SYNTHETIC RUBBER CANAL LINING

Laboratory and Field Investigations of Synthetic Rubber Sheeting for Canal Lining - Open and Closed Conduit Systems Program

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Engineering and Research Center
Bureau of Reclamation

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16. ABSTRACT
Accelerated laboratory tests and field performance evaluations indicate that butyl and ethylene propylene diene monomer (EPDM) rubber sheeting can be used satisfactorily as buried membrane and exposed lining for canals and reservoirs. For successful use as exposed lining, service conditions must be such that the rubber lining is protected from mechanical damage and vandalism. Butyl and EPDM rubber sheetings are suitable for relining old concrete canals and reservoirs. In canals where flowing water acts upon the lining, special attention must be given to adequately bonding and anchoring the rubber liner to the concrete. The butyl and EPDM linings are available with or without nylon reinforcement in thicknesses ranging from 20 to 125 mils (0.51 to 3.18 mm), and are adaptable to a variety of waterproofing applications; the type and thickness of lining are dictated by the size of installation and service requirements. The relatively high cost of these linings limits use to special applications where use of less costly membrane materials are not possible because of severe operational conditions.

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BUREAU OF RECLAMATION
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INTRODUCTION

Under the Bureau of Reclamation Open and Closed Conduit Systems Program, laboratory research and field experimentation was conducted on synthetic rubber sheeting for canal lining.

Available from industry today are a number of synthetic rubber materials that are especially compounded for use as waterproofing membranes. Butyl, neoprene, ethylene propylene diene monomer (EPDM), and chlorosulfonated polyethylene sheeting materials are the most common. Only the butyl and EPDM rubber sheetings were evaluated under this investigation as canal lining materials. The neoprene sheeting is being evaluated under another Bureau of Reclamation program for roofing and other waterproofing applications. The chlorosulfonated polyethylene is a relatively new product and testing of this material has not progressed sufficiently for including in this report; however, early indications are this material holds promise, appearing to have splicing and weathering advantages. The term "butyl rubber" as used in this report refers to a rubber formulation that is basically butyl but can be a blend of EPDM rubber with butyl.

The rubber membranes are usually supplied in thicknesses of 1/32 inch (0.79 mm), 1/16 inch (1.59 mm), 3/32 inch (2.38 mm), and 1/8 inch (3.18 mm). Also, they can be obtained as rubber-coated fabric; i.e., reinforced with cotton or nylon. Reinforced rubber membranes are available in varying thicknesses with 20-, 30-, 45-, and 60-mil gage being more common. (These dimensions in millimeters are 0.51, 0.76, 1.14, and 1.52, respectively.) The rubber sheeting can be shop fabricated into large sizes for quick and easy field applications. Special rubber cements and gum tapes are used in making field splices.

A program of laboratory tests of butyl rubber sheeting was begun in 1960, with some preliminary testing conducted as early as 1957. Rubber sheeting from 10 different manufacturers was included in the program. The Bureau's first field test installation of rubber lining was made in 1961. The installation was on the W. C. Austin Project, Oklahoma, where butyl rubber sheeting was used as both buried and exposed membrane. These and following installations were made in cooperation with the Bureau regional and project offices.

This report summarizes laboratory and field investigations of butyl and EPDM rubber sheeting as buried and exposed membrane lining. Also, general information relative to methods of installation and cost is included.

CONCLUSIONS

1. Accelerated laboratory testing and field investigations indicate that 1/32-inch (0.79-mm) thick butyl rubber sheeting can be used satisfactorily as buried membrane and exposed linings for canals and reservoirs. For successful use as exposed lining, it is necessary that the service conditions be such that the rubber lining be protected from mechanical damage and vandalism. Laboratory analysis of butyl rubber linings after 9 years' service, both exposed and buried, indicates essentially no change in these materials. Laboratory research has shown that ozone deterioration and poor resistance to shrinkage are the more common deficiencies that may be expected in inferior rubber lining. With proper compounding and curing, butyl rubber lining has good weathering properties.

2. Butyl rubber lining is suitable for relining concrete canals and reservoirs. For some installations, nylon-reinforced rubber lining may be advantageous, especially on steep slopes. In canals where flowing water acts upon the lining, the success of the installation will depend upon the adequacy of bonding and anchoring the lining to the concrete. Severe service requirements may dictate the use of a thicker gage rubber than the 1/32-inch (0.79-mm) liner.

3. Limited laboratory tests on the newer EPDM rubber lining indicate that this material has physical properties equal or better than butyl rubber. Normally, the EPDM rubber lining would be expected to weather better than butyl rubber as its ozone resistance greatly exceeds that of butyl. Shrinkage can be a problem with EPDM rubber if not properly formulated and cured, and with some EPDM rubber linings, joint splicing cements may not bond as strongly as with butyl lining.

4. Large installations of rubber lining necessitate the fabrication of considerable footage of field splices. Long service life of rubber lining applications is dependent upon the quality of these splices and, therefore, the greatest of care must be exercised in their fabrication. Laboratory tests of different adhesives and techniques for field splicing and bonding rubber lining to substrates have generally revealed that the best policy is to accomplish the work in strict accordance with the rubber lining manufacturer's instructions using the manufacturer's recommended adhesive system.

5. The relatively high material cost of butyl rubber lining, approximately $2 per square yard for 1/32-inch (0.79-mm) thickness, limits its use to special applications. Because of its flexibility, toughness, ease

of application, good aging properties, and resistance to most chemicals and abrasion, rubber lining can be used to meet specific service requirements that are not possible with less costly membrane materials.

SUMMARY OF LABORATORY TEST RESULTS

1. Accelerated soil burial testing (acceleration estimated to be 5 to 10 times that of field conditions) showed butyl and EPDM rubber lining to be highly resistant to bacteriological deterioration. Tensile strength and elongation properties were only slightly affected after 5 years' testing of the EPDM and 7 years' testing of the butyl rubber lining.

2. There was no significant change in tensile strength and elongation properties of nylon-reinforced butyl rubber lining subjected to 7 years of accelerated soil burial. Two cotton-reinforced butyl rubber samples tested in soil burial for 7 years was reduced in tensile strength and elongation by 50 percent or more.

3. Physical property values for 40 different butyl rubber lining samples were determined as follows: specific gravity range of 1.15 to 1.31 with 1.19 average; tensile strength range of 1,135 to 1,880 psi (79.8 to 132.2 kg/cm^2) with 1,490 psi (104.8 kg/cm^2) average; elongation range 255 to 603 percent with 414 percent average; modulus at 300 percent elongation range of 640 to 1,840 psi (45.0 to 129.4 kg/cm^2) with 1,215 psi (85.4 kg/cm^2) average; shore hardness range of 50 to 62 with 54 average; and tear strength range of 125 to 320 pounds per inch (ppi) (22.3 to 57.1 kg/cm) with 210 ppi (37.5 kg/cm) average. Of the 40 samples heat age tested, only one failed to meet the minimum 70 percent retained tensile strength requirement and seven failed to meet the minimum 70 percent retained elongation requirement. All 40 samples had satisfactory ozone resistance.

4. Physical property values obtained on seven EPDM rubber samples are as follows: specific gravity range of 1.10 to 1.18 with 1.13 average; tensile strength range of 960 to 2,075 psi (67.5 to 145.9 kg/cm^2) with 1,640 psi (115.3 kg/cm^2) average; elongation 263 to 469 percent with 358 percent average; modulus at 300 percent elongation range of 1,300 to 1,455 psi (91.4 to 102.3 kg/cm^2) with 1,275 psi (89.6 kg/cm^2) average; shore hardness range of 50 to 64 with 57 average; and tear strength range 125 to 275 ppi (22.3 to 49.1 kg/cm) with 195 ppi (34.8 kg/cm, average. Of the seven samples heat age tested, all met the minimum 70 percent retained tensile strength requirement and three failed to meet the minimum 70 percent retained elongation requirement. All seven samples had satisfactory ozone resistance.

5. Tests of 10 different nylon-reinforced butyl rubber lining samples ranging in thickness from 19 to 50 mils (0.48 to 1.50 mm) produced varied physical property values depending largely upon the characteristics of the nylon fabric used. Physical property values for these materials of different thickness ranged as follows: weight 17.0 to 52.5 oz/sq yd (576.4 to 1,780.1 g/m^2); tensile strength, longitudinal direction, 98 to 254 pounds (44 to 115 kg); elongation; longitudinal direction, 18 to 28 percent; tear strength, longitudinal direction, 8 to 68 ppi (1.4 to 12.1 kg/cm), and Mullen hydrostatic strength 136 to 335 psi (9.6 to 23.6 kg/cm^2). Heat aging resulted in changes ranging from −2.1 to +15.0 percent for tensile strength, −10.0 to +10.0 percent for elongation, and −1.7 to +54.0 percent for Mullen hydrostatic strength. All 10 samples showed a weight gain in the water immersion test with percentage values ranging from 2.1 to 9.5. Only one sample failed the ozone resistance test.

6. Hydrostatic puncture tests over 3/4- to 1-1/2-inch (2- to 4-cm) size rock base showed that 1/32-inch (0.79-mm) thick butyl rubber lining may puncture under a hydrostatic head of 40.0 psi (2.81 kg/cm^2). Butyl rubber lining of 1/16-inch (1.6-mm) thickness or greater will resist puncture in excess of 57.5-psi (4.04-kg/cm^2) hydrostatic head. EPDM and nylon-reinforced rubber lining have puncture resistance comparable to the butyl rubber.

7. Outdoor exposure tests of butyl, EPDM, and nylon-reinforced butyl rubber linings indicated that these materials have excellent weatherability. Of 35 butyl rubber lining samples exposed for as long as 9-1/2 years to the outdoors, two were observed to be in poor condition, two in good condition with slight shrinkage, and the remaining in excellent condition.

8. Tests showed that ozone resistance of butyl rubber is highly variable, not only between different sources but sometimes between different lots from the same source. Tests of ozone exposure of 50 parts per hundred million (pphm) at 100° F (37.8° C), 20 percent elongation showed different butyl samples to have a failure range from 7 to 138+ days. Under the same test conditions, EPDM rubber was tested for as long as 500 days without failure. It is indicated that the nylon-reinforced butyl and EPDM rubbers have ozone resistance comparable to the unreinforced butyl and EPDM materials.

9. Tests of 22 different adhesive materials for splicing rubber linings did not reveal any one material to be outstanding for all rubber linings of different manufacturers. Three-inch (8-cm) wide splice strengths (shear) developed by most adhesives and butyl rubber lining materials were stronger than the 1/32-inch (0.79-mm) thick lining tensile strength and weaker

than the 1/16-inch (1.59-mm) thick lining tensile strength. A 6-inch (15-cm) wide splice would be necessary to develop strength near the sheet strength for 1/16-inch (1.59-mm) thick butyl lining. Splice strengths of nylon-reinforced butyl rubber are stronger than nonreinforced butyl for the same adhesives, as the reinforcement restricts stressing and distortion of the seam area, thus reducing stress action on the adhesive. Generally, for most EPDM rubber linings the peel bond strength of spliced sheets is lower than with butyl rubber for the same adhesives.

APPLICATIONS

Synthetic rubber lining, butyl or EPDM, unreinforced or nylon reinforced, has use for varied waterproofing applications. The choice of type and thickness of material will be dictated by the service requirements of each individual project. Although the Bureau's greatest use of rubber membranes is for lining canals and reservoirs and waterproofing roof decks and concrete spillway and outlet structures, these membranes have been used also as liners for sewage and waste lagoons, brine storage ponds, wall, foundation, and plaza deck waterproofing, dam and levee cores, reservoir covers, and in a variety of other smaller applications. The Bureau has made limited use of rubber membrane as a cutoff curtain in a vertical trench in downhill canal slope to stop leakage in localized areas. This same application may be useful in stopping salt water intrusion through a limited aquifer. Also, rubber lining is adaptable to placement under concrete lining to resolve subgrade problems of expansive clay and cavernous limestone formations.

LABORATORY TESTS

Tensile Strength and Elongation

Tensile strength and elongation for unreinforced rubber were determined as specified in ASTM Designation: D 412, Tension Testing of Vulcanized Rubber. ASTM Designation: D 751, Testing Coated Fabrics (Grab Method), was used for reinforced rubber. Tensile testing was accomplished in an electronic recorder-type testing machine housed in an environmental control chamber which provides precisely controlled temperature, humidity, and cleanliness conditions meeting ASTM and Bureau specifications testing requirements. These facilities are shown in Figures 1 and 2.

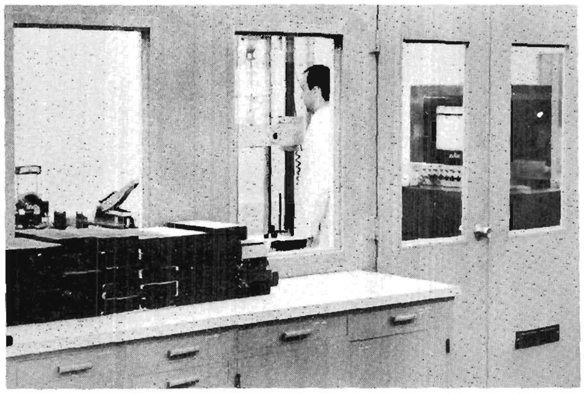


Figure 1. Environmental control chamber where physical properties testing of rubber sheeting is conducted under closely controlled temperature and humidity conditions. Photo PX-D-61982

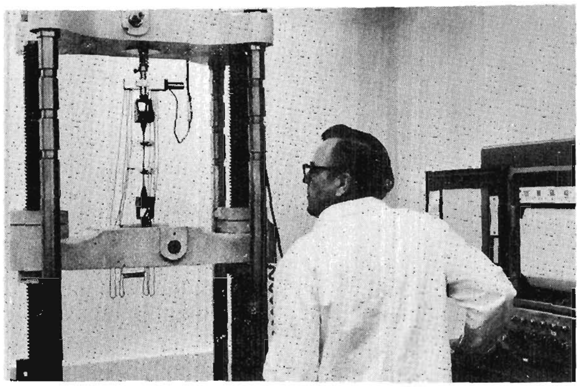


Figure 2. Sixty-thousand-pound Universal testing machine with recorder and extensometer equipment for measuring tensile strength and elongation properties of rubber sheeting. Photo PX-D-66762

Soil Burial

The soil burial test was performed by preparing 6-inch (15-cm) long by 1-inch (3-cm) wide test specimens, three in machine direction and three in transverse direction, and burying them vertically to a depth of about 5 inches (13 cm) in soil rich in cellulose-destroying micro-organisms. At different ages of soil burial, the tensile strength and elongation were determined as described in the above paragraph. The soil used for specimen burial was composted soil prepared according to usual greenhouse practice having a pH of 6.5 to 7.5. The moisture content of the soil was maintained between 25 and 30 percent on an ovendry basis. The soil containers with test specimens were stored in a cabinet, Figure 3, maintained at 90° F (32.2° C) temperature and 80 percent relative humidity. The microbiological activity of the soil was frequently checked by burying untreated 10-ounce cotton duck for 1- and 2-week periods. Satisfactory activity is indicated by tensile strength losses above 70 percent of strength in 1 week and above 90 percent in 2 weeks.

Figure 3. Soil burial test cabinet for aging of specimens set in composted soil placed in plastic containers. A constant temperature of 90° F (32.2° C) and 80 percent relative humidity is maintained in the test cabinet. Photo PX-D-60275

Specific Gravity

The specific gravity determination was conducted in accordance with ASTM Designation: D 297, Chemical Analysis of Rubber Products.

Weight

The weight of reinforced rubber sheeting was determined as prescribed in ASTM Designation: D 751, Testing Coated Fabrics.

Shore "A" Hardness

The Shore "A" hardness test was conducted as described in ASTM Designation: D 2240, Indentation Hardness of Rubber and Plastics by Means of a Durometer.

Ozone Resistance

Ozone resistance for unreinforced rubber was determined in accordance with ASTM Designation D 1149, Accelerated Ozone Cracking of Vulcanized Rubber. Test was conducted for 7 days at 50 pphm, 100° F (37.8° C) and 20 percent extension. For the reinforced rubber sheeting, the loop method of Procedure B, ASTM Designation: D 518, Surface Cracking Resistance of Stretched Rubber Compounds, was used.

Heat Aging

The heat aging test was conducted as specified in ASTM Designation: D 573, Accelerated Aging of Vulcanized Rubber by the Oven Method. Heat aging test was conducted at 240° F (115.6° C) for 7 days.

Tricresyl Phosphate and Water Immersion

Volume change of unreinforced rubber after 70 hours of immersion in tricresyl phosphate at 212° F (100° C) and weight change of reinforced rubber after 70 hours of immersion in water at 200° F (93° C) was determined in accordance with ASTM Designation: D 471, Change in Properties of Elastomeric Vulcanizates Resulting from Immersion in Liquids.

Tear Resistance

The tear test for unreinforced rubber was conducted as prescribed in ASTM Designation: D 624, Tear Resistance of Vulcanized Rubber. The specimens were cut with die "B". For reinforced rubber, the tear test was made in accordance with ASTM Designation: D 751, Testing Coated Fabrics.

