SUMMARY

ASPHALT-CRUMB RUBBER WATERPROOFING MEMBRANE

By Ronald K. Frobel, R. A. Jimenez,
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This paper is concerned with laboratory testing and field investigations of a water seepage barrier consisting of asphalt cement and crumb-rubber from reclaimed tire peels. The investigation focuses upon the use of asphalt-rubber on bridge decks, in canals and in water or effluent containment reservoirs.

ABSTRACT: This report is concerned with laboratory testing and field investigations of a water seepage barrier consisting of asphalt cement and reclaimed crumb-rubber tire peel. The test methods that were utilized and evaluated included the following: water vapor transmission (ASTM E96-72, Procedure BW), water absorption (ASTM 570-72), ductility (ASTM D113-74), viscosity, toughness, and brittleness/impact resistance (ASTM 0994-72). The test results showed that the asphalt-rubber as a membrane is relatively impermeable and absorbs an insignificant amount of water. The crumb rubber effectively increases the viscosity of the asphalt cement while decreasing the ductility value. The asphalt-rubber combination exhibits a tough, impact resistant membrane with excellent waterproofing properties.

KEYWORDS: Asphalts, Membranes, Waterproofing, Seepage, Water Resources.

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INTRODUCTION

The economical control of seepage has long been a problem whenever surface water is stored. Large-scale applications of a relatively low cost seepage control method are being needed at an ever increasing rate with the advent of increased construction of nuclear power plants, mining facilities, desalination plants and other large water users. These facilities require many acres of evaporation ponds for use in the disposal of brine effluent or mine tailings where deep well injection or other disposal methods are not allowed due to increasingly strict regulations to prevent pollution of the underground and surface environment. In surface disposal, the high cost is due partly to the large surface area required and partly to the lining used in construction. The high cost of lining applies also to man-made lakes and other water containment structures.

Asphalt cement mixed with crumb-rubber has been used successfully in highway construction for several years in Arizona and other states (9). Its primary use has been in seal coat applications, crack filling, and as a stress absorbing membrane interlayer (SAMI) within the pavement structure.

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Its waterproofing properties have been recognized but no previous laboratory or field investigations have been attempted to determine asphalt-rubber physical properties as related to a waterproofing membrane material. The rubber used in the mixture comes from reclaimed rubber tires which are granulated to a specified sieve size. From an ecological viewpoint, large scale use of this mixture would result in recycling old tires which are now a disposal problem.

The advantages of spray application of an asphalt-rubber membrane as opposed to sheet lining include: elimination of field seams, easy repair by hand spray methods, ease in application and economical savings in construction, time and labor. Also, asphalt-rubber is very competitive in physical properties and less costly than catalytically blown asphalt. It has low temperature susceptibility, a high degree of toughness, resistance to tearing or breaking, good durability and is highly impermeable.

LABORATORY TESTING PROGRAM

The laboratory test procedures chosen to evaluate the asphalt-rubber as a membrane material were the following: water vapor transmission, water absorption (ASTM D570-72), ductility (ASTM D113-74), viscosity, toughness and brittleness/impact resistance (ASTM D994-72).

Material Identification and Mixing

The base asphalt cement used in this investigation was AR 1000. AR 4000 was also used as a variable in the viscosity, ductility and impact resistance testing. The number in each asphalt designation refers to the relative viscosity of the asphalt.

Three types of granulated tire rubber, based on particle size, were also used as variables in the testing. The first type, designated as

TP.044, represented the coarse rubber particle size. The second type of rubber, designated as TP.027, represented the fine particle size. The third type was a particle size distribution designated as TP.044/TP.027 and represented a blended mixture of equal parts of fine and coarse rubber. The sieve analysis of the three types are shown in Figure 1.

The mixture proportions of the two components, by weight, were 75 percent asphalt and 25 percent granulated rubber. The mixing method (used to approximate the field mixing procedure) was as follows: a specific amount of the asphalt cement was heated in a stainless steel pan to a temperature of 370°F ±5°F (188°C ±3°C). At this temperature, the required amount of rubber was added as quickly as possible to the hot asphalt while continuously stirring the mixture. After all the rubber was added to the asphalt, stirring of the two materials continued for a period of 30 minutes. Mixing temperature was maintained between 350 and 400°F (177 and 204°C). At the completion of the required mixing time, the asphalt-rubber was molded into the required test specimens.

Specimen Molding for Membrane Testing

Water vapor transmission, water absorption and brittleness testing require specimens that are uniform in thickness for repetitive testing. It was necessary, therefore, to design a relatively simple forced-molding technique. The forced-molding apparatus consisted of a plexiglass mold and a piston-sleeve device as shown in Figure 2. The molding procedure involved the following steps:

1. Using a top-loading balance, the desired amount of hot asphalt-rubber mixture was placed in the plexiglass mold (c). To prevent the mixture from sticking, release paper having the same diameter as the specimen was placed on the interior bottom surface of the

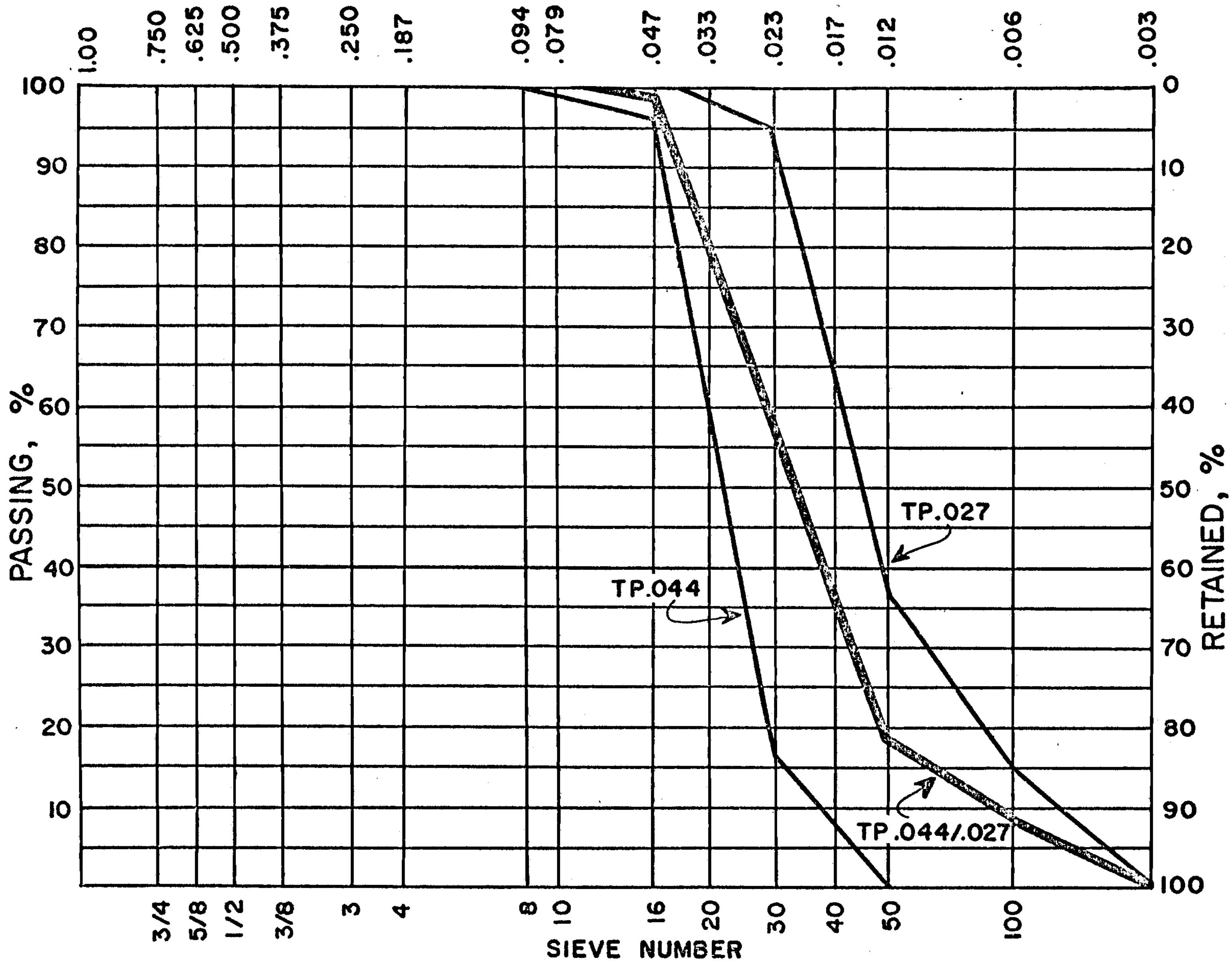

FIGURE 1. PARTICLE SIZE DISTRIBUTION OF CRUMB RUBBER
USED ASPHALT-RUBBER TESTING

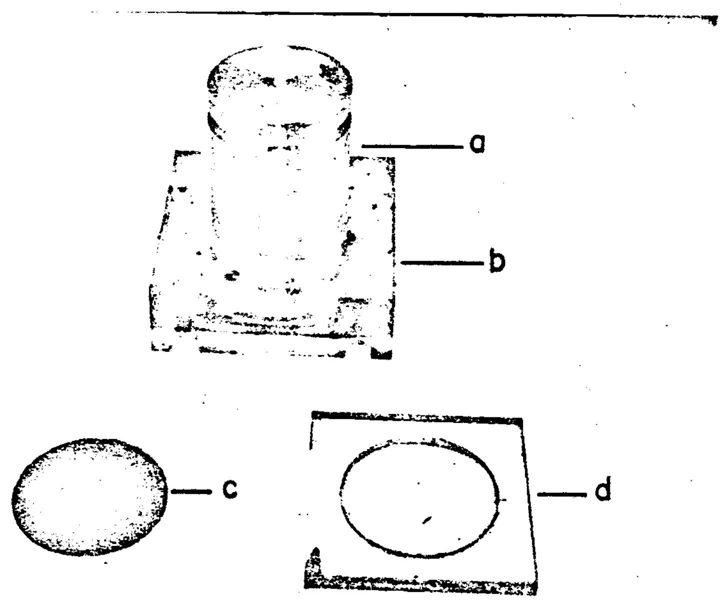

FIGURE 2. MOLDING APPARATUS FOR ASPHALT-RUBBER MEMBRANE SPECIMENS
a - piston; b - sleeve (centering block); c - finished specimen; d - mold

mold. The amount of asphalt-rubber mixture placed in the mold was dependent on the application rate needed.

