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DOES MORE ROOF INSULATION CAUSE PREMATURE ROOFING MEMBRANE FAILURE OR ARE ROOFING MEMBRANES ADEQUATE?

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As the energy crisis intensifies, the trend toward ever thicker, more thermally efficient insulation has aroused fears of shortened membrane life. This fear springs from the belief that sun-baked membranes will reach higher temperatures, presumed to result from these membranes' increased isolation from the building interior. These higher membrane temperatures will increase the oxidizing rate of the membrane bitumen, thus accelerating its chemical degradation. And since a heavily insulated membrane's winter temperature will theoretically drop lower than that of a lightly insulated membrane, increased insulation will subject the membrane to additional stresses in cold weather.

The NRCA's "Alert Bulletin," issued in January, 1975, exemplifies these fears of accelerated membrane deterioration. "Greatly increased amounts of roof insulation may dramatically shorten the life of most membranes being applied." Summer, according to this bulletin, would "produce much higher roof temperatures and consequent accelerated aging." Winter would reportedly produce "More rapid changes in the roof membrane temperature. Such thermal shock creates very large contractive forces in the roof membrane."

Contradicting this view are several papers indicating that the impact of increased roof insulation is inconsequential to the long-term performance of the roofing membrane. The National Bureau of Standards has published "Effect of Insulation on the Surface Temperature of Roof Membranes" [2], a theoretical model that examines the heat transfer through the built-up roofing and temperature differences associated with the use of more roof insulation. NBS authors W. J. Rossiter, Jr. and R. G. Mathey report that the surface temperature increased from 152°F for a "U" value of 0.30 to 157°F for a "U" value of 0.049 where the insulation "k" was 0.24 for a black-surfaced membrane. For a white surface, the temperatures were 124.1°F and 127.3°F respectively. Color apparently has more effect on surface temperature—about 30°F—for black vs. white than the change in insulation thickness—maximum 5°F, for the two "U" values compared.

To provide additional empirical data, Owens-Corning Fiberglas initiated a field experiment in 1976 to measure the actual temperatures that a roofing system experiences when varying thicknesses of roof insulation are installed beneath the roofing membranes.

We also tested built-up membranes, to obtain data of their expected performance against thermal shock and residual strength after a rapid temperature change.

Judged by the OCF test program data, increased insulation has minimal effect on membrane surface temperature and thus should do no significant harm in promoting degradation or rapid aging of the membrane during warm weather. During cold weather a heavily insulated membrane may have even less temperature change than a lightly insulated membrane (and thus no higher Thermal Shock stress).

Programs

To obtain temperature data for different thicknesses of roof insulation, a building at our Technical Center in Granville, Ohio was used for the installation, observation, recording and analysis of the data. Five thicknesses of roof insulation were installed over 3/4" wood sheathing on wooden joists (see Figure 1). All had three plies of glass fiber felt, top-coated with asphalt except for one with a glass fiber mineral surface cap sheet. A glass-fiber base ply was mechanically fastened to the wood sheathing to serve as a mopping base.

The systems installed were:

1. No roof insulation
2. 3/4" fibrous glass roof insulation "C" = 0.36
3. 1-7/16" fibrous glass roof insulation "C" = 0.17
4. 2-7/16" fibrous glass roof insulation "C" = 0.10
5. 2 layers—2-7/16" fibrous glass roof insulation "C" = 0.05
6. 3 layers—2-7/16" fibrous glass roof insulation "C" = 0.033

Thermocouples to record temperature were placed under the built-up roofing membrane, under the roof insulation, inside and outside the building. The building is a workshop area with forced hot-air overhead heating ducts. This resulted in some temperature fluctuations beneath the roof system.

Standard Copper-Constantan thermocouples with welded ends were used. A 30-point recorder automatically recorded the temperature at hourly intervals which were then keypunched and plotted on a daily basis. Weekly temperatures were then averaged using the hourly temperatures. Selected data is reported in Table 1 and Chart 1.

