

## WATER IMPOUNDMENT APPLICATIONS FOR SBR/ASPHALT MEMBRANE SYSTEMS

by

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### INTRODUCTION

Engineering studies of one year duration (1979) examined the permeability, leachability, chemical resistance and stress/strain characteristics of hot sprayed styrene-butadiene block copolymers in asphalt blends applied directly to soil. The purpose of this study was to determine if such thermoplastic, elastomeric systems were suitable for use as pond and reservoir lining membranes for the impoundment of waste and/or potable waters. Permeability values were lower than that obtainable with Hypalon® liners of equivalent thickness. Substances which could be leached from the hot sprayed membrane were of an extremely low order. Chemical resistance is excellent to most inorganic ions including strong acids or bases. An ultimate elongation of 1300% and favorable stress/strain characteristics allow the material to be used on unstable substrates. Overall evaluation of the data shows that a large cost savings, compared to alternatives, can be realized on most projects.

### BACKGROUND

Asphalt has a long history of use as a water-stop material; some applications have been successful, some have not. The main drawback to the use of asphalt has been its limited range of cohesive flexibility which is generally restricted to the range of 4° to 38°C (40° to 100°F). In cold weather, asphalt is brittle and will shatter when stressed. It is soft and fluid in hot weather. Also, any deformation is usually permanent as the material lacks resilience.

Asphalt does, however, have some very good points that need to be considered. Besides being a relatively low cost material, it exhibits low permeability to water, it is inert to most inorganic acids, bases and salts, and is usually in good supply.

Most successful water-stop applications have relied on the use of modifications to the base asphalt to extend its useful temperature range and improve other properties. These modifications have included such things as air blowing, adding chemical catalysts, adding organic or inorganic fillers (ground or fibers) and blending with polymers. All of the above modifications improve the performance of asphalt at temperatures above 38°C (100°F), but only the addition of elastomeric polymers significantly improves low temperature flexibility and adds resilience. These latter two properties are of extreme importance if the water-stop material is to maintain its integrity when used on substrates which are unstable, non-cohesive, discontinuous or have significant expansion/contraction movement with temperature change.

Although there are many elastomeric polymers which can be used with asphalt, this paper is restricted to discussing the properties of only one, styrene-butadiene block copolymers (SBR).

### THERMOPLASTIC SBR

SBR refers to any of a multitude of styrene-butadiene rubbers. All of the possibilities have one thing in common, the styrene exists as discrete, rigid blocks within the butadiene rubber polymer chain (Saltman, 1973). The styrene blocks usually serve as the termination or anchor points for several butadiene rubber chains so that the bulk material consists of an interconnected network of discrete rubber chains with styrene blocks at the nodes. The bulk properties of the SBR polymer depend on the styrene to butadiene ratio and the repeating polymer chain length as well as the degree

to which chain length and number of chains per node are uniform. SBR used for tires is very random in chain length and chains per node and is vulcanized (cross-linked) during the manufacturing process, while SBR intended for thermoplastic hot-melts is more uniform in composition and is not vulcanized. It is the thermoplastic varieties of SBR that will be considered.

Thermoplastic SBR has unique properties, in that, it behaves as a cured elastomeric rubber at room temperature. When heated above the glass transition temperature of polystyrene, ~ 100°C (~ 212°F), the styrene segments lose their rigidity and the polymer behaves like an uncured elastomer (Saltman, 1973). The technical and commercial importance of thermoplastic elastomers was estimated by Kesser (1960), but since that time, actual commercial developments have far exceeded the early predictions. For those interested, various methods of preparing thermoplastic elastomers have been reported in the literature (Zelinski and Childers, 1968; Petters, date unknown).

#### SBR/ASPHALT MEMBRANE SYSTEMS

By blending thermoplastic SBR polymers with prime grades of asphalt, it has been possible to achieve a thermoplastic material which in its bulk properties behaves as if the whole were an elastomeric polymer. This material is very inert to inorganic acids, bases and salts and has low permeability to water. The useful temperature range has been extended, -40° to 82°C (-40° to 180°F), and resilience is exhibited throughout the range. Also, the blended membrane is still relatively low in cost. This is because the bulk material contains 70 to 80 weight percent asphalt.