2. The mold was immediately removed from the balance and the centering block (b) was placed over the mold.
3. The piston (a) was centered in the block and the mixture was compressed so as to spread evenly across the contained mold diameter, thus producing a uniform specimen size and thickness for this film testing. To prevent the mix from sticking to the piston, the contact area of the piston was lightly greased and covered with mold 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 paper discs were peeled off, and the membrane was ready for testing.

Viscosity Testing

Due to the relatively high viscosities and granular nature of the asphalt-rubber mixture, conventional viscosity determinations could not be used. The falling coaxial viscometer as developed and studied by Traxler and Schweyer (10) was chosen as a viable viscosity determination method. A detailed theoretical analysis of the viscometer method can be found in the publication entitled "Measurement of High Viscosity, A Rapid Method" (10). The following equipment was used in the viscosity test:

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

The viscosity determinations were performed by using the viscometer shown in Figure 3. The procedure for running a viscosity test by utilizing the falling coaxial viscometer involved the following steps:

1. The hot asphalt-rubber mix was forced into the viscometer annular space between piston and brass ring making sure there were no void spaces.
2. The viscometer was then placed on a lubricated (silicone grease) glass plate and allowed to cool to room temperature at which time it was moved to the water bath for one hour before testing.
3. A telescopic sight was pointed just a small distance below a well-defined mark on the piston. A minimum of three successive vertical piston displacements of 0.1 cm each were timed utilizing two or three stopwatches. At least four weights were used to vary the piston velocity.
4. 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:

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

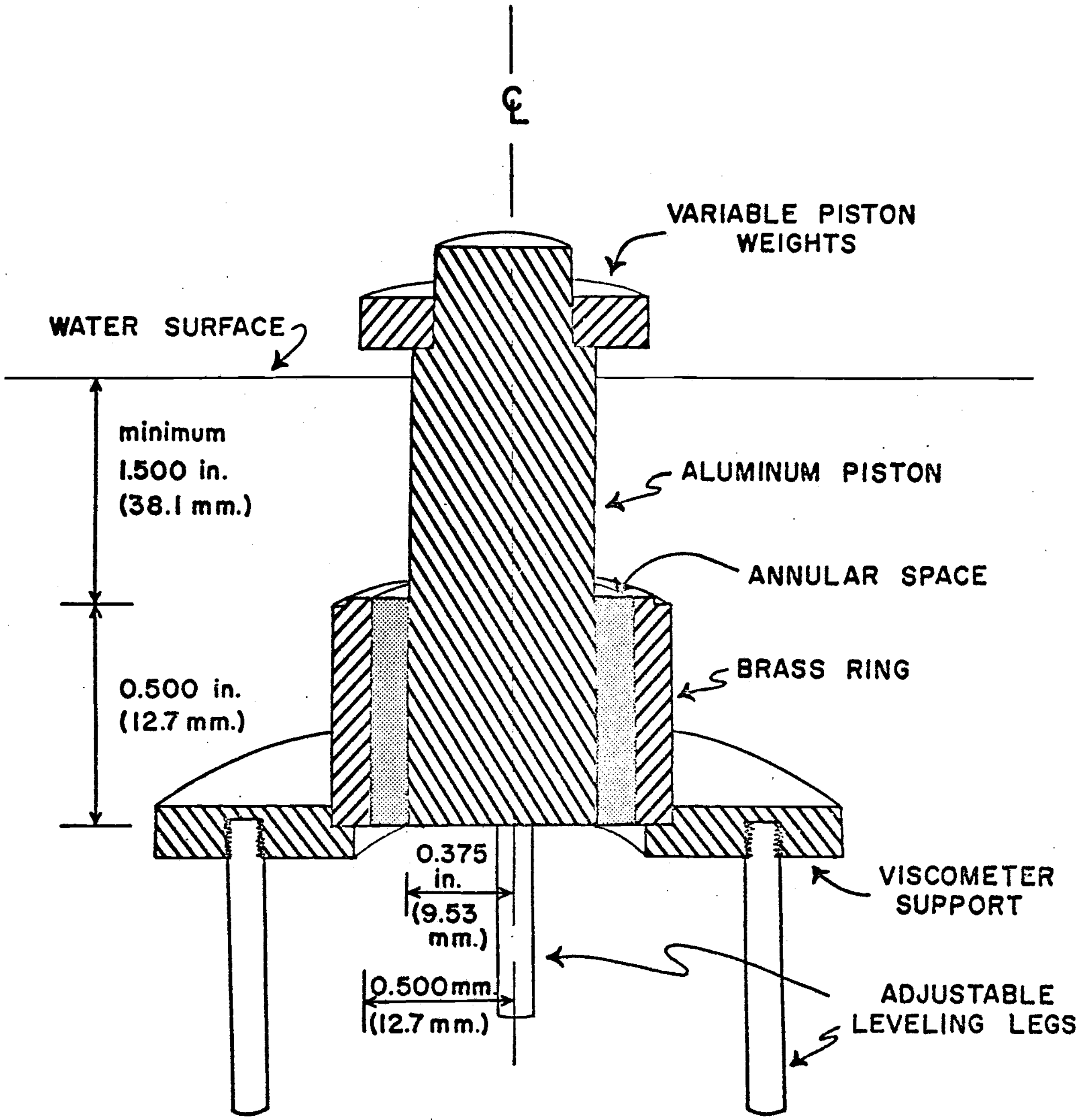

FIGURE 3. FALLING COAXIAL VISCOMETER

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:

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

where W_{eff} = the effective weight in gm (the total weight minus the buoyant force),

g = 980 cm/sec^2, acceleration of gravity

r = radius of the piston in cm, and

L = the length of the brass ring in cm.

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

$$\eta = \frac{S_s}{S_r} \quad (3)$$

It is to be noted that the previous procedure applied 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 (11), the ductility test was part of a study on rubberized 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 rubberized asphalt blend was tested in accordance with ASTM designation D113-44, except that a temperature of 39.2°F (4°C) was used. In the final analysis, it was found that increasing the amount of 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 (4). The ductility value of an asphalt-rubber mixture was measured by the distance to which it elongated 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 2 in/min (5 cm/min).

Water Vapor Transmission Test

The purpose of this test was to determine the rate at which water vapor is transmitted through a given membrane thickness of asphalt-rubber when wetted on one surface only. With minor changes, it was carried out in accordance with the standard test specified in ASTM designation E96-72, procedure BW (2). The 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, retaining ring and 20 mesh galvanized screen with dimensions as shown in Figure 4.
2. RC-250 asphalt, distilled water and a sensitive balance with readability to 0.01 gm and precision to 0.005 gm.
3. Vacuum chamber.

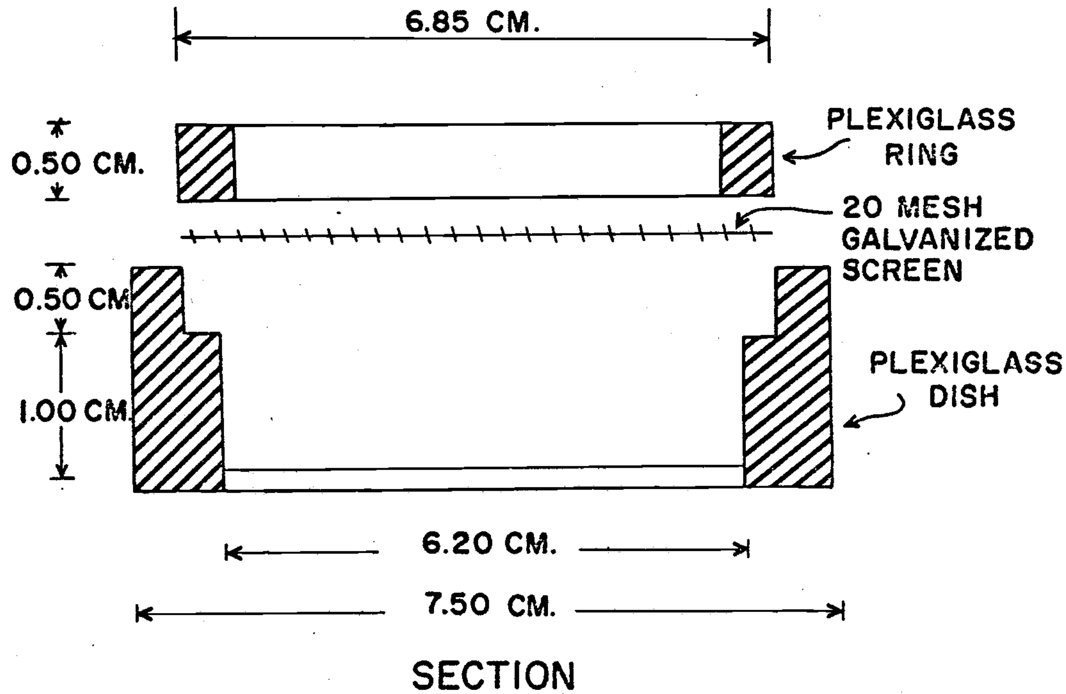

FIGURE 4. WATER VAPOR TRANSMISSION TEST DISH

An attempt to test AR 1000 asphalt without rubber failed because of the high susceptibility to flow at the test temperature of 77°F (25°C). The asphalt cement was observed to be flowing out through the retaining screen during testing.

The apparatus used for the vapor transmission test required minor changes before testing asphalt-rubber mixtures. The apparatus consisted of a small, lightweight dish, restraining ring and a 20 mesh galvanized screen as shown in Figure 4. The dish was an open-mouthed plexiglass cup with a depth of 0.38 inch (1.0 cm) and a diameter of 2.44 inch (6.2 cm) (see Figure 4). 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 was 30 square centimeters. To hold the membrane in the dish, the wire mesh and 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 test. RC-250 asphalt was used to seal the ring to the dish and specimen, thus preventing edge failure due to leaks.