Another aspect of built-up roofing membrane performance is the effect of thermal shock and its residual strength when exposed to severe temperature changes. Investigating claims that roofs can pull themselves apart from thermal change, our initial findings ("Practical Experiments on Thermal Contraction in Roofing Systems," presented by the late Miles Jacoby at the November, 1964 Midwest Roofing Contractors Association's annual convention) concluded that:

"1. Roofs, properly restrained, do not split themselves.
2. To split a properly restrained roof, localized weakness and/or point loading must occur:
    A. structural movement
    B. deck or substrate movement
    C. damaged materials
    D. moisture or aging deterioration"

Another common cause of splitting may be sandwiching of the membrane in ice. This occurs where there is ponding, with water below the membrane. There is no laboratory research to support this opinion.

Work has been done by others [3, 4] that would support the conclusions that built-up membranes, properly constructed, do not split from internal stress due to the thermal shock expected.

To obtain additional information on membrane performance related to thermal changes, Bowser-Morner Testing Laboratories, Inc. was commissioned to perform tests on 20 different built-up membranes using thirteen different roofing felts, purchased from local sources. The membranes were prepared using steep asphalt or pitch. The systems were constructed and tested in accordance with ASTM D-2523-70 "Load-Strain Properties of Roof Membranes." A load rate of 0.08" per minute, an extensometer 2" gauge length and test temperatures of 30°F, 0°F and -30°F were used, similar to those used by NBS. Five specimens were prepared for the machine direction and five for the cross machine direction. Five additional specimens were tested for membranes that will be identified as construction 10 and 19 in Table 2.

Thermal expansion tests were conducted in accordance with the "Proposed Method of Test for Coefficient of Linear Thermal Expansion of Roofing and Waterproofing Membranes" (ASTM standard part 15-1975) at two temperature ranges of 30°F to 0°F and 0°F to -30°F. For each temperature range, three machine direction and three cross machine direction specimens were tested. The membrane identified as construction 1 had six machine direction specimens tested.

Thermal Shock Factors (TSF) were calculated for the membrane using average values. The data are reported in Table 2.

After the Thermal Shock Factor tests were completed, a new test series was undertaken by Bowser-Morner to determine the residual strength of the same built-up membranes tested for Thermal Shock Factor. To obtain membrane residual strength, a procedure currently being evaluated by ASTM in round-robin testing was used. This method uses the following general procedure:

1. Prepare sample in accordance with ASTM D-2523.
2. Clamp specimen in the instron jaws within the cold box.
3. Preload specimen to approximately 10 pounds which is then immediately reduced to 2 pounds at 75°F.
4. Drop temperature to 25°F in 30 minutes, recording temperature and load build-up.
5. When the temperature of the specimen reaches 25°F, activate jaws (at rate of 0.05" per minute) to break specimen in tension.

The membrane residual strength is the force needed, above the thermal contraction force, to break the specimen. (For summarized results, see Table 3.)

As a secondary purpose of our testing program, we evaluated the test methods and procedures used in round-robin testing. A limited number of materials and membranes were used in the tests with no attempt to select those that might meet minimum standards if they are established for the product. The roofing membranes were laboratory samples that may not represent a built-up roofing assembly, since they were not placed over insulation nor attached to a substrate. Aging, moisture effects and surface treatment were not taken into account in the laboratory membrane analysis.

Having investigated these three areas—membrane temperature, thermal shock resistance and membrane residual strength—we report the resultant data in tables that follow.

Table 1 contains daily temperature data for two weeks—one for cold weather and one for warm weather observations—listing high and low daily temperature and their difference for the following:

1. Outside air.
2. Membrane above the roof insulation having a "C" - 0.05.
3. Membrane above the roof insulation having a "C" - 0.36.
4. Membrane where no roof insulation used.

During cold weather, the tabulated data indicate:

- Membrane daily minimum temperature is higher for higher "C" values.
- Membrane daily maximum temperature is higher for higher "C" values.
- Membrane daily minimum and maximum temperatures were higher for the non-insulated versus the insulated areas.
- Membrane average daily temperature change is greater for the higher "C" value than the lower "C" value and for the non-insulated areas.