#### PAST USE HISTORY

SBR/asphalt membrane systems are not something new. Some, such as Membrane No. 5 as manufactured by the Gilsabind Co., Mack, Colorado, have been used for selected services for almost 15 years. In general, these services have involved hot spray application of the membrane only to solid, competent substrates such as concrete, steel or asphalt paving. These uses have included application as:

Bridge deck membrane. Used between the concrete structural bridge deck and the asphalt paving wear surface to keep the salts used during the winter season from destroying the supporting structure.

Stress absorbing membrane. Used between old and new paving lifts to stop reflection cracking. Especially useful when overlaying old concrete paving with asphalt paving.

Expansion joint material. Used to form watertight expansion joints in engineered structures such as bridges, buildings, and concrete lined canals and reservoirs.

Water-stop membranes. Used on concrete sewer pipe and below grade concrete construction to stop ground water infiltration and to protect the concrete from the deleterious action of ground water salts.

Crack and joint fillers. Used for street and highway applications to prevent further paving/deterioration.

Miscellaneous applications. Corrosion protection for steel and other materials.

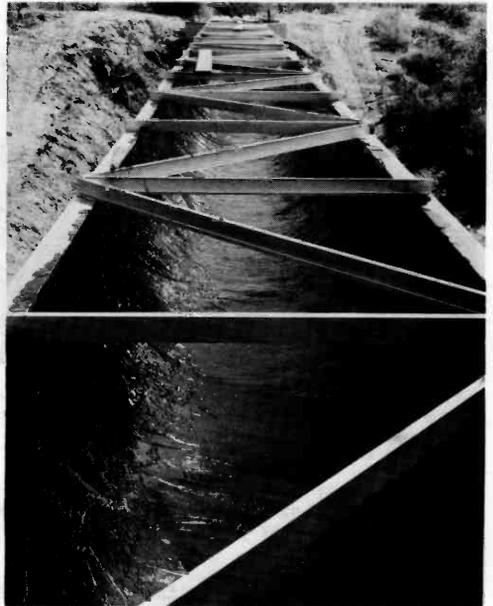
The use of SBR/asphalt membranes on large diameter sewer pipe has been detailed elsewhere (Nicholson, 1979). Figures 1-3 show bridge and steel structure applications.

More recently, service applications have been perfected to allow the use of SBR/asphalt membranes for roofing installations. This was a departure from the solid substrate concept (most roofs are flexible and have significant movement with temperature change), but the unqualified success of these applications has led to the understanding that a stable substrate is not a valid requirement for satisfactory performance.

#### WATER IMPOUNDMENT APPLICATIONS ON SOIL SUBSTRATES

As a natural outgrowth of looking for suitable new service applications for SBR/asphalt membranes, soil substrates were investigated. Tests showed that soil was indeed a suitable substrate for Membrane No. 5, when properly prepared. The unique properties of Membrane No. 5 allow it to serve as a water-stop membrane in spite of an unstable base. Proper preparation of the soil includes the following:

Fig. 1 (top). Application of Gilsabind Membrane No. 5 to concrete bridge deck prior to laying asphalt paving, 2.54 mm (0.1 in.) thick coating. Fig. 2 (bottom left). Overall view of an elevated steel canal flume that was protected on the water side by Membrane No. 5. Fig. 3 (bottom right). Coated surface of canal flume. Membrane was hot troweled, 3.18 mm (0.125 in.) thick coating.



