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A STUDY OF THE WEATHERING QUALITY OF ROOFING FELTS MADE FROM VARIOUS FIBERS

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ABSTRACT

An investigation to determine the relative effect of different fibers on the life and serviceability of asphalt-saturated and coated felts has been in progress at the National Bureau of Standards since 1926. Experimental felts composed of varying proportions of the usual felt-making fibrous materials and some with a high content of substitutes not employed commercially in roofing felts, were made for the investigation.

The papermaking materials employed were no. 2 roofing rags, old jute and manila bagging, old newspapers, sulphite pulp, and finely ground wood sawdust. Some of the felts were made on a commercial cylinder felt-making machine, while others were made on a small fourdrinier paper machine, but all the felts were saturated and coated in commercial roofing mills, and thus converted into roofing material.

Measurements were made on the dry or unsaturated felts, on the saturated felts, and on the finished roofing. On the last two products the measurements were made before and after exposure outdoors. These measurements show that there was no significant difference in the resistance to weathering of asphalt roofing which may be attributed to the kind of fiber or combination of fibers employed.

CONTENTS

I. INTRODUCTION

The paper felts used as the base of asphalt roofing materials are made of rags, with or without the addition of substitutes. Owing to the increased cost of rags in recent years, more extensive use has been made of substitute materials in admixture with the rag stock. In this paper are reported the results of an investigation to determine the effect of different fibers on the life and serviceability of roofing materials.

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Paper felts composed of varying mixtures of the usual felt-making fibrous materials, and with a high content of substitutes, were made for this investigation. The papers produced were subsequently converted into asphaltic roofing materials. In order to determine the effect of weathering upon the various fibers, the tensile and tearing strengths and other physical properties of these roofing materials were determined before and after exposure outdoors.

The production of these roofing materials was described in a previously published paper. [2] The present paper is concerned with the behavior of these materials toward weathering. For the sake of completeness some of the information and data in the previous paper are repeated in the present paper, but the commercial felts (F series) have been renumbered.

II. DESCRIPTION OF MATERIALS

For this investigation, unsaturated felts, saturated felts, and smooth-surfaced roofings were prepared. Dry or unsaturated felt is made by pulping fibrous material and converting the prepared pulp into a dry, continuous sheet on a paper machine. For preparing saturated felt, the felt is impregnated with asphalt by running the sheet through a tank containing hot asphalt. In the industry this latter operation is called saturation, the asphalt employed is termed the saturant, and the impregnated felt is known as saturated felt. The smooth-surfaced roofing is prepared by coating both sides of the saturated sheet with asphalt (coating asphalt), and then sifting talc, sand, or other granular material on the surface. The details of the manufacturing process of felts and of the saturated and coated materials were described in the paper cited above and so need not be given here.

The various stocks that were used in the production of the felts were agreed upon by a committee of the Dry Felt Manufacturers Association in cooperation with the Asphalt Shingle and Roofing Institute. Felts for roofing materials are usually made from cotton rags of varying quality. For the present investigation it was the intention to combine no. 2 roofing rags with large amounts of substitutes, and, in order to make the roofings comparable, the felts were to be impregnated (saturated) with asphalt to 140 percent by weight. This degree of saturation was formerly standard practice, although at the present time the requirements are much higher.

The manufacture of the felts was undertaken on a commercial-size cylinder machine, of Arrowhead Mills, Inc., Fulton, N. Y. Thirteen different felts were manufactured there and are identified in the accompanying tabulations as F1 to F13, inclusive. These felts were saturated and coated with asphalt at the plant of McHenry-Millhouse Co., Fulton, N. Y.

Owing to the inability to produce felts containing as much "substitute material" as was desired on the available machine at Arrowhead Mills, arrangements were made with the National Bureau of Standards to prepare other felts on the semicommercial 29-inch fourdrinier machine in the paper laboratory of the Bureau in Washington, D. C. These additional felts are identified in the accompanying tabulations as B1 to B6, inclusive. They were saturated and coated with asphalt at the plant of the Ruberoid Co., Joliet, Ill.

[2] BS J. Research 2, 1001 (1929) RP67.

The asphalt saturants and coatings used at the two plants were from different sources. However, all the felts of each series were saturated and coated with the same materials. The characteristics of the saturant and coating asphalts employed in each series of felts are shown in tables 2 and 4.