During warm weather, the data indicate these results:

- Membrane daily minimum temperature is lower for lower "C" values.
- Membrane daily maximum temperature is about the same for high and low "C" values.
- Membrane daily minimum temperature was higher for the non-insulated area, and the daily membrane maximum temperature was lower for the non-insulated area than the insulated areas.
- Membrane average daily temperature change is greater for the lower "C" value than the higher "C" value as well as non-insulated area.

Greatest change in membrane temperatures occurs in warm weather versus cold weather. Membrane temperature can be below outside air temperature during warm weather for insulated or non-insulated areas with the lower "C" values exhibiting the lowest temperatures.

Chart 1 shows the membrane weekly average temperature for the three systems and the outside air.

From the chart data, the results indicate:

- Average air temperature is below the membrane average temperature during cold and warm weather.
- Average, non-insulated membrane temperature is higher than average air temperature, and higher than the insulated membrane average temperature during cold and warm weather.
- Average membrane temperature difference is larger between systems at colder temperatures.

The test data obtained to calculate the thermal shock factor are contained in Table 2, which lists the construction of the twenty built-up membranes tested. Thermal Shock Factor (TSF) is an indicator of the membrane's ability to withstand the normal temperature changes of its environment. The following equation is used to calculate TSF:

$$\mathrm{TSF} = \frac{P}{Md}$$

P = tensile strength at 0°F
M = load-strain modulus at 0°F
d = coefficient of expansion for the temperature range of 0°F to - 30°F

From the table data, the results indicate:

1. Membranes with fewer plies may have a better thermal shock factor, but a lower tensile strength.
2. The membrane Thermal Shock Factor in descending order seems to be:
   A. Asphalt glass fiber felt (new product)
   B. Asphalt organic felt
   C. Asphalt glass fiber felt
   D. Pitch organic felt
   E. Asphalt asbestos felt
3. The membrane tensile strength in descending order seems to be:
   A. Asphalt glass fiber felt (new product)
   B. Asphalt organic felt
   C. Pitch organic felt
   D. Asphalt glass fiber felt
   E. Asphalt asbestos felt
4. The membrane coefficient of thermal expansion in descending order seems to be:
   A. Asphalt glass fiber felt
   B. Asphalt organic felt
   C. Pitch organic felt
   D. Asphalt asbestos felt
5. The membrane load-strain modulus in descending order seems to be:
   A. Pitch organic felt
   B. Asphalt asbestos felt

C. Asphalt organic felt
D. Asphalt glass fiber felt

The data for the third area of testing, membrane residual strength,are contained in Table 3. The table lists the membranes, the ultimate strength, thermal stress and the residual strength. The membrane residual strength is an indicator of the strength remaining after a rapid thermal change. The residual strength is the tensile strength remaining after the membrane thermal load, developed when the membrane temperature is reduced from 75° F to -25°F, is subtracted from the ultimate load at -25°F.

(Insert Table 3.)

From the table data, the results indicate:

1. The weakest direction is normally the machine direction (except for one glass fiber specimen).
2. The membrane residual strength in descending order seems to be:
   A. Asphalt organic felt
   B. Asphalt glass fiber felt (New product)
   C. Pitch organic felt
   D. Asphalt asbestos felt
   E. Asphalt glass fiber felt
3. The more plies and/or asphalt used, the higher the thermal load is for asphalt systems.
4. The more plies and/or asphalt used, the higher the tensile load is for the asphalt systems.

SUMMARIZED CONCLUSIONS

From the membrane temperature data obtained from the experiment with different thicknesses of roof insulation we make the following observations:

1. Use of a lower "C" rather than a higher "C" value roof insulation has minimal effect on the membrane maximum surface temperature during warm weather. Thus, there should be little additional effect on the degradation or rapid aging of the membrane.
2. Temperature change can be less for a lower "C" than a higher "C" value roof insulation during cold weather, thus there would be no higher thermal shock force exerted on the membrane when a lower "C" value is used.
3. Average membrane weekly temperature difference is higher using a lower "C" rather than a higher "C" value roof insulation, which would indicate more heat flow from the building thru the thinner roof insulation.
4. Maximum daily temperature change during cold weather did not approach 100°F.
5. These observations seem to support the theoretical data from the NBS study.

