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Abstract

The properties of coal-tar pitch roofing membranes approximately 21 years old were compared to the properties of new membranes and the suggested level of performance for such membranes reported previously by the National Bureau of Standards (NBS). Samples of old membranes were taken from eight buildings having roof areas that ranged from 0.5 to 1.5 million square feet (0.05 to 0.14 km^2). The buildings were located at three sites in or near the state of Kentucky. The roof membranes on these buildings had been subjected to different maintenance procedures.

Laboratory tests conducted on 47 membrane samples included tensile strength, load-strain determination and coefficient of thermal expansion. The thermal shock factor was calculated for each sample. Laboratory observations were made to determine between-ply bitumen thickness, weight per unit area, ply adhesion, pliability and condition of the membrane.

The tensile strengths of the old membranes determined at 0°F (-18°C) in their longitudinal and transverse directions and values of the coefficient of thermal expansion measured over the temperature range of 0 to -30°F (-18 to -34°C) were comparable to those values reported earlier by NBS. The moduli of elongation were considerably higher for the old membranes than for the new ones which resulted in lower values of thermal shock factor. The lower values of extensibility (higher moduli of elongation) of the old membranes were attributed to their brittleness caused by aging. Differences in roof maintenance procedures appeared to have caused significant differences in the properties of membranes from the three different sites.

Key Words: Bituminous roof membranes; built-up roof membranes; coal-tar pitch; performance criteria; physical and engineering properties; test methods.

1. INTRODUCTION

A study was conducted to determine the properties of 21 year old coal-tar pitch membranes and to compare their properties to those reported for similar new membranes in NBS Building Science Series 55, "Preliminary Performance Criteria for Bituminous Membrane Roofing" [1]*. Samples of old roofing membranes for laboratory tests and observations were taken from eight buildings located at three sites in or near the state of Kentucky. The roof areas ranged from 0.5 to 1.5 million square feet (0.05 to 0.14 km^2). The buildings at the three sites were constructed about the same time with similar types of construction and were exposed to comparable interior and exterior climatic conditions. The inside temperature in the buildings at roof level was approximately 120°F (49°C). All of the roofs had slope sufficient for adequate drainage, with a few exceptions. All roofing samples taken for test were from well-drained areas. The roof construction consisted of heavy gage steel decks with small flutes, fiberglass insulation measuring between 1/2 and 3/4 in (13 and 19 mm) thick, coal-tar built-up membranes and gravel surfacing. Two-ply bituminous built-up vapor barriers covered the steel decks. Two types of built-up membranes were used on the buildings. At one site, designated as A, the membranes generally contained a base

* Numbers in brackets indicate references listed in Section 6.

sheet and three plies of coal-tar saturated organic felts. At the two other sites, designated as B and C, the membranes contained four plies of coal-tar saturated organic felts. The felts had been laid in shingle fashion except at site A where the first ply, generally a base sheet, was applied and then three plies laid in shingle fashion.

The maintenance of the roofs varied at the three sites. The roofs at site A were in very good condition. They had been well maintained and were recoated and graveled twelve years after fabrication. During the resurfacing process the bitumen and gravel were removed to the top ply by means of water jets. After the membrane surfaces had dried, hot coal-tar pitch was applied and the roof surfaced with gravel. The gravel was well distributed and the flood coat provided a good protection to the roofing membrane. Pipe vents three inches (76 mm) in diameter and spaced about fifty feet (15 m) apart were installed prior to resurfacing.

The roofing at site B was in good condition which was attributed in part to periodic and adequate maintenance. These roofs had not been recoated as was the case for roofs at site A, however, the flood coat was intact and was in general protecting the membrane.

The general condition of the roofing membranes at site C ranged from fair to poor. There were many areas of exposed felts and many blisters and ridges in the membranes. These roofs had not been maintained as well as those at site B.

2. LABORATORY EVALUATIONS

Forty-seven roofing membrane samples, 14 x 40 in (0.4 x 1.0 m), were cut from the roofs at the three sites. These samples had their long dimension perpendicular to the direction in which the plies of felt were applied. A strip 4 x 40 in (0.1 x 1.0 m) was cut from each of the 47 samples to determine by visual examination the number of plies, ply adhesion, bitumen interply thickness and the general condition of the membrane samples. Specimens for determining the tensile strength and the weight per unit area were prepared from the remaining portion of each membrane sample. The tensile test specimens conformed to those described in ASTM Standard D 2523 [2]. Two specimens in both the longitudinal and transverse direction of the felt orientation were tested in tension at 0°F (-18°C). As part of the tension test, the strain was measured and the moduli of elongation were determined by the method described in ASTM Standard D 2523 [2]. The coefficient of linear thermal expansion was determined using the tensile test specimens (prior to the tensile tests) for the temperature range of 0 to -30°F (-18 to -34°C), according to the procedure described in the proposed ASTM method of test for determining the coefficient of linear thermal expansion of roofing membranes [3].

The weight per unit area of the membrane samples was determined by weighing 6 x 12 in (150 x 300 mm) specimens. The gravel surfacing was removed prior to weighing, but some of the flood coat and some bitumen which bonded the membrane to the insulation were present in most specimens.

Samples of insulation, 6 x 6 in (150 x 150 mm), were taken to determine qualitatively if the insulation was wet at the same location on the roofs where the membrane samples were cut.

It is important to note that the roof membrane samples were taken from areas of the roofing that were not subjected to ponding and appeared to be in good condition. Subsequent laboratory inspections revealed that the top plies of some membrane samples exhibited some deterioration. This deterioration had been obscured during the field inspection by the gravel surfacings and flood coats on the membranes. In the selection of the membrane samples for laboratory test, problem areas of roofing are not desirable because testing of obviously deteriorated membrane samples would yield little practical information. In this study the deterioration of the top plies was not considered extensive enough to render the test specimens unusable.