Water Absorption Test

This test was concerned with the determination of the relative rate of absorption of water by asphalt-rubber mixtures when immersed in distilled water. It 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 (1) was chosen as the best reliable procedure to achieve the desired results. The three asphalt-rubber combinations used in this test were AR 1000/TP.044, AR 1000/TP.027, and AR 1000/TP.044-.027.

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

The desired asphalt-rubber mixture was prepared using the mixing procedure specified previously. The hot mixture was molded into a sample membrane of uniform thickness of approximately 1/8 inch (3.2 cm). Five specimens were then cut from the cold sample membrane, each measuring 3 inches (76.2 mm) by 1 inch (25.4 mm). The specimens were allowed to cure at room temperature for a period of at least 24 hours before testing. After curing, the specimens were weighed and transferred to a water bath. A minimum of five specimens of each mix were tested. The amount of water absorption for each mixture, at the end of any specified time period, was then calculated as the average value of the five specimens tested.

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

Brittleness - Impact Resistance

This test was used in an attempt to determine the relative low temperature impact resistance of the asphalt-rubber blend. With minor procedural changes, it was carried out in accordance with ASTM designation D994-72 (3). 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).

The generalized brittleness test procedure was as follows: An asphalt-rubber specimen was immersed in chilled water at the prescribed test temperature for two hours. Each specimen was then removed from the water and immediately placed on a wooden block resting on a solid concrete surface. A 1.0 lb (0.454 kg) stainless steel ball was then dropped on the specimen from a height of 3 feet (0.915 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.

Toughness Testing

This test was a modification of one developed by Jewell R. Benson and described in the paper "Tentative Standard Method of Test for Toughness and Tenacity of Rubberized Asphalts" (5). Originally, the test procedure was designed to test the toughness and tenacity of rubberized asphalt employing 3 to 5 percent liquid latex or powdered rubber. The objective in using this test was to attempt to determine the relative toughness or resistance to deformation of asphalt-rubber mixtures as compared to the base asphalt cement.

Equipment and Materials - The A-R mixtures used in this study were plain AR 1000; AR 1000/TP.044, AR 1000/TP.027 and AR 1000/TP.027-.044.

The apparatus designed and fabricated for this test procedure is shown in Figure 5 and includes the following:

(a) Molds - the molds consisted of metal cups having an interior diameter of 3 inches (76.2 mm) and a depth of 1-1/2 inches (38.1 mm).

(b) Restraining base - this was designed to center and clamp the individual mold cups containing the asphalt-rubber mixtures. The restraining base was designed to attach firmly to the testing machine.

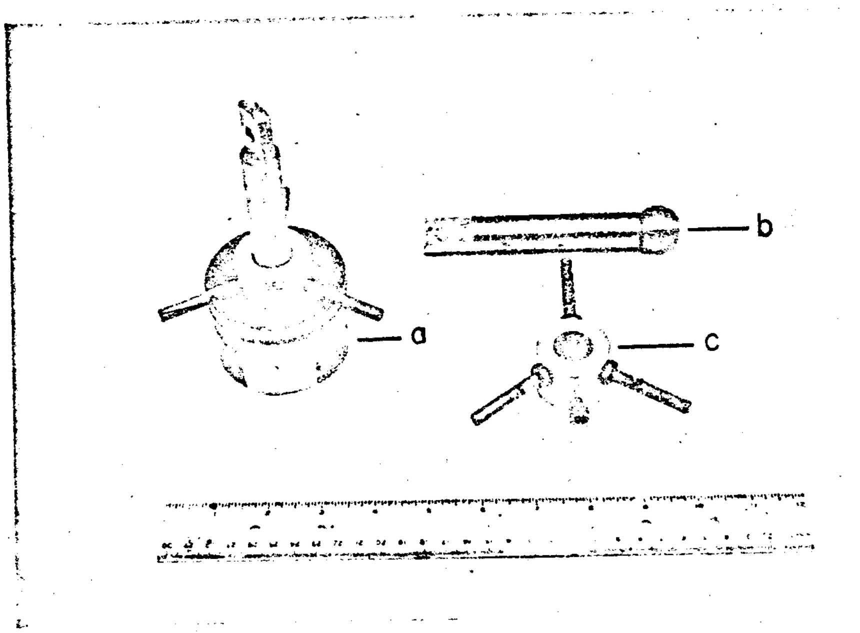

FIGURE 5. TOUGHNESS TESTING APPARATUS
a - mold can; b - tension head;
c - spider support

(c) Tension head - the tension head consists of a polished stainless steel hemispherical head having 1/2 inch (12.7 mm) radius and integrally attached to a 1/4 inch (6.4 mm) diameter rod designed to permit rapid connection to the testing machine head.

(d) Spider support - the spider was fabricated to provide accurate centering of the tension head into the mold and to provide vertical support for the tension head and connecting rod. The spider is provided with a restraining screw so that the hemisphere may be accurately imbedded into the sample mix. The spider is not physically attached to the mold can but rather provides centering and support only for the tension head.

An Instron Universal Testing Machine, Model TT-C with a 10,000 lb (4536 Kg) capacity F-load cell was used for performing the Toughness/Tensile-Pullout tests. Samples were first conditioned at 77°F (25°C) with the use of a constant temperature water bath. They were then removed from the bath and immediately tested.

Procedure - The asphalt-rubber samples were mixed in accordance with previously described mixing procedures and immediately placed in the mold cans. The steel hemisphere was then positioned in the hot mixture, centered in the mold and restrained by the spider support. After a cure time of 24 hours the samples and apparatus were placed in a water bath for a minimum of 2 hours. After conditioning, the samples were positioned between the upper and lower jaws in the Instron testing machine as shown in Figure 6 and immediately tested. For these tests, a crosshead speed of 20 inches per minute (559 mm/min) was used as outlined by Benson's procedures (5). A high speed Leeds and Northrup graphic recorder was used to record the load vs. deformation when the hemisphere was pulled out of the asphalt-rubber

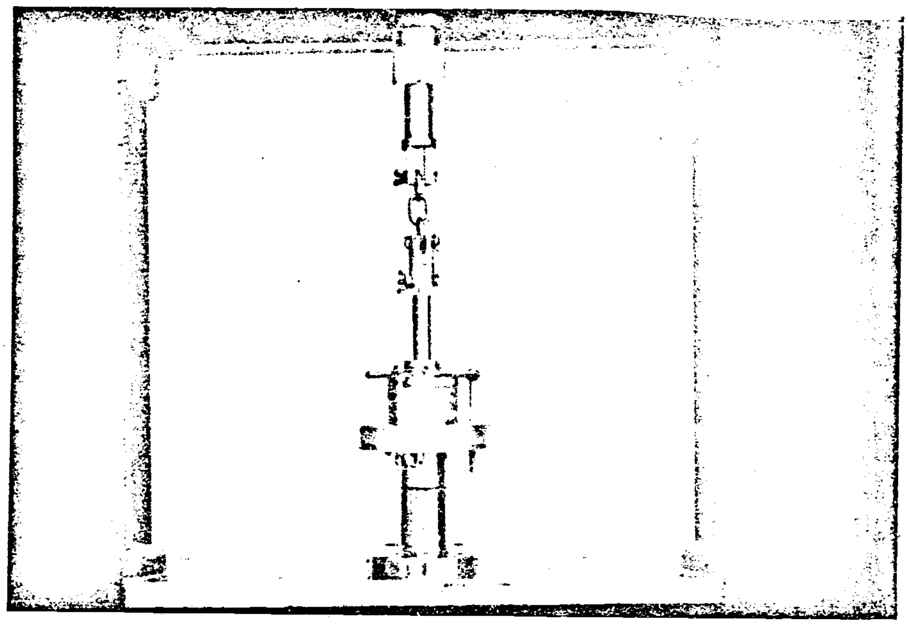

FIGURE 6. TOUGHNESS TESTING APPARATUS POSITIONED IN THE INSTRON MODEL TTC

mixture. The chart speed was also set at 20 inches per minute (559 mm/min).

LABORATORY TEST RESULTS AND DISCUSSION

Viscosity Testing

During its application and use, the asphalt-rubber mixture is subjected to heat, changes in temperature, variable shear or loading, and weathering. The physical parameters can change the consistency (physical properties) of the asphalt-rubber mixture and, consequently, influence the performance of the material. The viscosity test as used in this study attempts to characterize the asphalt-rubber physical properties so that its flow behavior (rheology) and performance under variable conditions can be predicted and controlled. The practical uses of the viscosity test are in the preparation and field placement of asphalt. In this report, the test temperature range reflects the field or in place behavior as opposed to application temperature characteristics. 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 mixtures are shown in the graphs on the following pages.

Figure 7 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. An asphalt-rubber mixture always has a higher viscosity value than the same asphalt without rubber.
2. The viscosity values for asphalt-rubber is dependent on rubber particle size. The viscosity increases as the rubber particle size increases.

