND DISCUSSION

The objectives of this study were to determine the properties of asphalt-rubber mixtures that are most useful for seepage control application. The study consisted of devising the testing apparatus, procedures, and determining the relative characteristics of the test results. The testing procedures have been described in the preceding section. The overall evaluation and discussion of the results are described in the following sections.

Viscosity Test

During its application and use, the asphalt-rubber mixture is subjected to heat, changes in temperature, variable shear or loading, and weathering. These factors change the consistency or hardness of the asphalt-rubber mixture and, consequently, influence the performance of the material. The viscosity test has been devised to measure the relative consistency of the material and characterize its physical properties so that, to some extent at least, its flow behavior (rheology) and performance under variable conditions can be controlled and predicted. As a result, the practical uses of the viscosity test are in the preparation and field placement of asphalt-rubber mixtures. In this particular report, the test temperature range reflects the field or in place behavior rather than application. It should be noted that the high viscosities of asphalt-rubber may prohibit spraying through some distributors and that any improvement in viscosity is desirable, e.g. finer rubber particle size distribution.

As noted previously, the variables involved in this test are asphalt type, rubber particle size, and temperature. The effects of each of these variables on the viscosity of asphalt-rubber mixes are shown in the graphs on the following pages.

Figure 8 represents the effect of asphalt type and rubber particle size on the viscosity of the mix at 77°F (25°C). Close inspection of the graph reveals the following results:

1. When rubber is added to asphalt cement, the resulting asphalt-rubber mixture always has a higher viscosity value than the plain asphalt.

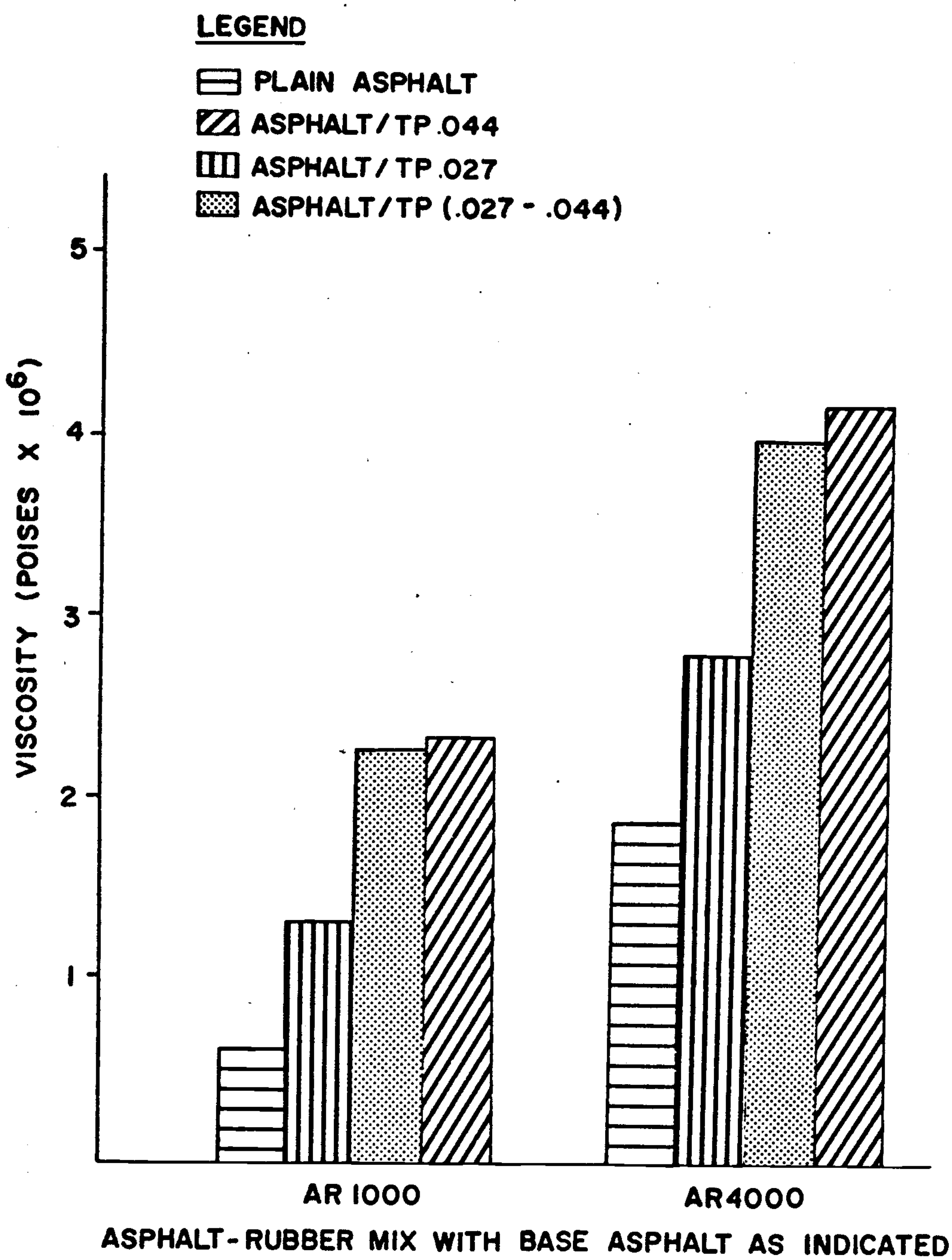


Figure 8. Relative Viscosities of Asphalt-Rubber Mixes at 77°F (25°C)

2. Addition of variable rubber particle sizes results in variable viscosity values for asphalt-rubber. Also, the larger the rubber particle size used in the mixture, the higher the viscosity value obtained.

These findings are logically acceptable. The mixing of rubber, which is a solid material, with the fluid asphalt should obviously result in a mixture with a lower potential for flow than plain asphalt. This lower potential for flow reflects a higher consistency measure of the asphalt-rubber mixture and, consequently, a higher viscosity value than plain asphalt. Furthermore, the coarser the rubber used with a specific type of asphalt, the greater its effect in reducing the flow potential of asphalt-rubber. As a result, a higher viscosity value is expected. The effect of the asphalt hardness on the viscosity of the asphalt-rubber mixture is significant. It is a proven fact in asphalt technology that harder asphalt has a higher viscosity than the softer one at the same temperature. This fact is reflected in the viscosity results of asphalt-rubber combinations that have the same rubber size but different grade asphalt cement.

Figure 9 also explains the effect of asphalt grades and rubber sizes on the viscosity of asphalt-rubber mixtures. The only difference in this case is that the test temperature is 104°F (40°C). The characterizing results of this graph are the same as those for Figure 8. It is to be noted, however, that the viscosity values obtained in Figure 9 are lower than the values obtained in Figure 8. This difference is due to the temperature change effect. Detailed analysis of the temperature effect on the viscosities of the different asphalt-rubber combinations is presented in Figure 10.

As for asphalt, the asphalt-rubber mixture is a thermo-plastic material; that is, the material changes its consistency with changes in temperature. The variation in consistency with temperature is important because, in the application of the asphalt-rubber mixture in the field, the actual consistency at different temperatures must be noted to carry out proper design and construction. A common technique to study the change in viscosity with the change in temperature (temperature susceptibility) is to specify the slope of the temperature vs. viscosity relationship of the asphalt-rubber mixture when the viscosity is plotted in absolute units (poises). A straight line relationship is assumed when the log-log viscosity vs. log-absolute temperature is plotted graphically. Figure 10 illustrates the method of plotting and comparison of temperature vs. viscosity characteristics for AR 1000 and three different asphalt-rubber combinations.

As noted previously, viscosity values are determined at a constant shear rate of $5 \times 10^{-2} sec^{-1}$. Comparison was made on the basis of the numerical value of the slope of each line in the graph of Figure 10. The steeper the slope, the more temperature susceptible the material. Close inspection of this figure reveals the following:

1. When rubber was added to an AR 1000 asphalt, the resulting asphalt-rubber mixture had a lower temperature susceptibility than the asphalt.