3. VISUAL EXAMINATION OF MEMBRANE AND INSULATION SAMPLES

Roofing membrane strips, 4 x 40 in (0.1 x 1.0 m), cut from the membrane samples were cooled to -40°F (-40°C) and delaminated. Individual plies were examined and their condition, between-ply adhesion, pliability and number of plies per sample were recorded. Information from the visual examinations of the membrane strips is presented in tables 1, 2 and 3.

Visual examinations of the 47 fiberglass insulation samples showed that only one sample, C9, was wet. All the other samples of insulation were apparently dry. These insulation samples appeared to be firm except for 12 of which 7 were soft, 3 were delaminated and 2 were disintegrated. Reasons for these conditions were not investigated.

4. LABORATORY TESTS

An average value of the approximate weight of the between-ply bitumen per 100 ft^2 (9 m^2) of roof area for each of the membrane samples is given in tables 1, 2 and 3. These weights were calculated from the bitumen thicknesses between each of the plies measured at two locations on each tensile test specimen using a machinist's microscope. The procedure for measuring between-ply bitumen thickness has been described by Rossiter and Mathey [4]. The measurements of between-ply bitumen thicknesses for the old coal-tar membranes were converted to bitumen weight using the relationship that 0.01 inch equals 6 lb/100 ft^2 (0.1 mm equals approximately 0.1 kg/m^2).

Most of the membrane samples were four ply, although one was three ply, seven had five plies and one had six plies. It is possible to cut tensile test specimens which have more plies than indicated from delamination of the 40 in (1.0 m) long membrane samples. This is because tensile test specimens may be cut where laps in the felts occur.

The weights of the roofing membranes per 100 ft^2 (9 m^2) of roof area are given in tables 4, 5 and 6. The values are in general somewhat less than would be expected for a four-ply membrane of this type. A four-ply coal-tar pitch membrane consisting of type 15 felts and no flood coat would weigh about 135 lb/100 ft^2 (6.6 kg/m^2). This weight is based on 60 lb/100 ft^2 (2.9 kg/m^2) for four plies of coal-tar saturated organic felt and 75 lb/100 ft^2 (3.7 kg/m^2) for three layers of between-ply coal-tar pitch. The calculated weights of the between-ply coal-tar pitch given in tables 4, 5 and 6 are considerably lower than the normally expected 25 lb/100 ft^2 (1.2 kg/m^2). Since the weights of the membrane samples were only somewhat less than the expected weights of properly applied membranes, it is therefore assumed that some of the between-ply coal-tar pitch was absorbed by the felts. This would account for the relatively high weights of the membranes in comparison to the low weights of the between-ply bitumen.

The tensile strengths, moduli of elongation, coefficients of thermal expansion and thermal shock factors for the 47 membrane samples are listed in tables 4, 5 and 6 and plotted in figures 1, 2, 3 and 4. The tensile strengths, moduli of elongation and coefficients of thermal expansion were determined by procedures outlined previously in Section 2. Four tests of each of the 47 membrane samples were conducted to determine these properties; two tests in the "machine" or longitudinal direction of the felt and two tests in the "cross machine" or transverse direction of the felt.

The thermal shock factor (TSF) for each specimen was calculated from the following equation:

$$\text{TSF} = \frac{\text{Tensile Strength}}{(\text{Coefficient of Expansion}) \times (\text{Modulus of Elongation})}$$

The ranges and average values of tensile strength, modulus of elongation, coefficient of thermal expansion and thermal shock factor are listed in table 7 and shown in figures 1, 2, 3 and 4. These values are presented for both the "machine" and "cross machine" orientations of the felts for membrane samples from each of the three sites. No attempt was made to analyze statistically the data given in tables 4, 5 and 6. The average values are presented as a convenience to the reader.

5. COMPARISON OF MEMBRANE PROPERTIES WITH THE PRELIMINARY PERFORMANCE CRITERIA

Values of tensile strength, modulus of elongation, coefficient of thermal expansion and thermal shock factor can be compared with values of laboratory prepared four-ply coal-tar membranes reported by Mathey and Cullen [1] in their paper dealing with preliminary performance criteria for bituminous membrane roofing. Their data for four-ply coal-tar saturated organic felt membranes are presented in table 8 and noted on figures 1, 2, 3 and 4 along with the corresponding suggested preliminary performance criteria for bituminous roofing membranes.

It can be seen from figure 1 that the average values of tensile strength of the old membranes tested in this study were less than values reported by Mathey and Cullen [1]. Figure 3 indicates that the average values of the coefficient of thermal expansion of the old membrane specimens were in general agreement with those determined from new specimens.

The strength of the membranes appeared to reflect the quality of maintenance that they had received. Membranes at site A were better maintained than those at sites B and C. Membranes at site B were maintained better and were in better condition than those at site C. It can be seen from figure 1 that membranes from site A had the highest average strength and those from site C had the lowest. This comparison of membrane strengths assumes that their initial properties were similar.

The values of load-strain modulus (modulus of elongation) for the old membranes were in most cases considerably higher than values reported for new membranes as readily seen in figure 2. As the membranes age they tend to become brittle, their ability to elongate under tensile stress is reduced.

The values of thermal shock factor varied considerably for the old membranes but were, in general, low compared to those for the new membranes as shown in figure 4. These low values are attributed to the old membranes' inability to extend as much under tensile load which accounts for the higher values of the load-strain modulus.

With one exception, the average values of the tensile strength and coefficient of thermal expansion for the old membranes at all three sites agreed with or met the suggested preliminary performance criteria for bituminous membrane roofing [1]. The average tensile strength at site C was about 12 percent lower than the suggested value. The average values of the thermal shock factor ranged from 32 to 40 percent of the suggested performance criterion [1].