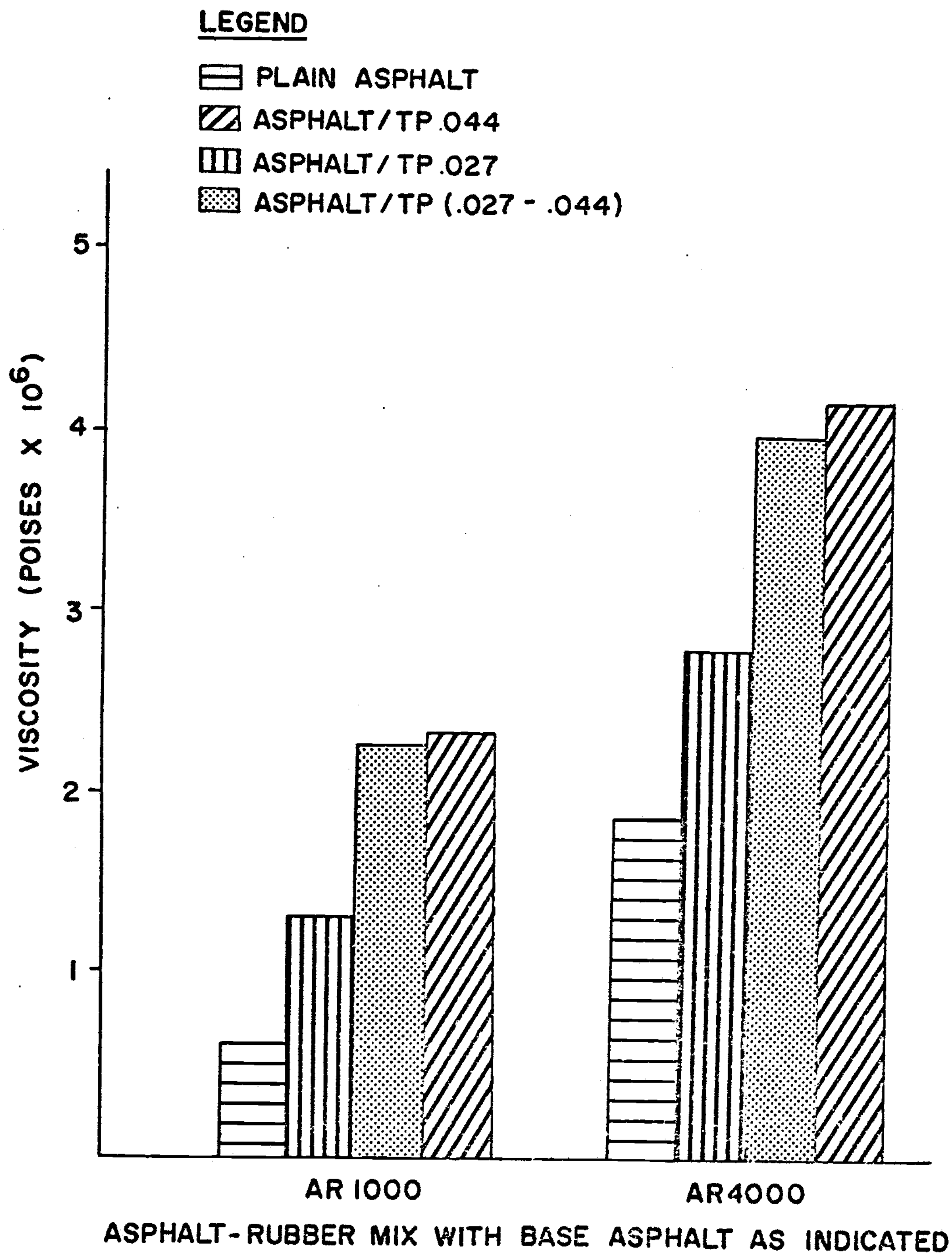

FIGURE 7. VISCOSITY OF ASPHALT AND ASPHALT-RUBBER MIXTURES TESTED AT 77°F (25°C).

These findings are logically acceptable. The mixing of rubber, which is a solid material, with the fluid asphalt should result in a mixture with a lower potential for flow than the asphalt without rubber. This lower potential for flow reflects 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 is reflected in the asphalt-rubber combinations that have the same rubber size but a different grade of asphalt cement.

Figure 8 also shows 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 was 104°F (40°C). The characteristics of this graph are the same as those for Figure 7. It is to be noted, however, that the viscosity values obtained in Figure 8 are lower than the values obtained in Figure 7. 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 9.

Asphalt cement and asphalt-rubber mixtures are thermo-plastic materials; 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 used to study the change in viscosity with the change in temperature (temperature susceptibility) is to specify

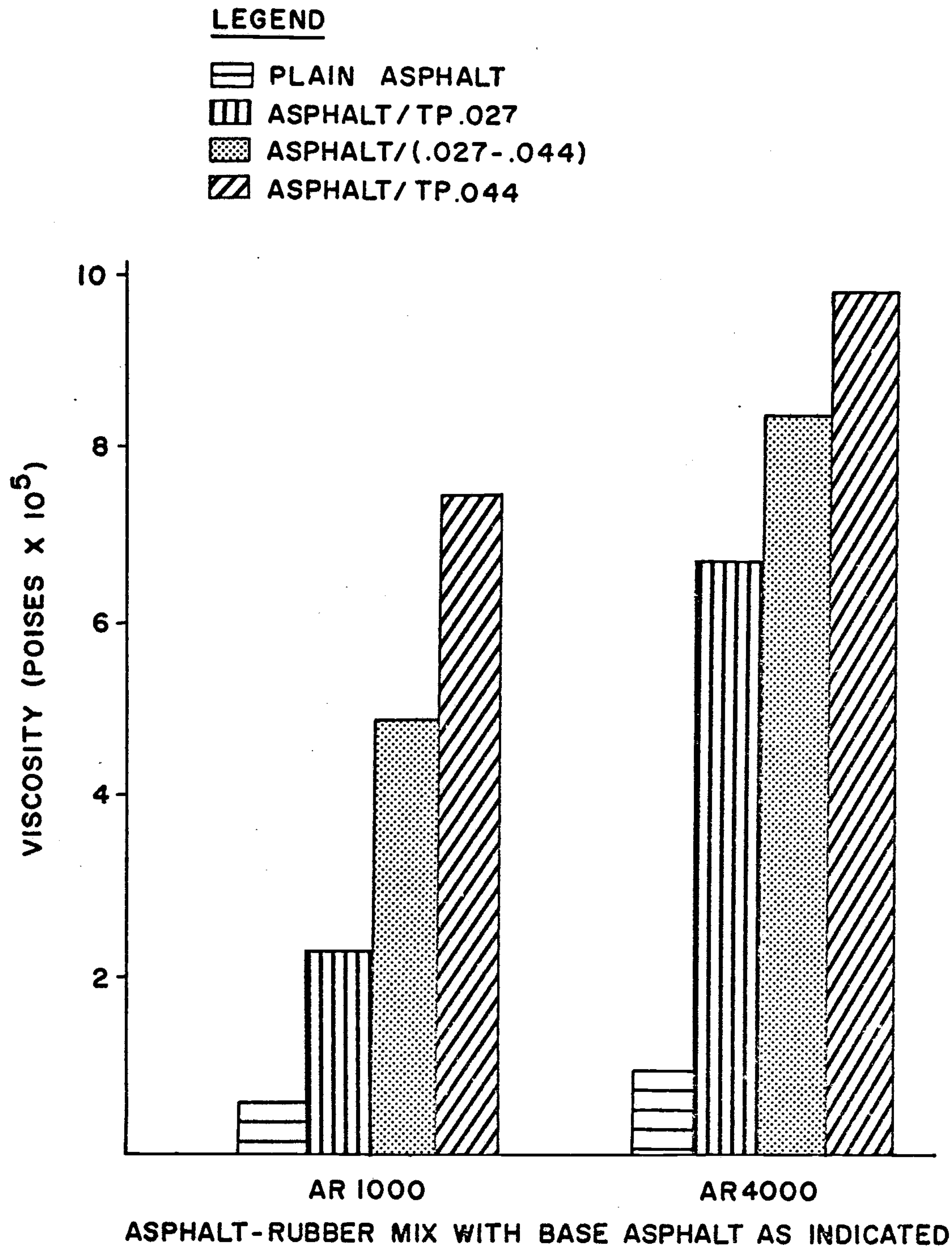

FIGURE 8. VISCOSITY OF ASPHALT AND ASPHALT-RUBBER MIXTURES TESTED AT 104°F (60°C).