- 1) Dewater the site if required.
- 2) Excavation.
- 3) Smooth the surface. This is usually done with a vibratory roller. If the surface is a coarse textured gravel, fine material must be spread on the surface until a smooth texture can be obtained. Compaction, while not of great importance, must be sufficient to prevent rutting by the tires on the distributor equipment.
- 4) Prime the soil surface with about  $0.1$  to  $0.3 \text{ L/m}^2$  ( $0.031$  to  $0.095 \text{ gal/yd.}^2$ ). This is to lay the surface dust to prevent its incorporation into the membrane. Priming also displaces surface moisture so it will not interfere with membrane application at  $177^\circ$  to  $190^\circ\text{C}$  ( $350^\circ$  to  $375^\circ\text{F}$ ).
- 5) Apply membrane to the thickness specified for the project.

Side slopes of less than 3:1 (run:rise) can be installed as above. A polyester scrim cloth is usually recommended for slopes steeper than 3:1. The membrane can even be applied to vertical sides if the base is competent rock or undisturbed cohesive soil.

The above installation technique along with the physical and chemical properties of the material open a wide variety of new applications for SBR/asphalt membranes. Most of these applications have to do with:

Water impoundment. Linings to prevent seepage in waste water evaporation and/or holding ponds, sewage oxidation ponds, water recycling ponds and fresh water storage ponds or reservoirs.

Water harvesting. Converting aquifer recharge water to surface runoff in selected areas where the harvested water can be impounded. Also used to laterally transport soil moisture from unused adjacent areas to tree rows or other vegetation where it is needed.

Water transporting. Linings to prevent seepage in canals or ditches.

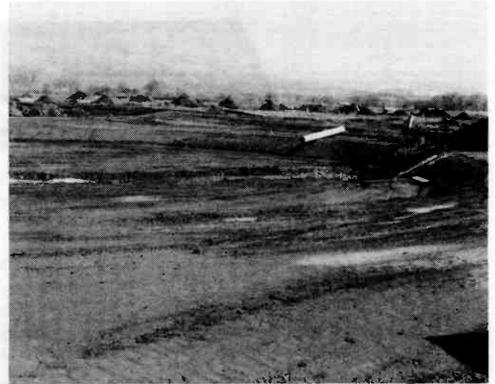


Fig. 4 (left) and Fig. 5 (right). A 2023 m<sup>2</sup> (½ acre) recreation and pumped lawn irrigation pond being constructed in Grand Junction, Colorado. The pond is located in a residential park. After lining with Gilsabind Membrane No. 6, the membrane will be covered with soil and riprap and landscaped. The membrane will not be visible.

The material used for testing the above applications was Gilsabind Membrane No. 6. This material has a lower viscosity than Membrane No. 5 to allow spraying at lower temperatures, otherwise all of the properties of both materials are the same.

#### PROPERTIES OF SBR/ASPHALT MEMBRANE

The following section gives results and discusses the properties of SBR/asphalt membranes that are important to water impoundment applications on unstable substrates.

#### PHASE COMPATIBILITY

For the SBR/asphalt membrane to be able to achieve maximum performance with a minimum amount of polymer in the blend (to minimize cost), the SBR must be in true solution with the asphalt. Any trace of phase incompatibility will cause lower physical performance ratings in the material.

Unfortunately, one does not automatically get a phase compatible blend with most asphalts. Most asphalts are low in aromatic content which prevents the dissolution of the polymer. Aromatic extender oils are used in these cases to achieve the desired phase compatibility. The extender oils used are of high molecular weight, have no solubility in water, and are permanently incorporated within the membrane matrix.

The old method of determining phase compatibility was to place a container of a trial blend in a 177°C (350°F) oven for 24 hours, which would allow total phase separation of an incompatible blend, followed by visual inspection. By using in-house developed slide preparation techniques, we have been able to make this determination in 30 minutes utilizing phase contrast microscopy.