The types of laboratory tests and visual observations described in this paper can be used as the basis for the evaluation of the condition of old built-up roofing membranes. The data presented herein give an insight into some of the properties of bituminous roofing membranes and changes in these properties which may occur with aging. The data also reflect the effect of different maintenance procedures on the properties of built-up roofing membranes. Even though the membranes were over twenty years old, some of their properties were similar to those reported for new coal-tar membrane roofing.

6. ACKNOWLEDGMENT

The authors acknowledge the important contribution of Mr. Jessie C. Hairston who performed the extensive laboratory tests.

7. REFERENCES

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Table 1. Properties of Membranes Determined by Visual Inspection (Site A)

Sample	Appearance[1]	Pliability[2]	Number of Plies	Ply Adhesion	Between Ply Bitumen Weight[3]	
					$lb/100\ ft^2$	kg/m^2
A1	Excellent	Brittle	4	Good	8	0.4
A2	Excellent	Brittle	3 + 1[4]	Good	8	0.4
A3	Excellent	Brittle	4 + 1	Fair	8	0.4
A4	Very good	Brittle	4	Good	7	0.3
A5	Very good	Brittle	4	Good	5	0.2
A6	Excellent	Brittle	4	Good	8	0.4
A7	Excellent	Flexible	3 + 1	Good	33	1.6
A8	Excellent	Very brittle	3 + 1	Good	8	0.4
A9	Very good	Brittle	3 + 2	Good	9	0.4
A10	Excellent	Brittle	3 + 1	Good	10	0.5
A11	Excellent	Very brittle	3 + 1	Good	7	0.3
A12	Excellent	Brittle	3 + 1	Good	8	0.4
A13	Excellent	Brittle	3 + 1	Good	24	1.2
A14	Excellent	Brittle	3 + 1	Fair	5	0.2

1/ Visual examination prior to delamination.

2/ Visual and manual examination at room temperature, 70°F (21°C).

3/ Average value determined from measurements using a machinist's microscope.

4/ Indicates phase application with 3 plies applied in shingle fashion over one ply.

Table 2. Properties of Membranes Determined by Visual Inspection (Site B)

Sample	Appearance[1]	Pliability[2]	Number of Plies	Ply Adhesion	Between Ply Bitumen Weight[3] lb/100 ft^2	Between Ply Bitumen Weight[3] kg/m^2
B1	Fair	Brittle	4 + 2[4]	Good	9	0.4
B2	Good	Brittle	4 + 1	Good	11	0.5
B3	Good	Brittle	4	Good	6	0.3
B4	Fair	Brittle	5	Good	7	0.3
B5	Fair	Brittle	3	Good	6	0.3
B6	Fair	Brittle	4	Good	5	0.2
B7	Fair	Brittle	3 + 1	Good	14	0.7
B8	Good	Brittle	5	Good	6	0.3
B9	Fair	Brittle	4	Good	7	0.3
B10	Excellent	Brittle	4	Good	8	0.4
B11	Poor	Brittle	4	Good	6	0.3
B12	Good	Brittle	5	Fair	6	0.3
B13	Good	Brittle	4	Good	5	0.2
B14	Good	Brittle	4	Fair	6	0.3
B15	Fair	Brittle	4	Good	7	0.3
B16	Fair	Brittle	4	Good	7	0.3
B17	Good	Brittle	4	Good	6	0.3
B18	Good	Brittle	4	Good	5	0.2
B19	Good	Brittle	5	Good	14	0.7
B20	Excellent	Brittle	4	Good	6	0.3

1/ Visual examination prior to delamination.

2/ Visual and manual examination at room temperature, 70°F (21°C).

3/ Average value determined from measurements using a machinist's microscope.

4/ Indicates phase application with 4 plies applied in shingle fashion over 2 plies which were applied shingle fashion.

Table 3. Properties of Membranes Determined by Visual Inspection (Site C)

Sample	Appearance[1]	Pliability[2]	Number of Plies	Ply Adhesion	Between Ply Bitumen Weight[3]	
					lb/100 ft^2	kg/m^2
C1	Fair	Brittle	4	Good	7	0.3
C2	Fair	Very brittle	4	Fair	5	0.2
C3	Fair	Very brittle	4	Good	6	0.3
C4	Good	Very brittle	4	Good	8	0.4
C5	Good	Very brittle	4	Good	6	0.3
C6	Fair	Very brittle	4	Good	6	0.3
C7	Good	Very brittle	4	Fair	6	0.3
C8	Very poor	Very brittle	4	Fair	6	0.3
C9	Very poor	Very brittle	4	Good	5	0.2
C10	Fair	Very brittle	4	Good	5	0.2
C11	Very poor	Very brittle	4	Good	6	0.3
C12	Poor	Very brittle	4	Good	7	0.3
C13	Poor	Very brittle	4	Good	6	0.3

1/ Visual examination prior to delamination.

2/ Visual and manual examination at room temperature, 70°F (21°C).

3/ Average value determined from measurements using a machinist's microscope.