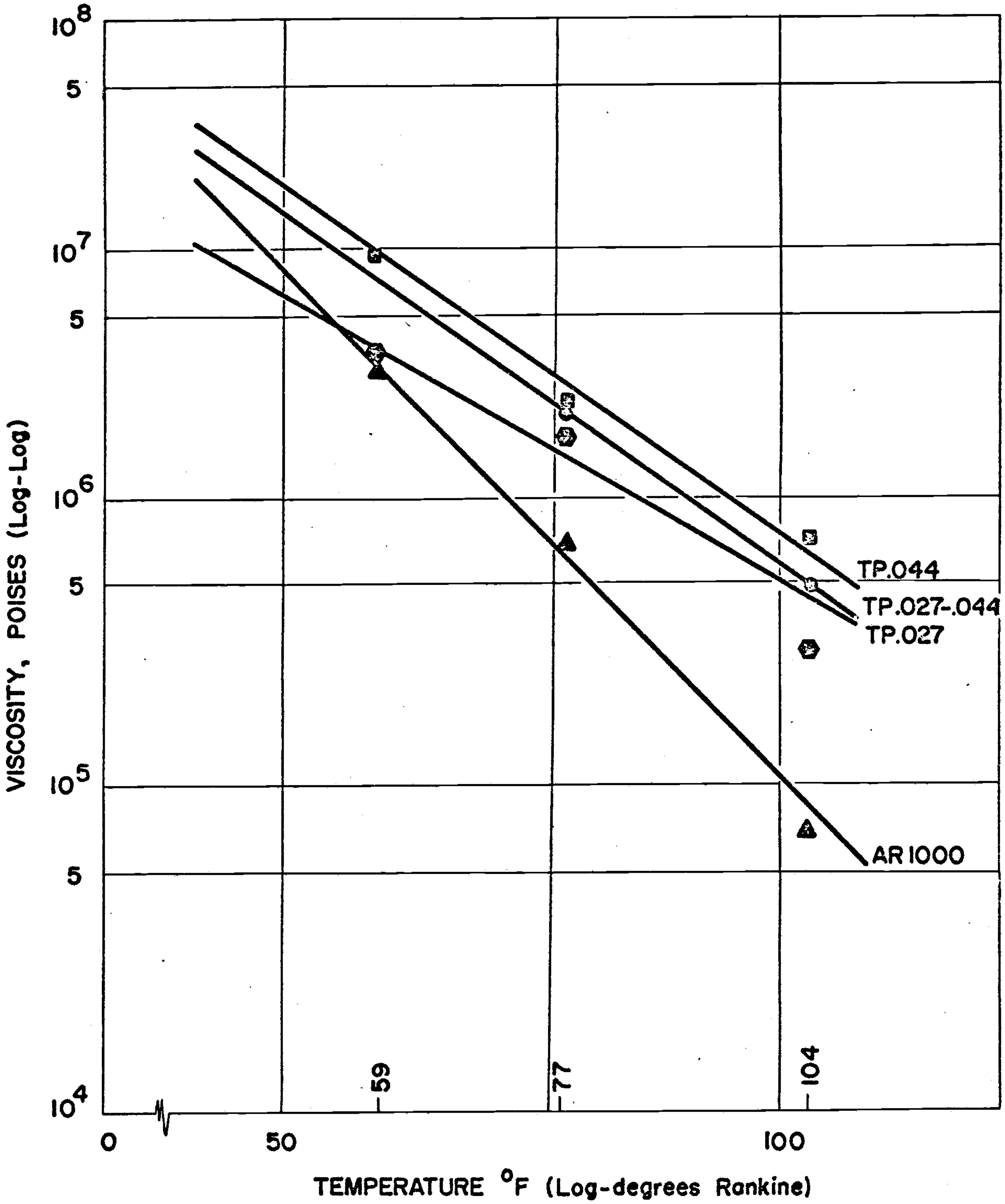

FIGURE 9. VISCOSITY - TEMPERATURE RELATIONSHIP FOR ASPHALT AND ASPHALT-RUBBER MIXTURES

the slope of the temperature vs. viscosity relationship of a material when the viscosity is plotted in absolute units (poises). A straight line relationship is exhibited when the log-log viscosity vs. log-absolute temperature is plotted graphically. Figure 9 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 shear rate of 5×10^{-2} sec^{-1}. A comparison was made on the basis of the numerical value of the slope of each line in the graph of Figure 9. The steeper slope indicates that the material is more temperature susceptible than material with a flatter slope. Close inspection of this figure reveals the following:

1. When rubber was added to asphalt cement, the resulting asphalt-rubber mixture had a lower temperature susceptibility than the parent asphalt material.
2. The temperature susceptibility of the mixture is dependent on rubber particle size. The larger the rubber particle size used in the mixture, the lower is the temperature susceptibility.

<u>Ductility Testing</u>

Figure 10 illustrates 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 cement results in a mixture with a considerably lower ductility value than the asphalt without rubber.
2. For the AR 1000 asphalt, the larger the rubber particle size, the lower is the ductility value of the resulting mixture.

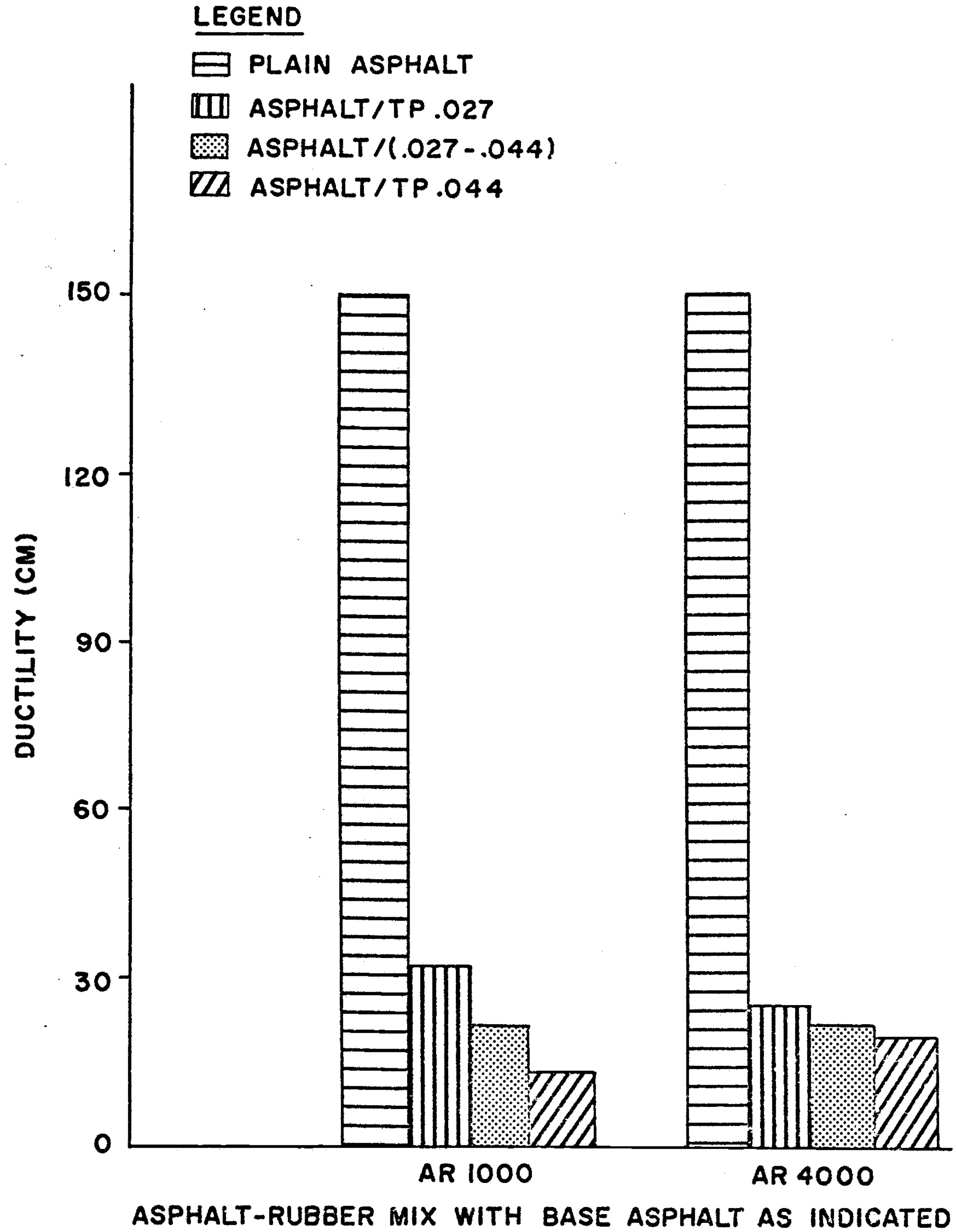

FIGURE 10. DUCTILITY VALUES FOR ASPHALT AND ASPHALT-RUBBER MIXTURES TESTED AT 77°F (25°C).

3. Figure 10 indicates that even though the ductility value of the asphalt is reduced by the rubber, the finer the rubber particle the less is the reduction in ductility value. However, it appears that variation in ductility values among the particle sizes is not great.

4. It is assumed, for the purposes of this report, that rubber behaves very similar to an elastic aggregate when mixed with asphalt. The rubber particles form a skeleton through the specimen to reduce the amount of asphalt at a cross-section. Consequently, a lower ductility value is expected for the asphalt-rubber mixture.

The exact amount of rubber that may go into solution with asphalt when the two materials are mixed has not yet been determined (8). It is apparent, however, that more rubber from the fine particles may dissolve in the asphalt than the coarse particles due primarily to a greater reactive rubber surface area. This extra portion of dissolved rubber from fine particles reflects a higher elasticity in the resulting asphalt-rubber mixture. As a result, the mixture of fine rubber particles and asphalt will have a higher ductility value than that of coarse rubber particles 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.

Water Vapor Transmission Test

This test attempted to measure the relative water vapor transmission (WVT) 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:

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

Figure 11 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 and subsequent permeability.

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 (closer 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 11 at the two application rates of .5 gal/yd^2 (2.26 l/m^2) and 1 gal/yd^2 (4.53 l/m^2). At .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

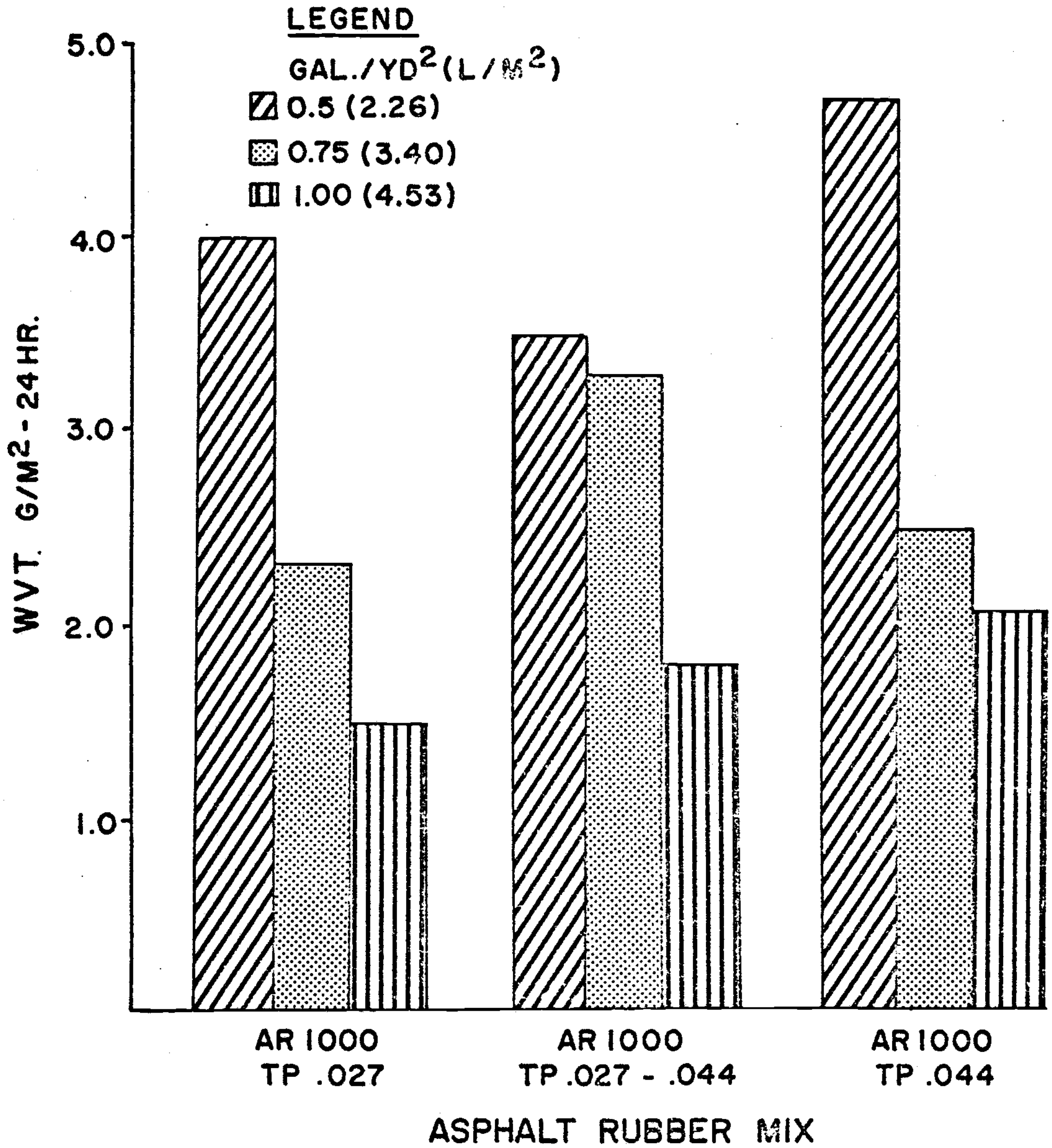

FIGURE 11. WATER VAPOR TRANSMISSION RATE FOR VARIOUS ASPHALT-RUBBER MEMBRANES

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 11).