III. OUTDOOR EXPOSURES

For purposes of test, specimens of the saturated felts of both series, together with their corresponding coated products (smooth-surfaced roofing), were exposed outdoors at an angle of 45 degrees, facing south, on specially constructed racks provided by the Asphalt Shingle and Roofing Institute, and located on the roof of the Industrial Building, National Bureau of Standards, Washington, D. C. (fig. 1).

The faces of the racks were 36 inches high and were so constructed that the boards formed a continuous surface; hence the back sides of the specimens of roofing materials were not exposed to the weather. To prevent adhesion of the back sides of the specimens, the racks were first coated with a suspension of talc in water. The specimens of roofing materials (36 inches in length), with an overlap of one inch between adjacent pieces, were fastened to the racks with roofing cleats. There were 19 varieties of saturated felts and 19 varieties of smooth-surfaced roofing exposed in this manner. A sufficient number of specimens of each of these varieties were placed on the racks so they could be removed and tested at certain intervals of time. In all, enough samples were placed on the racks so that seven complete series of tests could be made.

The relative behavior of the materials toward weathering was determined from changes in weight, tensile strength, and other measurable properties, brought about by exposure. The results of these measurements were supplemented by opinions based on visual examination.

IV. MEASUREMENTS ON MATERIALS BEFORE EXPOSURE

The physical properties [3] of the dry or unsaturated felts, the saturated felts, and the smooth-surfaced roofings before exposure are discussed under the following headings:

1. DRY OR UNSATURATED FELTS

Table 1 shows the fiber composition, the weights, thicknesses, saturability tests, the tensile and tearing strengths, and the ash content of the different felts.

[3] The methods of test were described in the previously published paper, BS J. Research 2, 1001 (1929) RP67. See also Herbert Abraham, Asphalt and Allied Substances, 3d ed. (D. Van Nostrand Co.). Also Standard Methods of Tests of the Technical Association of the Pulp and Paper Industry, 122 E. 42d St., New York, N. Y.

TABLE 1.—*Test data on the dry felts*

a	b		c	d	e	f	g	h	i	j	k
Sample	Composition		Wt 108 sq ft	Thickness	Kerosene test	Xylol test	Tensile Strength of strips 1 in. wide [1]		Tearing test [1]		Ash
	Amt. by wt	Material					Machine direction	Across machine direction	Machine direction	Across machine direction	
	%		lb	in.	%	sec	lb	lb	g	g	%
F1	100	Rag	11.0	0.053	203	25	37	19	38	26	6.8
F2	60 40	Rag Sulphite	11.2	.053	189	25	45	21	48	34	5.3
F3	80 20	Rag Sulphite	12.3	.062	200	21	40	21	54	34	5.3
F4	90 10	Rag Ground wood	12.6	.067	220	19	40	20	56	35	5.8
F5	80 20	Rag Newspaper	12.1	.068	240	16	35	19	47	32	6.0
F6	90 10	Rag Newspaper	11.4	.063	219	17	37	18	48	30	5.4
F7	80 20	Rag Mixed papers	11.4	.059	210	18	38	18	44	31	6.5
F8	90 10	Rag Mixed papers	10.3	.054	212	22	37	18	42	26	6.3
F9	60 40	Rag Burlap	11.4	.058	217	28	34	17	43	26	6.4
F10	80 20	Rag Burlap	10.8	.057	221	28	33	17	44	22	6.2
F11	70 30	Rag Carpet	11.0	.060	231	17	33	16	45	28	6.6
F12	85 15	Rag Carpet	10.8	.058	238	16	31	15	41	22	7.1
F13	80 20	Rag Ground wood	10.5	.059	231	16	35	18	42	29	6.0
B1	100	Rag	9.8	.042	162	69	34	25	31	24	7.1
B2	60 30 10	Rag Newspaper Sawdust	10.0	.050	187	61	29	18	29	20	5.6
B3	10 60 30	Rag Newspaper Sawdust	9.9	.054	191	55	37	27	24	16	2.1
B4	60 20 20	Rag Bagging Newspaper	9.0	.041	161	66	38	27	32	25	5.8
B5	67 33	Bagging Newspaper	9.1	.045	187	37	40	31	32	23	5.6
B6	100	Bagging	9.3	.049	217	17	33	27	32	24	6.0

[1] These results are the average of 10 determinations.