Table 4. Mechanical and Physical Properties of Membranes (Site A)[1]

Sample	Weight		Tensile Strength[2]		Modulus of Elongation[2]		Coefficient of Expansion[3]		Thermal Shock Factor[4]	
	lb/100 ft^2	kg/m^2	lb/in	kN/m	lb/in x 10^4	MN/m	$°F^{-1}$ x 10^{-6}	$°C^{-1}$ x 10^{-6}	°F	°C
A1 - Machine	145	7.1	491	86	28.4	50	18.2	32.8	98	54
A1 - Cross Machine			234	41	14.8	26	24.3	43.7	66	37
A2 - Machine	139	6.8	588	103	15.0	26	18.5	33.3	211	117
A2 - Cross Machine			251	44	15.3	27	28.9	52.0	75	42
A3 - Machine	144	7.0	483	85	24.2	42	18.0	32.4	193	107
A3 - Cross Machine			230	40	60.5	106	23.9	43.0	57	32
A4 - Machine	116	5.7	491	86	13.6	24	19.0	34.2	205	114
A4 - Cross Machine			176	31	80.2	140	31.1	56.0	14	8
A5 - Machine	133	6.5	450	79	18.2	32	15.8	28.4	167	93
A5 - Cross Machine			195	34	10.8	19	23.1	41.6	78	43
A6 - Machine	135	6.6	448	78	24.5	43	18.1	32.6	130	72
A6 - Cross Machine			179	31	41.5	73	24.6	44.3	18	10
A7 - Machine	339	16.5	477	84	18.6	33	20.0	36.0	143	79
A7 - Cross Machine			218	38	56.3	99	24.4	43.9	21	12
A8 - Machine	128	6.2	459	80	38.4	67	15.8	28.4	122	68
A8 - Cross Machine			195	34	64.4	113	25.6	46.1	18	10
A9 - Machine	155	7.6	425	74	84.5	148	18.6	33.5	67	37
A9 - Cross Machine			195	34	115.2	202	32.6	58.7	6	3
A10 - Machine	152	7.4	327	57	131.0	229	24.6	44.3	64	36
A10 - Cross Machine			251	44	72.2	126	33.0	59.4	20	11

Table 4. Mechanical and Physical Properties of Membranes (Site A)[1] (cont.)

Sample	Weight		Tensile Strength[2]		Modulus of Elongation[2]		Coefficient of Expansion[3]		Thermal Shock Factor[4]	
	lb/100 ft^2	kg/m^2	lb/in	kN/m	lb/in x 10^4	MN/m	$°F^{-1}$ x 10^{-6}	$°C^{-1}$ x 10^{-6}	°F	°C
A11 - Machine	151	7.4	550	96	60.4	106	20.5	36.9	97	54
A11 - Cross Machine			172	30	60.9	107	27.8	50.0	11	6
A12 - Machine	141	6.9	366	64	221.4	388	22.9	41.2	14	9
A12 - Cross Machine			200	35	51.9	91	28.9	52.0	15	8
A13 - Machine	158	7.7	345	60	14.2	25	20.4	36.7	120	67
A13 - Cross Machine			157	27	13.0	23	30.5	54.9	45	25
A14 - Machine	140	6.8	459	80	31.5	55	19.1	34.4	80	44
A14 - Cross Machine			226	40	91.0	159	28.2	50.8	9	5

1/ Values represent the average of test results of 2 specimens.

2/ Tested at 0°F (-18°C).

3/ For the temperature range 0 to -30°F (-18 to -34°C).

4/ Average values and they cannot be calculated from other values given in this table.

Table 5. Mechanical and Physical Properties of Membranes (Site B)1/

Sample	Weight		Tensile Strength2/		Modulus of Elongation2/		Coefficient of Expansion3/		Thermal Shock Factor4/	
	lb/100 ft^2	kg/m^2	lb/in	kN/m	lb/in x 10^4	MN/m	°F^{-1} x 10^{-6}	°C^{-1} x 10^{-6}	°F	°C
B1 - Machine	205	10.0	329	58	40.0	70	24.3	43.7	35	19
B1 - Cross Machine			171	30	35.2	62	36.0	64.8	20	11
B2 - Machine	152	7.4	557	98	18.5	32	16.2	29.2	191	106
B2 - Cross Machine			143	25	34.4	60	24.9	44.8	28	16
B3 - Machine	155	7.6	488	85	15.1	26	28.6	51.5	119	66
B3 - Cross Machine			273	48	20.6	36	38.7	69.7	69	38
B4 - Machine	125	6.1	374	65	50.2 5/	88	14.5	26.1	56 5/	31
B4 - Cross Machine			245	43	19.8	35	21.7	39.1	65	36
B5 - Machine	124	6.1	352	62	239.6	420	18.2	32.8	55	31
B5 - Cross Machine			159	28	20.2	35	30.6	55.1	26	14
B6 - Machine	121	5.9	405	71	22.2	39	16.6	29.8	109	61
B6 - Cross Machine			251	44	19.8	35	23.2	41.8	66	37
B7 - Machine	188	9.2	282	49	31.1	54	23.6	42.5	84	47
B7 - Cross Machine			104	18	42.3	74	45.1	81.2	24	13
B8 - Machine	122	6.0	522	91	40.2	70	14.0	25.2	93	52
B8 - Cross Machine			271	47	33.6 5/	59	23.2	41.8	40 5/	22
B9 - Machine	135	6.6	380 5/	67	34.4	60	37.3	67.1	34 5/	19
B9 - Cross Machine			167	29	117.5	206	49.1	88.4	3	2
B10 - Machine	117	5.7	333	58	227.0	397	16.6	29.9	12	7
B10 - Cross Machine			192	34	84.0	147	27.5	49.5	16	9
B11 - Machine	100	4.9	224	39	33.4	58	22.7	40.9	34	19
B11 - Cross Machine			227	40	13.4	23	27.0	48.6	35	19

Table 5. Mechanical and Physical Properties of Membranes (Site B)[1] (cont.)