Mullen Hydrostatic

The Mullen hydrostatic test was conducted in accordance with ASTM Designation: D 751 (Method A), Testing Coated Fabrics.

Puncture Resistance

The puncture resistance test was conducted using laboratory equipment as shown in Figure 4. This equipment consists of four 24-inch (61-cm) diameter pressure cells connected to a water supply source of maximum 55-psi (3.85-kg/cm^2) pressure. Testing was accomplished by placing graded aggregate in the pressure cell as a simulated subgrade. Two sizes of aggregate were used, Sieve No. 4 to 3/8 inch (10 cm) for mild testing and 3/4 to 1-1/2 inches (2 to 4 cm) for more severe testing. The rubber lining samples were cut circular in shape and placed over the aggregate subgrade. Lids were then positioned over the rubber sample and bolted to the cells and water introduced

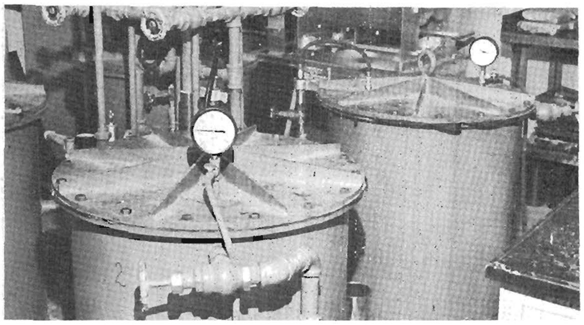


Figure 4. Pressure cell equipment for testing puncture resistance of rubber membrane lining. Photo PX-D-61985

into the cells near the top. The water under pressure acts upon the surface area of the rubber test specimen. The test is started at a low water pressure of 2.5 psi (0.175 kg/cm^2) and then increased in increments of 2.5 psi (0.175 kg/cm^2) for fixed periods until failure or the maximum test pressure of 55 psi (3.85 kg/cm^2) is reached.

Outdoor Exposure

Test panels 1-foot (30-cm) square are secured to a metal holder and placed on a 2:1 slope in test troughs, Figure 5, situated in the Bureau's outdoor test area.

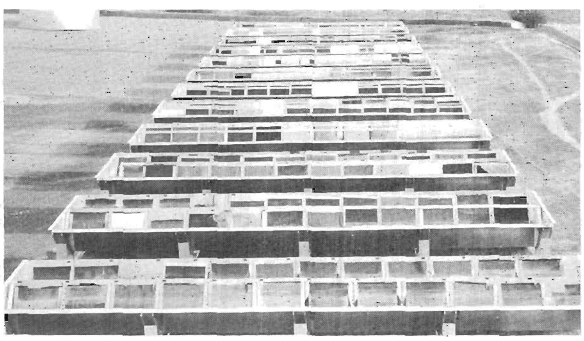


Figure 5. Outdoor exposure test facilities showing troughs for holding 1-foot (30-cm) square rubber specimens. Photo PX-D-61992

During the summer months, water is supplied to each trough. Through automatic siphons at the ends of the troughs, the water volume is controlled so that when the water level reaches a certain level on the specimens, the water automatically drains down to a specimen depth of about 4 inches (10 cm). This results in the upper third of the specimen being subjected to dry exposure, the middle third to wetting and drying exposure, and the bottom third to submerged exposure. During the winter months, the water is shut off and the specimens are exposed to natural weathering. The specimens are periodically evaluated and photographed.

Adhesive Bond Strength

Strength tests of adhesive bonds of rubber to rubber and rubber to concrete were conducted in accordance with ASTM Designation: D 1876, Peel Resistance of Adhesives. The shear strength tests of 3-inch (8-cm) lap-width rubber lining splices were in accordance with ASTM Designation: D 412, Tension Testing of Vulcanized Rubber. Test specimens were 1 inch (3 cm) wide. Grip separation rates of 20 inches (51 cm) per minute and 12 inches (30 cm) per minute for unreinforced and reinforced rubber, respectively, were used.

DISCUSSION OF LABORATORY TEST RESULTS

Soil Burial

Butyl rubber lining from four manufacturers, EPDM rubber lining from four manufacturers, nylon-reinforced butyl rubber lining from two manufacturers, and cotton-reinforced butyl rubber lining from two manufacturers were evaluated under soil burial conditions. The results are listed in Tables 1 and 2. These results for the butyl and EPDM linings are presented graphically in Figure 6.

After 5 and 7 years of soil burial testing of the EPDM and butyl rubber linings, respectively, these materials showed only slight loss in tensile strength and elongation. The average tensile strength and elongation for the butyl changed from 1,450 to 1,360 psi (100 to 95 kg/cm^2) and from 390 to 380 percent. For the EPDM, the average tensile strength and elongation changes were from 1,550 to 1,460 psi (110 to 100 kg/cm^2) and from 310 to 280 percent. Average tensile strength and elongation values indicated that nylon-reinforced butyl rubber lining is not significantly affected by soil burial. Two cotton-reinforced butyl rubber samples were reduced in tensile strength and elongation by 50 percent or more after 5 years' soil burial. This was expected as the micro-organisms in the soil are of the cellulose-destroying type and, therefore, the cotton reinforcement was vulnerable to attack.

Physical Properties

Table 3 lists standard physical properties values for 40 samples of butyl rubber sheeting varying in thickness

Table 1

BUTYL RUBBER LINING
Tensile and Elongation Properties Before and After Soil Burial

Lab No.	Manufac-turer	Thickness		Tensile strength																				Elongation, percent									
				Original				1/2 to 1 year				2 to 3 years				4 to 5 years				6 to 8 years				Original		1/2 to 1 year		2 to 3 years		4 to 5 years		6 to 8 years	
		mils	mm	L		T		L		T		L		T		L		T		L		T		L	T	L	T	L	T	L	T	L	T
				ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm										
B-3335	A	15	0.38	23.2	4.1	19.6	3.5	23.8	4.3	18.4	3.3	19.5	3.5	22.2	3.9	-	-	-	-	17.6	3.1	23.0	4.1	310	330	300	340	322	317	-	-	266	270
B-3582	C	18	0.46	25.6	4.6	22.2	4.0	23.6	4.2	21.1	3.8	25.0	4.5	22.6	4.0	26.4	4.7	19.9	1.8	24.5	4.4	22.6	4.0	640	580	590	550	577	547	534	453	555	490
B-3446	A	23	0.58	34.1	6.1	33.0	5.9	-	-	-	-	-	-	29.7	5.3	-	-	26.8	4.8	-	-	27.0	4.8	427	350	-	-	-	330	-	286	-	257
B-3941	A	25	0.64	38.2	6.8	33.8	6.1	39.1	7.0	36.6	6.5	38.6	6.9	35.1	6.3	-	-	-	-	36.3	6.5	33.6	6.0	350	360	358	367	323	360	-	-	343	247
B-3435	A	30	0.76	42.0	7.5	-	-	-	-	-	-	38.7	6.9	-	-	-	-	-	-	-	-	38.3	6.8	500	-	-	-	463	-	-	-	-	410
B-4263	D	30	0.76	35.1	6.3	-	-	23.6	4.2	-	-	-	-	-	-	-	-	-	-	25.0	4.5	-	-	302	-	297	-	-	-	-	-	250	-
B-4637	D	30	0.76	52.6	9.4	-	-	-	-	-	-	53.6	9.6	-	-	-	-	-	-	-	-	-	-	321	-	-	-	290	-	-	-	-	-
B-3057	A	31	0.79	-	-	43.5	7.8	-	-	44.3	7.9	-	-	39.0	6.9	-	-	44.8	8.0	-	-	48.7	8.7	-	350	-	340	-	320	-	330	-	300
B-3583	C	31	0.79	47.9	8.6	-	-	46.4	8.3	-	-	42.6	7.6	-	-	46.7	8.3	-	-	46.0	8.2	-	-	670	-	600	-	580	-	552	-	556	-
B-3942	A	31	0.79	58.3	10.4	52.0	9.3	57.6	10.3	54.9	9.8	59.7	10.7	50.1	8.9	-	-	-	-	57.0	10.2	45.3	8.1	350	380	355	403	329	320	-	-	293	283
B-4125	D	33	0.84	36.9	6.6	38.7	6.9	-	-	-	-	37.0	6.6	-	-	-	-	-	-	31.3	5.6	32.6	5.8	573	590	-	-	510	-	-	-	416	463
B-4272	B	33	0.84	53.0	9.4	43.2	7.7	47.6	8.5	41.3	7.4	-	-	-	-	-	-	-	-	51.6	9.2	45.6	8.1	441	442	370	369	-	-	-	-	350	363
B-4632	B	33	0.84	53.3	9.5	-	-	-	-	-	-	50.0	8.9	-	-	-	-	-	-	-	-	-	-	320	-	-	-	290	-	-	-	-	-
B-4630	D	35	0.89	32.6	5.8	-	-	-	-	-	-	34.0	6.1	-	-	-	-	-	-	-	-	-	-	308	-	-	-	200	-	-	-	-	-
B-4633	B	36	0.91	48.3	8.6	-	-	-	-	-	-	53.0	9.5	-	-	-	-	-	-	-	-	-	-	554	-	-	-	450	-	-	-	-	-
B-4638	A	37	0.94	58.2	10.4	-	-	-	-	-	-	56.3	10.1	-	-	-	-	-	-	-	-	-	-	244	-	-	-	213	-	-	-	-	-
B-3436	A	62	1.58	80.8	14.4	-	-	-	-	-	-	79.5	14.2	-	-	-	-	-	-	81.0	14.4	-	-	530	-	-	-	510	-	-	-	460	-
B-3943	A	62	1.58	112.0	20.0	95.5	17.0	114.0	20.4	103.7	18.5	109.0	19.5	101.6	18.1	-	-	-	-	96.0	17.1	70.0	12.5	370	370	390	407	333	383	-	-	320	350
B-2670	A	62	1.58	70.0	12.5	-	-	68.0	12.1	-	-	65.5	11.7	-	-	-	-	-	-	76.4	13.6	-	-	400	-	400	-	380	-	-	-	373	-
B-4271	B	63	1.60	101.2	18.1	-	-	99.7	17.8	-	-	-	-	-	-	-	-	-	-	102.5	18.3	-	-	370	-	340	-	-	-	-	-	325	-
B-4065	D	67	1.70	78.2	14.0	68.4	12.2	64.8	11.6	59.8	10.7	61.1	10.9	54.2	9.7	-	-	-	-	-	-	55.0	9.8	416	385	400	401	366	334	-	-	-	380
B-4644	D	93	2.36	119.7	21.4	-	-	-	-	-	-	-	-	-	-	140.3	25.1	-	-	-	-	-	-	488	-	-	-	-	-	490	-	-	-
B-4522	B	95	2.41	147.2	26.3	135.6	24.2	-	-	-	-	-	-	-	-	147.0	26.2	140.6	25.1	-	-	-	-	430	430	-	-	-	-	380	380	-	-
B-4680	A	95	2.41	131.8	23.5	-	-	-	-	-	-	-	-	-	-	142.0	25.3	-	-	-	-	-	-	350	-	-	-	-	-	330	-	-	-
B-4629	D	96	2.44	159.6	28.5	-	-	-	-	-	-	-	-	-	-	149.3	26.7	-	-	-	-	-	-	340	-	-	-	-	-	300	-	-	-
B-4345	D	104	2.64	116.3	20.8	96.7	17.3	121.9	21.8	-	-	128.3	22.9	-	-	-	-	-	-	120.0	21.4	-	-	360	358	320	-	380	-	-	-	340	-

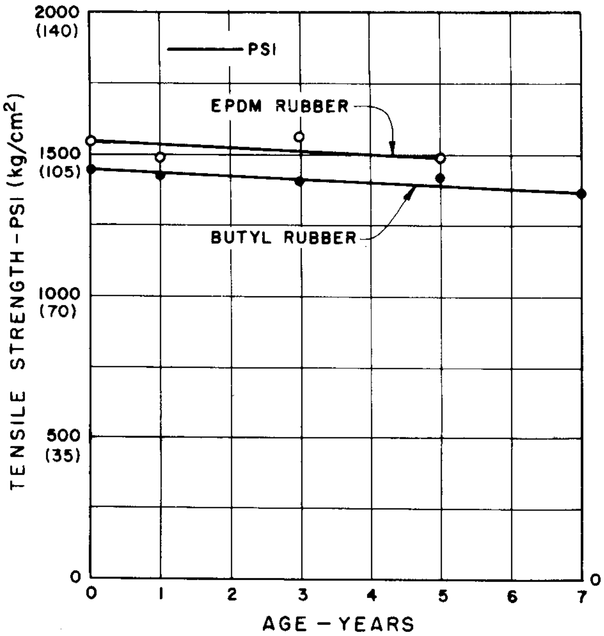
L and T denote longitudinal and transverse directions, respectively.

Table 2

EPDM AND REINFORCED BUTYL RUBBER LINING
Tensile and Elongation Properties Before and After Soil Burial

Lab No.	Manufac-turer	Thickness		Tensile strength																				Elongation, percent									
				Original				1/2 to 1 year				2 to 3 years				4 to 5 years				6 to 8 years				Original		1/2 to 1 year		2 to 3 years		4 to 5 years		6 to 8 years	
		mils	mm	L		T		L		T		L		T		L		T		L		T		L	T	L	T	L	T	L	T	L	T
				ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm	ppi	kg/cm										
Ethylene propolene diene monomer (EPDM):																																	
B-4295	D	31	0.79	44.8	8.0	39.5	7.1	43.1	7.7	37.9	6.8	-	-	-	-	48.6	8.7	36.6	6.5	-	-	-	-	336	356	314	322	-	-	300	263	-	-
B-4346	J	35	0.89	54.0	9.6	-	-	56.3	10.1	-	-	64.4	11.5	-	-	52.6	9.4	-	-	-	-	-	-	275	-	266	-	280	-	270	-	-	-
B-4642	E	40	1.02	81.3	15.6	-	-	-	-	-	-	-	-	-	-	70.6	12.6	-	-	-	-	-	-	498	-	-	-	-	-	380	-	-	-
B-4371	D	60	1.52	64.8	11.6	53.6	9.6	62.3	11.1	-	-	-	-	-	-	60.3	10.8	-	-	-	-	-	-	290	301	307	-	-	-	290	-	-	-
B-4372	D	62	1.58	82.8	14.8	78.4	14.0	81.3	14.5	-	-	-	-	-	-	80.0	14.3	-	-	-	-	-	-	338	354	297	-	-	-	330	-	-	-
B-3958	A	67	1.70	116.4	20.8	108.7	19.4	-	-	-	-	116.5	20.8	108.0	19.3	114.2	20.4	111.0	19.8	112.0	20.0	102.0	18.2	280	305	-	-	288	285	265	286	260	240
Nylon-reinforced butyl:																																	
B-4306	F	29	0.74	89.4	16.0	-	-	-	-	-	-	74.5	13.3	-	-	79.8	14.3	-	-	73.3	13.1	-	-	36	-	-	-	2t	-	30	-	20.0	-
B-4635	A	33	0.84	116.0	20.7	-	-	-	-	-	-	-	-	-	-	100.3	17.9	-	-	-	-	-	-	19	-	-	-	-	-	10	-	-	-
B-4024	A	37	0.94	142.3	25.4	137.9	24.6	-	-	-	-	134.1	23.9	126.4	22.6	-	-	-	-	120.0	21.4	120.0	21.4	37	52	-	-	21	27	-	20	23	-
B-2671	A	52	1.32	140.0	25.0	-	-	-	-	-	-	-	-	-	-	144.3	25.8	-	-	140.0	25.0	-	-	30	-	-	-	-	-	30	-	30	-
B-3957	A	64	1.63	137.0	24.5	94.9	16.9	-	-	-	-	131.2	23.4	91.2	16.3	107.0	19.1	66.0	11.8	123.0	22.0	85.0	15.2	28	24	-	-	-	-	24	26	20	20
Cotton-reinforced butyl:																																	
B-4104	A	15	0.38	33.9	6.1	27.2	4.9	-	-	-	-	19.4	3.5	10.0	1.8	-	-	9.0	1.6	-	-	-	-	3	19	-	-	3	11	-	10	-	-
B-4307	F	25	0.64	34.8	6.2	-	-	-	-	-	-	23.6	4.2	-	-	20.2	3.6	-	-	17.0	3.4	-	-	3	-	-	-	3	-	3	-	1.5	-

L and T denote longitudinal and transverse directions, respectively.