The significance of this test lies in the fact that it gives information about the relative waterproofing properties of asphalt-rubber mixtures. These properties are important for estimating the material's performance in the field. Table 1 summarizes the WVT rates and some corresponding permeability constants that are found in the literature. Depending on membrane thickness and mixture, 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 (7) which is slightly higher than the range of laboratory values for the asphalt-rubber (0.008 - 0.028 perms) as shown in Table 1. 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 (7).

Accurate dimensions of the specimens could not be obtained due to the plastic nature of the asphalt-rubber 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

Table 1. Permeability Constants for Various Asphalt-Rubber Mixtures and Application Rates.

Asphalt-Rubber Mixture (1)	Application Rate[a] (2)	Water Vapor Transmission Rate[b] (3)	K^c (4)	Permeability Constant[d] (5)	Perms[e] (6)
AR1000/TP.027	0.50	4.04	3.07×10^{-12}	1.52×10^{-8}	.024
	0.75	2.27	2.56×10^{-12}	1.27×10^{-8}	.013
	1.00	1.44	2.14×10^{-12}	1.06×10^{-8}	.008
AR1000/TP.027-.044	0.50	3.50	2.66×10^{-12}	1.32×10^{-8}	.021
	0.75	3.32	3.73×10^{-12}	1.85×10^{-8}	.020
	1.00	1.81	2.69×10^{-12}	1.34×10^{-8}	.011
AR1000/TP.044	0.50	4.71	3.58×10^{-12}	1.77×10^{-8}	.028
	0.75	2.53	2.84×10^{-12}	1.41×10^{-8}	.015
	1.00	2.11	3.14×10^{-12}	1.56×10^{-8}	.013

[a] 1 Gal/yd^2 = 4.53 l/m^2

[b] Water Vapor Transmission Rate = gm/m^2-24 hr

[c] K = cm/sec

[d] Permeability Constant = gm/cm^2-hr-mm Hg.

[e] Perms = grains/ft^2-hr-in Hg.

specimens before periodic weighings due to surface irregularities of the asphalt-rubber. 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 inches (76.2 mm) long, 1 inch (25.4 mm) wide and 1/8 inch (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 12. 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.044. Total water absorption for AR 1000/TP.027 was 0.8% for 28 day immersion. This higher absorption, although small, may be attributable to the fine particle size of rubber and thus greater absorptive surface area. Also, void spaces within the membrane would be attributable to water absorption. It should be noted that in a separate test on the plain crumb rubber, the total water absorbed by the rubber alone was 1.0%. Although the asphalt cement by itself does not absorb a measurable amount of water, obviously the rubber phase and void spaces within the asphalt-rubber mixture does.

It is apparent that the maximum absorption for the asphalt-rubber occurs within 14 to 21 days with little increase in weight after 28 days. This may be only 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

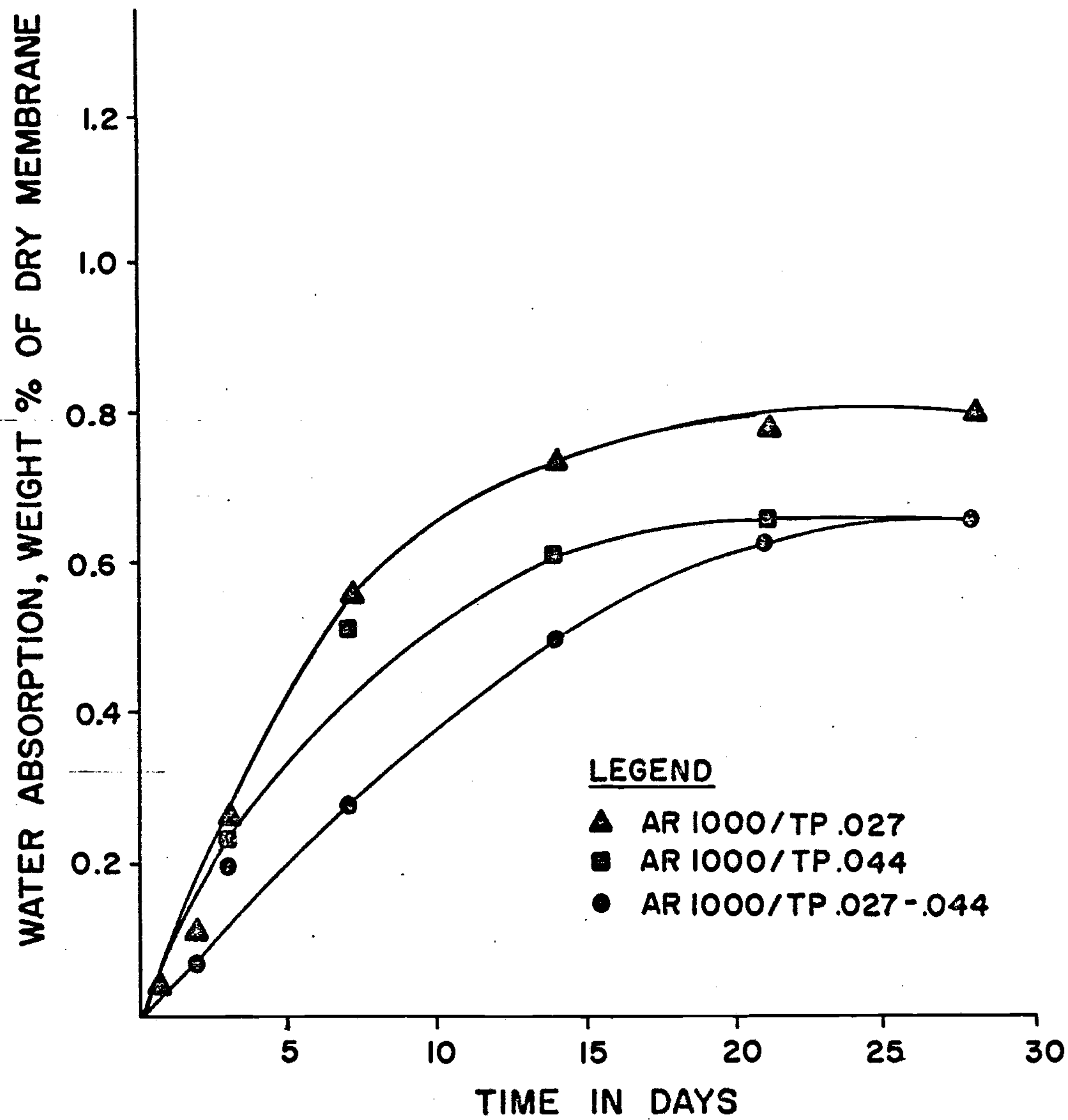

FIGURE 12. WATER ABSORPTION OF THE ASPHALT-RUBBER MEMBRANE WITH TIME

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.

Brittleness-Impact Resistance Testing

This test attempted to determine the relative impact resistance of the asphalt-rubber membrane when subjected to relatively low operating temperatures. The asphalt cement without rubber (both AR 1000 and AR 4000) failed at both the test temperatures of 20°F (-6.6°C) and 40°F (4.4°C). The results of the impact resistance testing are shown in Table 2. The asphalt-rubber specimens that did not fail exhibited very 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 asphalt-cement without rubber. It should be noted that the softer asphalt (AR 1000) in combination with TP.027 rubber resisted fracture failure 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 with virtually no sign of brittleness at this temperature. At temperatures below freezing, in this case 20°F (-6.6°C), the asphalt-rubber mix is susceptible to fracture. The only mix that may not fracture at lower temperatures is the AR 1000/ TP.027 due primarily to the softer asphalt grade and smaller rubber particle size which results in greater flexibility. It should be noted that an increase in total rubber content (in excess of 25%) would probably increase the impact resistance at very low temperatures. Also, the finer rubber particle size will exhibit better impact resistance.

Table 2. Impact Resistance Test Results

Material (1)	Test Temperature 40°F (4.4°C) (2)	Test Temperature 20°F (-6.6°C) (3)
AR 1000	F[a]	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

[a]F = Failure; NF = No Failure

Toughness Testing

An attempt was made at utilizing a test procedure originally designed by Benson (5) to test rubberized asphalt containing liquid latex or powdered rubber. According to Benson and also Endres (6), toughness may be defined as the resistance the asphalt or asphalt-rubber offers to deformation and may be measured as the work required to extract a steel hemisphere from the asphalt or asphalt-rubber at a predetermined rate of pull and temperature.