The Thermal Shock Factor data for the twenty membranes tested in this study would seem to indicate the following:

1. Most commonly used membrane systems would meet the suggested NBS minimum Thermal Shock Factor of 100°F.
2. Most systems' performance related to tensile strength would not be appreciably affected by using lower "C" value versus higher "C" value roof insulation.

Finally, the membrane residual strength data for the 20 tested membranes indicate the following:

1. No membrane would pull itself apart from a thermal change of 70°F to -25°F.
2. Membrane systems most widely used in colder climates have residual strength above the NBS-suggested minimum ultimate strength of 200 lb/in.

We conclude that there is no significant adverse impact on the deterioration or aging of the built-up roofing membrane when thicker roof insulation is used and that membranes do not pull themselves apart from rapid temperature changes.

REFERENCES:

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3. Cullen, William C. and Boone, Thoams H., *"Thermal Shock Resistance for Built-Up Membrane,"* National Bureau of Standards (USA) Building Science Series No. 9 (1967)
4. Mathey, Robert G. and Cullen, William C., *"Preliminary Performance Criteria for Bituminous Membrane Roofing,"* NBS Building Science Series No. 55, National Bureau of Standards (USA) November, 1974.

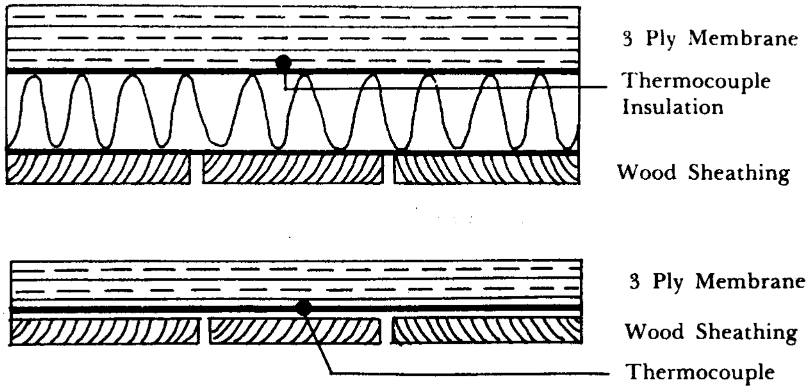

FIGURE 1 - ROOF CONSTRUCTION DETAIL

CHART 1 - AVERAGE WEEKLY TEMPERATURE

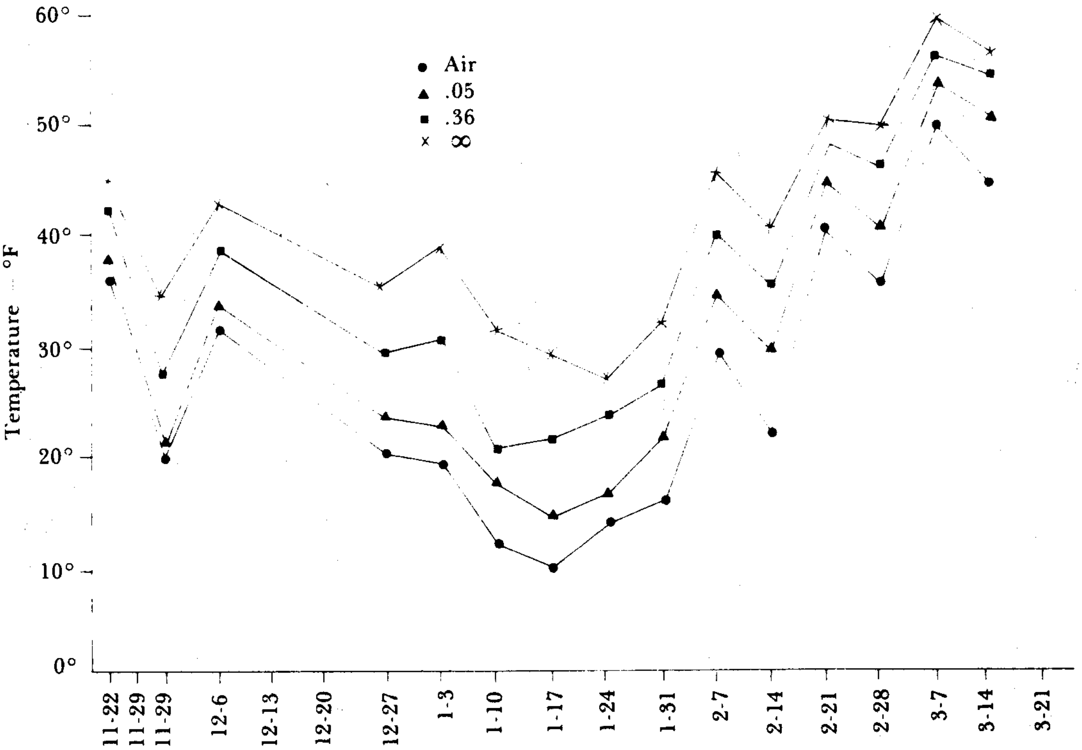

TABLE I

MAXIMUM - MINIMUM DAILY TEMPERATURES FOR AIR AND ROOFING MEMBRANES

	1-03-77			1-04-77			1-05-77			1-06-77			1-07-77			1-08-77			1-09-77		
	Max	Min	T	Max	Min	T	Max	Min	T	Max	Min	T	Max	Min	T	Max	Min	T	Max	Min	T
Air	30	18	12	38	22	16	35	5	30	28	5	23	25	-2	27	27	-2	29	18	13	5
.05	32	21	11	33	26	7	32	7	25	33	3	30	32	-2	34	32	-5	37	25	18	7
.36	35	30	5	72	23	49	65	14	51	50	13	37	35	7	28	54	6	48	38	25	13
Inf	53	35	18	75	35	40	75	25	50	52	25	27	49	20	29	55	23	32	43	30	13

	3-07-77			3-08-77			3-09-77			3-10-77			3-11-77			3-12-77			3-13-77		
	Max	Min	T	Max	Min	T	Max	Min	T	Max	Min	T	Max	Min	T	Max	Min	T	Max	Min	T
Air	43	25	18	64	23	41	69	43	26	70	44	26	75	35	40	58	55	3	60	45	15
.05	80	10	70	120	9	111	107	30	77	113	22	91	130	21	109	60	50	10	104	39	65
.36	82	22	60	120	18	102	105	35	70	110	26	84	135	26	109	62	52	10	105	41	65
Inf	88	27	61	113	27	86	102	40	62	106	30	76	130	30	100	60	53	7	95	44	51