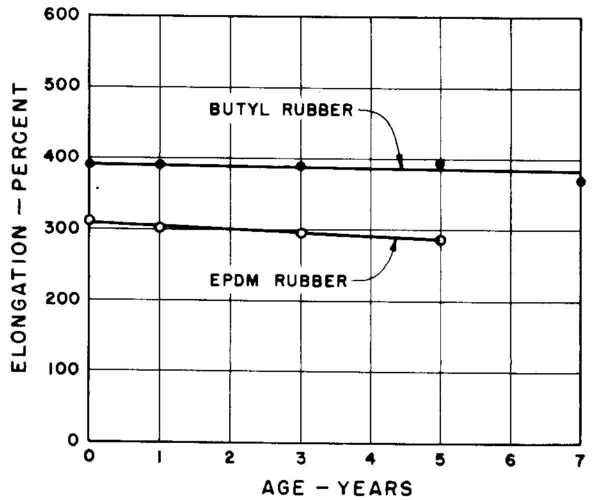


Figure 6. Average tensile strength and elongation properties of two rubber materials subjected to laboratory (accelerated) soil burial testing.

from 31 to 97 mils (0.79 to 2.46 mm) and for 7 samples of EPDM from 32 to 65 mils (0.81 to 1.65 mm) in thickness. The range and average values for specific gravity, tensile strength elongation, modulus at 300 percent elongation, shore hardness, and tear resistance are presented previously under "Summary of Laboratory Test Results." For the butyl rubber, it is indicated that more than half the samples tested representing four manufacturers had specific gravity values 1.19 or higher, tensile strengths 1,500 psi (105 kg/cm^2) or higher, elongation values 400 percent or higher, shore hardness 54 or higher, and tear strengths 200 ppi (36 kg/cm) or higher. Of the few EPDM rubber samples tested, it is indicated that the average tensile strength is higher and elongation lower than for the butyl rubber. Shore hardness, specific gravity, and tear strength average values were near those of the butyl. It is indicated that there should be no difficulty for butyl and EPDM materials to retain 70 percent of the original tensile strength after heat aging; however, retention of 70 percent of the original elongation may be borderline with some materials. There appears to be no problem for the butyl and EPDM materials meeting the requirement of not more than 10 percent volume swell when immersed in tricresyl phosphate 70 hours at 212° F (100° C).

The test results of 10 nylon-reinforced butyl samples from five manufacturers ranging in thickness from 19 mils (0.48 mm) to 59 mils (1.50 mm) are given in Table 4. The different manufacturers use nylon reinforcement of different weaves and weights that results in final products of varied physical properties for the same thickness. The physical properties of nylon-reinforced rubber lining are dependent much more on the characteristics of the nylon fabric used than the rubber coating. Figure 7 shows different nylon fabrics used by four manufacturers. For comparing strengths of nylon-reinforced butyl linings from different manufacturers, bursting strength as measured by the Mullen hydrostatic test appears much more meaningful than tensile strength tests. For example, one sample 33 mils (0.84 mm) thick from one manufacturer had tensile and bursting strengths of 254 pounds (115 kg) and 211 psi (14.8 kg/cm^2) while another manufacturer's sample nearly twice the thickness, 59 mils (1.50 mm), had tensile and bursting strengths of 193 pounds (88 kg) and 335 psi (23.6 kg/cm^2). It is indicated that the majority of nylon-reinforced butyl lining materials have bursting strengths about twice that of unreinforced butyl lining for the same thickness. Elongation test values, which are essentially that of the nylon fabric, are more consistent for the different samples than other properties. Tear strength is highly variable depending on the characteristics of the nylon fabric. Generally, the heat aging results show changes in physical properties that may be normally expected with unreinforced butyl rubber. One material showed a 54 percent increase in hydrostatic burst strength after heat aging which was caused by a stiffening of the rubber coating. On the whole, water absorption by nylon-reinforced butyl lining samples was higher than that normally obtained with unreinforced butyl lining. This is believed due in part to wicking action causing

Table 3

BUTYL AND EPDM RUBBER LINING PHYSICAL PROPERTIES TEST RESULTS

Lab No.	Manufacturer	Material type	Thickness mils	Thickness mm	Specific gravity	Tensile strength psi	Tensile strength kg/cm²	Elongation percent	Modulus at 300 percent elongation psi	Modulus at 300 percent elongation kg/cm²	Shore "A" hardness	Ozone resistance at 7 days	Heat aging - 7 days at 240° F (115.6° C): Tensile strength retained, percent of original	Heat aging - 7 days at 240° F (115.6° C): Elongation retained, percent of original	Maximum* volume change percent	Tear resistance ppi	Tear resistance kg/cm
B-4295	D	Butyl	31	0.79	1.17	1,410	99.1	315	1,360	95.6	50	No cracks	117	59	-10.8	125	22.3
B-4631	A	Butyl	31	0.79	1.18	1,605	112.8	300	1,610	113.2	58	No cracks	67	90	-0.3	220	39.3
B-5479	B	Butyl	31	0.79	1.20	1,420	99.8	502	990	69.6	55	No cracks	89	70	+0.8	152	27.1
B-4632	B	Butyl	32	0.81	1.18	1,685	118.5	289	1,630	114.6	57	No cracks	75	88	+0.6	236	42.1
B-4637	D	Butyl	33	0.84	1.15	1,765	124.1	358	1,580	111.1	53	No cracks	105	67	-23.4	199	35.5
B-5134	B	Butyl	34	0.86	1.19	1,415	99.5	482	1,005	70.7	53	No cracks	96	61	-0.3	191	34.1
B-4630	D	Butyl	35	0.89	1.15	1,135	79.8	310	910	64.0	50	No cracks	120	68	-21.2	139	24.8
B-4634	C	Butyl	35	0.89	1.21	1,170	82.3	286	1,140	80.1	51	No cracks	73	96	+0.1	191	34.1
B-5059	B	Butyl	36	0.91	1.20	1,550	109.0	520	1,000	70.3	53	No cracks	92	70	+1.5	192	34.3
B-4638	A	Butyl	41	1.04	1.18	1,435	89.1	255	1,385	97.4	60	No cracks	91	57	+1.0	235	42.0
B-4633	B	Butyl	45	1.14	1.18	1,400	98.4	603	845	59.4	52	No cracks	85	58	+7.3	219	39.1
B-4891	B	Butyl	53	1.35	1.31	1,800	126.6	300	1,800	126.6	54	No cracks	87	80	+1.1	190	33.9
B-4864	A	Butyl	58	1.47	1.19	1,660	116.7	310	1,640	115.3	54	No cracks	91	81	-0.3	191	34.1
B-5790	A	Butyl	58	1.47	1.19	1,590	111.8	450	1,065	74.9	52	No cracks	82	81	-5.1	275	49.1
B-6029	D	Butyl	58	1.47	1.19	1,520	106.9	445	1,220	85.8	52	No cracks	101	89	-15.9	186	33.2
B-5885	A	Butyl	59	1.50	1.20	1,595	112.1	380	1,310	92.1	54	No cracks	88	78	-3.9	215	38.4
B-5886	A	Butyl	59	1.50	1.20	1,605	112.8	384	1,305	91.8	53	No cracks	83	81	-3.8	246	43.9
B-5578	A	Butyl	61	1.55	1.19	1,460	102.6	370	1,250	87.9	54	No cracks	93	71	-5.5	207	37.0
B-6028	D	Butyl	61	1.55	1.19	1,510	106.2	454	1,240	87.2	52	No cracks	106	88	-17.0	204	36.4
B-5709	A	Butyl	64	1.63	1.19	1,880	132.2	300	1,840	129.4	57	No cracks	88	91	-1.2	172	30.7
B-5518	A	Butyl	64	1.63	1.19	1,860	131.8	305	1,840	129.4	53	No cracks	88	91	-1.4	320	57.1
B-4372	D	Butyl	64	1.63	1.18	1,250	87.9	338	1,125	79.1	51	No cracks	128	73	+0.9	183	32.7
B-5073	D	Butyl	67	1.70	1.20	1,710	120.2	430	1,435	100.9	60	No cracks	110	91	-13.4	219	39.1
B-5428	B	Butyl	69	1.75	1.17	1,260	88.6	576	640	45.0	50	No cracks	95	73	-5.2	198	35.4
B-5483	B	Butyl	69	1.75	1.18	1,300	91.4	595	640	45.0	50	No cracks	96	73	-5.5	250	44.6
B-5579	B	Butyl	70	1.78	1.18	1,410	99.1	555	770	54.1	56	No cracks	95	76	-4.9	180	32.1
B-5805	B	Butyl	71	1.80	1.18	1,300	91.4	570	715	50.3	55	No cracks	95	71	-4.8	179	32.0
B-5848	B	Butyl	71	1.80	1.19	1,250	87.9	420	1,000	70.3	51	No cracks	104	79	-4.8	199	35.5
B-6030	D	Butyl	71	1.80	1.20	1,385	94.6	440	1,070	75.2	55	No cracks	99	74	-4.5	230	41.1
B-5751	B	Butyl	73	1.85	1.18	1,225	86.1	530	705	49.6	51	No cracks	96	70	-4.5	188	33.6
B-5795	D	Butyl	82	2.08	1.18	1,800	126.6	525	1,080	75.9	53	No cracks	87	90	+0.2	255	45.5
B-5808	D	Butyl	85	2.16	1.19	1,540	108.3	440	1,240	87.2	52	No cracks	108	86	-17.7	200	35.7
B-5091	D	Butyl	88	2.24	1.19	1,455	102.3	461	1,135	79.8	62	No cracks	108	88	-13.9	244	43.6
B-5865	D	Butyl	88	2.24	1.19	1,500	105.5	480	1,200	84.4	56	No cracks	107	86	-13.8	235	42.0
B-4644	D	Butyl	90	2.29	1.19	1,380	97.0	476	1,050	73.8	54	No cracks	116	86	-15.3	275	49.1
B-4522	B	Butyl	93	2.36	1.20	1,500	105.5	430	1,215	85.4	56	No cracks	98	70	+2.9	238	42.5
B-4680	A	Butyl	94	2.39	1.17	1,340	94.2	347	1,340	94.2	58	No cracks	76	81	+0.8	254	45.4
B-5350	A	Butyl	97	2.46	1.20	1,505	105.8	320	1,420	99.8	55	No cracks	89	86	-2.7	164	29.3
B-5407	A	Butyl	97	2.46	1.17	1,505	105.8	353	1,365	96.0	55	No cracks	63	68	-4.5	212	37.9
B-5439	A	Butyl	97	2.46	1.20	1,625	114.2	340	1,520	106.9	58	No cracks	82	74	-4.4	208	37.1
B-4597	B	EPDM	32	0.81	1.10	1,450	101.9	304	1,390	97.7	63	No cracks	120	55	-21.9	125	22.3
B-5525	A	EPDM	32	0.81	1.15	1,750	123.0	390	1,455	102.3	53	No cracks	102	77	-13.4	190	33.9
B-4601	C	EPDM	35	0.89	1.13	1,630	114.6	354	1,300	91.4	52	No cracks	121	93	-21.4	226	40.8
B-4476	B	EPDM	40	1.02	1.11	960	67.5	385	825	58.0	53	No cracks	117	48	-23.5	153	27.3
B-4642	E	EPDM	43	1.09	1.14	2,075	145.9	469	1,285	90.3	50	No cracks	103	74	-14.4	275	49.1
B-3958	A	EPDM	65	1.65	1.13	1,975	138.9	263	-	-	65	No cracks	101	79	-13.7	158	28.2
B-4602	B	EPDM	65	1.65	1.18	1,645	115.7	340	1,400	98.4	64	No cracks	122	43	-17.7	240	42.9

*Tricresyl phostate immersion, ASTM D 471-66.

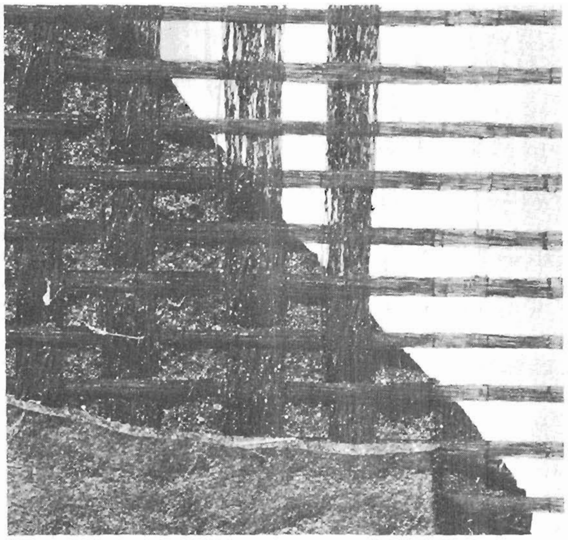
Table 4

NYLON-REINFORCED BUTYL RUBBER LINING PHYSICAL PROPERTIES TEST RESULTS

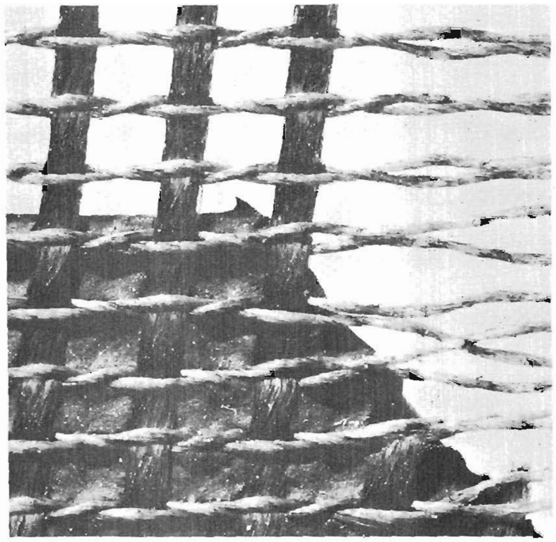
Lab No.	Manufacturer	Thickness		Weight		Tensile strength				Elongation		Tear strength				Mullen hydrostatic		Heat aging - 7 days at 240° F (115.6° C)								Water immersion 70 hours at 250° F (121.1° C) weight change percent	Ozone* resistance at 7 days
						lb		kg		percent		lb		kg				Tensile strength			Elongation		Mullen hydrostatic				
		mils	mm	oz/sq yd	g/m^2	L	T	L	T	L	T	L	T	L	T	psi	kg/cm^2	lb	kg	percent change	percent	percent change	psi	kg/cm^2	percent change		
B-5600	F	19	0.48	17.0.	576.4	98	95	44	43	23	25	8.0	14.0	3.6	6.4	136	9.6	98	44	0	22	-4.4	150	10.5	+10.3	+4.1	No cracks
B-5730	I	19	0.48	18.2	617.1	108	105	49	48	18	16	12.5	18.9	5.6	8.5	189	13.3	117	53	+8.3	18	0	197	13.9	+4.2	+9.5	No cracks
B-5601	F	22	0.56	20.2	684.9	114	106	52	48	18	20	8.0	16.0	3.6	7.3	185	13.0	113	51	-0.9	19	+5.5	188	13.2	+1.6	+7.4	No cracks
B-5602	F	29	0.74	28.2	956.1	110	113	50	51	18	22	18.0	16.0	8.1	7.3	189	13.3	112	51	+1.8	18	0	190	13.4	+0.5	+6.0	No cracks
B-5560	H	32	0.81	34.3	1,163.0	126	110	57	50	19	22	9.4	17.5	4.3	7.9	200	14.1	133	60	+5.5	20	+5.3	198	13.9	-1.0	+2.8	No cracks
B-5540	G	33	0.84	29.6	1,003.6	254	253	115	115	20	22	68.0	77.0	30.8	34.9	211	14.8	233	106	-2.1	18	-10.0	325	16.5	+54.0	+7.8	Cracked
B-5555	F	38	0.97	37.7	1,278.3	122	112	55	51	20	22	11.1	17.6	5.0	8.0	195	13.7	124	56	+1.6	22	+10.0	195	13.7	0	+2.1	No cracks
B-5603	F	40	1.02	38.2	1,295.2	112	114	51	52	18	21	15.0	13.0	6.8	5.9	191	13.4	114	52	+1.8	18	0	195	13.7	+2.1	+4.1	No cracks
B-5606	D	49	1.25	43.1	1,461.3	73	51	33	23	20	25	6.0	9.0	2.7	4.1	121	8.5	74	34	+1.4	21	+5.0	119	8.4	-1.7	+2.7	No cracks
B-4606	I	59	1.50	52.5	1,780.1	193	206	88	93	28	36	56.0	19.0	25.4	8.6	335	23.6	222	101	+15.0	29	+4.0	369	25.9	+10.0	+3.0	No cracks

Note: L and T denotes longitudinal and transverse directions, respectively.
Heat aging tensile and elongation values are for longitudinal direction.

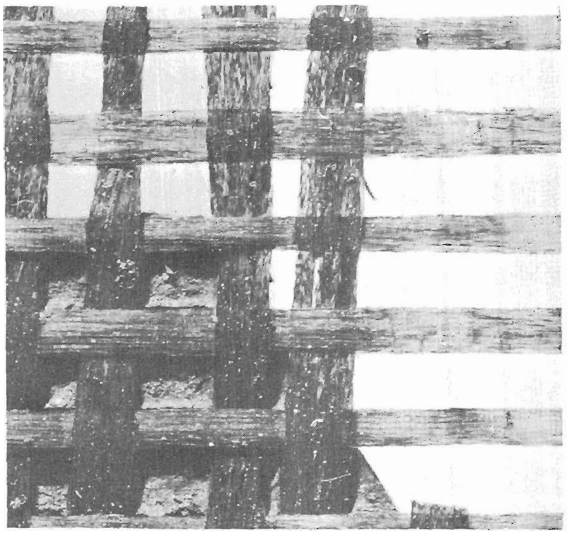
*50 PPHM ozone at 100° F (37.8° C).