The basic procedure involves placing a ~ 3mm (~ 1/8 inch) diameter piece of the material to be tested on a microscope slide that has been preheated to 177°C (350°F). As soon as the test material has liquified, the edge of a second preheated slide is used to spread it the length of the slide into a thin film that will pass light. The prepared slide is then placed in a 177°C (350°F) oven for 20 minutes to allow any phase separation tendency to develop to the point that it can be identified. The slide is then cooled and examined, without using a cover glass, with a phase contrast microscope using a 40x objective and a 10x eyepiece. If the polymer is not phase compatible with the asphalt, it will show up as discrete internal phase droplets within an asphalt continuous phase. Figures 6-9 show the type of equipment used and several typical photomicrographs. The original color photomicrographs show much more detail than the black and white copies reproduced for this report.

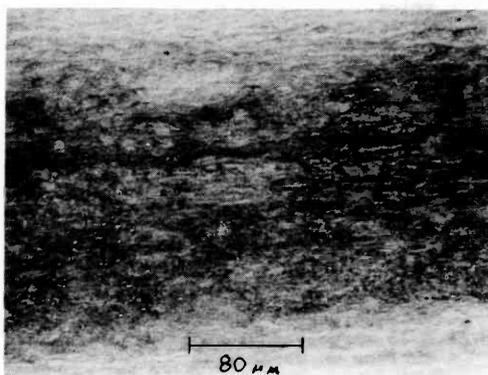
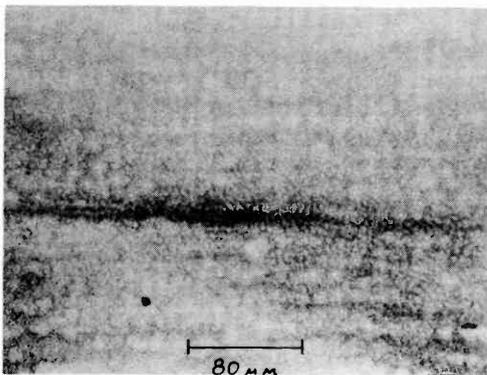
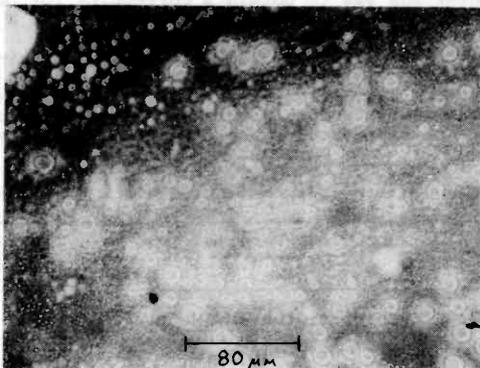


Fig. 6 (top left). Binocular phase contrast microscope used to make phase compatibility determinations. Fig. 7 (top right). Grossly incompatible blend. The maximum diameter of the SBR internal phase droplets is 15  $\mu\text{m}$ . Fig. 8 (bottom left). Mildly incompatible blend. The maximum diameter of internal phase droplets is 4  $\mu\text{m}$ . Fig. 9 (bottom right). Phase compatible blend, no internal phase droplets visible.

#### PERMEABILITY

The published values for permeability of film or sheet materials seldom agree with good correlation when data from different sources are compared. This is because there is a wide variety of testing methods and procedures. Unfortunately, test conditions seldom accompany the published values. Accordingly, to obtain good comparative data,

we performed a small series of tests in which several common water vapor barrier materials were compared to SBR/asphalt membranes. All materials tested were supplied commercially for the experiment. The SBR/asphalt membrane tested was Membrane No. 6 as manufactured by the Gilsabind Co., Mack, Colorado. All tests were identical, except for material thickness, and were performed at the same time and under the same conditions.

The test conditions were those specified in procedure "BW" of ASTM E-96, Tests for Water Vapor Transmission. The test materials were sealed to the open mouth of suitable containers (containing water of 25.4 mm (1 in.) depth). Each sealed container was weighed to the nearest 0.01 mg, inverted and placed in a desiccator so that one side of the test material was flooded with a 25.4 mm (1.0 in.) head of water and the other was exposed to circulating air of 0% relative humidity. The containers were reweighed every 24 hours. Two blanks were carried through the same series. One was a container, with water, sealed with a piece of 0.51 mm (0.020 in.) thick brass sheet. This blank was to obtain a correction for water vapor loss through the container walls (poly-carbonate plastic). The other blank was an empty container, also sealed with brass sheet and was to obtain a correction for buoyancy effects due to changing barometric pressure. The test was terminated after 8 days. Test temperature was 25°C (77°F).