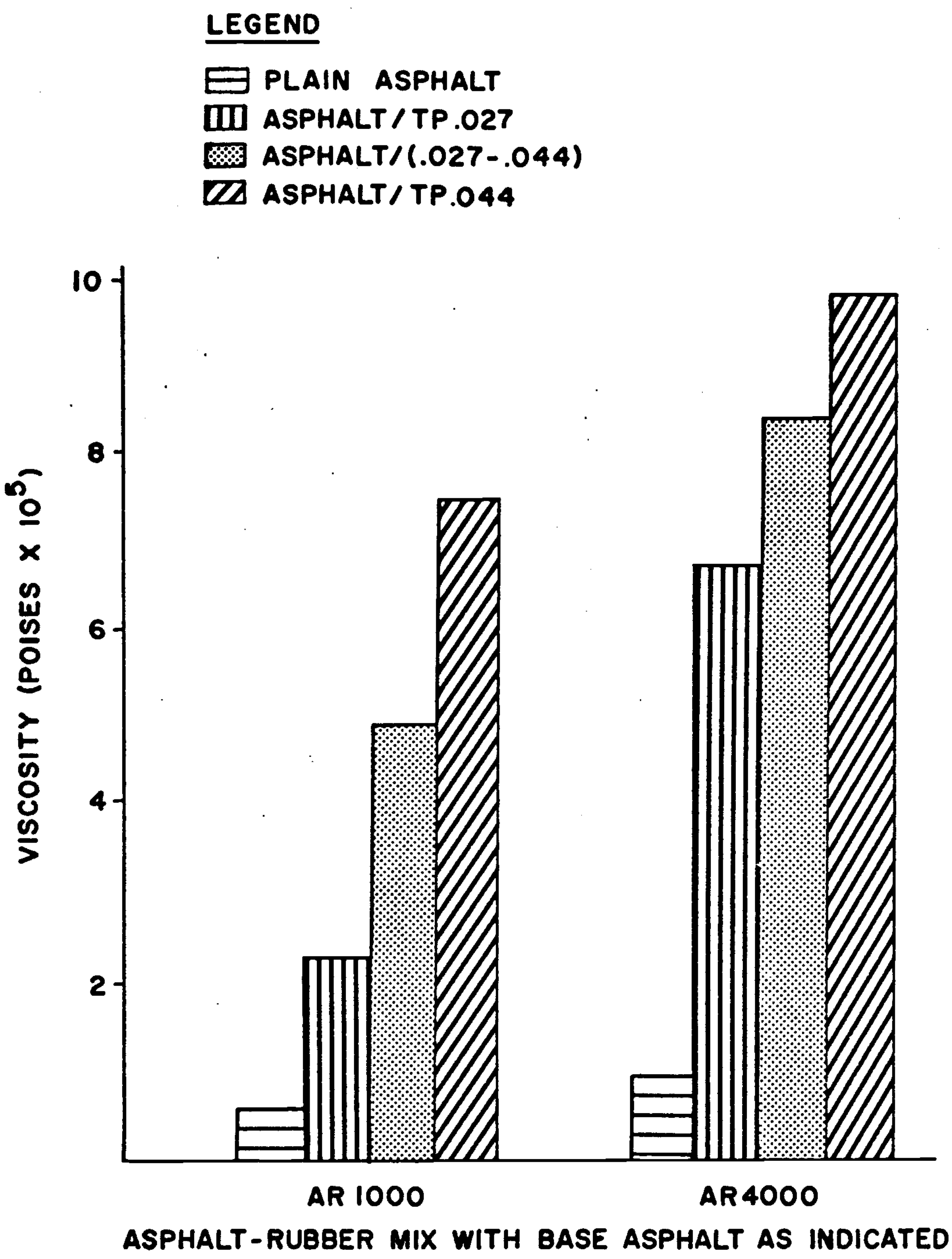


Figure 9. Relative Viscosities of Asphalt-Rubber Mixes at 104°F (60°C)

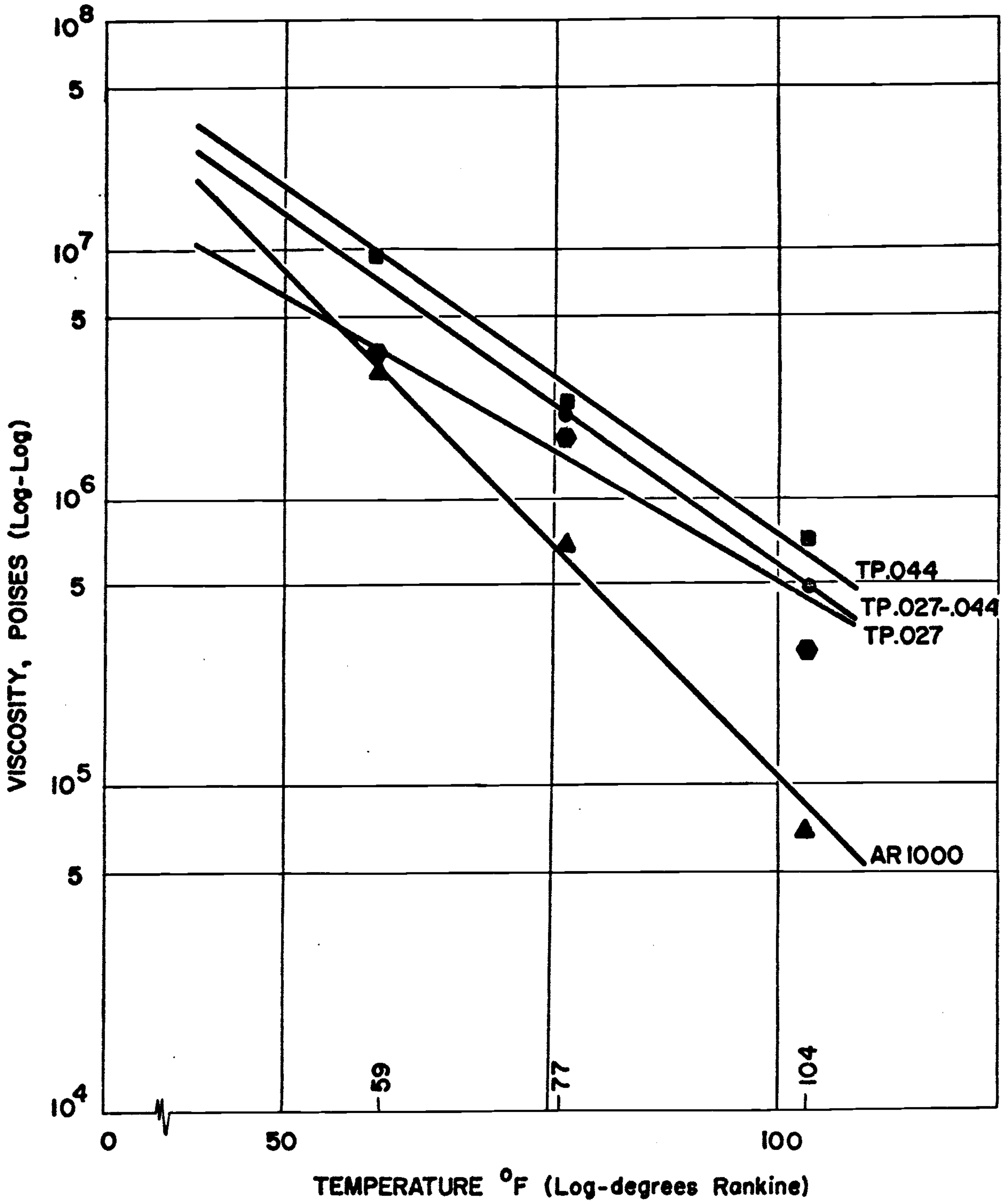


Figure 10. Effect of Temperature on the Viscosity of Asphalt and Asphalt-Rubber Mixtures

2. Addition of different rubber particle sizes results in a different temperature susceptibility of the mixture. Also, the greater the rubber particle size used in the mixture, the lower the temperature susceptibility obtained.

Ductility Test

Figure 11 shows the ductility values for asphalts and for asphalt-rubber mixtures tested at 77°F (25°C). The following results are derived directly from the graph:

1. The addition of rubber to asphalt results in a mixture with a considerably lower ductility value than the plain asphalt.

2. For a specific asphalt grade, the larger the rubber particle size, the lower the ductility value of the resulting mixture.

3. The degree of asphalt hardness has unpredictable effects on the ductility of the asphalt-rubber mixture at 77°F (25°C). When fine rubber (TP.027) was used, the harder asphalt gave a lower ductility value. On the other hand, when coarser rubber (TP.044) was used, the harder asphalt gave a higher ductility value than the soft one. This may change with variability in temperature.

4. Finally, no difference was observed when TP(.027 + .044) was mixed separately with both AR 1000 and AR 4000. The resulting two mixtures seemed to have the same ductility value.