Relative toughness is defined as the work in inch-pounds required to separate the hemispherical tension head from the cup containing the test mix at 77°F (25°C). The force-deformation curve obtained from the test was used to calculate the relative toughness by computing the area under the curve. A typical force-deformation curve for asphalt-rubber is shown in Figure 13b. All three asphalt-rubber mixtures tested indicated two distinct rates of force vs. deformation as shown by section ab and bc on the curve of Figure 13b. Rate ab represents the work required to pull the ball out of the mix when the mix is adhered to the total hemisphere. At b the mix begins to break away from the bottom of the hemisphere leaving a circumferential ring of less asphalt-rubber material adhering to the ball. The work required to pull the ball free from this configuration is represented by the rate bc and reflects the decrease in asphalt-rubber material. At point c total separation takes place. The area abcd represents the total work (toughness) required to pull the hemisphere free of the asphalt-rubber mix. As a comparison, Figure 13a shows a typical force-deformation curve for the AR 1000 asphalt. This curve could also represent the latex rubberized asphalt, as developed by Benson (5). Note that the asphalt without rubber extends a great deal farther than the asphalt-rubber at 77°F (25°C) and does not separate. This

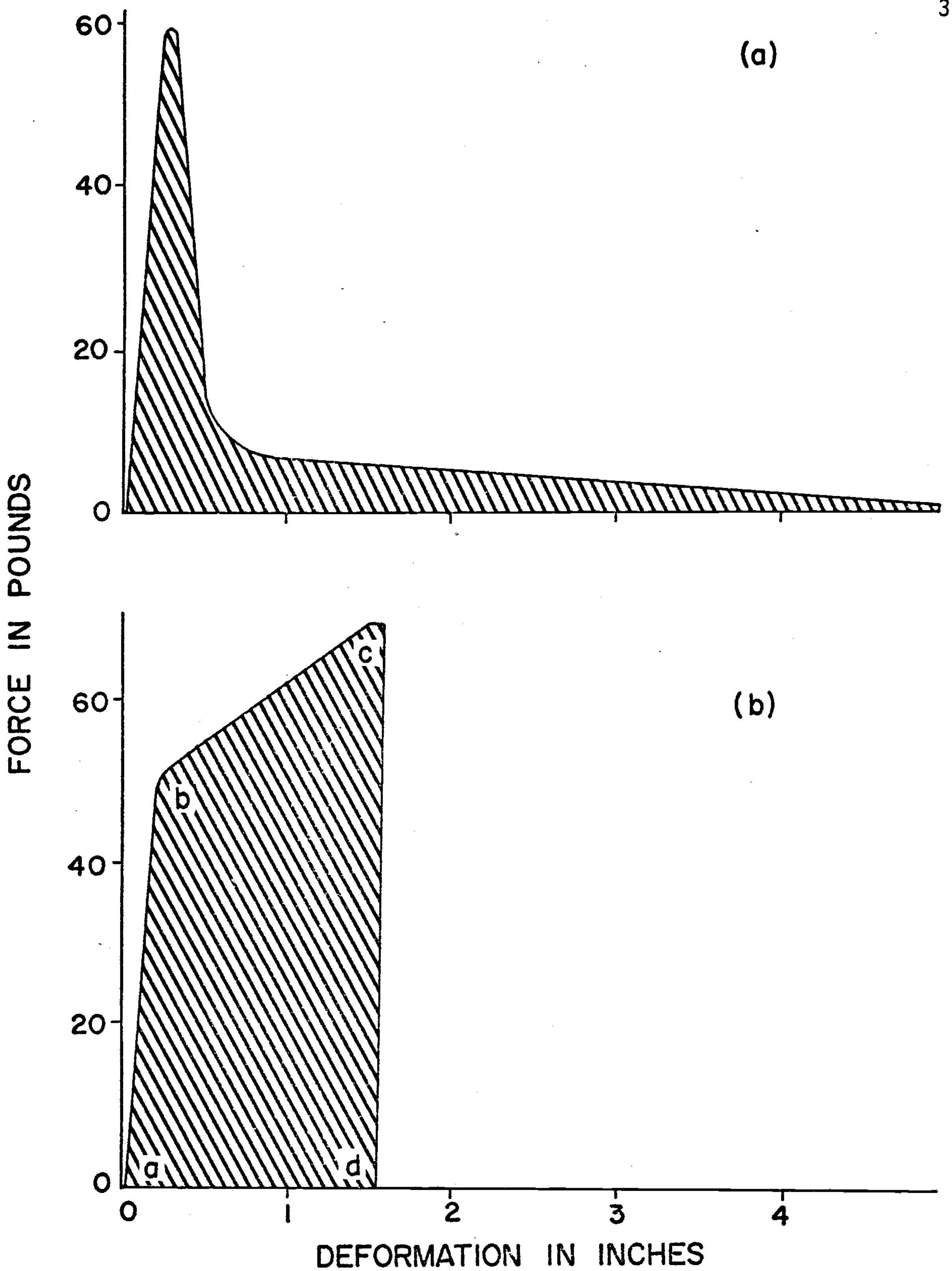

FIGURE 13. TYPICAL FORCE - DEFORMATION CURVES FOR (a) ASPHALT CEMENT AND (b) ASPHALT-RUBBER

observation also corresponds to the ductility test results for the various mixes tested at 77°F (25°C).

Due to the rubber aggregate composition of the various asphalt-rubber mixes, relative toughness comparisons could not be made with toughness values for rubberized asphalt of the liquid latex type. An attempt has been made, however, to compare the tensile pullout toughness of the various asphalt-rubber mixes under study with that of AR 1000 asphalt. The actual extensibility of the asphalt-rubber material, before separation, was found to be less than for liquid latex rubberized asphalt or AR 1000 asphalt without rubber (5). The crumb rubber mixture was highly resistant to tensile pullout of the steel ball and developed relatively strong intergranular cohesive strength. There was a definite increase in toughness when crumb rubber was added to asphalt as shown in Figure 14. Also shown in Figure 14, the larger the particle size, the greater is the degree of relative toughness. The finer particle size of rubber approaches the lower relative toughness value of plain asphalt. This corresponds with the relative ductility measurements (extensibility) made on the asphalt-rubber mixes, eg., higher ductility for the fine rubber particles, lower for the coarse particle size. In general, the percent increase in relative toughness after adding the rubber was 247% for TP.027; 346% for TP.027-TP.044; and 387% for TP.044.

Field Application

An existing 100,000 gallon (3,785 m^3) capacity reservoir was prepared and lined with asphalt-rubber. The reservoir was previously lined with polyethylene sheeting 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.