The fiber composition of the felts given in the table is the "mill furnish", i. e., the percentages by weight of the raw materials furnished to the beater in the manufacture of the felts. The microscopic analysis of the fiber composition of these felts has been described elsewhere.[4]

Felt weights are given on the basis of 108 square feet. The felts are customarily spoken of as "light", "medium", or "heavy", depending on the weight. Those given in the table are considered medium. The strength tests—tensile and tearing—and the thickness measurements were made under the standard atmospheric conditions for paper testing, 65-percent relative humidity and 70° F. The tensile-strength measurements were made on a Scott tensile

[4] R. E. Lofton, *Determination of the fiber composition of roofing felts*, Paper Trade J. 84, no. 14, p .57-58 (Apr. 7, 1927).

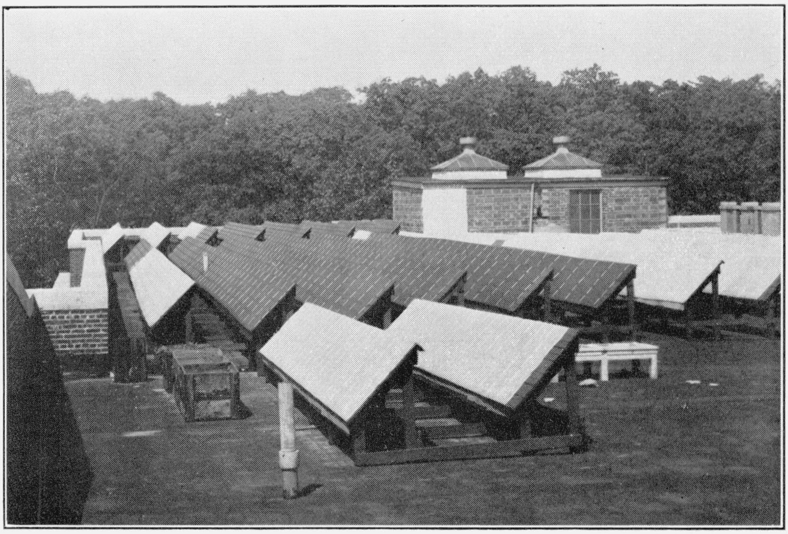

FIGURE 1.—*Exposure racks*

The dark samples are the saturated felts, the light ones are the smooth-surfaced roofing samples.

tester. The tearing tests were made with the Elmendorf tearing tester, but the standard design of this instrument is not adapted to heavy material, such as roofings and saturated felts, so a modification had to be made before these materials could be tested.[5] The modification consisted in doubling the weight of the swinging sector by the addition of a brass plate and multiplying the scale readings by 2.

The kerosene and xylol tests are absorption tests and were made to determine the saturating quality of the felts. The object of the kerosene test is to obtain the maximum saturating capacity of the felts. A sample of the dry felt is saturated with a measured volume of kerosene in order to determine the amount of voids. From the results obtained the so-called theoretical maximum percentages of asphalt saturation of the sheet are computed. The computation involves the weight of the sample, the volume of kerosene the sample absorbs, and the specific gravity of asphalt, which is assumed to be 1.03.[6]

The xylol test supplements the kerosene test and is used to determine the relative speed at which saturation will take place. The test consists in immersing in xylol a strip of the felt 15 cm wide to a marked depth of 1 cm, and measuring the time required for the xylol to rise to another mark 3 cm higher.

Pliability tests were made on the felts but are not recorded in the table. The tests, however, showed that the felts of the B series were somewhat less pliable than those of the F series, with the exception of B1, an all-rag felt. Felt B3 was particularly lacking in pliability and so was considered not adaptable to commercial use, but this lack of pliability had no deleterious effect upon the resistance of the saturated and coated products to weathering.

The main difference between the two series of felts, aside from fiber composition, was that the felts of the B series were more compact and paper-like than the felts of the F series. This compactness was due to fiber composition and to a slightly prolonged beater operation which brushed-out the fibers and caused them to become shorter and slightly gelatinized on the surface. Such fibers make a well-felted, smooth-surfaced sheet. The felts of the B series were about 16 inches in width, those of the F series were 32 inches in width.

No difficulty in the saturating and coating operations was observed with any of the felts of either series.

2. SATURATED FELTS

The weights and the data on the saturating qualities of the saturated felts, together with the physical properties of the saturants, are given in table 2.

[5] F. T. Carson and L. W. Snyder, *Increasing the capacity of the Elmendorf tearing tester*, Paper Trade J. 86, no. 13, 57–60 (March 29, 1928).