It is assumed, for the purposes of this report, that rubber behaves very similar to aggregate when mixed with asphalt. Ground tire rubber, having a smooth particle surface texture, results in poor adhesion when mixed with asphalt. This poor adhesive property reflects a lower capacity for stretching in the asphalt-rubber mixture as compared to the original asphalt. Consequently, a lower ductility value is expected for the asphalt-rubber mixture.

The exact amount of rubber that goes into solution with asphalt when the two materials are mixed has not yet been determined (McDonald, 1969). It is apparent, however, that more fine rubber dissolves in asphalt than the coarse do primarily to a greater reactive rubber surface area. This extra portion of dissolved fine rubber reflects a higher elasticity in the resulting asphalt-rubber mixture. As a result, the mixture of fine rubber and asphalt will have a higher ductility value than that of coarse rubber and asphalt.

When using a different grade asphalt, the above analysis also applies. However, different ductility values were obtained for the resulting asphalt-rubber mixtures. This difference could be due to the variation in the rheologic properties of different asphalt grades as well as to the complex, undetermined behavior of the asphalt-rubber mixture.

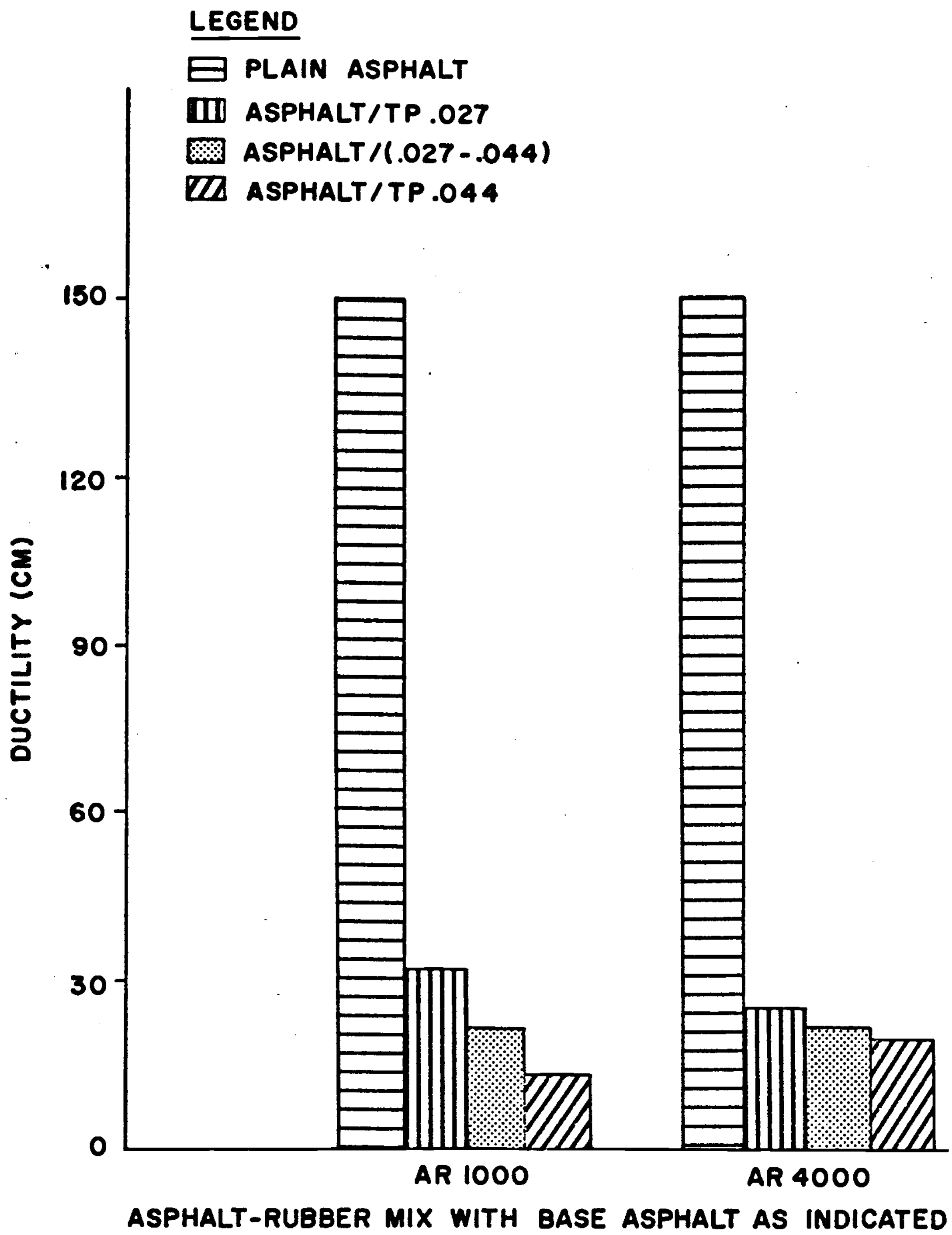


Figure 11. Ductility Values for Asphalt and Asphalt-Rubber Tested at 77°F (25°C).

Water Vapor Transmission Test

This test attempted to measure the relative water vapor transmission (W.V.T.) rate and subsequent permeability constant (K) for asphalt-rubber mixtures. The permeability constant, K (in cm/sec), is obtained by direct application of Darcy's equation:

$$K = \frac{Qd}{AH_w t} \tag{5}$$

Figure 12 shows the water vapor transmission rates for three asphalt-rubber mixtures tested at the three application rates: 0.5, 0.75, and 1 gal/yd^2 (2.26, 3.40, 4.53 l/m^3). The following two observations summarize the graphical representation:

1. Among the three mixtures tested, AR 1000/TP(.044 + .027) is found to give the lowest water vapor transmission rate. This value is obtained at an application rate of 1 gal/yd^2 (4.53 l/m^3). Consequently, it is the most impermeable mixture of those tested.

2. For a particular mixture, increasing the application rate apparently reduces the water vapor transmission rate.

As for any other material, the permeability or perviousness of an asphalt-rubber mixture is concerned with the ease with which air as well as water may pass into or through the mixture. The void content is an indication of the susceptibility of the asphalt-rubber mixture to the passage of air, water, or water vapor. More significant, however, is the interconnection of voids and their access to surface water. AR 1000/TP(.027 + .044), being a blended mixture of coarse and fine rubber mixed with asphalt, obviously will result in a lower void content (close packing ratio) than the other two asphalt-rubber mixtures. Consequently a lower water vapor transmission rate would be expected. This is seen in the graph of Figure 12 at the two application rates of 0.5 gal/yd^2 (2.26 l/m^2) and 1 gal/yd^2 (4.53 l/m^2). At 0.75 gal/yd^2 (3.40 l/m^2) application rate, AR 1000/TP(.027 + .044) apparently has a higher water vapor transmission rate than the other two mixtures.

AR 1000/TP.044, having a larger particle size rubber than AR 1000/TP.027, will provide a higher void ratio within the mix. This would result in higher WVT rates (see Figure 12).

The significance of this test lies in the fact that it gives essential information about the relative waterproofing properties of asphalt-rubber mixtures. These properties are important for determining the material performance in the field. Table 6 summarizes the WVT rates and some corresponding permeability constants that are in common usage in the literature. Depending on membrane thickness and mix, K varies from a low of 2.14×10^{-12} cm/sec to a high of 3.73×10^{-12} cm/sec. These values, for all practical purposes, can be considered as impermeable. A typical oxidized asphalt possesses a permeability of 0.0171 - 0.0330 perms (Hoiberg, 1965)