TABLE 2

THERMAL SHOCK FACTOR DATA

	Construction	Orientation*	Ultimate Tensile Strength lb / in 0° F	Load-Strain Modulus $X10^4$ lb / in	Coefficient Thermal Exp. 0 to -30° F Inches/Inch/° F X10-6	Thermal Shock ° F
1.	2 - asphalt glass fiber (new)	M	171	1.34	21.22	601
		CM	206	2.41	15.53	550
2.	3 - asphalt glass fiber (new)	M	304	2.06	25.87	570
		CM	277	1.90	24.10	605
3.	4 - asphalt glass fiber (new)	M	418	4.28	18.48	528
		CM	372	2.42	28.89	532
4.	Combination Glass Fiber Sheet 2 - asphalt glass fiber felt (11)	M	275	1.91	27.85	882
		CM	158	1.37	43.26	358
5.	Combination Glass Fiber Sheet 1 - asphalt glass fiber felt (11)	M	169	1.28	35.56	371
		CM	107	.98	54.05	202
6.	2 - asphalt glass fiber felt (11)	M	144	1.12	33.94	222
		CM	128	1.02	44.22	211
7.	3 - asphalt glass fiber felt (11)	M	234	1.63	35.94	399
		CM	171	1.33	46.68	275
8.	Combination Glass Fiber Sheet 1 - asphalt glass fiber felt (6)	M	139	1.22	36.24	314
		CM	69	.75	59.28	155
9.	Organic Base Sheet 3 - No. 15 asphalt organic	M	437	4.88	24.98	358
		CM	302	3.88	33.63	231
10.	Organic Base Sheet 2 - No. 30 asphalt organic	M	417	5.08	33.86	242
		CM	277	3.36	38.82	212
11.	4 - No. 15 asphalt organic	M	400	2.94	21.99	618
		CM	233	1.74	61.94	216
12.	Asbestos Base Sheet 2 - No. 15 asphalt asbestos	M	269	8.52	15.17	208
		CM	152	5.53	14.20	194
13.	Asbestos Base Sheet 3 - No. 15 asphalt asbestos	M	317	5.86	12.93	418
		CM	165	5.25	35.31	89
14.	Organic Base Sheet 2 - No. 15 asphalt asbestos	M	254	5.28	12.69	379
		CM	126	3.65	42.95	80
15.	4 - No. 15 pitch organic	M	477	7.15	22.06	302
		CM	311	4.69	32.84	202
16.	2 - No. 15 asphalt asbestos	M	168	12.83	24.57	53
		CM	80	3.11	26.43	97
17.	2 - No. 15 asphalt organic	M	204	1.88	21.76	499
		CM	123	1.27	24.24	400
18.	2 - coated asphalt organic base sheet	M	282	3.27	25.68	336
		CM	133	1.70	39.88	196
19.	3 - No. 30 asphalt organic	M	469	5.36	20.20	433
		CM	133	1.70	39.88	196
20.	Organic Base Sheet 3 - No. 15 pitch organic	M	426	6.15	21.99	315
		CM	230	9.21	29.69	84

* M = Longitudinal or Machine Direction

CM = Transverse or Cross - Machine Direction

TABLE 3

RESIDUAL TENSILE STRENGTH DATA

	Construction	Orientation*	Ultimate Tensile Strength lb / in	Thermal Contraction Load lb / in	Residual Tensile Strength @ -25° F lb / in
1.	2 - asphalt glass fiber (new) (R)	M	180	26	154
		CM	174	31	143
2.	3 - asphalt glass fiber (new) (R)	M	251	28	223
		CM	250	34	216
3.	4 - asphalt glass fiber (new) (R)	M	337	44	293
		CM	370	36	334
4.	Combination Glass Fiber Sheet 2 - asphalt glass fiber felt (11)	M	251	48	203
		CM	183	36	147
5.	Combination Glass Fiber Sheet 1 - asphalt glass fiber felt (11)	M	176	33	143
		CM	113	27	86
6.	2 - asphalt glass fiber felt (11)	M	127	31	96
		CM	119	30	89
7.	3 - asphalt glass fiber felt (11)	M	232	40	192
		CM	169	33	136
8.	Combination Glass Fiber Sheet 1 - asphalt glass fiber felt (6)	M	137	25	112
		CM	80	29	51
9.	Organic Base Sheet 3 - No. 15 asphalt organic	M	538	54	484
		CM	341	42	299
10.	Organic Base Sheet 2 - No. 30 asphalt organic	M	498	51	447
		CM	300	39	261
11.	4 - No. 15 asphalt organic	M	507	40	467
		CM	334	45	289
12.	Asbestos Base Sheet 2 - No. 15 asphalt asbestos	M	319	47	272
		CM	290	47	243
13.	Asbestos Base Sheet 3 - No. 15 asphalt asbestos	M	386	43	343
		CM	242	43	199
14.	Organic Base Sheet 2 - No. 15 asphalt asbestos	M	332	48	284
		CM	186	42	144
15.	4 - No. 15 pitch organic	M	458	73	385
		CM	314	76	238
16.	2 - No. 15 asphalt asbestos	M	199	29	170
		CM	92	26	66
17.	2 - No. 15 asphalt organic	M	250	28	222
		CM	151	20	131
18.	2 - coated asphalt organic base sheet	M	298	47	251
		CM	142	33	109
19.	3 - No. 30 asphalt organic	M	533	36	497
		CM	380	44	336
20.	Organic Base Sheet 3 - No. 15 pitch organic	M	487	54	433
		CM	290	51	239

* M = Longitudinal or Machine Direction
CM = Transverse or Cross - Machine Direction