[6] Test is fully described in *The kerosene test for roofing felt*, P. W. Codwise, Paper Trade J. 87, no. 12, 60 (September 20, 1928).

TABLE 2.—*Composition of the saturated felts*

a	b	c	d
Sample	Weight, 108 sq. ft.	Saturation[1]	Actual saturation in terms of theoretical maximum
	lb	%	%
F1	31.3	163	80
F2	28.0	142	75
F3	31.3	147	74
F4	30.2	161	73
F5	32.5	177	73
F6	32.4	177	81
F7	31.3	165	79
F8	28.0	162	76
F9	29.2	174	80
F10	30.2	159	77
F11	30.2	177	77
F12	31.3	180	76
F13	31.3	179	77
B1	23.8	133	82
B2	25.9	156	83
B3	24.8	136	71
B4	24.8	144	87
B5	23.8	168	90
B6	24.8	179	82

SATURANT USED—ASPHALT

	F series	B series
Specific gravity at 77/77° F	1.035	1.001
Softening point (ring-and-ball) (° F)	114	113.5
Penetration at 77° F, 100 g, 5 sec (in 0.01 cm units)	121	143
Penetration at 32° F, 200 g, 60 sec (in 0.01 cm units)	35	64
Soluble in CS_2 (%)	99.8	99.5
Ductility at 77° F, 5 cm per minute (in cm units)	>100	48.3
Loss on heating—5 hours at 325° F (%)	.18	.07
Ash (%)	.23	.10

[1] Determined by analysis.

For convenience of comparison with the weathered samples, the results of the tensile-strength determinations and other data for these saturated felts are given in table 3.

Because of the different physical characteristics of the fibers used, the felts differed considerably in saturating capacities. To keep the saturation from exceeding 140 percent, as desired, was very difficult, of course, and was not always achieved, as table 2 shows. However, the saturation is fairly uniform when considered in terms of the maximum possible saturation, as indicated by the kerosene test. The ratio, obtained by dividing the percentage saturation by the maximum saturation (kerosene test), ranges from 73 to 81 percent. In this sense the felts were rather uniformly undersaturated, even though saturation of all the materials to the extent of 140 percent of the weight of the felts, as originally desired, was not accomplished.

TABLE 3.—*Test data on the saturated felts before and after exposure*

[The series of figures in the boxes indicate age of specimen, in years, when test was made]

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x
Sample [1]	Wt of 108 sq. ft. [2]				Saturation				Tensile strength of strips 1 in. wide [3]						Tearing strength [3]						Water absorption (at 25° C for 24 hours)		
									Machine direction			Across machine direction			Machine direction			Across machine direction					
	0	1½	4	7	0	1½	4	7	0	1½	4	0	1½	4	0	1½	4	0	1½	4	0	1½	4
	lb	lb	lb	lb	%	%	%	%	lb	lb	lb	lb	lb	lb	g	g	g	g	g	g	%	%	%
F1	31	30	25	19	163	156	152	147	78	97	63	43	54	36	118	75	39	105	59	36	28	27	38
F2	28	27	24	19	142	140	137	129	86	86	58	46	49	33	116	63	35	95	46	30	35	29	38
F3	31	30	28	21	147	152	154	136	89	91	62	46	55	37	138	73	37	115	53	34	37	27	42
F4	30	30	27	21	161	168	161	144	70	82	55	40	47	35	111	63	35	96	48	28	30	26	38
F5	33	32	30	21	177	182	181	163	74	84	67	39	55	37	123	73	50	113	62	37	36	23	37
F6	32	31	27	18	177	173	175	159	70	83	58	39	51	35	119	62	40	97	55	31	34	22	34
F7	31	30	26	19	165	164	162	157	72	88	64	37	51	36	123	69	36	101	55	33	32	25	37
F8	28	26	22	16	162	163	150	131	72	74	52	36	44	29	99	51	31	85	41	24	37	25	42
F9	39	29	24	16	179	169	162	145	68	81	58	35	48	33	117	65	40	94	48	31	37	28	36
F10	30	29	23	20	159	167	156	149	72	87	66	39	51	34	121	72	39	97	51	30	43	23	46
F11	30	29	24	19	177	167	163	150	71	76	53	38	45	34	113	68	36	97	52	30	32	30	43
F12	31	30	25	20	180	192	171	167	60	75	54	34	48	30	139	66	37	109	53	31	36	32	44
F13	31	29	26	16	179	187	176	171	71	79	60	39	52	37	119	63	38	95	54	31	37	22	36
B1	24	22	22	19	133	112	97	78	63	44	34	46	35	23	75	44	30	65	41	25	13	19	29
B2	26	24	22	21	156	163	127	106	52	43	31	39	32	28	68	36	23	62	33	24	9	8	32
B3	25	24	21	19	136	153	119	99	58	40	27	44	32	24	35	24	14	38	25	16	12	14	38
B4	25	24	21	19	144	124	109	81	66	58	38	49	39	28	57	38	26	58	31	22	10	19	32
B5	24	22	18	19	168	139	126	107	60	52	33	51	40	32	56	35	24	52	37	23	13	25	41
B6	25	24	23	20	179	162	147	130	------	54	38	------	44	30	61	38	23	64	35	24	13	17	38