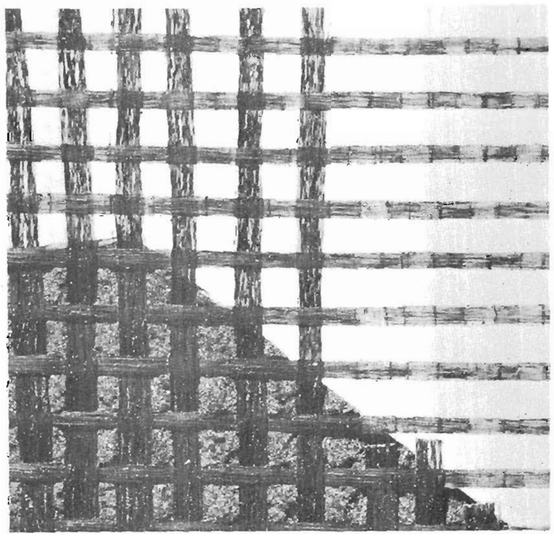
Manufacturer F. 30 mils (0.76 mm), B-5602. Photo P222-D-65685



Manufacturer A. 60 mils (1.52 mm), B-4606. Photo PX-D-68886



Manufacturer G. 30 mils (0.76 mm), B-5540. Photo PX-D-68887



Manufacturer H. 30 mils (0.76 mm), B-5560. Photo PX-D-68888

Figure 7. Nylon-reinforced, butyl lining samples showing different weaves and weights of nylon used by four manufacturers. (Six times magnification.)

water to be drawn around the individual threads and strands of woven nylon fabric. However, the generally high volume swell would also indicate some absorption of water by the coating. The loop stress method used in ozone testing showed one material to fail the 7-day test at 50-pphm ozone and 100° F (37.8° C).

Puncture Resistance

Test results of unreinforced and reinforced butyl and EPDM lining materials are shown in Tables 5 and 6, respectively. Generally, the test results show that unreinforced butyl and EPDM rubber linings 1/32 inch (0.79 mm) thick are apt to puncture at about 40-psi (2.81-kg/cm^2) water pressure when placed over 3/4- to 1-1/2-inch (2- to 4-cm) size rock. The 1/16-inch (1.59-mm) thick butyl and EPDM rubber effectively resisted puncture over this size rock under water pressure of up to 57.5 psi ($4.04\ \text{kg/cm}^2$). It is indicated that the puncture resistance of the reinforced materials is only slightly better than the unreinforced linings; however, usually the punctures are smaller with the reinforced materials.

Ozone Resistance

The results of ozone tests of 18 butyl, 5 EPDM, 10 nylon-reinforced butyl, and two nylon-reinforced EPDM lining materials are listed in Table 7. These data show that the ozone resistance of butyl rubber can vary considerably with different samples. With ozone exposure of 50 pphm at 100° F (37.8° C) and 20 percent elongation, one sample began cracking at 7 days while four samples showed no cracking after 100 days of ozone exposure. Although Bureau of Reclamation specifications require no cracking after 7 days' testing, it is desired to have a safety factor of two or three times in case the rubber while in service becomes stressed beyond 20 percent elongation at a localized area. Excessive, localized stressing of butyl rubber can result in ozone attack.

The test results indicate that EPDM rubber of formulations similar to the samples tested are inert to ozone attack. This is an outstanding advantage over the butyl rubber material. In service, it would be expected that the nylon-reinforced butyl rubber lining would be less vulnerable to ozone attack than the unreinforced butyl, as the reinforcing would restrict the stressing of the lining, and therefore, minimizing conditions conducive to ozone deterioration. Figures 8 and 9 show typical ozone cracking failure of nonreinforced and nylon-reinforced butyl rubber linings.

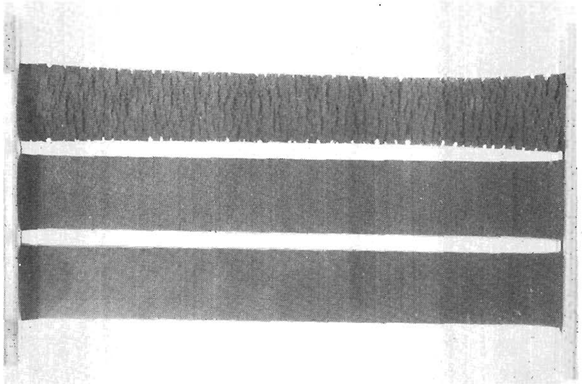


Figure 8. Typical ozone cracking failure of unreinforced, butyl-rubber lining (top sample) after testing in ozone oven in elongated condition. Photo PX-D-68889

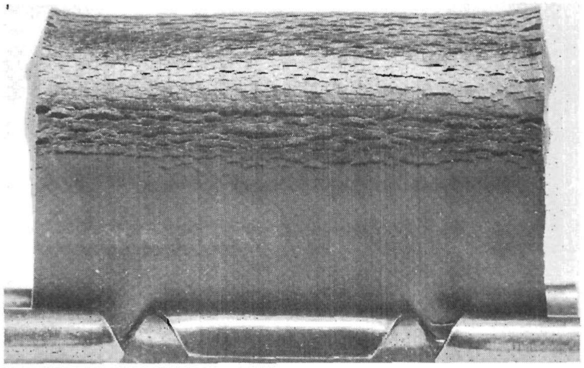


Figure 9. Typical ozone cracking failure of nylon-reinforced, butyl-rubber lining after loop testing in ozone oven. Photo PX-D-68890

Outdoor Exposure

Outdoor exposure test results of butyl rubber, EPDM rubber, and reinforced butyl rubber linings are summarized in Tables 8 and 9. Generally, it is indicated that butyl and EPDM rubber lining materials have good weather resistance. The longest tested materials, butyl rubber for 9-1/2 years, EPDM for 6-1/3 years, glass-fiber reinforced butyl for 12-1/2 years, nylon-reinforced butyl for 6-1/3 years, and cotton-reinforced butyl for 4-3/4 years all were observed to be in excellent condition.

Of the 58 rubber lining materials exposed to the outdoors for periods ranging from 1-1/2 to 12-1/2 years, all were in excellent condition with the exception that two unreinforced butyl linings showed slight shrinkage and two unreinforced butyl linings

Table 5

BUTYL AND EPDM RUBBER LINING PUNCTURE RESISTANCE TEST RESULTS
Over 3/4- to 1-1/2-inch (2- to 4-cm) Size Rock

Laboratory No.	Material type	Manufacturer	Thickness		*Water pressure at puncture			Remarks—Small holes are less than 1/16-inch (1.59-mm) diameter
			mils	mm	psi	kg/cm^2	puncture time	
B-3582	Butyl	C	15	0.38	20.0	1.41	After 4 hours	Three small holes
B-3446	Butyl	A	20	0.51	27.5	1.93	After 3 hours	One small hole
B-3941	Butyl	A	20	0.51	55.0	3.87	After 3 hours	One large hole
B-4263	Butyl	D	31	0.79	52.5	3.69	After 3 hours	One large hole
B-4295	Butyl	D	31	0.79	57.5	4.04	After 1 hour	One large hole
B-4631	Butyl	A	31	0.79	57.5	4.04	No puncture	
B-3583	Butyl	C	32	0.81	40.0	2.81	After 4 hours	Two large holes
B-3923	Butyl	D	32	0.81	40.0	2.81	After 4 hours	One large hole
B-3942	Butyl	A	32	0.81	57.5	4.04	No puncture	
B-4632	Butyl	B	32	0.81	57.5	4.04	No puncture	
B-5059	Butyl	B	32	0.81	57.5	4.04	No puncture	
B-4259	Butyl	A	33	0.84	57.5	4.04	No puncture	
B-4637	Butyl	D	33	0.84	57.5	4.04	No puncture	
B-4125	Butyl	D	34	0.86	40.0	2.81	After 1 hour	One large hole
B-4272	Butyl	B	34	0.86	57.5	4.04	After 4 hours	One large hole
B-5134	Butyl	B	34	0.86	50.0	3.52	After 4 hours	One large hole
B-4630	Butyl	D	35	0.89	50.0	3.52	After 4 hours	One large hole
B-4634	Butyl	C	35	0.89	57.5	4.04	No puncture	
B-4145	Butyl	B	40	1.02	40.0	2.81	After 1 hour	One large hole
B-4638	Butyl	A	41	1.04	57.5	4.04	No puncture	
B-4371	Butyl	D	60	1.52	57.5	4.04	No puncture	
B-3922	Butyl	D	64	1.63	57.5	4.04	No puncture	
B-4065	Butyl	D	64	1.63	57.5	4.04	No puncture	
B-4271	Butyl	B	64	1.63	57.5	4.04	No puncture	
B-4372	Butyl	D	64	1.63	57.5	4.04	No puncture	
B-4144	Butyl	B	75	1.91	57.5	4.04	No puncture	
B-4522	Butyl	D	93	2.36	57.5	4.04	No puncture	
B-4597	EPDM	D	32	0.81	57.5	4.04	No puncture	
B-4601	EPDM	B	32	0.81	57.5	4.04	No puncture	
B-4476	EPDM	B	40	1.02	42.5	2.99	After 4 hours	One large hole
B-4642	EPDM	E	43	1.09	57.5	4.04	No puncture	
B-3958	EPDM	A	65	1.65	57.5	4.04	No puncture	

*Water pressure increased by 2.5 psi (0.176 kg/cm^2) at 4-hour increments. Puncture time indicates time of puncture after reaching highest water pressure. 57.5 psi (4.04 kg/cm^2) was maximum test pressure available. Where no puncture is reported, 57.5 psi (4.04 kg/cm^2) was held for 7 days
EPDM denotes ethylene propylene diene monomer.

Table 6

REINFORCED BUTYL AND EPDM RUBBER LINING PUNCTURE RESISTANCE TEST RESULTS
Over 3/4- to 1-1/2-inch (2- to 4-cm) Size Rock

Sample No.	Material type	Manufac-turer	Thickness		*Water pressure at puncture			Remarks—Small holes are less than 1/16-inch (1.59-mm) diameter
			mils	mm	psi	kg/cm^2	puncture time	
B-4104	Butyl, nylon-reinforced	A	16	0.41	10.0	0.70	After 2 hours	One small hole
B-5534	Butyl, nylon-reinforced	F	16	0.41	5.0	0.35	After 1 hour	Eight small holes
B-5600	Butyl, nylon-reinforced	F	16	0.41	25.0	1.76	After 2 hours	One small hole
B-5069	Butyl, cotton-reinforced	F	20	0.51	17.5	1.23	After 4 hours	Eleven small holes
B-5070	Butyl, nylon-reinforced	F	20	0.51	37.5	2.64	After 2 hours	One small hole
B-5601	Butyl, nylon-reinforced	F	22	0.56	50.0	3.52	After 4 hours	Three small holes
B-5602	Butyl, nylon-reinforced	F	29	0.74	57.5	4.04	No puncture	
B-4024	Butyl, nylon-reinforced	A	31	0.79	57.5	4.04	No puncture	
B-4635	Butyl, nylon-reinforced	A	31	0.79	57.5	4.04	No puncture	
B-4985	Butyl, nylon-reinforced	E	31	0.79	57.5	4.04	No puncture	
B-5560	Butyl, nylon-reinforced	H	32	0.81	40.0	2.81	After 3 hours	Two small holes
B-5540	Butyl, nylon-reinforced	G	33	0.84	57.5	4.04	After 1 hour	One small hole
B-5555	Butyl, nylon-reinforced	F	38	0.97	57.5	4.04	After 1 hour	One large hole
B-5603	Butyl, nylon-reinforced	F	40	1.02	57.5	4.04	No puncture	
B-4986	Butyl, nylon-reinforced	F	50	1.27	57.5	4.04	No puncture	
B-4606	Butyl, nylon-reinforced	A	59	1.50	57.5	4.04	No puncture	
B-3957	Butyl, nylon-reinforced	A	62	1.58	57.5	4.04	No puncture	
B-5606	EPDM, nylon-reinforced	D	49	1.24	57.5	4.04	No puncture	

*Water pressure increased by 2.5 psi (0.176 kg/cm^2) at 4-hour increments. Puncture time indicates time of puncture after reaching highest water pressure.
57.5 psi (4.04 kg/cm^2) was maximum test pressure available. Where no puncture is reported, 57.5 psi (4.04 kg/cm^2) was held for 7 days.
EPDM denotes ethylene propylene diene monomer.

Table 7

UNREINFORCED AND REINFORCED BUTYL AND EPDM RUBBER LINING
Ozone Test Results

Laboratory No.	Manufacturer	Material	Ozone exposure, 50 pphm at 100° F, (37.8° C), *20 percent elongation: Time to failure, days	Ozone exposure, 50 pphm at 100° F, (37.8° C), *20 percent elongation: Time test ended without failure, days
B-3747	A	Butyl	28	
B-3956	A	Butyl	17	
B-4631	A	Butyl	35	
B-4632	B	Butyl	33	
B-4634	C	Butyl	7	
B-4637	D	Butyl	14	
B-4638	A	Butyl	19	
B-4680	A	Butyl	44	
B-4686	A	Butyl	14	
B-4864	A	Butyl	16	
B-4891	B	Butyl	40	
B-5019	D	Butyl		138
B-5059	B	Butyl		110
B-5134	B	Butyl		110
B-5709	A	Butyl	21	
B-5751	B	Butyl		120
B-5865	D	Butyl		60
B-5885	A	Butyl	10	
B-4346	J	EPDM		500
B-4371	D	EPDM		500
B-4529	B	EPDM		190
B-4601	C	EPDM		160
B-5525	A	EPDM		500
B-4606	A	Nylon-reinforced butyl		51
B-4985	F	Nylon-reinforced butyl		270
B-4986	F	Nylon-reinforced butyl	41	
B-5600	F	Nylon-reinforced butyl		415
B-5601	F	Nylon-reinforced butyl		415
B-5602	F	Nylon-reinforced butyl		415
B-5603	F	Nylon-reinforced butyl	10	
B-5730	I	Nylon-reinforced butyl		415
B-5798	G	Nylon-reinforced butyl		150
B-5801	F	Nylon-reinforced butyl		150
B-5605	D	Nylon-reinforced EPDM		415
B-5797	G	Nylon-reinforced EPDM		150

*20 percent elongation does not apply to the nylon-reinforced rubbers, elongation of these materials was attained by using loop test method.

Table 8

BUTYL RUBBER LINING
Outdoor Exposure Test Results

Sample No.	Manufacturer	Thickness mils	Thickness mm	Exposure time years—months	Remarks on physical condition
B-3057	A	32	0.81	9–6	Excellent condition
B-3335	A	15	0.38	8–10	Excellent condition
B-3436	A	20	0.51	7–9	Good condition, slight shrinkage
B-3582	C	15	0.38	7–8	Excellent condition
B-3583	C	30	0.76	7–8	Excellent condition
B-3922	D	64	1.63	6–8	Excellent condition
B-3923	D	31	0.79	6–8	Excellent condition
B-3941	A	20	0.51	6–6	Excellent condition
B-3942	A	31	0.79	6–6	Excellent condition
B-3943	A	62	1.58	6–6	Excellent condition
B-4045	B	67	1.70	6–2	Poor condition, stiffened and cracked
B-4056	B	36	0.91	6–2	Poor condition, stiffened, cracked, with hole development
B-4065	D	62	1.58	6–0	Excellent condition
B-4125	D	31	0.79	5–9	Excellent condition
B-4144	B	62	1.58	5–8	Excellent condition
B-4145	B	32	0.81	5–8	Excellent condition
B-4259	A	32	0.81	5–5	Excellent condition
B-4271	B	64	1.63	5–2	Excellent condition
B-4272	B	34	0.86	5–2	Excellent condition
B-4295	D	32	0.81	4–11	Excellent condition
B-4345	D	105	2.67	4–8	Excellent condition
B-4361	B	96	2.44	4–7	Excellent condition
*B-4371	D	32	0.81	4–6	Excellent condition
B-4372	D	64	1.63	4–5	Excellent condition
B-4522	B	93	2.36	4–1	Good condition, slight shrinkage
B-4629	D	97	2.46	3–7	Excellent condition
B-4630	D	35	0.89	3–7	Excellent condition
B-4631	A	31	0.79	3–7	Excellent condition
B-4632	B	32	0.81	3–7	Excellent condition
B-4634	C	35	0.89	3–7	Excellent condition
B-4637	D	33	0.84	3–7	Excellent condition
B-4638	A	41	1.04	3–7	Excellent condition
B-4644	D	90	2.29	3–7	Excellent condition
B-4680	A	94	2.39	3–6	Excellent condition
B-5059	B	32	0.81	3–0	Excellent condition

*Light gray in color.