The results of the permeability testing are reported in two different ways. Materials engineers will be familiar with the metric perm-centimeter which expresses the permeability as grams per 24 hours per square meter per millimeter Hg (head plus vapor pressure) per centimeter of thickness. Soils engineers will be more familiar with values expressed as the coefficient of permeability, K, centimeters/second.

Table 1. Permeability values for several vapor barrier materials.

Test Material	Metric perm-centimeter, g/24h/m <sup>2</sup> /mm Hg/cm	K, cm/s
Hycar <sup>®</sup> , <sup>2</sup> rubber, Mercer HY-2660, 1.91 mm thick	0.006 95	3.27x10 <sup>-11</sup>
Neoprene rubber, 2.29 mm thick	0.007 28	2.85x10 <sup>-11</sup>
Hypalon rubber, 1.98 mm thick	0.006 24	2.82x10 <sup>-11</sup>
Hycar/ SBR rubber, Mercer H-1262, 1.96 mm thick	0.019 12	8.75x10 <sup>-11</sup>
Viton <sup>®</sup> , <sup>3</sup> rubber, 2.03 mm thick	0.005 70	2.51x10 <sup>-11</sup>
Polyken <sup>®</sup> , <sup>4</sup> 980-20 pipeline coating, 0.3 mm polyethylene film plus 0.2 mm butyl rubber, butyl on water side	0.000 79	1.39x10 <sup>-11</sup>
Same as above, polyethylene on water side	0.000 88	1.55x10 <sup>-11</sup>
Polyken 950-15 pipeline coating, 0.38 mm polyethylene film, slick surface on water side	0.000 58	1.36x10 <sup>-11</sup>
Same as above, dull surface on water side	0.000 74	1.74x10 <sup>-11</sup>
Gilsabind <sup>®</sup> , <sup>5</sup> Membrane No. 6, SBR/asphalt membrane, 1.65 mm thick	0.003 93	2.13x10 <sup>-11</sup>

Table 1 reveals the performance of Membrane No. 6 to be superior to the other elastomeric materials as to permeability. The polyethylene film materials have lower permeability than Membrane No. 6, but they also have some serious drawbacks in that they are non-elastic, have limited elongation capability (200% versus 1300% for

Membrane No. 6), and have poor low temperature characteristics because they become brittle.

### CHEMICAL RESISTANCE

Membrane No. 6 has excellent resistance to most inorganic chemicals including strong acids and bases. The exception is concentrated solutions of strong oxidizing acids such as nitric or sulfuric. Lower concentrations of these acids, however, are resisted well. In all cases, the chemical resistance of Membrane No. 6 is equal to or better than the chemical resistance of the base polymer used in the formulation. Concentrated organics do have a deleterious effect, but dilute amounts have very little, if any, effects. Aromatics have more effect than do paraffinic substances.

Chemical resistance was evaluated by comparing the visual appearance, weight and tensile stress/strain characteristics of the original coupons to those that had been in submerged exposure for 14 weeks. Weight and stress/strain results are expressed as a percentage change from the original.

Table 2. Tabular evaluation data of Membrane No. 6 to 14 weeks submerged exposure to the listed dissolved chemicals. Test temperature was 25°C (77°F).