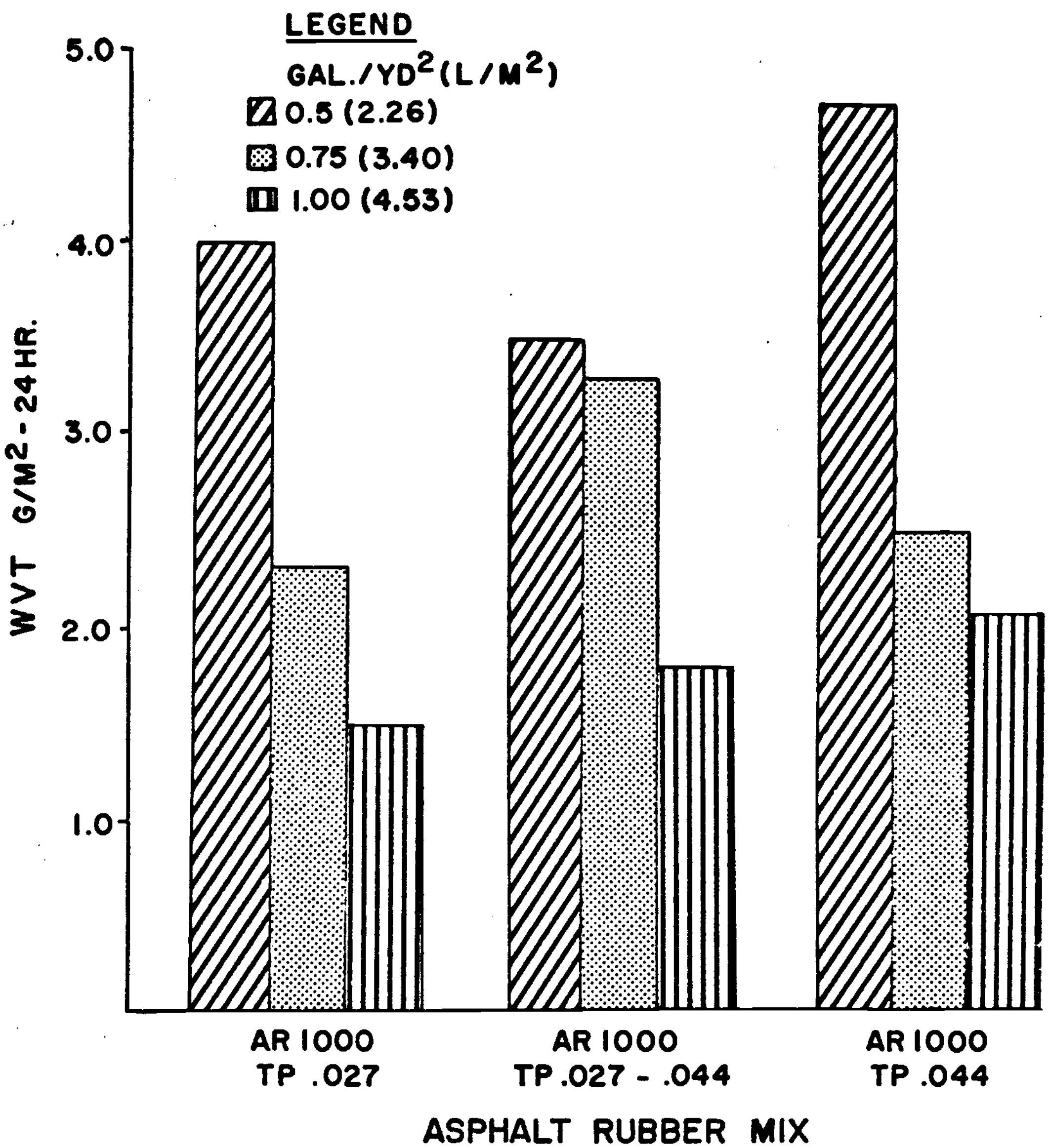


Figure 12. Relative WVT Rates for Various Asphalt-Rubber Mixes

Table 6. Water Vapor Transmission Test Results

AR MIX	APPLICATION RATE [Gal/yd^2 (l/m^2)]	WVT (gm/m^2-24 hr)	K (cm/sec)	PERMEABILITY CONSTANT (gm/cm^2-hr-mm Hg.)	PERMS (grains/ft^2-hr-in Hg.)
AR1000/TP.027	0.50 (2.26)	4.04	3.07×10^{-12}	1.52×10^{-8}	.024
	0.75 (3.40)	2.27	2.56×10^{-12}	1.27×10^{-8}	.013
	1.00 (4.53)	1.44	2.14×10^{-12}	1.06×10^{-8}	.008
AR1000/TP.027-.044	0.50 (2.26)	3.50	2.66×10^{-12}	1.32×10^{-8}	.021
	0.75 (3.40)	3.32	3.73×10^{-12}	1.85×10^{-8}	.020
	1.00 (4.53)	1.81	2.69×10^{-12}	1.34×10^{-8}	.011
AR1000/TP.044	0.50 (2.26)	4.71	3.58×10^{-12}	1.77×10^{-8}	.028
	0.75 (3.40)	2.53	2.84×10^{-12}	1.41×10^{-8}	.015
	1.00 (4.53)	2.11	3.14×10^{-12}	1.56×10^{-8}	.013

which is slightly higher than the range of laboratory values for the asphalt-rubber (0.008 - 0.028 perms) as shown in Table 6. This indicates that the rubber aggregate has no appreciable detrimental effect on the overall permeability of a plain asphalt membrane.

Water Absorption Tests

The water absorbed by the asphalt-rubber is of little significance in most asphalt-rubber applications. That is, the function performed by the asphalt-rubber is not directly dependent on this property but rather on changes it might cause in other physical properties. For asphalts these changes are usually very minor in nature (Hoiberg, 1965).

Accurate dimensions of the specimens could not be obtained due to the plastic nature of the A-R membrane material. Many specimens deformed slightly upon handling during intermittent weighings and therefore could not be accurately measured for dimensional change during testing. It was also difficult to completely surface dry all specimens before periodic weighings due to surface irregularities of the A-R. Some human error, therefore, in the weighing procedures may be present.

The test specimens were cut from a molded membrane sample in the form of rectangular sections 3 in. (76.2 mm) long, 1 in. (25.4 mm) wide and 1/8 in. (3.2 mm) in thickness. A minimum of five specimens for each sample were placed in a container of distilled water at a temperature of 77°F (25°C). Due to the relatively little water absorption after 24 hours, long-term immersion testing was used to determine the water absorption with time. Graphical results of water absorption vs. time are presented in Figure 13. The lowest water absorption rate occurred with the AR 1000/TP(.027 + .044) mix. The maximum 28 day total absorption of 0.67%, however, was approximately the same as for the AR 1000/TP.027 which was 0.80%. This higher absorption, although small, may be attributable to the fine particle size of rubber and thus greater absorptive surface area. It should be noted that in a separate test on the plain crumb rubber, the total water absorbed by the rubber alone was exactly 1.0%. Although the asphalt cement by itself does not absorb a measurable amount of water, obviously the rubber phase in the A-R does.

It is apparent that the maximum absorption for the A-R occurs within 14 to 21 days with little increase in weight after 28 days. This may only be a surface absorption phenomenon over a relatively short time span. Water immersion testing over months or years may yield slightly higher water absorption values. For the purposes of this study, it is safe to say that the maximum water absorption is in the range of 0.6 to 0.8 percent by weight of the dry membrane. Although additional testing may be needed, it is not felt there is any appreciable deterioration in the physical properties of asphalt-rubber when totally immersed in water.

Permeability Test

Actual test results indicated that asphalt-rubber mixtures have a very low coefficient of permeability, ranging from 2.0×10^{-6} to 9.62×10^{-7} cm/sec.