Table 9

REINFORCED BUTYL AND UNREINFORCED EPDM RUBBER LINING
Outdoor Exposure Test Results

Sample No.	Manufac-turer	Material type	Thickness mils	Thickness mm	Exposure time years–months	Remarks on physical condition
B-329	A	Glass fiber reinforced butyl	25	0.64	12–6	Excellent condition
B-3957	A	Nylon-reinforced butyl	62	1.58	6–4	Excellent condition
B-4024	A	Nylon-reinforced butyl	31	0.79	6–2	Excellent condition
B-4104	F	Nylon-reinforced butyl	16	0.41	6–0	Excellent condition
B-4306	F	Nylon-reinforced butyl	30	0.76	4–9	Excellent condition
B-4307	F	Cotton-reinforced butyl	25	0.64	4–9	Excellent condition
B-4635	A	Nylon-reinforced butyl	31	0.79	3–7	Excellent condition
B-4985	F	Nylon-reinforced butyl	33	0.84	3–2	Excellent condition
B-4986	F	Nylon-reinforced butyl	50	1.27	3–2	Excellent condition
B-5069	F	Cotton-reinforced butyl	20	0.53	2–4	Excellent condition
B-5070	F	Nylon-reinforced butyl	20	0.53	1–6	Excellent condition
B-5534	F	Nylon-reinforced butyl	16	0.41	1–6	Excellent condition
B-5540	G	Nylon-reinforced butyl	33	0.84	1–6	Excellent condition
B-5555	F	Nylon-reinforced butyl	45	1.14	1–6	Excellent condition
B-5560	H	Nylon-reinforced butyl	31	0.79	1–6	Excellent condition
B-3958	A	EPDM	62	1.58	6–4	Excellent condition
B-4263	D	EPDM	30	0.76	5–4	Excellent condition
B-4346	J	EPDM	34	0.86	4–9	Excellent condition
B-4476	J	EPDM	40	1.02	4–3	Excellent condition
B-4601	C	EPDM	35	0.89	3–9	Excellent condition
B-4602	B	EPDM	63	1.60	3–9	Excellent condition
B-4642	E	EPDM	43	1.09	3–7	Excellent condition
B-5606	D	EPDM	45	1.14	1–6	Excellent condition

were in poor condition, having stiffened and cracked. The latter two linings were of inferior material, undoubtedly a result of faulty compounding or curing at the factory. Other samples from this same manufacturer with about as much exposure time are in excellent condition. The outdoor exposure test equipment provides for the lower one-third of the sample to be submerged, the middle one-third subjected to wetting and drying, and the upper one-third exposed to natural weathering. These different exposure conditions had no noticeable affect on the various rubber lining samples. Figures 10 through 15 show the appearance of various rubber linings after outdoor exposure testing.

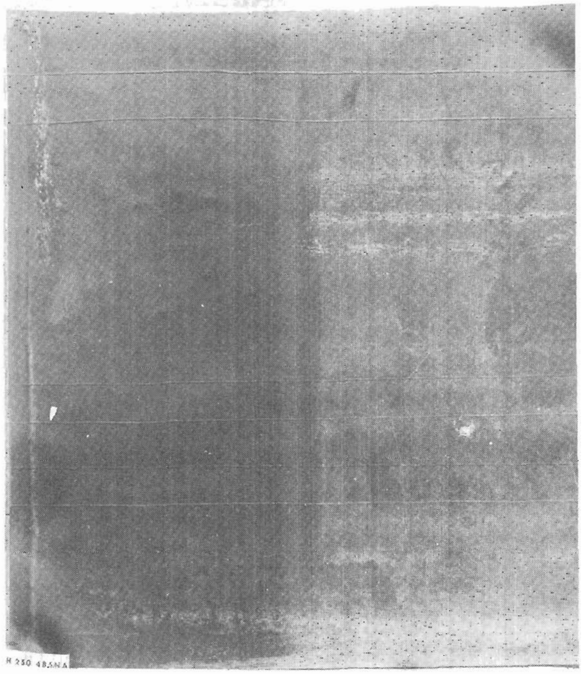


Figure 10. Fiberglass-reinforced, butyl-rubber lining, 25 mils (0.64 mm) thick, in excellent condition after 12-1/2 years' outdoor exposure. Left half of sample was washed. Photo PX-D-68891

Shrinkage

Excessive shrinkage in rubber linings can impair the serviceability of installations. Shrinkage may result in splitting of the lining membrane, pulling the seams apart, or disbonding of the lining from the substrate at bends or corners. This condition necessitates early repairs to an installation that otherwise may be perfectly sound. The results of limited shrinkage tests on unreinforced and nylon-reinforced butyl rubber lining samples, some of which were early formulations, are presented graphically in Figures 16 and 17. It is

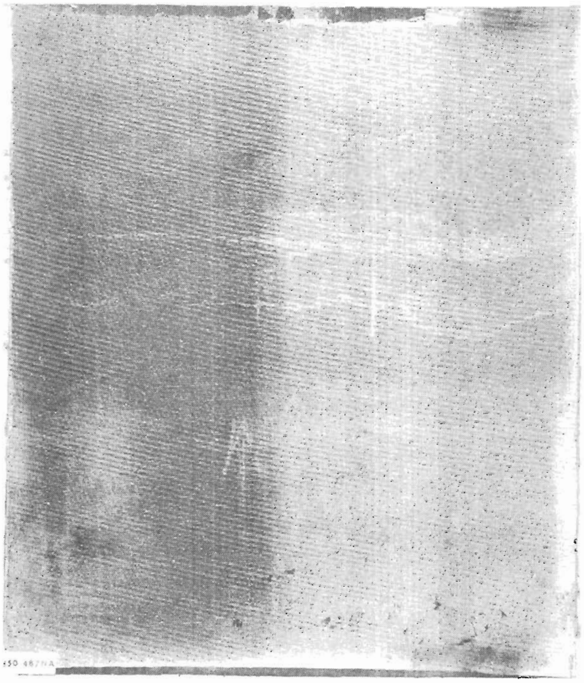


Figure 11. Nylon-reinforced, butyl-rubber lining, 62 mils (1.57 mm) thick, in excellent condition after 6-1/3 years' outdoor exposure. Left half of sample was washed. Photo PX-D-68892

indicated that at temperatures up to 140° F (60° C), it is possible to have 1 percent or more shrinkage with some unreinforced butyl rubber lining materials. At this temperature with nylon-reinforced butyl, shrinkage may be one-half percent or less. With temperatures elevated to 220° F (104.4° C), shrinkage may vary from less than 1 percent to over 5 percent for unreinforced and from less than 1 percent to more than 2 percent for nylon-reinforced butyl. These data generally show that shrinkage could be a problem with some butyl rubber linings and therefore during the installation, the lining should be placed in a very relaxed condition. Where the lining is expected to be subjected to prolonged relatively high temperatures, shrinkage tests should be made of samples of the proposed lining to insure low shrinkage material is being obtained. These shrinkage precautions also apply to EPDM rubber linings.

Splice Cement Test Results

The results of 3-inch (8-cm) overlap splice peel strength tests with eight different cements and three unreinforced and two nylon-reinforced butyl linings of different manufacturers are given in Tables 10, British units, and 10A, metric units. Included are results for cemented splice curing ages of 1 month and 1 year in

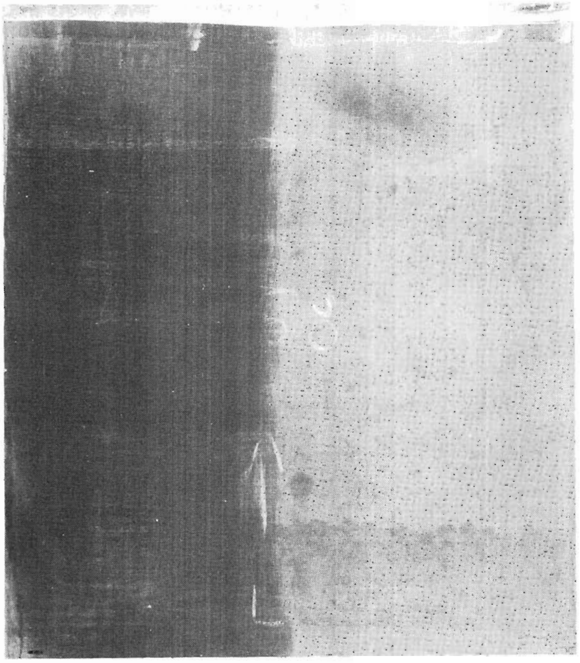


Figure 12. EPDM rubber lining, 62 mils (1.57 mm) thick, in excellent condition after 6-1/2 years' outdoor exposure. Left half of sample was washed. Photo PX-D-68893

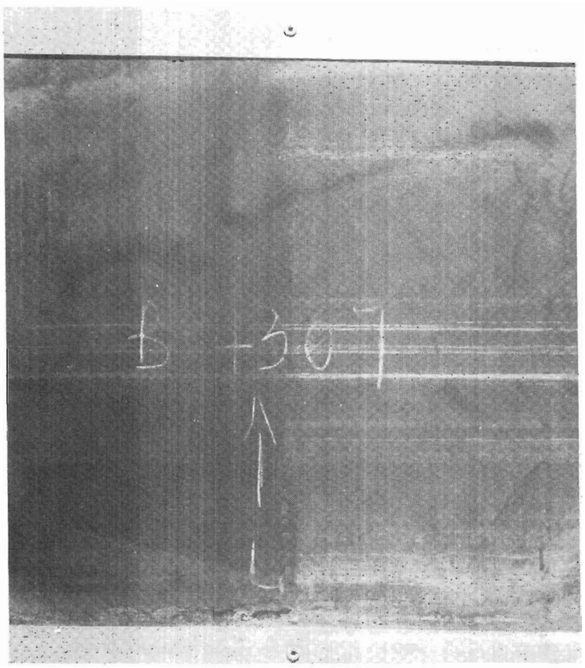


Figure 13. Cotton-reinforced, butyl-rubber lining, 25 mils (0.64 mm) thick, in excellent condition after 4-3/4 years' outdoor exposure. Left half of sample was washed. Photo PX-D-68894

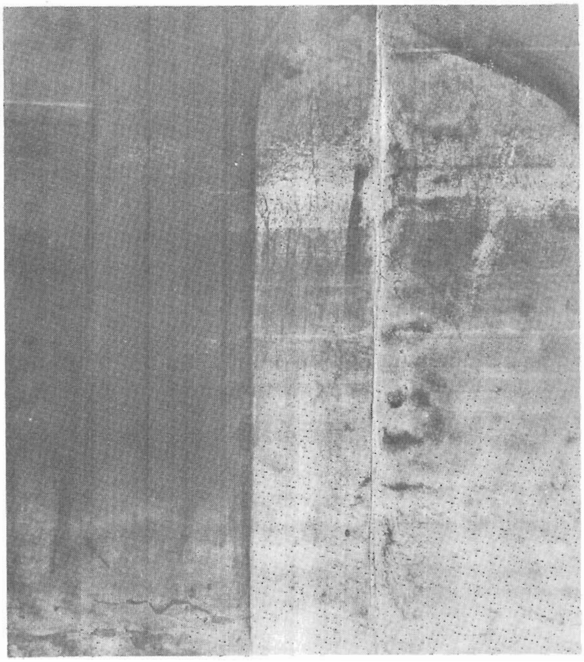


Figure 14. Butyl-rubber lining, 32 mils (0.81 mm) thick, in excellent condition after 9-1/2 years' outdoor exposure. Left half of sample was washed. Photo PX-D-68895

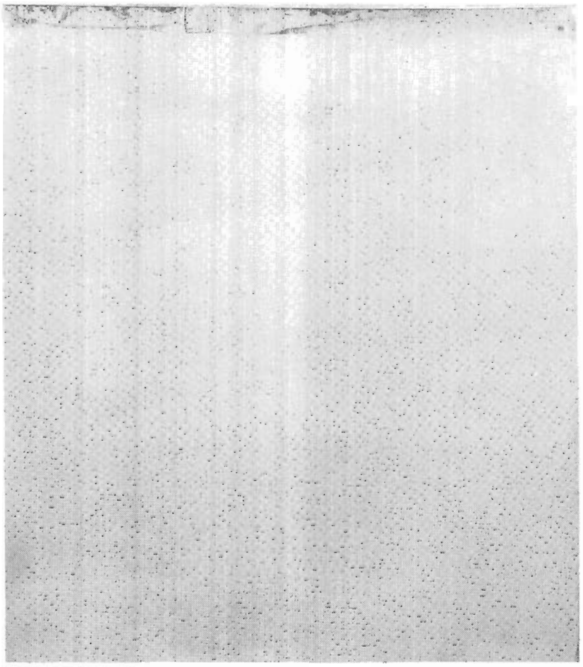


Figure 15. Gray-colored, butyl-rubber lining, 32 mils (0.81 mm) thick, in excellent condition after 4-1/2 years' outdoor exposure. Left half of sample was washed. Photo PX-D-68896

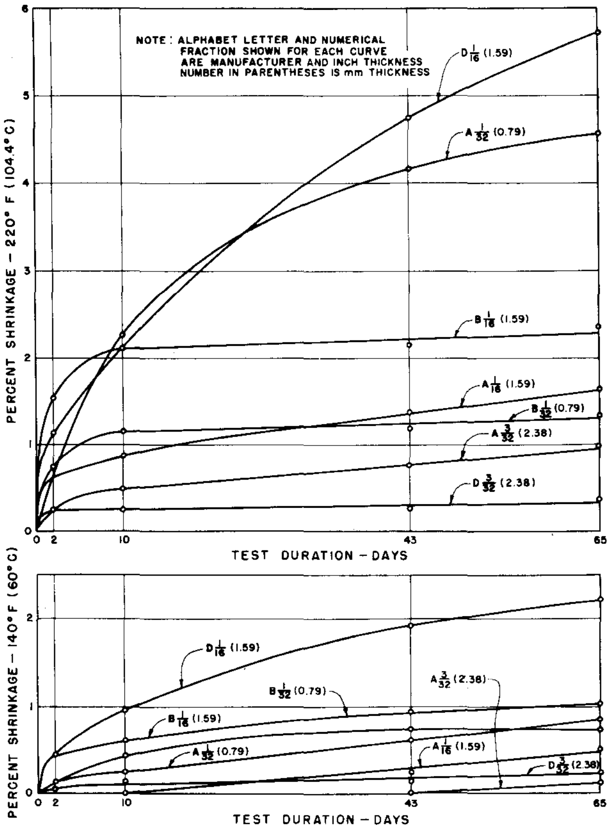


Figure 16. Shrinkage properties of different unreinforced butyl rubber linings exposed to oven temperatures of 140° F (60° C) and 220° F (104.4° C).

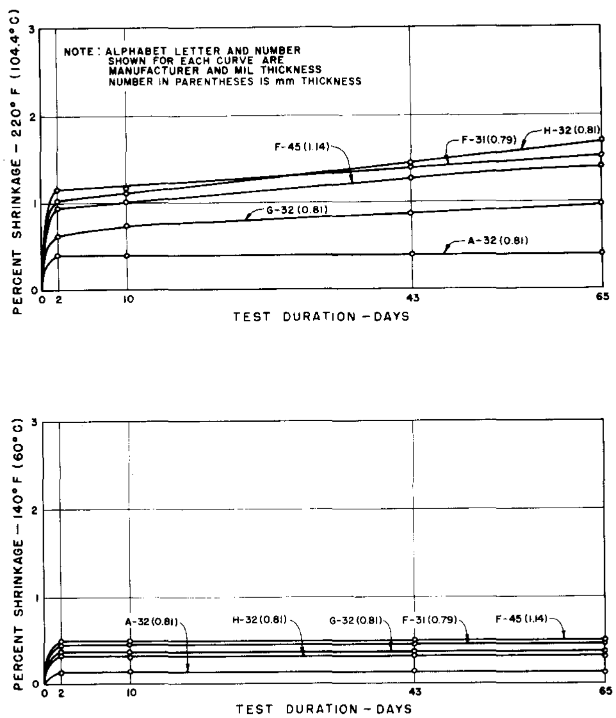


Figure 17. Shrinkage properties of different nylon-reinforced butyl rubber linings exposed to oven temperatures of 140° F (60° C) and 220° F (104.4° C).

air and 1 year submerged in water. Also, both uncleaned and solvent-cleaned rubber lining was used in the splice fabrications. Generally, the results indicate that the bond strength developed by a given cement is different for rubber lining of different manufacturers. No one cement appeared outstanding for all lining materials. With most lining materials and splice cements, solvent cleaning the rubber lining greatly improved bond strength. The data indicated that for most combinations of splice cements and rubber linings with solvent cleaning, bond strength was less at 1 year than 1 month in air and bond strength at 1 year in water was less than at 1 year in air. Bond strength values obtained on splices of nylon-reinforced butyl lining were notably higher than for nonreinforced butyl lining. This is due to less stressing and distortion of the splice area because of the reinforcement.