Solution	Appearance*	Weight change %	Percentage change in tensile stress necessary to cause the following deformation:		
			100%	200%	300%
Ethyl Alcohol,					
5 vol. %	E	+ 1.27	+ 50	+ 13	+ 6
20 vol. %	E	+ 2.71	0	0	0
50 vol. %	G	+ 3.64	0	0	- 7
100 vol. %	F	-24.6	+150	+116	+ 75
Methyl Alcohol,					
5 vol. %	E	+ 0.94	+ 25	0	+ 6
20 vol. %	E	+ 1.24	+ 25	0	- 12
50 vol. %	E	+ 1.91	0	- 16	- 12
100 vol. %	E	- 8.61	+ 50	+ 33	+ 25
Deionized Water	E	+ 0.89	+150	+ 75	+ 62
Sodium Chloride,					
5 wt. %	E	+ 0.30	+ 50	0	0
10 wt. %	E	+ 0.29	0	0	- 8
20 wt. %	E	+ 0.26	0	+ 8	0
Sodium Carbonate,					
5 wt. %	E	+ 0.19	+ 50	+ 16	0
10 wt. %	E	+ 0.36	+ 50	+ 16	0
20 wt. %	E	+ 0.43	+ 50	+ 16	+ 12
Potassium Chloride,					
5 wt. %	E	+ 0.29	+ 25	0	0
10 wt. %	E	+ 0.33	+ 12	0	0
20 wt. %	E	+ 0.24	+ 12	0	0
Potassium Carbonate,					
5 wt. %	E	+ 0.40	0	- 11	- 16
10 wt. %	E	+ 0.30	+ 12	0	0
20 wt. %	E	+ 0.40	+ 37	+ 16	+ 12
Ferric Sulfate,					
5 wt. %	E	+ 0.69	+ 25	0	0
Potassium Chromate,					
5 wt. %	E	+ 0.44	+ 50	+ 16	+ 12
20 wt. %	E	+ 0.26	+ 50	+ 33	+ 31
Ferric Chloride,					
5 wt. %	E	+ 0.85	+ 50	+ 16	+ 6
20 wt. %	E	+ 0.46	+ 12	+ 8	+ 6

Sodium Hydroxide, 5 wt. %	E	+ 0.46	+ 50	+ 16	0
20 wt. %	E	+ 0.34	+ 36	+ 25	+ 25
Ammonium Hydroxide, 5 vol. %	E	+ 1.44	+ 48	+ 9	+ 9
15 vol. %	E	+ 1.66	+ 25	+ 16	+ 12
100 vol. %	E	+ 1.75	+ 50	+ 33	+ 25
Sodium Nitrate, 5 wt. %	E	+ 0.43	+ 36	+ 25	+ 22
Hydrochloric Acid, 5 vol. %	E	+ 0.55	0	0	0
15 vol. %	E	+ 0.24	+ 25	0	0
100 vol. %	G	+ 6.75	+200	+133	+100
Sulfuric Acid, 98%, 5 vol. %	E	+ 0.14	+ 50	+ 16	0
15 vol. %	G	+ 0.22	+ 50	+ 33	+ 25
Nitric Acid, 71%, 5 vol. %	G	+ 0.77	+ 25	0	0
15 vol. %	G	+ 0.79	+ 50	+ 33	+ 25
Acetic Acid, 99.7%, 5 vol. %	E	+ 6.64	0	0	0
15 vol. %	G	+ 8.59	+ 43	+ 56	+ 37
Calcium Chloride, 5 wt. %	E	+ 0.44	+ 50	+ 16	0
10 wt. %	E	+ 0.74	0	0	0
20 wt. %	E	+ 0.36	0	0	0
Calcium Hypochlorite, 100 ppm	E	+ 1.64	0	0	0
1000 ppm	E	+ 1.12	+ 25	0	0
10000 ppm	E	+ 1.07	+ 25	0	0
Phenol, 100 ppm	E	+ 0.93	+ 25	0	0
1000 ppm	E	+ 1.86	0	- 14	- 12
Boric Acid, 5 wt. %	E	+ 0.51	0	0	0
15 wt. %	E	+ 0.64	+ 12	0	0
Phosphoric Acid, 5 vol. %	E	+ 0.32	0	0	- 12
15 vol. %	E	+ 0.29	0	0	0
Magnesium Chloride, 5 wt. %	E	+ 0.42	+ 12	0	0
10 wt. %	E	+ 0.63	0	0	- 12
20 wt. %	E	+ 0.19	0	0	0
Saturated	E	+ 0.25	0	- 16	- 25
Sodium Sulfate, 5 wt. %	E	+ 0.40	0	0	0
10 wt. %	E	+ 0.77	0	0	0
20 wt. %	E	+ 0.53	0	0	0
Saturated	E	+ 0.56	0	0	- 12