[1] The compositions of the felts corresponding to these numbers are given in table 1.
[2] The results are reported to the nearest whole number.
[3] The tensile- and tearing-strength tests were made under the standard atmospheric conditions of 65-percent relative humidity and 70° F. The results given are the average of 5 determinations. Strength tests were not made for the 7-year period, owing to the difficulty of obtaining suitable samples, nor did such tests seem necessary.

3. SMOOTH-SURFACED ROOFING

The finished roofings were all of the smooth-surfaced type, medium weight. As previously explained, they were made by saturating the dry felts and then coating both sides with a coating asphalt. The weights and the compositions of the roofings, together with the physical properties of the coating asphalts, are given in table 4.

TABLE 4.—*Composition of the smooth-surfaced roofings*

Sample	Weight 108 sq. ft. [1]	Contents per 108 sq ft, by analysis			
		Felt	Saturant	Coating	Surfacing
	lb	lb	lb	lb	lb
F1	62	10.8	19.8	27.6	3.4
F2	60	11.9	19.3	25.7	3.6
F3	62	12.2	17.0	28.7	3.9
F4	64	10.1	17.6	33.5	2.5
F5	59	13.0	16.3	26.1	4.0
F6	60	10.2	20.0	27.2	3.1
F7	63	12.2	21.0	26.3	3.1
F8	58	11.4	22.4	19.5	4.9
F9	55	10.6	19.3	18.6	3.6
F10	59	11.3	22.5	22.3	3.3
F11	62	11.7	22.7	24.8	2.5
F12	62	11.6	23.6	23.3	3.1
F13	57	11.1	23.1	19.1	3.9
B1	49	10.8	15.0	21.8	1.0
B2	46	11.4	19.2	14.8	1.0
B3	44	10.3	16.3	15.6	1.1
B4	42	10.2	14.1	17.4	.4
B5	43	9.3	15.8	16.8	1.3
B6	47	8.8	17.1	20.6	1.0

COATING USED—ASPHALT

	F series	B series
Specific gravity at 77/77° F	1.034	1.020
Softening point (ring-and-ball) (°F)	214	208
Penetration at 77° F, 100 g, 5 sec (in 0.01 cm units)	19.7	16
Penetration at 32° F, 200 g, 60 sec (in 0.01 cm units)	14.9	11
Penetration at 115° F, 50 g, 5 sec (in 0.01 cm units)	40.6	37
Soluble in CS_2 (%)	99.3	99.5
Ductility at 77° F, 5 cm per minute (in cm units)	4.1	4.3
Loss on heating 5 hours at 325° F (%)	.16	.02
Ash (%)	.48	.10

[1] These results are reported to the nearest whole number.

Additional data for the smooth-surfaced roofings were obtained, but for convenience of comparison with the weathered samples these are given in table 5.

TABLE 5.—*Test data on the smooth-surfaced roofings before and after exposure*

[The series of figures in the boxes indicate age of specimen, in years, when test was made]