Tables 11, British units, and 11A, metric units, show splice shear strength data for the same splicing cement and rubber lining materials listed in Tables 10 and 10A for splice peel strength. The average tensile strengths for 1/32-inch (0.79-mm) thick and 1/16-inch (1.59-mm) thick unreinforced butyl rubber lining are 48 and 90 ppi (8.5 and 16.1 kg/cm), respectively. With most splicing cements and rubber linings, the 3-inch (8-cm) wide splice shear strength was stronger than the average strength of 1/32-inch (0.79-mm) thick butyl sheet and weaker than the average strength of 1/16-inch (1.59-mm) thick butyl sheet. For many splicing cements and rubber lining combinations, the splice shear strength would be only about 50 percent of the sheet strength for 1/16-inch (1.59-mm) thickness. This would indicate that a 6-inch (15-cm) wide splice would be required to develop near sheet strength for 1/16-inch (1.59-mm) butyl lining. There is an apparent need for improvement in splicing cements for butyl rubber lining materials. The splice shear strengths developed with the different splicing cements and nylon-reinforced rubber linings were all stronger than the sheet strength of 45-mil (1.14-mm) thick lining.

The splice peel strengths developed by different cements and EPDM rubber linings are given in Table 12. For comparative purposes, the splice peel strengths of butyl linings are also given. Generally, for most EPDM rubber linings the splice peel strengths are lower than for butyl linings. However, by using 4-inch (10-cm) splice width for 1/32-inch (0.79-mm) lining

Table 10

BUTYL- RUBBER LINING
Splice Peel Strength in Pounds Per Inch Width

Splicing cement manufacturer	Sheet cleaning	Butyl-rubber sheeting									Nylon-reinforced butyl sheeting					
		Manufacturer A rubber (B-5518) 1/16-inch thick			Manufacturer B rubber (B-5428) 1/16-inch thick			Manufacturer D rubber (B-5019) 1/16-inch thick			Manufacturer F rubber (B-5555) 45-mil thick			Manufacturer G rubber (B-5540) 32-mil thick		
		air		water	air		water	air		water	air		water	air		water
		1 mo	1 yr	1 yr	1 mo	1 yr	1 yr	1 mo	1 yr	1 yr	1 mo	1 yr	1 yr	1 mo	1 yr	1 yr
A																
One component	None	3.8	3.7	4.5	1.4	2.4	1.5	4.7	3.9	2.0	8.1	7.8	14.0	3.1	5.0	5.0
with gum tape	Hexane	6.1	6.0	5.4	6.1	3.7	2.5	4.4	3.0	2.2	9.2	6.5	13.2	7.5	8.0	9.4
B																
Two component	None	3.5	1.6	0.6	7.7	1.4	1.2	3.6	1.1	1.5	4.7	4.5	3.8	7.6	5.2	3.5
with gum tape	Hexane	6.8	1.9	3.2	8.8	4.5	1.1	4.3	0.7	1.2	13.5	10.5	14.3	15.2	10.5	12.7
D																
Two component	None	2.2	2.2	1.2	2.7	1.5	1.2	0.6	1.0	0.3	3.5	4.8	1.8	3.6	2.3	3.0
with gum tape	Hexane	4.7	3.2	1.3	3.2	2.7	1.1	3.0	1.0	0.5	4.9	4.4	3.0	4.0	3.5	2.0
F	None	3.5	4.5	1.7	7.3	7.0	5.0	1.6	1.4	0.6	14.8	9.9	12.6	5.0	4.4	3.1
One component	Hexane	4.9	5.2	3.6	8.5	8.6	6.0	1.1	1.1	1.1	12.6	9.4	*	6.3	7.2	6.3
K	None	3.0	3.3	3.2	10.6	10.5	7.2	1.2	1.7	1.5	19.4	15.7	*	6.5	4.1	4.4
One component	Hexane	7.9	6.7	5.5	11.2	11.5	6.2	2.2	1.1	1.4	22.6	*	*	8.0	5.8	5.4
L	None	5.8	8.0	4.0	12.9	15.2	11.5	4.0	3.0	2.1	16.6	22.4	12.6	7.9	4.0	3.6
One component	Hexane	18.2	16.5	12.3	16.3	14.4	13.6	4.3	2.7	1.5	33.2	34.0	10.4	14.0	12.5	11.0
M																
One component	None	4.1	4.0	4.0	9.0	14.3	10.2	1.3	1.4	1.3	8.2	10.5	*	7.8	4.1	5.9
No. 10	Hexane	10.8	5.5	7.8	6.5	15.8	11.5	1.3	1.4	0.8	12.3	*	*	13.4	9.0	9.2
M																
One component	None	4.4	6.1	4.7	14.0	11.6	10.4	3.5	2.0	2.0	19.5	*	*	6.0	5.4	7.6
No. 20	Hexane	8.8	7.9	6.9	16.4	17.0	15.1	3.5	1.9	1.5	17.6	*	*	17.5	10.7	10.7

*Splice stronger than bond strength of butyl coating to nylon fabric.
3-inch (8-cm) wide splice used.

Table 10A

BUTYL-RUBBER LINING

Splice Peel Strength in Kilograms Per Centimeter Width

Splicing cement manufacturer	Sheet cleaning	Butyl-rubber sheeting									Nylon-reinforced butyl sheeting					
		Manufacturer A rubber (B-5518) 1.59-mm thick			Manufacturer B rubber (B-5428) 1.59-mm thick			Manufacturer D rubber (B-5019) 1.59-mm thick			Manufacturer F rubber (B-5555) 1.14-mm thick			Manufacturer G rubber (B-5540) 0.81-mm thick		
		air		water	air		water	air		water	air		water	air		water
		1 mo	1 yr	1 yr	1 mo	1 yr	1 yr	1 mo	1 yr	1 yr	1 mo	1 yr	1 yr	1 mo	1 yr	1 yr
A One component	None	0.68	0.66	0.80	0.25	0.43	0.27	0.84	0.70	0.36	1.45	1.39	2.50	0.55	8.93	8.93
with gum tape	Hexane	1.09	1.07	0.96	1.09	0.66	0.45	.79	.54	.39	1.64	1.16	2.36	1.34	1.43	1.68
B Two component	None	0.63	0.29	0.11	1.38	0.25	0.21	.64	.20	.27	0.84	0.80	0.68	1.36	0.93	0.63
with gum tape	Hexane	1.21	0.34	0.57	1.57	0.80	0.20	.77	.13	.21	2.41	1.88	2.55	2.71	1.88	2.27
D Two component	None	0.39	0.39	0.21	0.48	0.27	0.21	.11	.18	.05	0.63	0.86	0.32	0.64	0.41	0.54
with gum tape	Hexane	0.84	0.57	0.23	0.57	0.48	0.20	.18	.07	.05	0.88	0.79	0.54	0.71	0.63	0.36
F	None	0.63	0.80	0.30	1.30	1.25	0.89	.29	.25	.11	2.64	1.77	2.25	0.89	0.79	0.55
One component	Hexane	0.88	0.93	0.64	1.52	1.54	1.07	.20	.20	.20	2.25	1.68	*	1.13	1.29	1.13
K	None	0.54	0.59	0.57	1.89	1.88	1.29	.21	.30	.27	3.46	2.80	*	1.16	0.73	0.79
One component	Hexane	1.41	1.20	0.98	2.00	2.05	1.11	.39	.20	.25	4.04	*	*	1.43	1.04	0.96
L	None	1.04	1.43	0.72	2.30	2.71	2.05	.71	.54	.38	2.96	4.00	2.25	1.41	0.71	0.64
One component	Hexane	3.25	2.95	0.22	2.91	2.57	2.43	.77	.48	.27	5.93	6.07	1.86	2.50	2.23	3.98
M One component	None	0.73	0.71	0.71	1.61	2.55	1.82	.23	.25	.23	1.46	1.88	*	1.39	0.73	1.05
No. 10	Hexane	1.93	0.98	1.39	1.16	2.82	2.05	.23	.25	.14	2.20	*	*	2.39	1.61	1.64
M One component	None	0.79	1.09	0.84	2.50	2.07	1.86	.63	.36	.36	3.48	*	*	1.07	0.96	1.36
No. 20	Hexane	1.57	1.41	1.23	2.93	3.04	2.70	.63	.34	.27	3.14	*	*	3.13	1.91	1.91

*Splice stronger than bond strength of butyl coating to nylon fabric.
3-inch (8-cm) wide splice used.

Table 11

BUTYL-RUBBER LINING
Splice Shear Strength in Pounds Per Inch Width

Splicing cement manufacturer	Sheet cleaning	Butyl-rubber sheeting						Nylon-reinforced butyl sheeting			
		Manufacturer A rubber (B-5518) 1/16-inch thick		Manufacturer B rubber (B-5428) 1/16-inch thick		Manufacturer D rubber (B-5019) 1/16-inch thick		Manufacturer F rubber (B-5555) 45-mil thick		Manufacturer G rubber (B-5540) 32-mil thick	
		air 1 mo	water 1 yr	air 1 mo	water 1 yr	air 1 mo	water 1 yr	air 1 mo	water 1 yr	air 1 mo	water 1 yr
A One component	None	36	65	29	61	35	40	*71	*48	*160	*110
with gum tape	Hexane	51	72	41	69	33	38	*71	*58	*96	*72
B Two component	None	36	45	*57	48	37	55	*78	–	*126	–
with gum tape	Hexane	57	63	45	45	38	54	*76	–	*147	–
D Two component	None	21	29	15	23	25	19	73	*59	*73	*60
with gum tape	Hexane	35	31	17	28	27	19	*77	*55	*80	*71
F	None	41	36	39	39	18	21	*75	–	*162	–
One component	Hexane	48	51	41	38	21	16	*73	–	*180	–
K	None	35	38	55	47	17	18	*92	–	*167	–
One component	Hexane	63	58	47	41	20	20	*69	–	*113	–
L	None	63	71	57	65	28	39	*76	*60	*147	*95
One component	Hexane	*93	105	58	62	36	43	*76	*60	*153	*95
M One component	None	47	43	64	*69	28	21	*88	–	*174	–
No. 10	Hexane	83	93	55	*69	25	19	*85	–	*105	–
M One component	None	50	50	*65	64	32	27	*90	–	*124	–
No. 20	Hexane	66	76	*61	*64	34	27	*77	–	*162	–

*Indicates rubber sheet ruptured without seam failure.
3-inch (8-cm) wide splice used.

Table 11A

BUTYL-RUBBER LINING

Splice Shear Strength in Kilograms Per Centimeter Width

Splicing cement manufacturer	Sheet cleaning	Butyl-rubber sheeting: Manufacturer A rubber (B-5518) 1.59-mm thick		Manufacturer B rubber (B-5428) 1.59-mm thick		Manufacturer D rubber (B-5019) 1.59-mm thick		Nylon-reinforced butyl sheeting: Manufacturer F rubber (B-5555) 1.14-mm thick		Manufacturer G rubber (B-5540) 0.81-mm thick	
		air 1 mo	water 1 yr	air 1 mo	water 1 yr	air 1 mo	water 1 yr	air 1 mo	water 1 yr	air 1 mo	water 1 yr
A One component with gum tape	None	6.4	11.6	5.2	10.9	6.3	7.1	12.7	8.6	17.1	19.6
	Hexane	9.1	12.9	7.3	12.3	5.9	6.8	12.7	10.4	28.6	12.9
B Two component with gum tape	None	6.4	8.0	10.2	8.6	6.6	9.8	13.9	–	22.5	–
	Hexane	10.2	11.3	8.0	8.0	6.8	9.6	13.6	–	26.3	–
D Two component with gum tape	None	3.8	5.2	2.7	4.1	4.5	3.4	13.0	10.5	13.0	10.7
	Hexane	6.3	5.5	3.0	5.0	4.8	3.4	13.8	9.8	14.3	12.7
F One component	None	7.3	6.4	7.0	7.0	3.2	3.8	13.4	–	28.9	–
	Hexane	8.6	9.1	7.3	6.8	3.8	2.9	13.0	–	32.1	–
K One component	None	6.3	6.8	9.8	8.4	3.0	3.2	16.4	–	29.8	–
	Hexane	11.3	10.4	8.4	7.3	3.6	3.6	12.3	–	20.2	–
L One component	None	11.3	12.7	10.2	11.6	5.0	7.0	13.6	10.7	26.3	17.0
	Hexane	16.6	18.8	10.4	11.1	6.4	7.7	13.6	10.7	27.3	17.0
M One component No. 10	None	8.39	7.7	11.4	12.3	5.0	3.8	15.7	–	31.1	–
	Hexane	14.8	16.6	9.8	12.3	4.5	3.4	15.2	–	18.8	–
M One component No. 20	None	8.9	8.9	11.6	11.4	5.7	4.8	16.1	–	22.1	–
	Hexane	11.8	13.6	10.9	11.4	6.1	4.8	13.8	–	28.9	–

*Indicates rubber sheet ruptured without seam failure.
3-inch (8-cm) wide splice used.

Table 12

BUTYL AND EPDM RUBBER LINING
Splice Peel Strength

Splicing cement manufacturer	Splice peel strength in pounds per inch width at 30 days' age							
	Manufacturer A		Manufacturer B		Manufacturer D		Manufacturer C	Manufacturer J
	Butyl B-5518	EPDM B-3958	Butyl B-5428	EPDM B-4602	Butyl B-5019	EPDM B-4597	EPDM B-4601	EPDM B-4476
A One component	6.1 (1.0)	3.0 (0.5)	6.1 (1.0)	6.5 (1.2)	4.4 (0.8)	2.9 (0.5)	3.4 (0.6)	2.7 (0.5)
B Two component	6.8 (1.2)	5.3 (0.9)	8.8 (1.6)	4.1 (0.7)	4.3 (0.8)	4.7 (0.8)	5.1 (0.9)	3.5 (0.6)
D Two component	4.7 (0.8)	3.1 (0.6)	3.2 (0.6)	3.5 (0.6)	3.0 (0.2)	3.3 (0.6)	3.4 (0.6)	2.3 (0.4)
F One component	4.9 (0.9)	0.4 (0.1)	8.5 (1.5)	2.0 (0.3)	1.1 (0.2)	1.0 (0.2)	1.5 (0.3)	2.8 (0.5)
K One component	7.9 (1.4)	0.6 (0.1)	11.2 (2.0)	3.4 (0.6)	2.2 (0.4)	1.8 (0.3)	0.8 (0.1)	3.1 (0.6)

Note: Values in parentheses are splice peel strengths in kilograms per centimeter width at 30 days.
3-inch wide (8-cm) wide splice used.
Gum tape was used in all test splices.

and 6-inch (15-cm) splice width for 1/16-inch (1.59-mm) lining, adequate splice strength should be developed with EPDM rubber.

Data on splice peel strengths for a variety of splicing cements cured in air and water for 28 days are presented in Table 13. Of the 17 splicing cements tested with butyl rubber, none was considered outstanding. Six cement materials showed peel strength values normally expected with standard cements. There was no significant difference in bond strength development for air and water curing conditions at 28 days.

The results of limited tests conducted on peel strength of rubber lining bonded to concrete are shown in Table 14. It is indicated that splicing cement is superior to standard substrate adhesive for bonding butyl lining to concrete. Especially after 2 and 7 years aging, the splicing cement showed less reduction in bond strength under water and outdoor exposure conditions. The advantage of the standard substrate adhesive is that it is considerably less costly.

FIELD INVESTIGATIONS

General

Butyl rubber lining, both unreinforced and nylon-reinforced, have been installed in canals on several Bureau projects for evaluation purposes. These installations were made on the W. C. Austin Project, Oklahoma; Tucumcari and Carlsbad Projects, New Mexico; Boulder Canyon Project, Arizona-Nevada-California; Central Valley Project, California; and Shoshone Project, Wyoming. A reservoir lining of nylon-reinforced butyl rubber lining was installed on the Chief Joseph Dam Project, Washington. The first lining installation was made on the W. C. Austin Project in 1961, where butyl rubber sheeting was used as both buried and exposed membrane.

Service Evaluation

Field evaluations made periodically have shown that 1/32-inch (0.79-mm) thick butyl rubber sheeting installed as buried membrane is performing satisfactorily.

In the spring of 1965 and 1970, examinations were made of buried 1/32-inch (0.79-mm) thick butyl rubber lining on the Tucumcari Project after 4 and 9 years' service. Excavations were made in the cover material to expose the rubber lining to evaluate the material condition and to obtain samples for laboratory testing. The butyl rubber lining was observed to be in good condition providing a watertight membrane. It was noted that the rubber lining could be treated quite roughly, by scraping action of shovels during the uncovering operation, without resulting in damage. The results of laboratory tests on the 9-year-old rubber lining sample, including physical properties tests and pressure cell puncture resistance tests, are presented in Table 15. It is indicated that there was essentially no change in physical properties after 9 years' field aging. The rubber lining was still well within the limits of the Bureau specifications requirements. The pressure cell test results show that the puncture resistance of the 9-year-old rubber lining sample is higher than obtained on a typical original sample.

To determine the watertightness of buried rubber lining, ponding seepage tests were conducted on a 3-year-old, 1/32-inch (0.79-mm) thick butyl installation on the W. C. Austin Project. After correcting for evaporation, the seepage loss was determined to be 0.04 cfd (cu ft/sq ft/day) (12.2 l/m^2/day). This is indicative of a watertight lining.