\* E = Excellent, G = Good, F = Fair

Comments on the chemical resistance tests: It is obvious that Membrane No. 6 is not the material of choice for 100% methyl or ethyl alcohol. Concentrations less than 50% can be tolerated. Concentrated hydrochloric acid and 15% acetic acid cause cross linkage of the rubber and an increase in tensile strength. All of the other tested chemicals were resisted exceptionally well. In fact, most caused less change in the material than did deionized water. Other chemicals are being tested and will be added to the list as results are obtained.

**STRESS/STRAIN BEHAVIOR**

Membrane No. 6 has an average elongation capability of 1300% and is fully elastic within this range. Typical tensile and compressive stress/strain values are given below; these values are average and the actual material as supplied can vary  $\pm$  15%.

Table 3. Tensile stress/strain data.

Stress, kPa	(PSI)	Strain, %
34.5	5	50
51.7	7.5	100
110.3	16	200
193.1	28	300
289.6	42	400
399.9	58	500
551.6	80	600
751.5	109	700
1034	150	800
1338	194	900
1703	247	1000
2220	322	1100
2758	400	1200
3372	489	1300

Table 4. Compressive stress/strain data.

Stress, kPa	(PSI)	Strain, %
13.8	2	10
27.6	4	20
41.4	6	30
55.2	8	40
68.9	10	50

The loading rate for the determination of the above tensile data was 30.5 cm/min. (12 in./min.) testing temperature was 25°C (77°F). It is readily seen that Membrane No. 6 can deform rapidly to conform to any localized settling or displacement such as might be caused by fault movement or a void collapse.



Fig. 10 (left) and Fig. 11 (right). Demonstration of the elongation capabilities of a 25.4 x 10.2 cm x 3.2 mm thick (1.0 x 4.0 in. x 1/8 in. thick) test coupon of Membrane No. 6. After release, the coupon returned to its original size in 45 seconds.

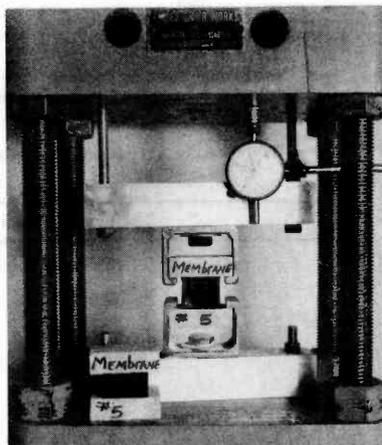
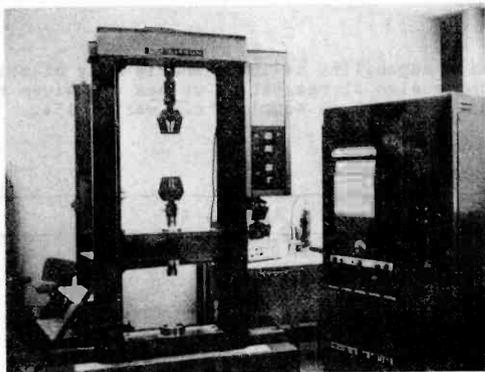


Fig. 12 (left). Test machine used for full range tensile strength determinations. Fig. 13 (right). Test machine used for limited range tensile strength and ambient temperature bond strength determinations. This machine can also be converted to do the compressive strength testing.

#### SOLUBILITY IN WATER

On a permanent basis, less than 10 ppm by weight can be leached from Membrane No. 6 by continuous contact with deionized water.