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t
Sample [1]	Wt of 108 sq ft [2]				Tensile strength of strips 1 in. wide [3]						Tearing strength [3]						Water absorption (at 25° F for 24 hours)		
					Machine direction			Across machine direction			Machine direction			Across machine direction					
	0	1½	4	7	0	1½	4	0	1½	4	0	1½	4	0	1½	4	0	1½	4
	lb	lb	lb	lb	lb	lb	lb	lb	lb	lb	g	g	g	g	g	g	%	%	%
F1	62	59	57	55	78	113	99	43	65	56	132	115	95	113	96	78	10	2	4
F2	60	50	60	44	94	123	114	52	67	66	140	90	95	106	83	80	9	1	5
F3	62	59	58	56	94	136	113	50	75	62	155	117	105	119	101	92	10	2	5
F4	64	60	60	58	81	123	104	46	70	67	147	113	103	128	98	93	10	0	4
F5	59	58	57	54	86	123	107	49	73	70	181	120	103	118	105	94	10	2	4
F6	60	59	57	57	80	113	95	46	69	61	139	83	97	114	82	83	9	1	3
F7	63	60	58	58	80	124	107	44	70	64	151	110	101	115	102	90	10	1	4
F8	58	57	56	54	81	117	104	47	64	62	131	103	94	110	100	86	5	0	3
F9	55	54	53	48	80	117	108	45	71	62	135	97	95	93	93	78	11	3	6
F10	59	55	58	43	83	120	106	45	70	62	152	102	103	114	94	89	10	0	4
F11	62	59	58	56	76	127	107	42	68	62	159	114	97	117	93	83	11	1	5
F12	62	59	57	55	76	118	102	42	65	56	166	113	102	114	93	83	9	0	4
F13	57	57	55	52	84	121	99	45	70	58	141	105	99	103	96	81	7	2	4
B1	49	45	46	47	78	106	93	58	82	66	91	63	60	90	59	64	2	3	2
B2	46	44	42	46	64	83	72	48	66	52	59	40	42	58	37	41	1	2	2
B3	44	40	39	37	62	73	63	50	56	55	39	35	38	44	35	38	0	1	7
B4	42	44	40	34	75	100	94	56	73	73	55	48	51	60	48	52	2	1	2
B5	43	39	42	44	70	83	84	63	72	73	61	51	42	58	48	46	0	0	2
B6	47	45	42	42	65	95	86	52	79	75	70	53	54	72	54	56	0	3	2

[1] The compositions of the felts corresponding to these numbers are given in table 1.
[2] The results are reported to the nearest whole number.
[3] The tensile- and tearing-strength tests were made under the standard atmospheric conditions of 65-percent relative humidity and 70° F. The results are the average of 5 determinations.

V. MEASUREMENTS ON MATERIALS AFTER EXPOSURE

As previously stated, samples of the saturated felts and of the smooth-surfaced roofing were exposed on racks to outdoor weathering (fig. 1). At certain intervals, namely, after exposure for 1½, 3½, 4, and 7 years, sets of the specimens were removed from the racks and tested. The results of the tests for the 3½ years of exposure are, however, not recorded in this paper, since they did not vary much from those of the 4-year period. The tables show the weights, the saturations, the tensile and tearing strengths, and the capacities for absorption of water of the saturated felts before and after exposure to the weather. Corresponding data for the smooth-surfaced roofings are also shown. As the tables show, not all the tests were made for the 7-year period, owing to the difficulty of obtaining suitable samples. However, tables 6, 7, 8, and 9 list some special determinations on the materials after 7 years of exposure.

1. SATURATED FELTS

Table 3 shows the weights of the saturated felts before and after exposure. In table 6, column g, the percentage losses in weight for the 7 years of exposure have been calculated for the saturated felts. In column d the weights are given for the desaturated (extracted) felts, while in column e the percentage losses are given. For these latter figures the weathered saturated felts were treated with carbon tetrachloride to remove the asphalt.

The saturated felts of the F series show an increase in tensile strength in both directions (table 3) up to about 2 years of exposure, owing to hardening of the asphalt, and thereafter show a constant decrease in strength. The B series of saturated felts show a decrease in strength after weathering for 1½ years. All tearing tests show a decrease in resistance to tearing after 1½ years of exposure.