Butyl rubber lining, 1/16 inch (1.59 mm) thick, was installed in 1961, as exposed lining on the W. C. Austin Project. The lining was placed on prepared subgrade with its edges buried in anchor trenches along the canal berms. With the exception of a minor hole repair due to vandalism, this test lining has performed very satisfactorily for 9 years. The results of a laboratory analysis conducted on a sample of this 9-year-old lining is given in Table 15. The data show that the physical properties of the exposed lining have changed very little; the material still meeting Bureau of Reclamation specifications requirements. There was no change noted in its puncture resistance as indicated by the puncture cell test.

During May 1964, 1/32-inch (0.79-mm) thick butyl rubber lining was installed in the Fern Canal, Imperial Irrigation District, California. The lining was installed as exposed membrane; however, the upper portion of this liner from about 1 foot (30 cm) below high water surface was installed as buried-type lining to minimize vandalism and to prevent damage during cleaning. Since water was kept in the canal year around, the water cover served to protect the exposed butyl lining from vandalism. At the end of 3 years, the lining was in satisfactory condition and no serious deterioration was evident.

Table 13

BUTYL-RUBBER LINING
Splice Peel Strength

Bonding material manufacturer	Type bonding material	28-day aging condition			
		air		water immersion	
		ppi	kg/cm	ppi	kg/cm
A	Single component rubber cement	6.2	1.1	6.2	1.1
A	Single component, butyl base	8.9	1.6	6.8	1.2
B	Two component, butyl base	6.7	1.2	6.0	1.1
D	Two component, butyl base	7.3	1.3	5.6	1.0
N	Single component rubber cement	5.4	1.0	4.8	0.9
O	Single component, butyl base	7.2	1.3	7.6	1.4
P	Two component, neoprene	4.8	0.9	4.4	0.8
Q	Epoxy resin	3.8	0.7	2.2	0.4
R	Plastic resin	0.4	0.1	0.4	0.1
S	Single component rubber cement	3.7	0.7	3.1	0.6
S	Single component rubber cement	5.3	0.9	5.4	1.0
T	Single component rubber cement	1.5	0.3	1.0	0.2
T	Single component rubber cement	3.4	0.6	3.5	0.6
T	Single component rubber cement	2.1	0.4	1.8	0.3
U	Single component rubber cement	5.6	1.0	3.7	0.7
V	Single component prime coat	1.9	0.3	1.8	0.3
W	Two component, butyl base	7.2	1.3	4.5	0.8

Manufacturer A, 1/16-inch (1.59-mm) thick butyl sheet used in all tests.
Bonded areas of rubber sheet were cleaned by solvent wipe.
3-inch (8-cm) wide splice used.

Table 14

BUTYL-RUBBER LINING
Peel Strength of Rubber Lining Bonded to Concrete

Type bonding material	Aging condition	Aging time					
		Original		2 years		7 years	
		ppi	kg/cm	ppi	kg/cm	ppi	kg/cm
Manufacturer A splice cement	Room protected from light	8.2	1.5	6.4	1.1	6.6	1.2
	Water immersion	8.2	1.5	4.1	0.7	4.2	0.8
	Outdoors	8.2	1.5	5.2	0.9	5.2	0.9
Manufacturer A substrate adhesive	Room protected from light	7.8	1.4	6.3	1.1	5.5	1.0
	Water immersion	7.8	1.4	2.2	0.4	2.6	0.5
	Outdoors	7.8	1.4	4.3	0.8	3.9	0.7

Note: 2-inch (5-cm) wide strips of 1/16-inch (1.59-mm) thick Manufacturer A rubber sheeting was used for bonding tests to concrete.

Table 15

LABORATORY TEST RESULTS ON FIELD SAMPLES OF BURIED AND EXPOSED BUTYL-RUBBER LINING
Physical Properties Test Results

Physical properties	USBR specifications	Typical original results	B-6095, 9-year-old buried field sample Tucumcari Project	B-6097, 9-year-old exposed field sample W. C. Austin Project
Thickness, inches	1/32 or 1/16 minimum	1/32+ and 1/16+	1/32+	1/16+
Specific gravity	1.25 ± 0.08	1.20	1.25	1.22
Tensile strength, psi	1,200 minimum	1,400	1,480	1,460
Elongation, percent	300 minimum	380	355	310
Modulus at 300 percent elongation, psi	600 minimum	1,250	1,330	1,450
Shore "A" hardness	60 ± 10	54	57	51
Ozone resistance at 7 days (50 pphm at 100° F and 20 percent elongation)	No cracks	No cracks	No cracks	No cracks
Heat aging (7 days at 240° F)				
Tensile strength retained, percent of original	70 minimum	71	87	93
Elongation retained, percent of original	70 minimum	93	98	99
Tricresyl phosphate immersion (70 hours at 212° F) volume swell, percent	10 maximum	1.0	1.14	3.64
Tear resistance, psi	150 minimum	200	175	180

Typical original results are from tests made on material similar to field sample (from same manufacturer). Original field samples were not available for testing.

PRESSURE CELL PUNCTURE RESISTANCE TESTS
Tested Over 3/4- to 1-1/2-inch (2- to 4-cm) Size Rock

Test material	Water pressure at puncture		
	psi	kg/cm^2	puncture time
Typical original, 1/32-inch (0.79-mm) thick butyl lining	40.0	2.81	After 2 hours
Typical original, 1/16-inch (1.59-mm) thick butyl lining	55.0	3.87	No puncture after 7 days
B-6095, 9-year-old, 1/32-inch (0.79-mm) thick buried field sample	55.0	3.87	After 3 days
B-6097, 9-year-old, 1/16-inch (1.59-mm) thick exposed field sample	55.0	3.87	No puncture after 7 days

Where the possibility of damage to exposed butyl rubber membrane is low, it is suited to lining sections of old leaky concrete canals and reservoirs. This is especially so where the canal or reservoir can be taken out of service for only a short time, thus making standard repairs an impossibility.

In 1964, a 400-foot (122-m) section of concrete lining in the Contra Costa Canal, Central Valley Project, was lined with 1/32-inch (0.79-mm) thick butyl rubber sheeting. The canal has a Q of 155 cfs (4.39 m^3/sec) and a V of 2.74 feet per second (84 m/sec). With some repairs, this lining is performing satisfactorily.

In 1966, exposed butyl rubber lining 1/32 inch (0.79 mm) thick was installed over concrete lining in the Main and Black River Canals and over earth subgrade in Lateral 24, all on the Carlsbad Project, New Mexico. After 3 years, the general condition of the lining in the Main Canal was good. There were several small tears and several holes, apparently from gunshots, noted in the lining. The Black River Canal lining contained several small holes and loose joints. Also, there was some damage to the top edge of the lining due to weed burning. The butyl lining in Lateral 24 was located in a pasture where cattle trampled in and out of the lateral, causing tears on the slopes. Considering the severity of this treatment, the lining performed remarkably well.

The Bureau has experienced two rubber lining failures installed over concrete lining in canals. In the Delta-Mendota Canal, Central Valley Project, rubber lining installed in 1965 underwent severe shrinkage after 2 years, necessitating extensive repairs. The shrinkage caused the liner to pull loose from the concrete at the toe of the slopes and at the upstream and downstream ends. Later, the fast-flowing water in this large canal, 48-foot (15-m) bottom, began pulling the lining loose at the downstream end. Other lining areas soon loosened and eventually the lining was removed. In another installation in a 240-foot (73-m) section of the Heart Mountain Canal, Shoshone Project, butyl rubber liner failed after 1 year of service making necessary its removal. Failure is believed to have resulted from a rock falling from an adjacent cliff and puncturing the rubber allowing water to get between the rubber and concrete lining.

During March 1966, 1/16-inch (1.59-mm) thick nylon-reinforced butyl rubber liner was installed over the surface of the concrete-lined regulating reservoirs on East Unit, Greater Wenatchee Division, Chief Joseph Dam Project. Three reservoirs, 2,000,000-gallon (7,570,000 l), 150,000-gallon (568,000 l), and 75,000-gallon (284,000 l) capacities, were lined requiring approximately 54,000 square feet (5,017 m^2) of rubber sheeting. All three installations are performing excellent service. Some minor maintenance of joints has been necessary.

Butyl rubber lining has been used successfully as a vertical cutoff curtain and as a watertight membrane under reinforced concrete canal lining. The cutoff curtain installation was completed in 1964, on the downhill side of the East Low Canal, Columbia Basin Project, Washington. Butyl membrane under concrete lining was installed in 1964, as a repair measure in the Heart Mountain Canal, Shoshone Project, Wyoming. This canal is situated over cavernous limestone rock where seepage through the concrete lining joints and cracks causes loss of the supporting foundation rock. This subsequently results in the collapse of the concrete lining and the irrigation water completely disappears into the limestone formation. This problem has been corrected by use of the butyl rubber membrane under the concrete lining. Since the initial installation, several similar repairs have been made.

In summarizing the Bureau's field experience, it has been demonstrated that butyl rubber lining can be used satisfactorily as buried membrane in canals. Although it is highly durable when exposed, rubber lining is subject to damage by physical forces such as livestock, falling rock, etc., and by vandalism. Therefore, exposed butyl rubber lining is practical in installations only where physical damage is considered negligible. Even then it should normally be used only in canal systems that carry water the year around.

Rubber sheeting can be successfully used as a liner over old concrete lining in canals and reservoirs. For these installations, nylon-reinforced butyl rubber lining is favored. In canals where flowing water acts upon the lining, it is necessary that utmost attention be given to design details for satisfactorily bonding and anchoring the rubber liner to the concrete. The rubber lining has miscellaneous uses such as waterproofing concrete pipe and control structures, underseal of concrete lining, and as cutoff curtains to stop leakage in localized areas.

RUBBER LINING CONSTRUCTION

Buried Membrane Lining

Ordinarily it would not be expected that rubber sheeting would be selected for buried membrane lining because of the availability of less costly membrane materials. Where service conditions require the use of rubber lining, butyl or EPDM rubber sheeting can readily be installed in canals and reservoirs as buried membrane. Construction of buried rubber lining in canals requires that the canal cross section be overexcavated a minimum of 1 foot (30 cm) to provide for placement of protective cover material. The side slopes should be sufficiently flat to produce a stable condition for maintaining the cover material on the slopes under operating conditions. The proper side slope will depend upon the type of cover material used; and under the best of conditions, the slope should not exceed 2:1. For 2:1 slopes, it is recommended that the protective cover consist of a free-draining irregularly shaped sandy to gravelly material. Bureau experience has shown that a canal cross section as detailed in Figure 18 produces the best design for stable cover and good operating conditions for buried membrane linings.

After the rough excavation is completed, the canal subgrade should be prepared to a firm, relatively smooth surface. Sharp rocks, roots, and other objects that might puncture the membrane should be removed or padded by covering with 3 or 4 inches (8 or 10 cm) of sand or fine-textured soil. Dragging the subgrade with a heavy marine-type chain or crawler-tractor track has proven to be a rapid and effective method for smoothing canal subgrades. Normally, rolling the subgrade is not necessary; however, if the subgrade is unusually irregular, soft, or contains considerable cloddy material, compacting and smoothing the subgrade can be accomplished by steel cylindrical rolling. For the bottom, pneumatic rubber-tired rollers have been used with good success. Anchor trenches 1-foot (30-cm) deep or berms about 18 inches (46 cm) wide are needed along the canal slopes for burying the edges of the rubber lining.

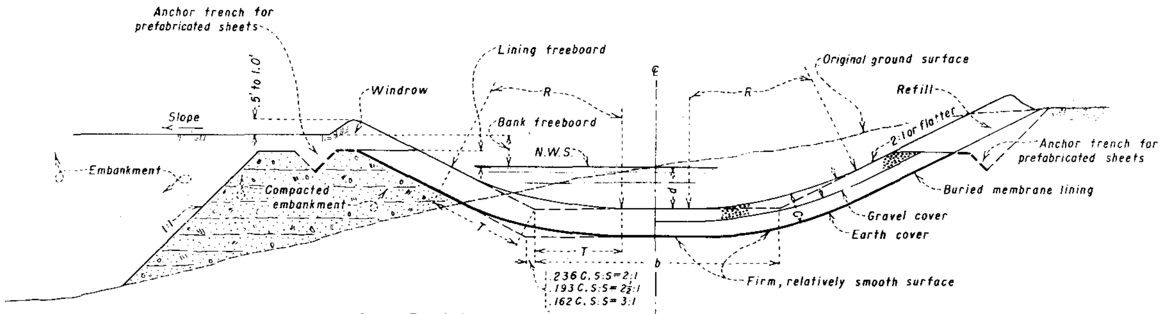
Butyl or EPDM rubber lining 1/32 inch (0.79 mm) thick can be supplied in large, shop-fabricated widths and to any length practical for handling. The lining is folded several times and then rolled on a cardboard core for shipment to the jobsite. When installing, the lining is unrolled into the bottom of the canal, then unfolded, and placed into position. Butyl rubber being installed as buried membrane is shown in Figure 19. Installation is normally begun at the downstream end. When tied into concrete structures, the ends of the rubber lining are bonded to the concrete surface with rubber cement. Where not tied into structures, the ends of the rubber lining should be buried into 12-inch (30-cm) deep transverse cutoff trenches. It is important that the rubber lining be placed in a slack condition. Also, in any installation it is recommended that the rubber lining be unrolled and allowed to relax the maximum allowable time before it is spliced. Sections of the rubber lining are joined by using 4-inch (10-cm) wide overlap splices for 1/32-inch (0.79-mm) lining and 6-inch (15-cm) wide overlap splices for 1/16-inch (1.59-mm) lining bonded together with rubber cement and gum tape. The splicing methods and adhesive system used should be that recommended by the manufacturer of the rubber lining. The edges of the rubber lining should be buried in anchor trenches or berms at the time of placement to prevent removal of the lining by unexpected wind gusts. Protective cover placement should begin as soon as the rubber lining is judged to be properly positioned, jointed, and repaired if necessary. The cover material can be placed with draglines, conveyors, or by other means, preferably starting in the invert and working upslope.

The same general procedures for construction of buried rubber lining in canals applies to reservoirs. The subgrade preparation and placement of the rubber lining is the same. For reservoir lining, generally rubber sheeting strips in sizes 10 to 20 feet (3 to 6 m) wide by 100 to 200 feet (30 to 61 m) long are field spliced together to cover the bottom and side slopes. On the side slopes, it is recommended that the rubber lining strips be placed with the long dimension running up and down the slopes. This provides for easier field splicing and also the splices in this direction are less stressed than if placed horizontally along the side slopes. In splicing rubber sheets in reservoir lining, either the 4-inch (10-cm) overlap joint or butt joints with 8-inch (20-cm) wide cap strips and 6-inch (15-cm) overlap joint or butt joints with 12-inch (30-cm) wide cap strips can be used.

The joints are bonded and sealed with rubber adhesive and gum tape. With reservoirs where damage to the rubber lining by livestock or mechanical means is not expected and earth cover is necessary to prevent removal by wind at times when reservoir is empty, the thickness of the cover material in the bottom may be reduced to 6 inches (15 cm). Because of wave action, protective cover thickness of 1 foot (30 cm) or more is advisable on the side slopes.

Exposed Lining

In earth subgrade canals and reservoirs, exposed rubber lining is constructed the same as for buried membrane with the exception that overexcavation and earth cover are eliminated from the bottom and sometimes the side slopes. For successful operation, it is best to place exposed rubber lining in installations that continually carry or contain water. The water cover discourages vandalism and provides some protection from physical forces. Also, in unwatered systems, wind uplift may damage or remove the lining. In reservoir lining installations continually covered with water, it may be desirable to earth cover the side slopes to provide

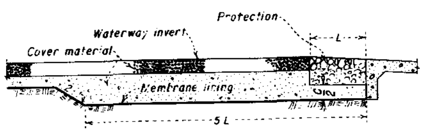


SINGLE LAYER COVER

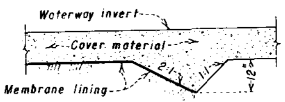
DOUBLE LAYER COVER

TRANSVERSE SECTION OF WATERWAY

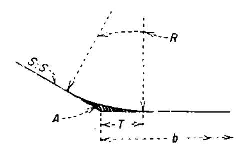
$C = 10'' + \frac{d}{12}$; Where C is in inches and d is water depth in inches. (12" Min.)