#### ELECTRICAL RESISTANCE

Volume resistance, ohms - cm, by ASTM D-257 is normally  $10^{14}$ . This can be decreased to any desired value by using additives or fillers.

#### BACTERIAL RESISTANCE

Membrane No. 6 is generally inert to bacteria and fungi. Bacteria can exist on the surface of the membrane, but, the material will not support growth.

#### BOND

Membrane No. 6 bonds well to concrete, asphalt, metals, glass, and all plastics and rubbers. Direct pull (tension) bond strength to concrete and metals is generally in the range of 103.4 to 206.8 kPa (15 to 30 psi). Bond strength to glass, plastic and rubber is generally 48.3 to 103.4 kPa (7 to 15 psi). The membrane bonds not at all to loose soil (only to the individual surface grains) as the cohesion of the soil fails in tension. The membrane can, however, bond to well compacted soils and develop bond strengths in the range of 6.89 to 34.5 kPa (1 to 5 psi). Bond strength has only minimal importance in pond and canal lining, however, as the membrane is held in place by the hydrostatic head.

#### RESISTANCE TO ULTRAVIOLET LIGHT

Continuous exposure to direct sunlight is a condition that should be avoided for Membrane No. 5 or No. 6 if possible. Both materials have built in protection against ultraviolet light (UV) exposure and will normally serve for several years before surface alligator cracking appears. This is a surface phenomenon that does not effect the barrier properties of the membrane — at least not for several more years. However, for short term esthetics and a 4 to 5 times extension of ultimate life, steps should be taken to provide some additional protection.

The most feasible way to provide this protection is to cover the membrane, where possible, with a few inches of soil. On steep side slopes above the water line where the soil would not stay, or where changing water level and wave action would remove the

soil, there are several elastomeric, reflective surface coatings available that can give the desired protection. There are also two rejuvenation products available which can heal and renew an already cracked surface by applying a light surface spray.

The manufacturer of the particular membrane should be consulted for approved specifications for the above treatments.

#### GENERAL PHYSICAL PROPERTIES:

Specific gravity @ 15.5°C (60°F), ASTM D-70	1.05 - 1.1
Viscosity, SSF @ 177°C (350°F), ASTM E-102	600 - 1100
Cone penetration @ 250°C (77°F), ASTM D-217	50 - 80
Softening point, °C (°F), ASTM D-2398	79.4 - 93.3 (175 - 200)
Resilience @ 25°C (77°F), 20 sec. recovery, ASTM D-3408	60 - 90
Flow, 5 hrs. @ 60°C (140°F) @ 75° angle, cm,	0.5 max.
Pliability, -17.8°C (0°F), bend around a 1.27 cm radius rod	No cracks to pass
Bond to concrete, -17.8°C (0°F), 1.27 cm extension, 3 cycles, ASTM D-3408	Pass
Compatibility with asphalt	Complete
Service temperature, °C (°F)	-40 to 82, (-40 to 180)

#### COST DATA

In spite of rapidly increasing materials and labor costs during 1979 and the first half of 1980, the installed cost of a Membrane No. 6 liner, exclusive of earthwork, has remained at 50 to 60% of the installed cost of a Hypalon or similar synthetic rubber liner.

#### CONCLUSIONS

Considering the useful properties and relatively low cost of SBR/asphalt membrane systems, it could very well become the material of choice for seepage control in water impoundment applications. It may require a few years, however, for this material to gain recognition for these new applications because it is, at present, an unknown contender. The successful use of this material in other applications for up to 15 years will help. Also, the fact that engineering solutions already exist for all foreseeable "site specific" problems makes these materials a creditable contender.

#### ACKNOWLEDGEMENT

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Endnotes

- 1, HYPALON is a trademark of the E. I. du Pont de Nemours & Co.
- 2, HYCAR is a trademark of the B. F. Goodrich Chemical Co.
- 3, VITON is a trademark of the E. I. du Pont de Nemours & Co.
- 4, Polykin is a trademark of the Kendall Co.
- 5, Gilsabind is a trademark of the Deery Oil Co.