Sample	Weight		Tensile Strength[2]		Modulus of Elongation[2]		Coefficient of Expansion[3]		Thermal Shock Factor[4]	
	$lb/100\ ft^2$	kg/m^2	lb/in	kN/m	$lb/in \times 10^4$	MN/m	$°F^{-1} \times 10^{-6}$	$°C^{-1} \times 10^{-6}$	°F	°C
B12 - Machine	130	6.3	223	39	8.5	15	17.2	31.0	160	89
B12 - Cross Machine			162	28	9.7	17	25.9	46.6	8	4
B13 - Machine	114	5.6	316	55	16.4	29	18.0	32.4	109	61
B13 - Cross Machine			168	29	73.6	129	24.0	43.2	65	36
B14 - Machine	121	5.9	351	61	25.2	44	18.5	33.3	78	43
B14 - Cross Machine			220	39	16.2	28	30.8	55.4	49	27
B15 - Machine	136	6.6	264	46	166.9	292	17.6	31.7	42	23
B15 - Cross Machine			274	48	15.1	26	26.2	47.2	69	38
B16 - Machine	123	6.0	351	61	25.0	44	18.4	33.1	108	60
B16 - Cross Machine			133	23	21.8	38	25.6	46.1	36	20
B17 - Machine	127	6.2	480	84	22.8	40	20.5	36.9	104	58
B17 - Cross Machine			192	34	7.8	14	26.6	47.9	101	56
B18 - Machine	101	4.9	272	48	19.8	35	18.2	32.8	77	43
B18 - Cross Machine			137	24	21.0	37	22.9	41.2	29	16
B19 - Machine	188	9.2	400	70	30.8	54	21.3	38.3	75	42
B19 - Cross Machine			200	35	32.2	56	27.6	49.7	23	13
B20 - Machine	121	5.9	411	72	31.2	55	15.0	27.0	102	57
B20 - Cross Machine			211	37	56.8	99	22.9	41.2	23	13

1/ Values represent the average of test results of 2 specimens.

2/ Tested at 0°F (-18°C).

3/ For the temperature range 0 to -30°F (-18 to -34°C).

4/ Average values and they cannot be calculated from other values given in this table.

5/ Value represents only 1 specimen.

Table 6. Mechanical and Physical Properties of Membranes (Site C)

Sample	Weight		Tensile Strength[2]		Modulus of Elongation[2]		Coefficient of Expansion[3]		Thermal Shock Factor[4]	
	lb/100 ft^2	kg/m^2	lb/in	kN/m	lb/in x 10^4	MN/m	$°F^{-1} \times 10^{-6}$	$°C^{-1} \times 10^{-6}$	°F	°C
C1 - Machine	125	6.1	309	54	23.6	41	17.3	31.1	44	24
C1 - Cross Machine			190	33	86.4	151	24.9	44.8	37	21
C2 - Machine	109	5.3	297	52	17.8	31	18.0	32.4	104	58
C2 - Cross Machine			146	26	33.2	58	23.9	43.0	26	14
C3 - Machine	95	4.6	300	53	13.8	24	19.5	35.1	114	63
C3 - Cross Machine			215	38	13.4	23	25.1	45.2	64	36
C4 - Machine	108	5.3	325	57	31.0	54	21.5	38.7	49	27
C4 - Cross Machine			214	37	11.4	20	21.3	38.3	73	41
C5 - Machine	116	5.6	546	96	16.6	29	15.9	28.6	207	115
C5 - Cross Machine			235	41	24.6	43	26.4	47.5	36	20
C6 - Machine	109	5.3	345	60	23.8	42	24.3	43.7	64	36
C6 - Cross Machine			133	23	66.0	116	22.2	40.0	28	16
C7 - Machine	118	5.6	380	67	6.7	12	19.6	35.3	292	162
C7 - Cross Machine			230	40	26.1	46	29.6	53.3	30	17
C8 - Machine	108	5.3	314	55	13.5	24	23.2	41.8	101	56
C8 - Cross Machine			143	25	19.6	34	37.5	67.5	24	13
C9 - Machine	114	5.6	344	60	22.8	40	20.3	36.5	76	42
C9 - Cross Machine			137	24	19.1	33	28.6	51.5	26	14
C10 - Machine	115	5.6	333	58	41.8	73	14.0	25.2	68	38
C10 - Cross Machine			178	31	43.6	76	24.8	44.6	38	21

Table 6. Mechanical and Physical Properties of Membranes (Site C)[1/] (cont.)

Sample	Weight		Tensile Strength[2/]		Modulus of Elongation[2/]		Coefficient of Expansion[3/]		Thermal Shock Factor[4/]	
	lb/100 ft^2	kg/m^2	lb/in	kN/m	lb/in x 10^4	MN/m	$°F^{-1} \times 10^{-6}$	$°C^{-1} \times 10^{-6}$	°F	°C
C11 - Machine	98	4.8	242	42	6.1	11	18.9	34.0	249	138
C11 - Cross Machine			154	27	54.4	95	24.1	43.4	16	9
C12 - Machine	109	5.3	292	51	14.6	26	16.6	29.9	121	67
C12 - Cross Machine			162	28	89.5	157	24.9	44.8	16	9
C13 - Machine	135	6.6	327	57	27.5	48	18.1	32.6	66	37
C13 - Cross Machine			145	25	144.5	253	27.8	50.0	4	2

1/ Values represent the average of test results of 2 specimens.

2/ Tested at 0°F (-18°C).

3/ For the temperature range 0 to -30°F (-18 to -34°C).

4/ Average values and they cannot be calculated from other values given in this table.