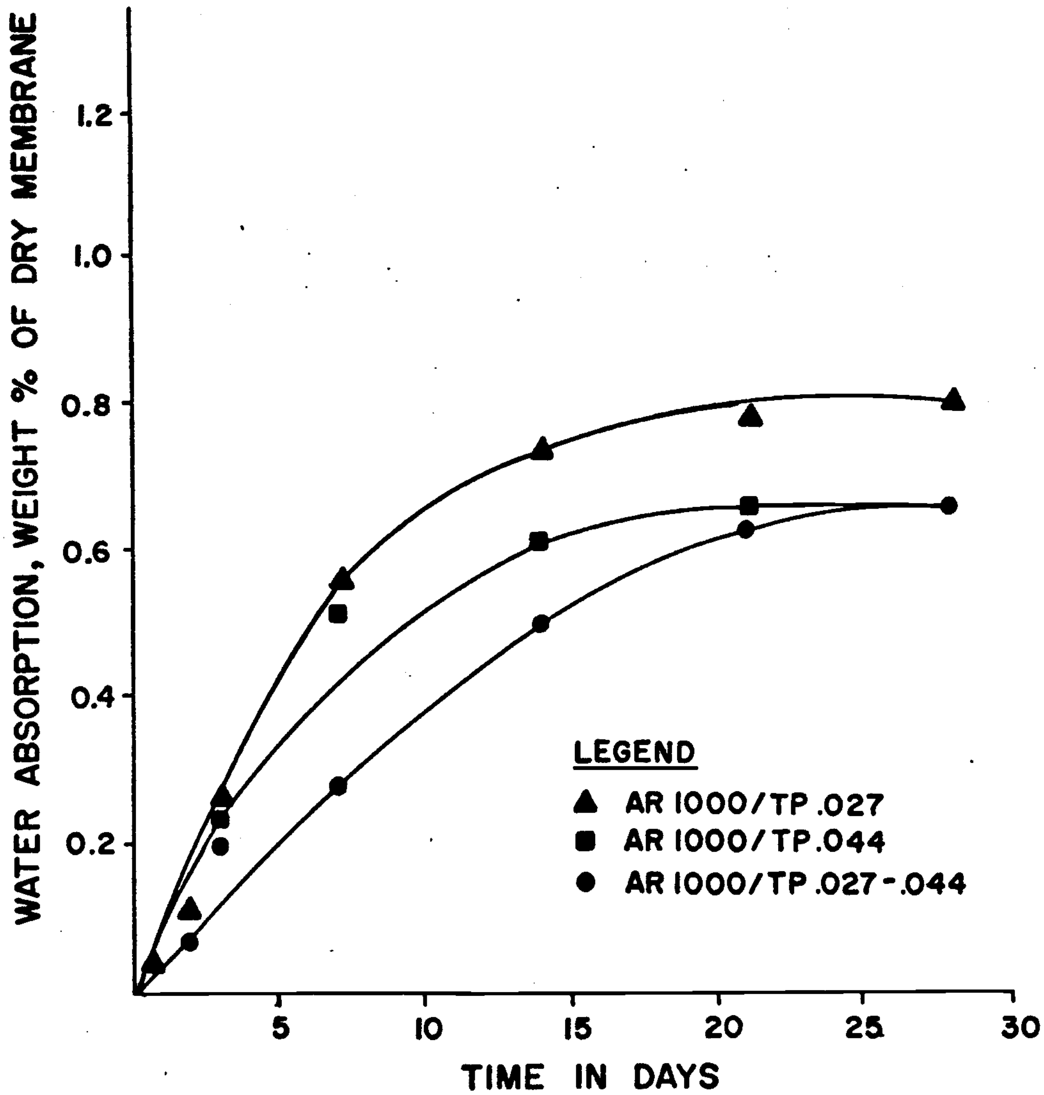


Figure 13. Relative Water Absorption Rates for Various Asphalt-Rubber Mixes

However, these results were felt to be unreliable for several reasons. A close inspection of test specimens indicated that most of the failures occurred at the porous stone/aluminum base plate interface. Several attempts for sealing the interface failed. When hard wax was used as a seal, several specimens did not show any visible flow rate. This difficulty in obtaining adequate edge seal, as well as the fact that the liquid phase (as opposed to water vapor phase) is very difficult to measure with respect to flow rate through asphalt-rubber, led to the conclusion that the permeability data was unreliable. When testing plain AR 1000 asphalt, no measurable water passed through the asphalt film. It is to be noted, however, that after 48 hours the plain asphalt flowed through the porous corundum stone and into the permeameter tubing. This occurred under 5 psi (.35 kg/cm^2) hydrostatic pressure. On the other hand, the asphalt-rubber mixtures did not penetrate the stone even after 72 hours of testing under as much as 15 psi (1.06 kg/cm^2). This reinforces the hypothesis that when rubber is added to asphalt the resulting mixture develops a higher resistance to deformation than the original asphalt.

Brittleness - Impact Resistance

This test attempted to determine the relative impact resistance of the asphalt-rubber membrane. Plain asphalt cement failed (shattered) at both test temperatures of 20°F (-6.6°C) and 40°F (4.4°C). Results of impact resistance testing are shown in Table 7.

Table 7. Brittleness Test Results

	Test Temperature	
Material	40°F	20°F
AR 1000	F*	F
AR 1000/TP.027	NF	NF
AR 1000/TP.044	NF	F
AR 1000/TP(.027 + .044)	NF	F
AR 4000	F	F
AR 4000/TP.027	NF	F
AR 4000/TP.044	NF	F
AR 4000/TP(.027 + .044)	NF	F

*F = Failure NF = No Failure

The asphalt-rubber specimens that did not fail exhibited only minor radial cracks that penetrated the surface only slightly. Those that failed fractured from the center radially outward and cracked the full thickness of the specimen. None of the asphalt-rubber specimens shattered as was the case with plain asphalt cement. It should be noted that the softer asphalt

(AR 1000) in combination with TP.027 rubber resisted fracture at 20°F (-6.6°C) and was the only mix to do so.

Generally, the rubber aggregate, when added to asphalt cement, greatly increases the flexibility and elasticity of the total mix at 40°F (4.4°C). This results in greatly improved impact resistance. At temperatures below freezing (in this case 20°F), the asphalt rubber mix is susceptible to fracture. The only mix that may not fracture at relatively lower temperatures is AR 1000/TP.027 due primarily to the softer asphalt grade and smaller rubber particle size which results in greater flexibility, elasticity, and toughness.

Flow/Slope Stability

The asphalt-rubber did not behave as anticipated in that the total test cube remained intact at the top of the slope. It was anticipated that the asphalt-rubber would react similarly to a filled asphalt cement and flow as a homogeneous mix. The cubes, however, did exhibit asphalt separation and subsequent asphalt flow down slope. Figure 14 shows the relative slope movements of the asphalt contained in the asphalt-rubber mixes. Slides 1 and 2 contain plain asphalt cement (AR 1000) which flowed the entire slide length within six hours from start of testing. Slides 3 and 4 contain AR 1000/TP.027 which exhibits only slight asphalt separation whereas slides 7 and 8 (AR 1000/TP.044) exhibit a greater degree of separation. This is an indication that the greater amount of crumb rubber aggregate surface area (smaller particle size), the more homogeneous the mix becomes due to increased surface interaction. This results in less asphalt separation and better slope stability for the finer rubber aggregate mix. The efficiency of various aggregate rubber sizes used as stiffening agents will vary with the type, source, particle size gradation and subsequent surface area of the crumb rubber.

Field Installations

Experimental field installations of asphalt-rubber treatments on prepared subgrades were made in an attempt to provide additional information on water proofing characteristics, subgrade preparation, and physical degradation. Also, a 100,000 gallon (3785 m^3) water storage reservoir was lined with asphalt rubber to test its effectiveness in site application and actual service.

Three asphalt-rubber field plots were installed at the outdoor exposure laboratory located at the Water Resources Research Center Field Laboratory, Tucson, Arizona. The outdoor exposure laboratory contains 21 experimental plots of various lining materials that are continuously monitored. Each plot measures 8 ft (2.44 m) by 16 ft (4.88 m) and is contained by a 4 inch (101.6 mm) high concrete curbing. The slope of all plots is 5 percent and all accumulated runoff is collected and measured to evaluate the effectiveness of each type of membrane. The plots used for the asphalt-rubber application were as follows:

Plot No. 13: Subgrade - Silty sand type SM

A-R application - AR 1000/TP(.027 + .044) applied at a rate of 0.5 gal/yd^2 (2.26 l/m^2)
Cover material - 3/8 inch (9.5 mm) washed stone applied at a rate of 25 lb/yd^2 (13.56 kg/m^2)

Plot No. 14: Subgrade - Silty sand type SM

A-R application - AR 1000/TP(.027 + .044) applied at a rate of 0.5 gal/yd^2 (2.26 l/m^2)
Cover material - Sand applied at a rate of 15 lb/yd^2 (8.14 kg/m^2)

Plot No. 16: Subgrade - Silty clay type CH

A-R application - AR 1000/TP(.027 + .044) applied at a rate of 0.5 gal/yd^2 (2.26 l/m^2)
Cover material - none

All field plots were monitored for rainfall-runoff data and any visual weathering or physical deterioration. After approximately one year of exposure, the following observations on the asphalt-rubber plots were made: Plots 13 and 14 exhibited outstanding waterproofing characteristics in that they both indicated rainfall-runoff efficiencies in excess of 95%. There were no signs of any physical deterioration of the membrane material. However, most of the sand cover on plot 14 has eroded and has accumulated at the base of the plot. The 3/8 inch (9.5 mm) stone cover material has not deteriorated and is providing an excellent protective cover. The asphalt-rubber membrane has deteriorated slightly on plot 16 due to the highly expansive clay subgrade and exposed condition. The expansive clay has caused the asphalt-rubber to crack with the subgrade. It should be noted that the cracks tend to reheal themselves with increase in surface temperature. Also, some atmospheric degradation has been noted because of the lack of cover material. Due to the cracking, the rainfall-runoff efficiency was less than 40%.