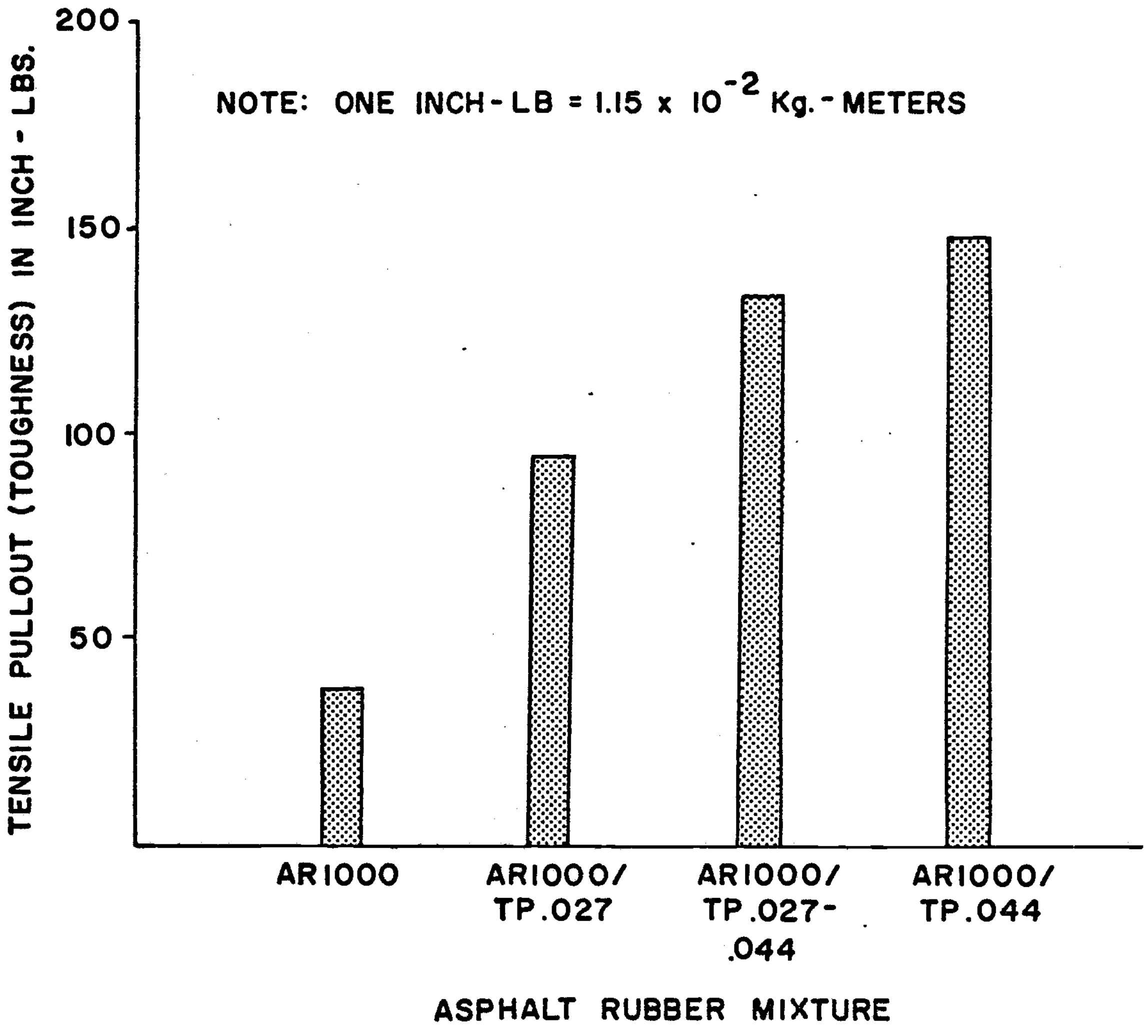

FIGURE 14. TOUGHNESS VALUES FOR ASPHALT AND ASPHALT RUBBER

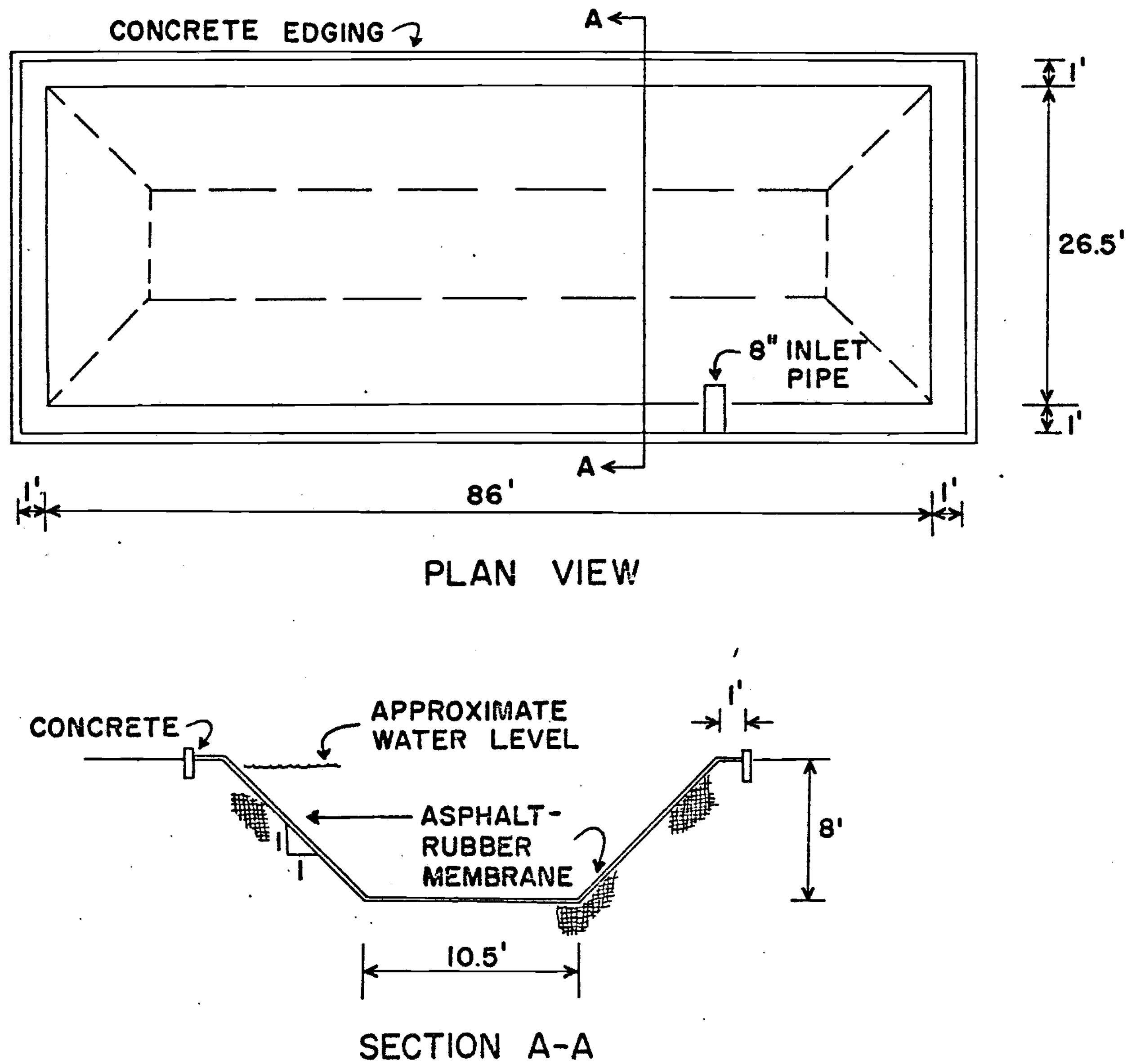

FIGURE 15. RESERVOIR USED FOR ASPHALT-RUBBER LINING INSTALLATION

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 bottom subgrade would support foot traffic without excessive depressions or irregularities in the subgrade.

The entire subgrade was primed with CSS-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, and was required due to the relatively unstable side-slopes. In addition to the tack coat on the excessively steep side slopes, unwoven fiberglass (10 mil thickness) was placed before the asphalt-rubber application to help compensate for the irregular subgrade. Also, the fiberglass was used to prevent excessive downslope movement by providing reinforcement for the asphalt-rubber membrane.

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 (18.7°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 with the aid of an internal stirring 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 forming a continuous, smooth membrane with no puddling or separation of asphalt. Only slight downslope 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

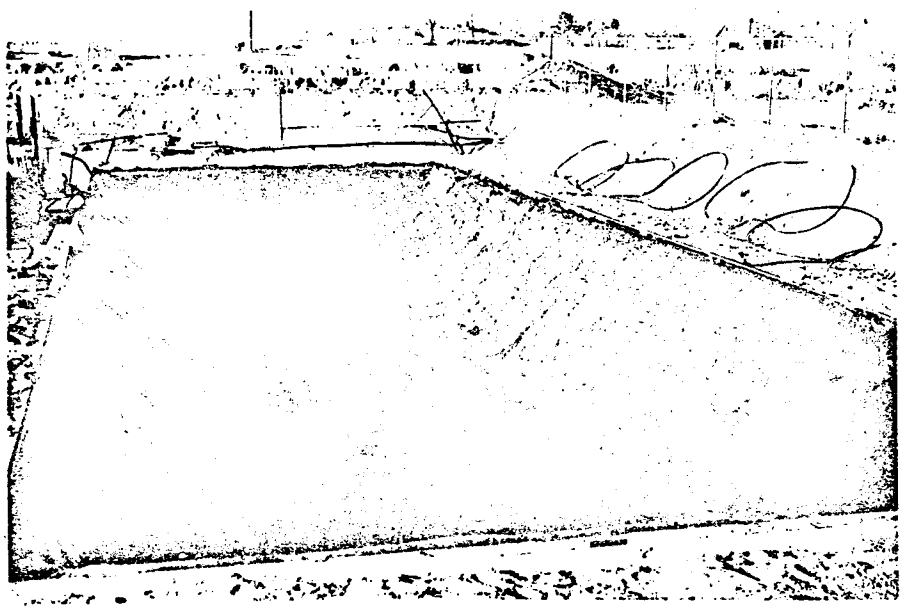

FIGURE 16. ASPHALT-RUBBER LINING INSTALLATION
UPPER - HAND SPRAY APPLICATION
LOWER - COMPLETED RESERVOIR

steep slopes, the asphalt-rubber was lightly coated with white acrylic roofing paint which effectively reduced summer surface temperatures. The finished reservoir without the white acrylic paint is shown in Figure 16.

After filling the reservoir to capacity, it was monitored for seepage losses. Taking into account evaporation losses, minimal seepage was detected over a one year period. Total cost of the lining installation was $464.00 or $1.27/yd^2 ($1.50/m^2) including labor and materials. For larger lining installations, this cost would be cut considerably due to mechanization (distributor trucks) and larger material quantities.

CONCLUSIONS

This investigation was initiated with the goal of determining several engineering characteristics of asphalt-rubber when used as a water seepage barrier. The physical characteristics investigated were viscosity, ductility, water vapor transmission, water absorption, brittleness/impact resistance and toughness. Also, the field installation of the material on an experimental reservoir provided additional information on subgrade preparation and application procedure.

The viscosity test results indicated that the addition of crumb rubber to asphalt cement AR 1000 or AR 4000 results in a mixture with a higher viscosity value than the original asphalt. Test results also show that the addition of rubber greatly reduces the temperature susceptibility of the material under consideration. This reduction was greater with coarse rubber than with the fine rubber particle size. These results should be given special consideration when choosing the appropriate asphalt distributor equipment for field application. Also, site characteristics such as maximum constructed slope should be considered when examining 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 value of asphalt cement was greatly reduced when crumb rubber was added to it. Asphalt-rubber was found to have a ductility value of about one-fifth that of plain asphalt cement. This is a further indication of the resistance to flow when rubber is added to asphalt. It should be noted that the coarser the rubber aggregate, the lower the ductility. The ductility of the asphalt-rubber is such that it will resist cracking due to possible subgrade movement.

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

The water absorption test indicated an increase in the water absorptive property of asphalt-rubber over that of plain asphalt cement. When substantially saturated, asphalt-rubber was found to have an absorption of at least 0.65% as compared to asphalt whose maximum absorption is 0.01% (7). This increase in absorption was due to the presence of the rubber particles and void spaces but is not considered detrimental to asphalt-rubber physical properties.

The low temperature impact resistance of asphalt cement was increased significantly with the addition of rubber aggregate. The softer asphalt (AR 1000) in combination with the fine rubber gradation (TP.027) apparently was the best mixture if impact resistance at 32°F (0°C) is a consideration.

The toughness (resistance to deformation) of the asphalt-rubber mixture increased as the rubber aggregate particle size was increased.

This was further illustrated with the decrease in the ductility value of the mixture as the rubber particle size increased. The rubber aggregate significantly increased the toughness of the mixture over that of the base asphalt.

Laboratory results in conjunction with field installations indicated that the asphalt-rubber material exhibits excellent water proofing properties. It is imperative that adequate subgrade preparation and structural bearing be provided for an effective asphalt-rubber membrane. If this cannot be provided, unwoven 10 mil fiberglass can effectively be used as a membrane reinforcement to help bridge subgrade irregularities. This addition should add less than 20 percent to the total cost. The asphalt-rubber is a tough, relatively homogeneous mixture that exhibits excellent elastic and impact resistant properties.

The advantages of utilizing asphalt-rubber over sheet-type lining include the following: (1) eliminates field seams, (2) facilitates repair by hand spray methods, (3) relatively easy to apply with modified asphalt distributor trucks, (4) conforms to slight irregularities in the subgrade and (5) adheres to and becomes a part of the subgrade.

It is imperative that the asphalt-rubber membrane be covered with a protective cover material such as 3/8 inch (0.96 cm) washed stone chips or 6 to 12 inches (152.4 to 304.8 cm) of soil cover. The cover material must remain relatively stable on side slopes, resisting erosion, wave action and sloughing. The cover material will also provide protection from solar radiation which oxidizes the asphalt and or rubber thus slowly deteriorating the membrane. This protection would be more important on water harvesting catchments and exposed portions of banks on large, open reservoirs.

ACKNOWLEDGMENTS

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The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of Arizona, Office of Water Research and Technology, or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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LIST OF FIGURE CAPTIONS