Table 7. Ranges and Average Values of the Membrane Properties for the Three Sites

Property	Site	Felt Orientation	Property Value: Range		Property Value: Average	
Tensile Strength[1/], lb/in (kN/m)	A	machine	345 - 588	(60 - 103)	454	(79)
		cross machine	157 - 251	(27 - 44)	206	(36)
	B	machine	223 - 557	(39 - 98)	366	(64)
		cross machine	104 - 274	(18 - 48)	195	(34)
	C	machine	242 - 546	(42 - 96)	335	(59)
		cross machine	133 - 235	(23 - 41)	176	(31)
Modulus of Elongation[1/], lb/in x 10^4 (MN/m)	A	machine	13.6 - 221.4	(24 - 388)	51.7	(91)
		cross machine	10.8 - 115.2	(19 - 202)	53.4	(94)
	B	machine	8.5 - 239.6	(15 - 420)	54.9	(96)
		cross machine	7.8 - 117.5	(14 - 206)	34.8	(61)
	C	machine	6.1 - 41.8	(11 - 73)	20.0	(35)
		cross machine	11.4 - 144.5	(20 - 253)	48.6	(85)
Coefficient of Expansion[2/], $°F^{-1} \times 10^{-6}$ ($°C^{-1} \times 10^{-6}$)	A	machine	15.8 - 24.6	(28.4 - 44.3)	19.3	(35)
		cross machine	23.1 - 33.0	(41.6 - 59.4)	27.6	(50)
	B	machine	14.0 - 37.3	(25.2 - 67.1)	19.9	(36)
		cross machine	21.7 - 49.1	(39.1 - 88.4)	29.0	(52)
	C	machine	14.0 - 24.3	(25.2 - 43.7)	19.0	(34)
		cross machine	21.3 - 37.5	(38.3 - 67.5)	26.2	(47)
Thermal Shock Factor[3/], °F (°C)	A	machine	14 - 211	(8 - 117)	122	(68)
		cross machine	6 - 78	(3 - 43)	32	(18)
	B	machine	12 - 191	(7 - 106)	84	(47)
		cross machine	3 - 101	(2 - 56)	40	(22)
	C	machine	44 - 292	(24 - 162)	120	(67)
		cross machine	4 - 73	(2 - 41)	32	(18)

1/ Tested at 0°F (-18°C).

2/ For the temperature range 0 to -30°F (-18 to -34°C).

3/ Average values and they cannot be calculated from other values given in this table.

Table 8. Average Property Values of Four-Ply Coal-Tar Membranes and Suggested Preliminary Performance Criteria for Bituminous Membrane Roofing, as Reported by Mathey and Cullen

Membrane Property	Values for Four-Ply Coal-Tar Pitch Membranes[1/] Felt Orientation: Machine		Cross Machine		Suggested Preliminary Performance Criteria[1/]
Tensile strength[2/], lb/in (kN/m)	468	(82)	265	(46)	200 (35) - minimum in the weakest direction of the felt tested at 0°F (-18°C)
Load-strain modulus[2/], lb/in x 10^4 (MN/m)	6.7	(11)	7.4	(13)	---[3/]
Coefficient of thermal expansion[4/], $°F^{-1} \times 10^{-6}$ ($°C^{-1} \times 10^{-6}$)	19.3	(34.7)	29.5	(53.1)	40 (72) - maximum, determined for the range 0 to -30°F (-18 to -34°C)
Thermal shock factor °F (°C)	360	(200)	120	(67)	100 (56) - minimum

1/ Reported by Mathey and Cullen in Building Science Series 55 [1].

2/ Tested at 0°F (-18°C).

3/ A performance criterion has not been suggested for load-strain modulus.

4/ Determined over the temperature range 0 to -30°F (-18 to -34°C).

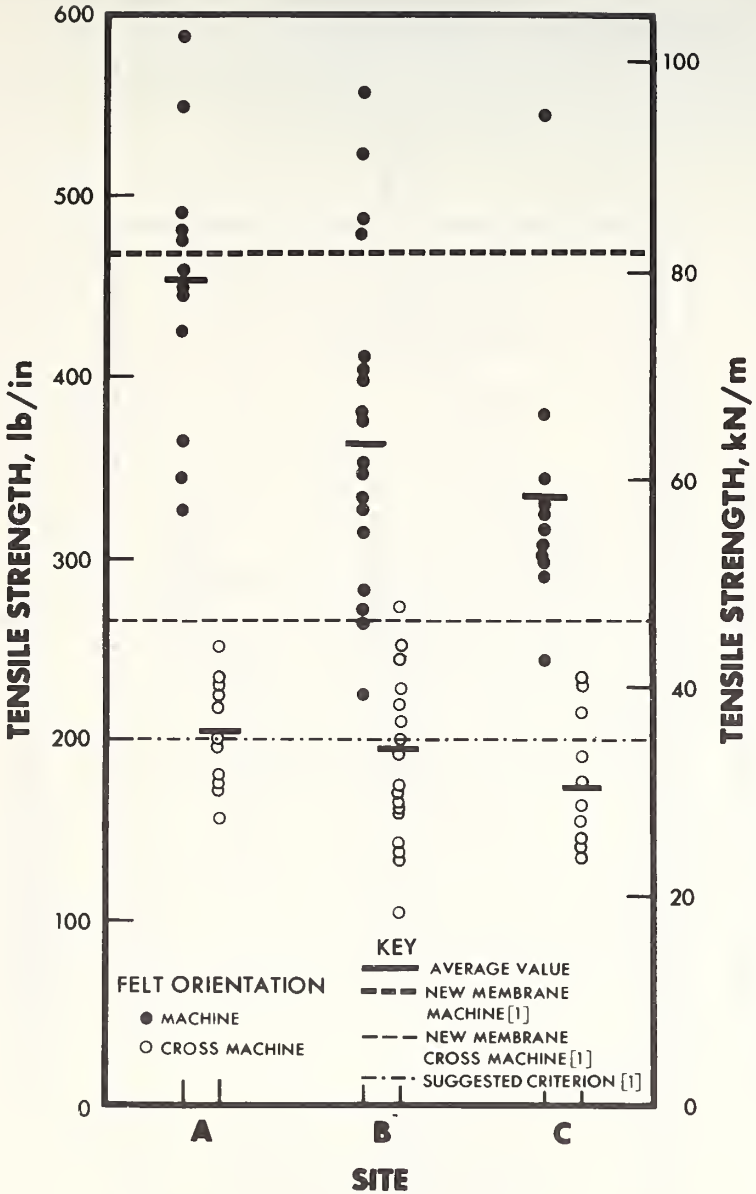

Figure 1. Tensile strengths of the membrane specimens for the three sites.