Reservoir Installation

An existing 100,000 gallon (3785 m^3) capacity reservoir was prepared and lined with asphalt-rubber. This particular structure was previously lined with polyethylene which had failed. A representative drawing of the reservoir shape and size is shown in Figure 15. The excavated reservoir had a finished subgrade generally consisting of a silty sand type SM. Side slopes and bottom were cleared and smoothed. All loose aggregate or foreign matter was removed. The excessive 1:1 side slopes prohibited complete smoothness due to sloughing of the embankment material. The bottom was smoothed and compacted with a vibratory flat plate compactor to insure that the subgrade would support a workman without causing excessive depressions or irregularities in the subgrade.

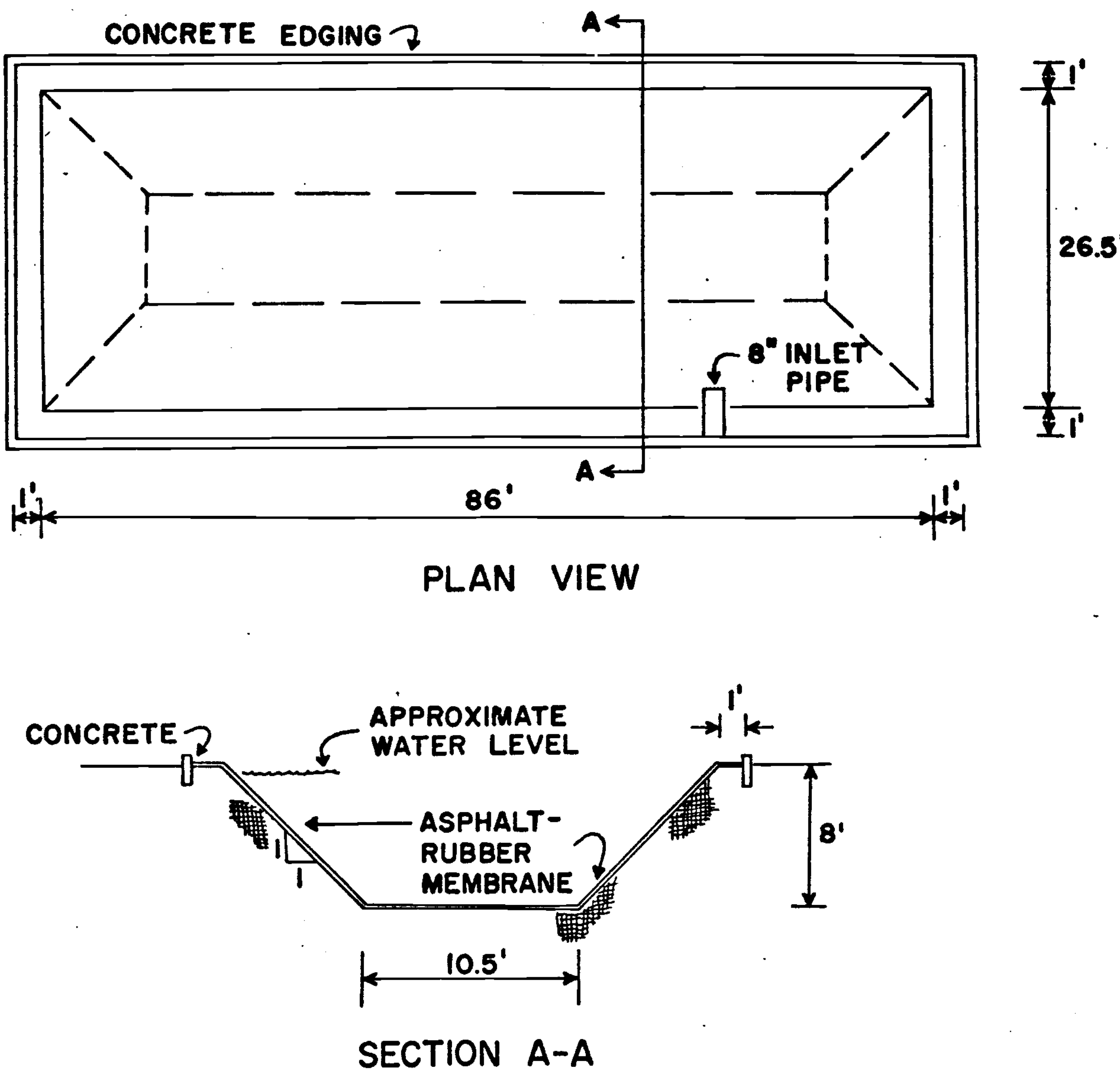


Figure 15. Reservoir Used for Asphalt-Rubber Membrane Lining

The entire subgrade was primed with SS-1h cationic emulsion at an application rate of approximately 0.2 gal/yd^2 (0.9 l/m^2). This was used to establish a penetrating tack coat for the asphalt-rubber, expecially for the relatively unstable side slope embankment material. The asphalt emulsion was allowed to cure for approximately 12 hours before asphalt-rubber application. Due to the short cure time, the tack coat was observed to pull easily from the subgrade when walked on causing an undesirable subgrade condition. A longer cure time (in excess of 24 hours) and less tack coat quantity would be recommended for future installations. In addition to the tack coat on the excessively steep side slope, unwoven fiberglass (10 mil thickness) was placed before asphalt-rubber application to help compensate for the irregular subgrade. Also, the fiberglass was used to help prevent excessive downslope movement.

The asphalt-rubber was applied at a rate of 1.0 gal/yd^2 (4.53 l/m^2) and consisted of the AR 1000/TP(.027 + .044) mix. The asphalt was heated to 370°F (187.77°C) in a 200 gal (0.757 m^3) portable distributor tank. The rubber was added in the proportion of 1 part rubber to 3 parts asphalt and mixed for a period of approximately 30 minutes (the distributor tank was specially equipped with an interval mixing device). The asphalt-rubber was applied by a hand spray applicator (single nozzle) as shown in Figure 16. Coating of the sides was from top to bottom in a sweeping side to side motion. The mix sprayed easily and evenly and formed a continuous, smooth membrane with no puddling or separation of asphalt. Only slight down slope movement was detected immediately after the asphalt-rubber application due to initially high temperatures and low viscosity. To prevent additional movement of the membrane on the very steep slopes, the asphalt rubber was lightly coated with white acrylic roofing paint which effectively reduced summer surface temperatures by reflecting the sun's energy. The finished reservoir without the white acrylic paint is shown in Figure 16.

After filling the reservoir to capacity, it was monitored for any noticeable seepage losses, taking into account evaporation losses, minimal seepage was detected. Total cost of the lining installation was $464.00 or $1.27/yd^2 including labor and materials. For larger lining installation, this cost would be cut considerably due to mechanization (distributor trucks) and larger material quantities.

Subgrade and application specifications were formulated based upon the above field work and previously described laboratory work. These specifications can be found in Appendix II.

CONCLUSIONS

This investigation was initiated with the goal of determining several engineering characteristics of asphalt-rubber used as a water seepage barrier and to develop preliminary specifications for its use. The physical characteristics investigated for this report were viscosity, ductility, water vapor transmission, water absorption, permeability, flow/slope stability and brittleness/impact resistance. Also, field installations provided additional information on mix design and application procedure.

The viscosity test results indicate that the addition of rubber to asphalt cement AR 1000 or AR 4000 results in a mixture with a higher viscosity value than the original asphalt. This increase is considerably greater at higher temperatures than at lower ones. AR 1000/TP.044, for example, is more than ten times as viscous as the AR 1000 at 104°F (60°C). At 77°F, (25°C), the viscosity of AR 1000/TP.044 is approximately four times greater than that of AR 1000. Test results also show that the addition or rubber greatly reduces the temperature susceptibility of the material under consideration. This reduction was greater when using coarse rubber than when using the finer rubber particle size. These findings should be given special consideration when choosing the appropriate asphalt distributor equipment (e.g., nozzle size) for field application. Also, site characteristics such as slope stability should be considered when looking at viscosity/temperature results. A slope of 2 horizontal to 1 vertical should be considered maximum for application unless reinforcement is incorporated within the membrane.

The ductility of asphalt is greatly reduced when rubber is added to it. Asphalt-rubber was found to have a ductility value of about one-fifth that of plain asphalt. This is a further indication of the toughness and resistance to flow when rubber is added to asphalt. It should be noted that the coarser the rubber aggregate, the lower the ductility.

The water vapor transmission rate and subsequent permeability values for asphalt-rubber were found to be very low. Therefore, one can conclude that the combination of asphalt and rubber aggregate results in a relatively impermeable membrane and that the rubber does not significantly effect the otherwise impermeable asphalt cement membrane.