TABLE 6.—*Composition of saturated felts before and after 7 years of exposure*

a	b	c	d	e	f	g	h	i	j	k
Sample	Weight per 108 sq ft			Change in weight of desaturated felt due to exposure for 7 years [2]	Wt of saturated felt after 7 years of exposure	Loss in weight of saturated felt due to exposure for 7 years	Composition of saturated felt before exposure. By analysis		Composition of saturated felt after weathering 7 years	
	Original dry felt	Original saturated felt before exposure	Desaturated felt after 7 years' exposure [1]				Felt	Saturant	Felt	Saturant
	lb	lb	lb	%	lb	%	%	%	%	%
F1	11.0	31.3	7.6	−31	18.8	40	38	62	40	60
F2	11.2	28.0	8.2	−27	18.8	33	41	59	44	56
F3	12.3	31.3	8.7	−29	20.5	35	40	60	42	58
F4	12.6	30.2	8.4	−33	20.5	32	38	62	41	59
F5	12.1	33.5	8.0	−34	21.0	37	36	64	38	62
F6	11.4	32.4	7.0	−39	18.1	44	36	64	39	61
F7	11.4	31.3	7.2	−37	18.5	41	38	62	39	61
F8	10.3	28.0	6.8	−34	15.7	44	38	62	43	57
F9	11.4	29.2	6.7	−41	16.4	44	36	64	41	59
F10	10.8	30.2	8.0	−26	19.9	34	39	61	40	60
F11	11.0	30.2	7.6	−31	19.0	37	36	64	40	60
F12	10.8	31.3	7.6	−30	20.3	35	36	64	37	63
F13	10.5	31.3	5.9	−44	16.0	49	36	64	37	63
B1	9.8	23.8	10.5	+7	18.7	21	43	57	56	44
B2	10.0	25.9	10.0	0	20.6	20	39	61	49	51
B3	9.9	24.8	9.7	−2	19.3	22	42	58	50	50
B4	9.0	24.8	10.5	+17	19.0	23	41	59	55	45
B5	9.1	23.8	9.1	0	18.8	21	37	63	48	52
B6	9.3	24.8	8.6	−8	19.8	20	36	64	43	57

[1] Obtained by extracting the exposed saturated felt samples with carbon tetrachloride. Seven strips (each 2 by 5 in.) of each material were extracted and the results are the average of these 7 strips.

[2] The causes of the increases in weight (+) shown by some of the samples are not known. The figures, however, do show that the felts in the F series have deteriorated considerably more than those of the B series.

The amounts of water absorbed by the materials before and after exposure are shown in table 3. These determinations were made by immersing the samples in water at 25° C for 24 hours and then determining the percentage increase in weight based on the weight of the original dry material.[7]

It will be noted from table 3 that the ratio of asphalt to felt (percentage saturation) decreased on exposure, and more so for the B series than the F series. The difference between the changes in ratio is explained by the fact that the more compact felts of the B series lost less material by exfoliation than the F series. Exfoliation takes

[7] See footnote 3.

place on the surface of the saturated felt and thus causes the felt fibers and asphalt to disappear simultaneously. In the case of the B felts, however, the fiber portion, owing to the compactness of the felts as previously described, did not disappear as rapidly as the asphalt portion and so the fiber or felt became larger in proportion to the asphalt and this accounts for the more rapid decrease in percentage of saturation in the B series of felts. This behavior is further illustrated by the data in columns h, i, j, k (table 6), which show the composition of the saturated felts before and after exposure; in column d, which shows the weights of the desaturated felts; and in columns g and e, which show losses in weight of the saturated and desaturated felts after exposure for 7 years. The data on thicknesses in table 7 further show the degree of exfoliation in the saturated felts, particularly the data given in column d.

TABLE 7.—*Change in thickness of saturated felts during exposure*

a	b	c	d	e	f	g
Sample	Thickness of original dry felt [1]	Thickness of saturated felt after desaturation (exposed 7 years)	Thickness loss in the desaturated felts	Thickness of original saturated felt before exposure	Thickness of saturated felt before desaturation (exposed 7 years)	Thickness change in saturated felts due to exposure for 7 years
	in.	in.	%	in.	in.	%
F1	0.053	0.038	28	0.057	0.052	−9
F2	.053	.042	21	.053	.051	−4
F3	.062	.040	35	.061	.054	−11
F4	.067	.041	39	.058	.053	−9
F5	.068	.040	41	.065	.054	−17
F6	.063	.035	44	.060	.051	−15
F7	.059	.036	39	.059	.054	−8
F8	.054	.032	41	.053	.046	−13
F9	.058	.031	47	.055	.051	−7
F10	.057	.036	37	.057	.053	−7
F11	.060	.037	38	.057	.057	0
F12	.058	.039	33	.063	.060	−5
F13	.059	.032	46	.062	.046	−26
B1	.042	.038	10	.044	.047	+6
B2	.050	.043	14	.052	.052	0
B3	.054	.045	17	.057	.052	−9
B4	.041	.041	0	.048	.048	0
B5	.045	.040	11	.046	.047	+2
B6	.049	.038	22	.049	.046	−6

[1] Felt saturated with asphalt and then extracted with carbon tetrachloride does not change in thickness.