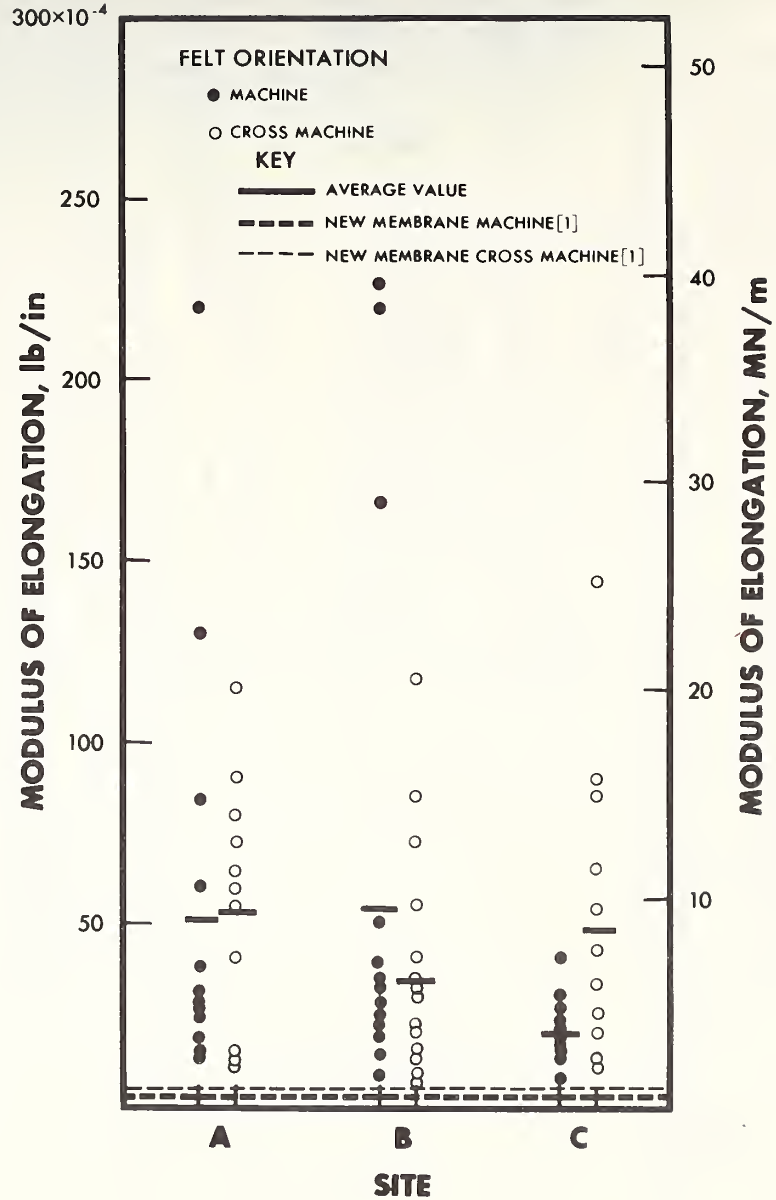

Figure 2. Moduli of elongation of the membrane specimens for the three sites.