The water absorption test indicates a higher percent absorption obtained when rubber is added to asphalt. When substantially saturated, asphalt rubber is found to have a percent absorption value of at least 0.65% as compared to plain asphalt whose maximum percent absorption is 0.01%. This increase in percent absorption is due to the surface water absorption tendency present in the granular tire rubber. This small amount of water absorption is not considered detrimental to asphalt-rubber physical properties.

As rubber aggregate is added to asphalt, the resulting mix greatly reduces flow or downslope movement over that of asphalt cement. As the rubber particle size decreases, more asphalt apparently goes into solution with the rubber (more rubber surface area) and subsequently reduces the amount of asphalt that can separate from the total A-R mix. A coarser particle size in the A-R mix will result in more asphalt separation if placed on a relatively steep slope.

The brittleness or impact resistance of asphalt cement is increased significantly with the addition of rubber aggregate especially at a relatively low temperature of 40°F (4.4°C). The softer asphalt cement (AR 1000) and fine rubber gradation should be used if impact resistance is a consideration below 32°F (0°C).

Field installations indicate that the asphalt-rubber as a membrane material exhibits excellent waterproofing properties. It is imperative that adequate subgrade preparation be provided for an effective asphalt-rubber membrane. If a smooth, compacted subgrade cannot be attained, the field installations have shown the advantage of using the woven fiberglass to

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APPENDIX I

LABORATORY MATERIAL SPECIFICATIONS

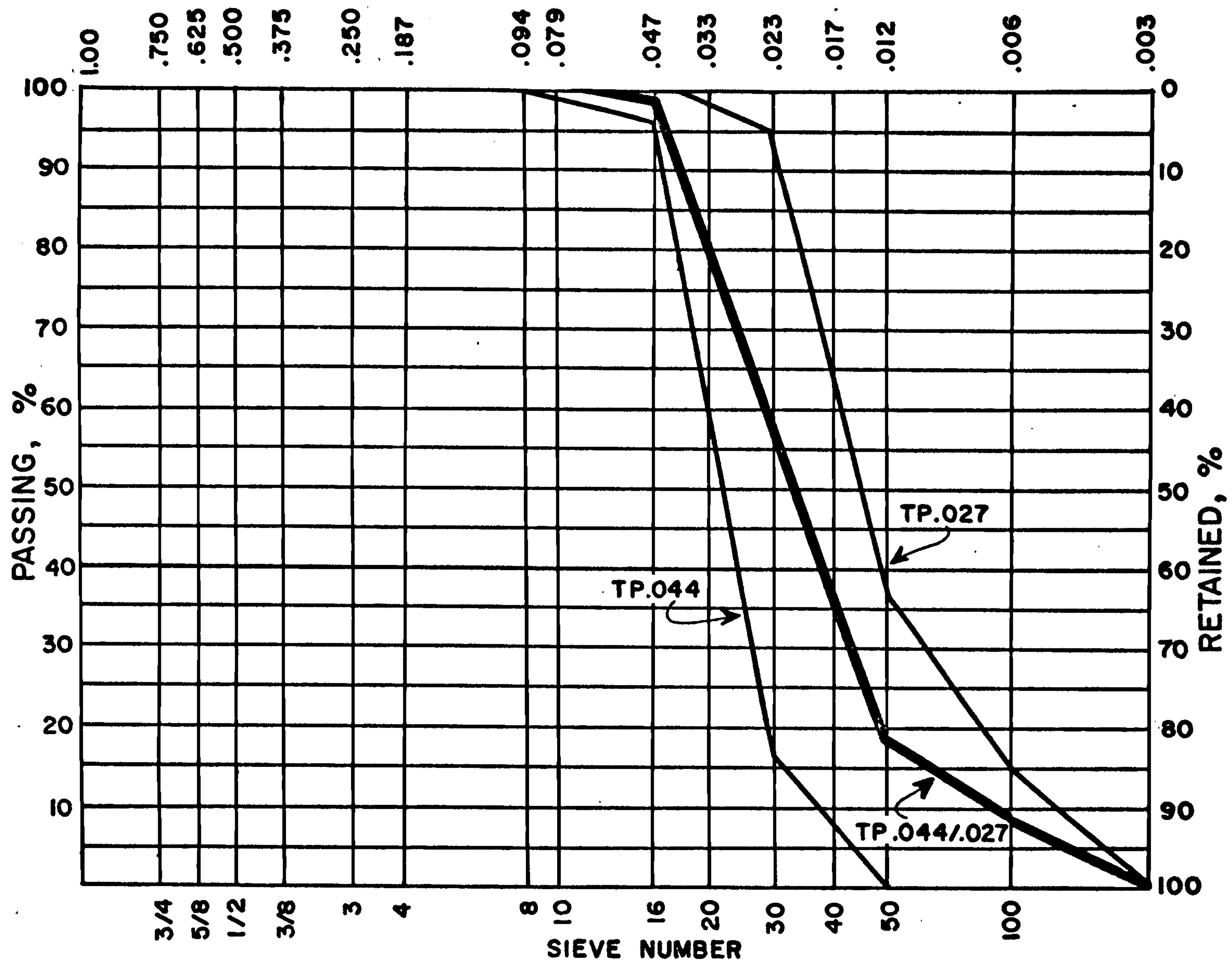

Figure I - 1. Particle Size Disribution of Crumb Rubber Used in the Asphalt-Rubber Testing.

Table I-1. Standard Specifications for Asphalt Cement Used in this Research.

Tests on Residue from AASHTO T240	AASHTO Test Method	Viscosity Grade	
		AR 1000	AR 4000
Viscosity, 140°F, poises	T202	750-1250	3000-5000
Viscosity, 275°F, minimum	T201	140	275
Penetration, 77°F, 100 gm, 5 sec, minimum	T49	65	25
Percent of original penetration, 77°F, minimum	-[a]	-	45
Ductility, 77°F, cm, minimum	T51	100[b]	75
Tests on Original Asphalt			
Flash point, Pensky-Marten closed tester, °F, minimum	T73	400	440
Solubility in trichloroethylene, %, minimum	T44	99	99

[a] Penetration of original asphalt as well as penetration of asphalt after the RTFC test will be determined in accordance with the requirements of AASHTO T49.

[b] If the ductility is less than 100, material will be accepted if the ductility at 60°F is more than 100.

APPENDIX II

GENERAL SPECIFICATIONS FOR SUBGRADE PREPARATION AND MATERIAL DISTRIBUTION FOR ASPHALT-RUBBER MEMBRANE INSTALLATIONS

GENERAL SUBGRADE SPECIFICATIONS FOR ASPHALT-RUBBER MEMBRANE LININGS USED IN RESERVOIR AND WATER HARVESTING INSTALLATIONS

1. General

1.1 This work involves the preparation of the subgrade surface before application of the asphalt-rubber membrane. These specifications apply to an unprepared soil subgrade and are not needed if an asphalt concrete or equivalent hard surface is provided for the lining. Also included are general specifications for the cover material.

2. Subgrade Preparation

2.1 The subgrade shall be firm enough to support the men or equipment to be used during the membrane installation. Adequate structural bearing shall be provided. In particular, determine the optimum moisture content which gives the greatest degree of compaction (maximum density) in accordance with ASTM designation D 698 or AASHO designation T 99. The subgrade soil in place in the field shall be compacted to a density of 95% of the maximum obtained in the laboratory. Moisture content shall not vary more than 2% above or below optimum. This section need not apply to water harvesting catchment installations.

2.2 All large clods, brush, roots, rocks, sod, or other foreign material, shall be eliminated from the area to be lined. All backfilled depressions, including areas where large rocks have been removed, are particularly subject to abnormal, localized settling and shall be compacted with care. Maximum surface particle size shall not exceed 1/2 inch before roller-compaction. Roller compaction is not needed for water harvesting membrane installations but is essential for reservoir installations. A roller may be needed to obtain a relatively smooth subgrade for some water harvesting applications.

2.3 For reservoir lining, inspect exposed subgrade soil for zones of coarse gravel, sand lenses, etc. All such zones should be over-excavated one foot and backfilled with suitable compactible material composed of stockpiled sandy clay soils, type SM or finer (as defined in ASTM designation D 2487).