All these data on weights, strength, and similar tests show that the individual saturated felts of the F series have weathered to approximately the same degree. Moreover, their appearance after weathering is similar. The conclusion is, therefore, drawn that all felts of the F series are about equally durable. Similarly, all saturated felts of the B series are equally durable, but the F series has deteriorated considerably more than the B series because of a greater degree of exfoliation.

2. SMOOTH-SURFACED ROOFINGS

Corresponding data for the smooth-surfaced roofings are found in tables 5, 8, and 9. In particular, the data show that the asphalt coating protected the saturated felts from weathering. Upon extracting the asphalt with carbon tetrachloride the felts showed relatively little change from their original condition. The smooth-surfaced roofings showed no marked differences in weathering in the F and B series, although the appearance was slightly in favor of the B series.

TABLE 8.—*Composition of smooth-surfaced roofings before and after 7 years of exposure*

a	b	c	d	e	f	g
	Wt. per 108 sq. ft.					
Sample	Original dry felt	Original smooth-surfaced roofing before exposure	Desaturated felt after 7 years' exposure [1]	Change in weight of desaturated felt due to exposure for 7 years [2]	Weight per 108 sq ft of smooth-surfaced roofing after 7 years, exposure	Change in weight of smooth-surfaced roofing due to exposure for 7 years
	lb	lb	lb	%	lb	%
F1	11.0	61.5	10.5	−5	55.3	−10
F2	11.2	60.4	10.9	−3	44.4	−26
F3	12.3	61.5	11.2	−9	56.1	−9
F4	12.6	63.7	12.7	+1	58.2	−9
F5	12.1	59.4	12.6	+4	54.4	−8
F6	11.4	60.4	10.9	−4	56.7	−6
F7	11.4	62.6	11.4	0	57.8	−8
F8	10.3	58.3	8.6	−17	54.0	−7
F9	11.4	55.0	10.3	−10	48.3	−13
F10	10.8	59.4	10.8	0	43.2	−27
F11	11.0	61.5	10.8	−2	56.2	−9
F12	10.8	61.5	10.8	0	55.3	−10
F13	10.5	57.2	9.9	−6	51.9	−9
B1	9.8	48.6	10.8	+10	47.3	−3
B2	10.0	46.4	11.4	+14	45.8	−1
B3	9.9	44.2	10.4	+5	37.4	−15
B4	9.0	42.1	11.1	+23	33.7	−18
B5	9.1	43.2	9.4	+3	44.2	+2
B6	9.3	47.5	8.5	−9	42.4	−11

[1] Obtained by extracting the weathered samples of smooth-surfaced roofing with carbon tetrachloride. Seven strips (each 2 by 5 in.) of each material were extracted and the results given are the average for these 7 strips.

[2] The causes of the increases in weight (+) shown by some of the samples are not known.

TABLE 9.—*Change in thickness of smooth roofings during exposure*

Sample	a	b	c	d	e	f
	Thickness of original dry felt	Thickness of roofing after desaturation. Exposed 7 years	Thickness change in the desaturated roofing	Thickness of original roofing	Thickness of roofing before desaturation. Exposed 7 years	Thickness change in the roofing due to exposure 7 years [a]
	in.	in.	%	in.	in.	%
F1	0.053	0.051	−4	0.105	0.116	+9
F2	.053	.050	−6	.104	.111	+6
F3	.062	.055	−11	.105	.119	+12
F4	.067	.063	−6	.109	.112	+3
F5	.068	.066	−3	.104	.105	+1
F6	.063	.056	−11	.108	.110	+2
F7	.059	.061	+3	.107	.106	−1
F8	.054	.051	−6	.097	.103	+6
F9	.058	.052	−10	.092	.098	+6
F10	.057	.055	−4	.099	.090	−9
F11	.060	.055	−8	.104	.112	+7
F12	.058	.057	−2	.106	.118	+10
F13	.059	.054	−8	.094	.110	+15
B1	.042	.044	+5	.086	.090	+44
B2	.050	.051	+2	.087	.087	0
B3	.054	.053	−2	.088	.084	−5
B4	.041	.049	+20	.074	.072	−3
B5	.045	.047	+4	.085	.090	+6
B6	.049	.043	−12	.090	.092	+2

[a] These thickness data are inaccurate owing to blister formations in the smooth-surfaced roofing which exaggerate the thickness measurements.

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