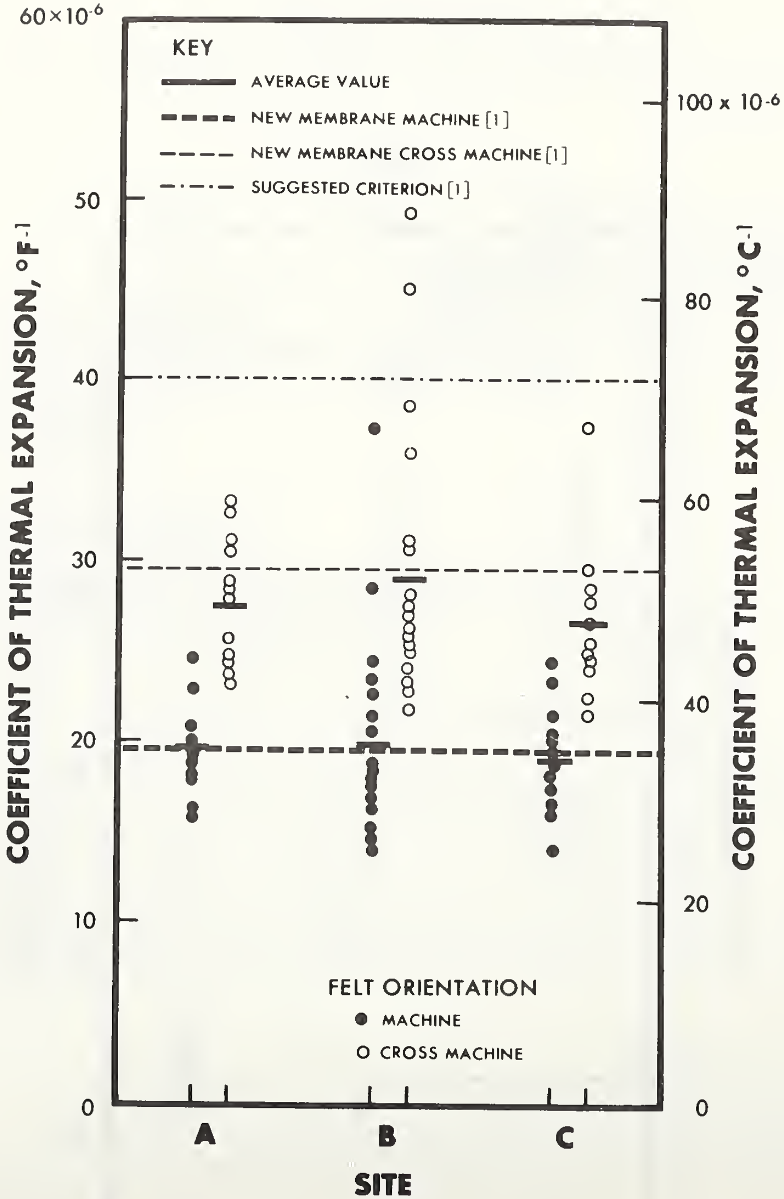

Figure 3. Coefficients of thermal expansion for the membrane specimens at three sites.

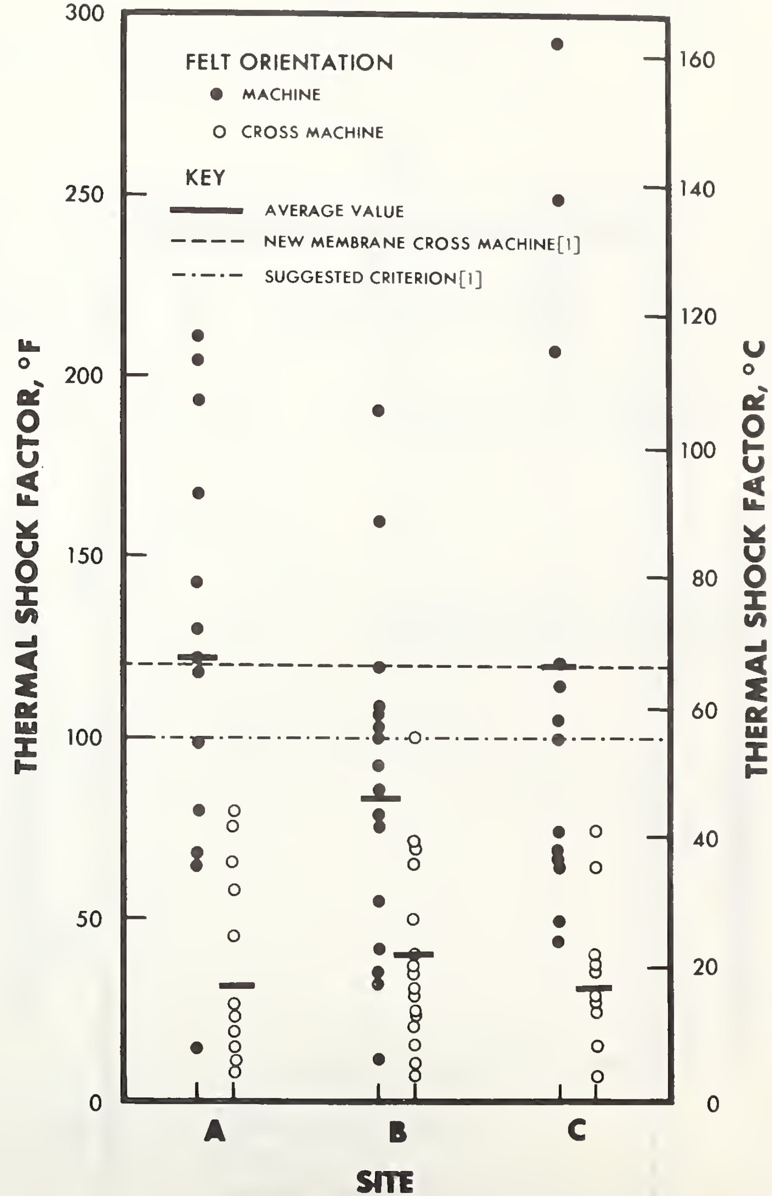

Figure 4. Thermal shock factors for the membrane specimens at the three sites.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The properties of coal-tar pitch roof membranes approximately 21 years old were compared to the properties reported for such membranes in NBS Building Science Series 55, "Preliminary Performance Criteria for Bituminous Membrane Roofing." Samples of the old membranes were taken from eight buildings having roof areas that range from 0.5 to 1.5 million square feet (4.6 to 15 km^2). The buildings were located at three sites in or near the state of Kentucky. The roof membranes on these buildings had been subjected to different maintenance procedures.

Laboratory tests conducted on 47 membrane samples included tensile strength, modulus of elongation and coefficient of expansion. The thermal shock factor was calculated for each sample. Laboratory observations were made of the membrane samples to determine between-ply bitumen thickness, weight per unit area, ply adhesion, pliability and condition of the membrane.

The tensile strengths of the membranes determined at 0°F (-18°C) in their longitudinal and transverse directions were comparable to values reported in NBS Building Science Series 55. Values of the coefficient of expansion measured over the temperature range of 0 to -30°F (-18 to -34°C) were also comparable to thos reported in NBS Building Science Series 55. The modulus of elongation was considerably higher for the old membrane samples which resulted in lower values of thermal shock factor. The lower values of extensibility of the old membranes were attributed to their brittleness caused by aging. The type and frequency of roof maintenance procedures was considered to have had a definite effect on the properties of these old roof membranes.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Bituminous roof membranes; built-up roof membranes; coal-tar pitch; performance criteria; physical and engineering properties; test methods.

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