2.4 Subgrade shall be graded and dressed to relatively uniform gradients and shall be rolled with steel wheel rollers to achieve the desired density and/or surface smoothness. Rollers shall not weigh less than 50 pounds per linear inch or drum width. At least two coverages by the roller shall be required for reservoirs. There shall be no sharp bends, ruts or sudden changes in the subgrade.

2.5 Fill or loose subgrade material that is to be compacted but is inaccessible to rollers should be compacted with pneumatic, vibrating, or other approved hand-tamping equipment. (Reservoir installation only),

2.6 If isolated areas in the subgrade are still coarse-textured and open after preparing and compacting, a light two-inch cushion layer of filter grade soil, type SW or finer (as defined in ASTM designation D 2487) should be applied and compacted. (Reservoir installation only).

2.7 If weed growth is considered to be a problem, a high quality, non-selective soil sterilant should be applied after preparation of the subgrade and before application of the tack coat. The asphalt-rubber membrane should not be applied over penetrating type plants unless they are completely removed. If liquid soil sterilants are to be used, their application can be done before rolling to provide the required moisture for compaction.

2.8 Excavations within reservoir bottoms shall not have slopes steeper than 1 vertical to 3 horizontal. Steeper slopes through channeled areas shall be terraced to prevent sloughing of the lining or cover material. The mean slope of the terraced section shall not be steeper than 1 vertical to 2 horizontal.

2.9 The contractor shall plan his operations so that all asphalt-rubber membrane material placed in a single working day shall be covered the same working day with the specified select cover material. A 3-foot strip along the edge of the membrane shall be left uncovered for the next pass of the distributor truck. Vehicles and/or construction equipment shall not operate directly on the uncovered asphalt-rubber membrane.

3. Select Fill Over Asphalt-Rubber Membrane

3.1 For reservoir construction, all asphalt-rubber membrane lining material shall be covered with a minimum of 12 inches of select material composed of stockpiled soil excavated from the reservoir area if acceptable. The bottom 3 to 6 inches of soil cover next to the membrane shall not be coarser than silty sand, type SM. The remaining cover material should pass a 1-inch square mesh screen and shall contain a minimum of 30% passing a Number 8 screen.

3.2 For water harvesting catchment construction, a cover material composed of 3/8 inch (9.5 mm) washed stone applied at a rate of 25 lb/yd^2 (13.56 Kg/m^2) shall be applied to the asphalt-rubber immediately after spray application. Stone distribution shall be by mechanized spreader immediately following the asphalt distributor truck.

3.3 Placing of cover material shall be conducted in such a manner that the lining will not be damaged by equipment or overburden. Care must be taken in the placement of the cover material when temperatures are over 100°F (38°C) as the puncture resistance of the asphalt-rubber membrane diminishes with increasing temperature.

3.4 The cover material shall be sufficiently stable to minimize wind erosion and/or liquid scouring on sloping sides of a reservoir as the water level fluctuates.

GENERAL SPECIFICATION FOR HOT ASPHALT-VULCANIZED CRUMB RUBBER MEMBRANE WATERPROOFING FOR RESERVOIR AND WATER HARVESTING APPLICATIONS

1. General

1.1 This work involves the placing of a hot asphalt-vulcanized crumb rubber waterproof membrane liner on prepared surfaces in accordance with the following specifications.

2. Materials

2.1 The asphalt cement membrane lining shall conform, prior to the addition of rubber, to the specifications for viscosity, grading AR 1000 or AR 4000 as specified by the Pacific Coast User's Conference.

2.2 The vulcanized crumb rubber shall meet the following requirements:

2.2.1 The total rubber aggregate phase of the asphalt-rubber mix shall consist of equal parts by weight of two rubber particle sizes supplied by the manufacturer as follows:

Particle Size No. 1 - Not less than 95% shall pass the No. 16 sieve and not more than 10% shall pass the No. 25 sieve (TP.044 ATLOS).

Particle Size No. 2 - Not less than 95% shall pass the No. 25 sieve and not more than 30% shall pass the No. 50 sieve (TP.027 ATLOS).

Sieves shall comply with ASTM Designation E-11 or AASHO Designation M-92. Sample size shall be 150-200 grams.

2.2.2 The granulated crumb rubber, irrespective of diameter shall be less than 1/8 inches in length and shall be free from fabric, wire, or other contaminating material.

2.2.3 The specific gravity of the crumb rubber shall be 1.15 ±.02 and shall be fully vulcanized. The crumb rubber shall be protected from atmospheric moisture or any adverse weather conditions. Up to 4% of a granulated, anhydrous compound such as calcium carbonate may be included to prevent the rubber particles from sticking together.

2.3 Tack Coat: A tack coat comprised of CSS-1 or CSS-1h emulsified asphalt, mixed with equal parts water shall be applied to the compacted base at a rate of approximately 0.10 gal/yd^2. The asphalt material shall meet the requirements of ASTM designation D 2397 or AASHO designation M 208.

3. General Specification for Mixing and Application of Asphalt-Rubber

3.1 Equipment

3.1.1 A self-powered pressure distributor equipped with a separate power unit, distributing pump capable of pumping the specified material at the specified rate through the distributor tips, and equipment for heating the bituminous material. The distribution bar on the distributor shall be fully circulating with nipples and valves so constructed that they are in such intimate contact with the circulating asphalt that the nipples will not become partially plugged with congealed asphalt upon standing, thereby causing preliminary streaked or irregular distribution of the asphalt. Any distributor that produces a streaked or irregular distribution of the material shall be promptly removed from the project. Distributor equipment shall include a tachometer, pressure gauges, volume measuring devices, mixing equipment inside distributor tank capable of being run off either separate power unit or power take off, and a thermometer for reading the temperature of the tank contents. The spray bars on the distributor shall be controlled by a bootman riding at the rear of the distributor in such a position that operation of all sprays is in full view and accessible to him for controlling overall spread widths and individual fan widths.

3.1.2 The method and equipment for combining the rubber and asphalt shall be so designed and accessible that the engineer can readily determine the percentages, by weight, of each of the rubber gradations added to the mixture. If the crumb rubber is packaged in bags, alternate sieve sizes (by bag) shall be placed in the distributor tank until the total rubber quantity is incorporated into the mix.

3.2 Mixing

3.2.1 The crumb rubber shall be added to the preheated asphalt as rapidly as possible for such a time and at such a temperature that the consistency of the mix approaches that of a semifluid material. The temperature of the asphalt before mixing shall be between 350° and 400° F. The engineer shall be the sole judge of when the material has reached application consistency. After all rubber has been added and the mix has reached proper consistency, application shall proceed immediately; and in no case shall the mixture be held at temperatures over 325°F for more than two hours after reaching that point.

3.2.2 The proportions of the mix shall be as follows: 33-1/3% of the asphalt, by weight, shall be vulcanized crumb rubber consisting of equal parts of the two rubber particle sizes as specified in 2.2.1.

3.2.3 No kerosene diluent shall be used in the asphalt-rubber mix.

3.3 Membrane Application

3.3.1 Prior to the asphalt-rubber membrane application, the surface to be sealed shall be prepared as specified under subgrade preparation.

3.3.2 The tack coat shall be applied a minimum of 24 hours prior to the application of the asphalt-rubber membrane. There shall be no "puddling" of the emulsified asphalt and all areas shall be relatively dry before applying the asphalt-rubber. The rate of application of the tack coat shall be ±0.10 gal/yd^2. It is desirable that the distributor trucks not "pick up" the tack coating with their tires when dispensing the asphalt-rubber. Application of asphalt-rubber should be made at relatively cool air and surface temperatures when possible. In lieu of an asphalt emulsion tack coat, a light spray of water may be desirable for certain climatic and soil conditions.

3.3.3 The application rate of the hot asphalt-rubber mixture shall be determined by water harvesting catchment subgrade and reservoir design parameters. Application shall produce a continuous membrane without holidays, streaking or "skips" at overlaps and shall be made in one pass of the distributor truck.

3.3.4 All overlaps shall be a minimum of one foot and shall be clean of any debris or adjacent cover material. Overlapping joints shall be continuous and an integral part of the membrane.

3.3.5 Areas that are inaccessible by distributor truck shall be covered by a hand hose applicator in such a manner as to produce the desired application rate.

3.3.6 For reservoir application, select cover material shall be placed over the asphalt-rubber membrane only after it has cooled and shall be placed with rubber-tired vehicles only. At no time shall vehicles or construction equipment be allowed on the exposed membrane without sufficient cover material in place.

3.3.7 For water harvesting catchment construction, the select cover stone shall be placed immediately after spray application of the asphalt-rubber.

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