PROPERTIES OF 21 YEAR OLD COAL-TAR PITCH MEMBRANES: COMPARISON WITH THE NBS PRELIMINARY PERFORMANCE CRITERIA

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ABSTRACT

The properties of 21-year old coal-tar pitch roofing membranes were compared to the properties of new membranes, and to the suggested level of performance reported previously by the National Bureau of Standards (NBS). Samples of old membranes were taken from eight buildings having roof areas ranging from 0.5 to 1.5 million square feet (0.05 to 0.14 km). The buildings were located in or near Kentucky. The roofs had received varying degrees of maintenance.

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 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 procedure apparently 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 with 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 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. Inside temperature in the buildings at roof level was approximately 120°F (49°C). With few exceptions, the roofs had adequate slope for drainage. Test samples were taken from well-drained areas. The roof construction consisted of heavy gauge steel decks with small flutes, fiberglass insulation measuring between ½ and ¾ 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 A, the membranes generally contained a base sheet and three plies of coal-tar saturated organic felts. At the two other sites designated B and C, the membranes contained four shingled plies of coal-tar saturated organic felts.

Roof maintenance 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 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) were installed prior to resurfacing.

*Numbers in brackets indicate references listed in Section 6.

Site B roofs were in good condition, attributed in part to periodic and adequate maintenance. These roofs had not been recoated as was the case for roofs at site A, but the flood coat was intact and generally protecting the membrane.

Site C roofs ranged from fair to poor. There were many areas of exposed felts and many blisters and ridges.

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, with their long dimension perpendicular to the felt direction. A strip 4 x 40 in. (0.1 x 1.0 m) was cut from each of the 47 samples for visual determination of 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. Tensile test specimens conformed to those described in ASTM Standard D 2523 [2]. Two specimens in both the longitudinal and transverse felt direction 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 from 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].

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

Insulation samples, 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.

Samples taken from unbonded areas 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. Problem areas of roofing are not desirable for test-sampling because testing of obviously deteriorated membrane samples would yield little useful 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

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. This data appears 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, and appeared to be firm, except for 12, of which 7 were soft, 3 were delaminated and 2 disintegrated. Reasons for these conditions were not investigated.

4. LABORATORY TESTS

Average approximate weights of between-ply bitumen per 100 ft^2 (9 m^2) of roof area for each of the membrane samples are in Tables 1, 2 and 3. These weights were calculated from the between-ply bitumen thicknesses 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 assuming 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. Because tensile test specimens may be cut at felt laps, it is possible to cut tensile test specimens having more plies than indicated from delamination of the 40 in. (1.0 m) long membrane samples.

Weights of the roofing membranes per 100 $ft.^2$ (9m^2) of roof area are given in Tables 4, 5 and 6. The values are generally less than would be expected for four-ply membranes of this type. A four-ply coal-tar pitch membrane consisting of type 15 felts without 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 slightly less than the expected weights of properly applied membranes, we assume 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 compared with the low weights of the between-ply bitumen.

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. 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: two in the "machine" or longitudinal direction of the felt and two in the "cross machine" or transverse direction of the felt.

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

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

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.

Figure 1 shows that the average values of tensile strength of the old membranes were less than values reported by Mathey and Cullen [1]. Figure 3 indicates that the average coefficients of thermal expansion of the old membrane specimens were in general agreement with those determined from new specimens.

Membrane strength apparently depends on the quality of maintenance. Membranes at site A were better maintained that 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.

Load-strain modulus (modulus of elongation) for the old membranes is generally considerably higher than values reported for new membranes (Figure 2). As membranes age they tend to become brittle, reducing their ability to elongate under tensile stress.

Thermal shock factor varied considerably for the old membranes but was, in general, low compared with 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 ranges from 32 to 40 percent of the suggested performance criterion [1].

The data gives an insight into some of the properties of bituminous roofing membranes and changes in these properties that may occur with aging. The data also show 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. ACKNOWLEDGEMENT

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7. REFERENCES

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2. *"Recommended Practice for Testing Load-Strain Properties of Roof Membranes,"* ASTM Designation D 2523-70, Part 15, ASTM Annual Book of Standards, 1976.
3. *"Proposed Test for Coefficient of Linear Thermal Expansion of Roofing and Waterproofing Membranes,"* Part 15, ASTM Annual Book of Standards, 1974.
4. Rossiter, Walter, J. Jr. and Mathey, Robert G., *"The Viscosities of Roofing Asphalts at Application Temperatures,"* National Bureau of Standards, Building Science Series 92, December 1976.

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 ft²	kg/m²
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 ft²	kg/m²
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 ft²	kg/m²
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 ft²	kg/m²	lb/in	kN/m	lb/in × 10⁴	MN/m	°F⁻¹ × 10⁻⁶	°C⁻¹ × 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	19.0	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
[illegible] - 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
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 lb/100 ft²	Weight kg/m²	Tensile Strength[2] lb/in	Tensile Strength[2] kN/m	Modulus of Elongation[2] lb/in x 10⁴	Modulus of Elongation[2] MN/m	Coefficient of Expansion[3] °F⁻¹ x 10⁻⁶	Coefficient of Expansion[3] °C⁻¹ x 10⁻⁶	Thermal Shock Factor[4] °F	Thermal Shock Factor[4] °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
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)1/

Sample	Weight lb/100 ft²	Weight kg/m²	Tensile Strength2/ lb/in	Tensile Strength2/ kN/m	Modulus of Elongation2/ lb/in x 10⁴	Modulus of Elongation2/ MN/m	Coefficient of Expansion3/ °F⁻¹ x 10⁻⁶	Coefficient of Expansion3/ °C⁻¹ x 10⁻⁶	Thermal Shock Factor4/ °F	Thermal Shock Factor4/ °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
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 Strength1/, 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 Elongation1/, lb/in x 10⁴ (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 Expansion2/, °F⁻¹ x 10⁻⁶ (°C⁻¹ x 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 Factor3/, °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/]				Suggested Preliminary Performance Criteria[1/]
	Felt Orientation				
	Machine		Cross Machine		
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).

