COLD PROCESS ROOFING: SYSTEM PERFORMANCE WITH FIBER GLASS AND FELT BASE MEMBRANES

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With the publication of **Preliminary Performance Criteria for Bituminous Membrane Roofing,** NBS researchers Cullen and Mathey gave the roofing industry a useful tool, much discussed and criticized, but insufficiently expanded and still underutilized [1]. We have found the Cullen-Mathey criteria extremely useful in evaluating a new cold-process membrane first reported at the Montreal ASTM meeting in June, 1975 [2]. Meanwhile, the system has been expanded with the addition of a fiber glass membrane, and we have collected additional performance data and made further field investigations. A total of 25 cold-process roofs varying in age from less than a year up to seven years have now been examined. Complementing our field investigations are laboratory measurements.

Judging by our field observations and laboratory tests, we believe that this new cold-process membrane offers comparable performance to conventional hot-applied membranes. Through its dimensional stability in the presence of water (resistance to hygroexpansion), the fiberglass membrane solves the moisture problems associated with poured-in-place lightweight concrete fills and poured gypsum decks. Though currently limited to the southern market, where moisture problems are relatively severe, this fiberglass membrane should be marketed throughout the U.S. in the future.

SYSTEM DESCRIPTION

This cold process system is bituminous, and the term "cold process" refers to adhesive application at ambient temperatures, rather than in the molten or "hot" condition.

This cold-process membrane comprises three components: felts, adhesive and surfacing. As originally introduced, the felts were asphalt-saturated and coated organic felts. An alternative membrane has recently been introduced for certain applications. This alternative membrane is asphalt-saturated and coated fiberglass mat. Both membranes' physical characteristics are shown in Table 1.

The adhesive is a fibrated-asphalt cutback, typically containing 60% total solids. A characteristic of special importance for proper application is viscosity. The adhesive is normally sprayed, and its viscosity must be limited to a critical range – high enough to permit application of adequate thickness in hot weather, low enough to be pumpable in cold weather. Foot traffic should be delayed four days after application of the field applied mastic.

Surfacing material is No. 11 roofing granules, used on asphalt roofing shingles. White is recommended, to maximize the roof's heat reflectivity, thereby reducing membrane temperature.

Table 2 shows the relationship of the components in a typical three-ply membrane. The organic felt membrane consists of three felts, weighing a total 144 lb./sq., four adhesive layers totaling 72 lb., and one 50-lb. granule layer. Total applied weight for this membrane is 266 lb./sq. of finished roofing. The fiber glass-based membrane has three felts totaling about 65 lb./sq., four mastic layers totaling 72 lb., and one 50 lb. granule layer. Total applied weight for this system is 187 lb./sq. of finished roofing. A third system employs a base ply of the glass felts in combination with two top plies of coated organic felts. Its finished roofing system weight is about 240 lb./sq. All these membranes are adaptable to the full range of slopes, from flat to vertical. A 4-in. minimum slope is recommended. Nailing is required for slopes of 4 in. or more.

APPLICATION

As with all roofing systems, application of the materials is as important as selection of the components. Commercially, these cold-process systems are applied with specifically designed trailer-mounted equipment, typically including a gasoline engine, an air compressor, an air-operated material handling pump, 300 feet of hose on a service reel and a granule hopper. The adhesive is pumped from 55 gallon drums, with the air-operated pump, conveyed to the work area through a hose on a service reel and a granule hopper. The adhesive is pumped from 55 gallon drums, with the air-operated pump, conveyed to the work area through a hose connected to a pole-type spray gun. Units of this type are operating in the field with both air-atomized and airless spray guns. In a typical application involving insulation, three felt plies are embedded shingle fashion in a continuous coating of adhesive, each sheet lapping the underlying sheet by 24¾ in.

Reasonably uniform application of interply adhesive at the prescribed rate of 2 to 2½ gal./square/ply is necessary.

Following felt application, a final top coating of adhesive is applied, also at the rate of 2 to 2½ gal./square, and granules are applied within 10 minutes.