LONGITUDINAL SECTION
MEMBRANE AT STRUCTURES



LONGITUDINAL SECTION
METHOD OF ENDING MEMBRANE



b	T	S:S = 2:1, R=4.23608 T, ΔWP=.00850 R, A=.00425 R²			S:S = 2½:1, R=5.19259 T, ΔWP=.00466 R, A=.00233 R²			S:S = 3:1, R=6.16226 T, ΔWP=.00280 R, A=.00140 R²		
		R	2ΔWP	2A	R	2ΔWP	2A	R	2ΔWP	2A
2	1.0	4.24	.07	.15	5.19	.05	.13	6.16	.03	.11
3	1.0	4.24	.07	.15	5.19	.05	.13	6.16	.03	.11
4	1.0	4.24	.07	.15	5.19	.05	.13	6.16	.03	.11
5	1.5	6.35	.11	.34	7.79	.07	.28	9.24	.05	.24
6	2.0	8.47	.14	.61	10.39	.10	.50	12.32	.07	.42
8	2.8	11.86	.20	1.20	14.54	.14	.99	17.25	.10	.83
10	3.5	14.83	.25	1.87	18.17	.17	1.54	21.57	.12	1.30
12	4.3	18.22	.31	2.82	22.33	.21	2.32	26.50	.15	1.97
14	5.0	21.18	.36	3.81	25.96	.24	3.14	30.81	.17	2.66
16	5.5	23.30	.40	4.61	28.56	.27	3.80	33.89	.19	3.22
18	6.0	25.42	.43	5.49	31.16	.29	4.52	36.97	.21	3.83
20	6.5	27.53	.47	6.44	33.75	.31	5.31	40.05	.22	4.49
22	7.0	29.65	.50	7.47	36.35	.34	6.16	43.14	.24	5.21
24	7.5	31.77	.54	8.58	38.94	.36	7.07	46.22	.26	5.98
26	7.9	33.47	.57	9.52	41.02	.38	7.84	48.68	.27	6.64
28	8.3	35.16	.60	10.51	43.10	.40	8.66	51.15	.29	7.33
30	8.7	36.85	.63	11.54	45.18	.42	9.51	53.61	.30	8.05
35	9.5	40.24	.68	13.76	49.33	.46	11.34	58.54	.33	9.60
40	10.5	44.48	.76	16.82	54.52	.51	13.85	64.70	.36	11.72
45	11.2	47.44	.81	19.13	58.16	.54	15.76	69.02	.39	13.34
50	12.0	50.83	.86	21.96	62.31	.58	18.09	73.95	.41	15.31

NOTES

The gradation, type and thickness of the cover material is dependent on tractive forces and velocities in the section, and the type of material available in the area.

ΔWp is the difference between 2T and the arc length. To obtain the wetted perimeter for a section, subtract 2ΔWp from the wetted perimeter for a trapezoidal section of width b.

A is the area of the fillet. To obtain the area for a section, subtract 2A from the area of a trapezoidal section of width b.

For freeboard see 103-D-341.

Figure 18. Details of buried membrane linings.

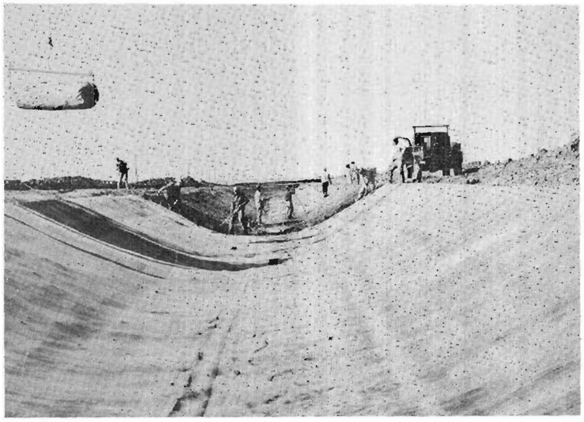


Figure 19. Installing 1/32-inch (0.79-mm) thick, butyl-rubber lining (April 1961) in Bugg Lateral on Tucumcari Project, New Mexico. Lining was covered with 1-foot (0.3-m) thick earth material. Photo P257-D-25948

protection to the lining during fluctuating water levels. In installations that are fenced and therefore protected from physical damage, the slope lining may remain exposed. In canals, it is necessary to cover only that portion of the side slopes above the normal operating waterline. An installation of this type is shown in Figure 20. In the smaller installations where possibility of physical damage is low, 1/32-inch (0.79-mm) thick

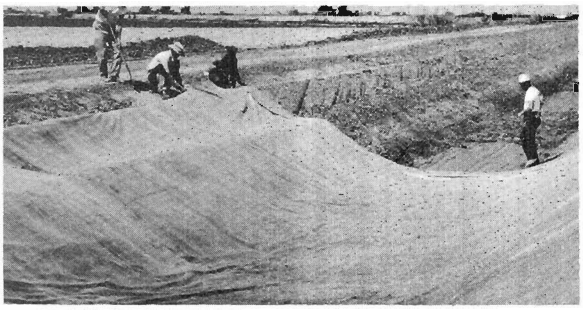


Figure 20. Installing 1/32-inch (0.79-mm) thick, butyl-rubber lining (May 1964) in Fern Lateral, Imperial Irrigation District, California. The lining was installed exposed, except the portions above the waterline were covered with earth. Photo PX-D-44236

butyl or EPDM rubber sheeting can be used as exposed lining. In large installations, a rubber lining thickness of 1/16 inch (1.58 mm) may be required. Where service requirements are severe, such as high-velocity flow in channels or in reservoirs where frequent cleaning is necessary, and long steep slopes are involved, considerations should be given to use of nylon-reinforced butyl or EPDM lining of 30-mil (0.76-mm), 45-mil (1.14-mm), or 60-mil (1.52-mm) thicknesses.

Relining Concrete-lined Canals and Reservoirs

The butyl and EPDM rubber lining may be used advantageously as a reliner in sections of leaky concrete-lined canals and reservoirs. For this application, it is best that selection of material type and installation techniques be made on an individual job basis. Many of the manufacturers and suppliers of rubber lining provide technical services that can be helpful in engineering the liner installation. The size and service conditions, condition of the concrete and underlying subgrade, and operational requirements such as cleaning, are factors affecting the overall liner installation.

In preparation for rubber relining, the concrete lining joints and cracks must be repaired and sharp edges and holes or spalled areas smoothed. The surfaces of the concrete where the rubber liner will be bonded should be thoroughly cleaned, preferably by light sandblasting.

In applying rubber lining to concrete canals, the major concern is to adequately anchor the liner to resist loosening and removal by the action of flowing water. In the smaller canals with slow-flowing water, strip bonding 1/32-inch (0.79-mm) thick butyl or EPDM rubber liner to the concrete, with rubber adhesive and use of some mechanical fastening would be expected to provide satisfactory service. Such an installation is shown in Figure 21. In large canals with fast-flowing water, consideration should be given to using

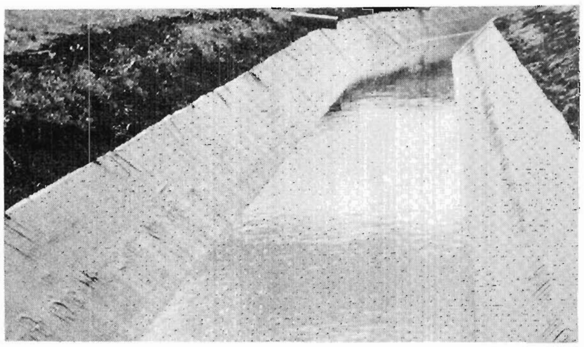


Figure 21. Installation of 1/32-inch (0.79-mm) thick, butyl lining over concrete-lined Contra Costa Canal, Central Valley Project, California. Installation made in 1964. Photo P214-D-43406

nylon-reinforced rubber fully or nearly fully bonded to the concrete. This should minimize tearing of the liner and allowing water to get underneath, thus avoiding serious damage or complete loss of the liner.

In concrete-lined reservoirs, the use of rubber lining is well suited for rehabilitation purposes. Lengths of butyl or EPDM rubber liner 10 to 20 feet (3 to 6 m) wide can be secured to the concrete by 2-foot (60-cm) wide strip bonding. The bonded strips should be located approximately 12 inches (30 cm) from any concrete construction joint so that joint movement will not result in high localized stresses in the liner over the joint. The rubber liner sections should be placed with the long dimension in the upslope and downslope direction to avoid horizontal seaming along the slope. Splicing of 1/32-inch (0.79-mm) thick rubber liner sections is accomplished by 4-inch (10-cm) wide overlap seams or butt joints with 8-inch (20-cm) wide cap strip using rubber adhesive and bonding techniques recommended by the rubber liner manufacturer. For rubber lining of 1/16-inch (1.58-mm) thickness, 6-inch (15-cm) overlap seams or butt joints with 12-inch (30-cm) wide cap strips should be used. The top edges of the liner can be secured by mechanical fastening to the concrete with redwood or metal strips or by burying the liner in an anchor trench excavated alongside the top of the reservoir. Because reservoirs often require periodic cleaning and the rubber liner is placed on steep concrete-lined slopes, it is recommended that nylon-reinforced rubber liner be used. The thickness should be 45 mils (1.14 mm) or 1/16 inch (1.58 mm), depending on the depth of the reservoir. A successful rubber liner in a concrete-lined reservoir is shown in Figure 22.

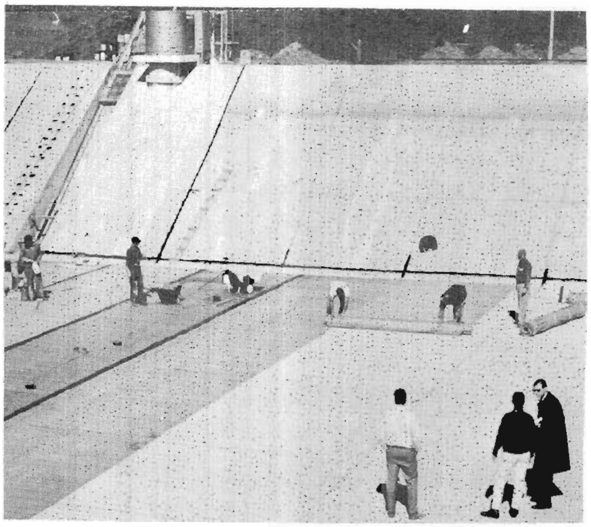


Figure 22. Nylon-reinforced, butyl-rubber lining, 1/16 inch (1.59 mm) thick, being placed over concrete-lined, 2-million-gallon reservoir, Greater Wenatchee Division, Chief Joseph Dam Project, Washington. Installation made April 1966. Photo P477-D-53281

Miscellaneous Lining Applications

In addition to lining canals, reservoirs, and storage ponds, rubber lining can be used as a cutoff curtain to intercept seepage through pervious zones. Also, rubber lining is adaptable to placing under concrete lining to seal off cavernous limestone rock foundation. Bureau installations of these applications are shown in Figures 23 and 24.

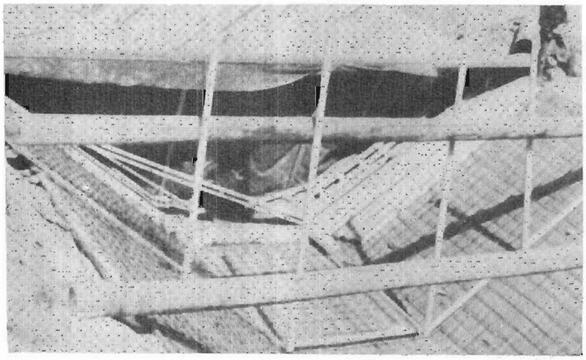


Figure 23. Butyl-rubber lining, 1/32 inch (0.79 mm) thick, being installed (April 1964) under reinforced-concrete lining as a repair measure, Heart Mountain Canal, Shoshone Project, Wyoming. Canal is situated over cavernous limestone where even slight seepage results in loss of supporting rock and eventually the concrete lining. Photo 26-D-1320

Costs

Butyl or EPDM rubber lining is generally not considered a low-cost seepage control method for canals or reservoirs. However, because these materials have exceptional resistance to puncture, outdoor exposure, extreme temperature changes, and are unaffected by most chemicals, they have use in special applications where, due to unusual service or operational conditions, initial cost is not the controlling criteria. The cost of rubber lining installations is quite variable depending upon thickness and whether the rubber lining is reinforced or not, and upon the volume of lining and complexity of the installation.

The contract cost of 1/32-inch (0.79-mm) thick unreinforced butyl or EPDM rubber lining installed as buried membrane including subgrade preparation, furnishing, placing the lining, and placing protective cover, may range from $3 to $4 per square yard. This same lining material installed as exposed lining would be expected to fall in the $2 to $3 per square yard range. Installation of 1/16-inch (1.58-mm) thick

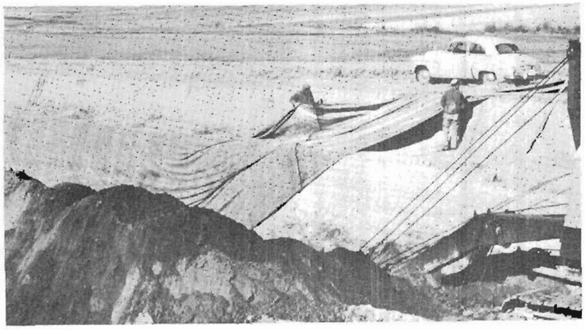


Figure 24. Installing 1/32-inch (0.79-mm) thick rubber lining as a vertical cutoff curtain on downhill side of East Low Canal, Columbia Basin Project, Washington. Installation made February 1964. Photo P222-D-68897

nylon-reinforced butyl or EPDM liner in large concrete-lined canals or reservoirs may cost as much as $5 per square yard.

APPENDIX

Bureau of Reclamation
Tentative Specifications for
Butyl Rubber Lining*

Synthetic rubber sheeting, Type I (butyl).—The Type I synthetic rubber sheeting shall be suitably compounded of high-quality ingredients to produce a flexible, durable, watertight membrane. Addition of all formula ingredients in the mix stage shall be such as to insure complete dispersion throughout the compound prior to calendering into sheets. All sheeting formulations shall include a suitable fungicide agent. The calendered sheeting shall be free from creases, bubbles, pits, tears, holes, or other defects and shall be uniform in color, thickness, and surface texture. The physical requirements of the sheeting supplied for use shall be as follows:

Property	Required	Test method
Thickness	_inch minimum	
Specific gravity	1.25 plus or minus 0.08	ASTM: D 297
Tensile strength pounds per square inch	1,200 minimum	ASTM: D 412
Elongation percent	300 minimum	ASTM: D 412
Modulus at 300 percent elongation pounds per square inch	600 minimum	ASTM: D 412
Shore "A" hardness	60 plus or minus 10 with 5-second interval before reading	ASTM: D 676
Ozone resistance at 7 days (50 pphm at 100° F and 20 percent elongation)	No cracks	ASTM: D 1149
Heat aging: (7 days at 240° F)		
Tensile strength retained, percent of original	70	ASTM D 573
Elongation retained, percent of original	70	ASTM: D 573
Tricresyl phosphate immersion: (70 hours at 212° F)		
Maximum volume swell, percent	10	ASTM: D 471
Tear resistance, pounds per inch	150 minimum	ASTM: D 624 Die "B"

Bonding materials.—Materials used in bonding the Type I synthetic rubber sheeting to concrete or other surfaces and in fabricating splices of the Type I synthetic rubber sheeting shall be as follows:

Butyl rubber adhesive.—Butyl rubber adhesive for bonding butyl rubber lining to contacting surfaces shall be as recommended by the manufacturer of the butyl rubber lining. The butyl rubber adhesive shall remain elastic at temperatures down to −20° F (−28.9° C) and shall be compatible with the butyl rubber sheeting and with other materials to which it is bonded.

Splicing cement.—Cement for splicing butyl rubber lining shall be a self-vulcanizing butyl compound recommended by the manufacturer of the sheet butyl rubber lining.

Butyl gum tape.—Butyl gum tape shall be at least 20 mils (0.51 mm) thick, including the backing, and shall be black unvulcanized butyl rubber with a polyethylene backing.

*The Bureau of Reclamation is working closely with Task Group, Subcommittee XIX, ASTM D-8—Elastomeric and Plastic-Lining Materials, on development of specifications for synthetic rubber linings of reinforced and nonreinforced butyl, EPDM, neoprene, and chlorosulfonated polyethylene. When available, these ASTM specifications will be adopted as standards for use in USBR construction specifications.

7-1750 (1-70)
Bureau of Reclamation

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 856-384

ABSTRACT

Accelerated laboratory tests and field performance evaluations indicate that butyl and ethylene propylene diene monomer (EPDM) rubber sheeting can be used satisfactorily as buried membrane and exposed lining for canals and reservoirs. For successful use as exposed lining, service conditions must be such that the rubber lining is protected from mechanical damage and vandalism. Butyl and EPDM rubber sheetings are suitable for relining old concrete canals and reservoirs. In canals where flowing water acts upon the lining, special attention must be given to adequately bonding and anchoring the rubber liner to the concrete. The butyl and EPDM linings are available with or without nylon reinforcement in thicknesses ranging from 20 to 125 mils (0.51 to 3.18 mm), and are adaptable to a variety of waterproofing applications; the type and thickness of lining are dictated by the size of installation and service requirements. The relatively high cost of these linings limits use to special applications where use of less costly membrane materials are not possible because of severe operational conditions.

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Hickey, M E
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Bur Reclam Rep REC-ERC-71-22, Div Gen Res, Apr 1971. Bureau of Reclamation, Denver,
p, 24 fig, 20 tab, append

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IDENTIFIERS--/ Open and Closed Conduit System Prog/ butyl rubber/ rubber sheeting

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