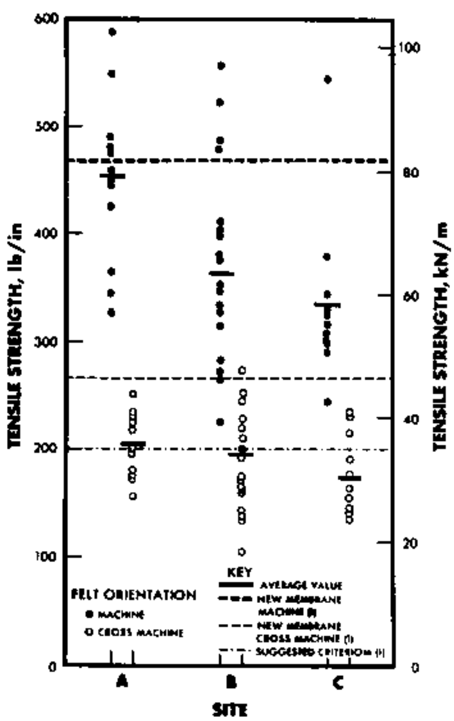

FIGURE 1 – TENSILE STRENGTHS OF THE MEMBRANE SPECIMENS FOR THE 3 SITES

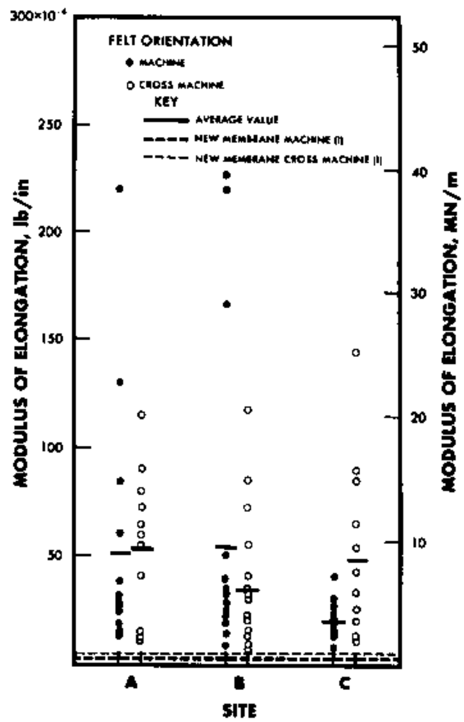

FIGURE 2 – MODULI OF ELONGATION OF THE MEMBRANE SPECIMENS FOR THE 3 SITES

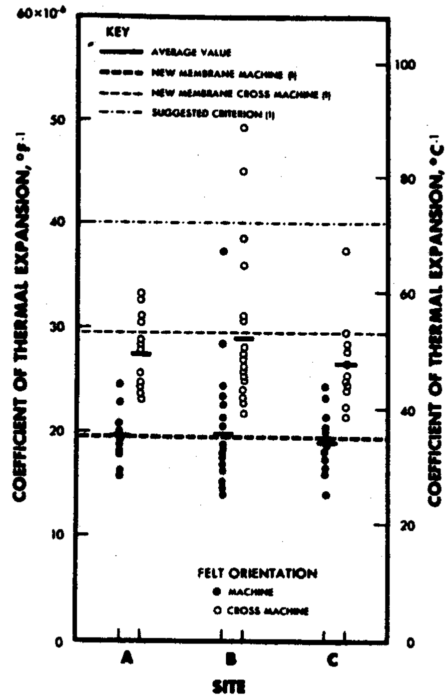

FIGURE 3 - COEFFICIENTS OF THERMAL EXPANSION FOR THE MEMBRANE SPECIMENS AT 3 SITES

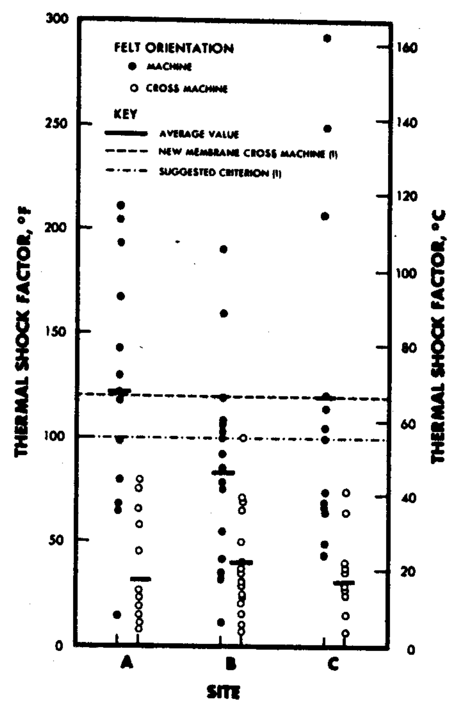

FIGURE 4 - THERMAL SHOCK FACTORS FOR THE MEMBRANE SPECIMENS AT THE 3 SITES