Granules are fed into a ground-level hopper and conveyed to the roof surface through a suitable hose by means of compressed air. On flat roof surfaces, embedment can be improved by spraying the granules upwards, so that they fall into the mastic from a heigh of about ten feet. On vertical surfaces and near roof perimeters, the granules are sprayed directly into the mastic. Granule application can be delayed until other trades complete their work, but the membrane must be sealed with a light coating of adhesive at the end of each working day.

This equipment system is an important aspect of the overall roofing system. It improves labor productivity and facilitates uniform application of the adhesive and surfacing at the specified rates.

PERFORMANCE EVALUATION

From the 1974 Cullen-Mathey report on preliminary performance criteria, we take the following attributes for laboratory investigation:

1. Tensile Strength
2. Thermal Expansion
3. Thermal Shock
4. Punching Shear and Impact Resistance
5. Wind Uplift Resistance
6. Fire Resistance
7. Weather Resistance

Tensile strength of three-ply cold process membranes increases as the volatile content decreases (see Fig. 1). The percentages shown refer to the volatile content of the adhesive, which decreases with time. The horizontal line at the 308 lb. level represents the tensile strength of four-plies of 15-lb. asphalt saturated felt in steep asphalt. The line at 200 lbs. represents the NBS suggested minimum, which is reached at about the 7% volatile level for the glass-based system. Tensile strength of a four-ply conventional system is approached thereafter. These data were obtained at 0°F., in the weakest direction, using ASTM test procedure D-2523, modified to meet our research needs. Three-ply sections were prepared with adhesive at the rate of 2½ gallons per square. Surfacings were omitted and dissipation of volatiles was accelerated by heating the test samples in a 133°F oven.

An obvious question, of course, involves the relationship between roof age and volatile level, and we will report current data in the field performance section of this paper. In general, the changes shown take place over a period of several years.

Figure 2 shows how the tensile strengths of the three-ply membranes vary with temperature; all lose tensile strength with rising temperature.

Continuing with the performance criteria, Figure 3 shows that Attribute 2, Thermal Expansion, also increases as the volatiles evaporate and approach the NBS-suggested maximum. The coefficient of expansion illustrated is for the − 80 to 0°F temperature range. Compared with the organic felt membrane, the glass-based membrane exhibited lower values throughout the range of volatile level.

Fig. 4 shows that thermal shock factor (TSF) remains well above the NBS suggested minimum, though it does decrease with age. Thermal shock is calculated from tensile, thermal movement, and load-strain data measured for Attributes 1 and 2. TSF for the glass-based system begins at a higher value during the aging process, but ends up at a level similar to that of the other systems.

Attribute 4, Punching Shear and Impact Resistance, results indicate that the three-ply cold process systems meet the suggested minimum in the case of Punching Shear after a conditioning period. Since no hail gun was available for impact resistance, a 2-in. diameter steel ball was dropped from a height of 9.3 ft. The kinetic energy of the steel ball at the point of impact was calculated equal to that of a 1½ in.-diameter ice sphere traveling at the rate of 112 feet per second. The specimen was supported on 1-in. perlite board insulation over a concrete deck. This test procedure indicates that, with increasing age, the cold-process systems approach the standard four-ply roof.

Wind Resistance and Fire Resistance, Attributes 5 and 6, are established criteria for roofing systems. The felt-based cold process system meets the requirements of the Factory Mutual Field Uplift Test with values in excess of 75 lb./ft.^{2} versus a required 60 lb./ft.^{2} minimum. It also has an ASTM Fire Tests of Roof Coverings (E 108-58 · 1970) Class A fire rating over non-combustible decks, with or without insulation, on slopes up to 2 in. Static wind uplift tests on the felt-based system were run at Construction Research Laboratories in Miami. The tests were run on a large-scale roof section (10 ft. x 10 ft.) over metal decks. Acceptable building heights were established for Dade County, Florida, with four types of insulation board: Fiber glass, urethane, perlite and fiberboard. For the purpose of wind and fire testing, the cold process systems are subjected to minimum aging of 30 days at ambient temperature. The wind and fire resistance testing of the fiber glass-based system is in progress.

Figure 5 shows the weathering ability (Attribute 7) of the adhesive used compared to some hot applied asphalts. The adhesive film was applied to Weather-Ometer panels and allowed to cure at room temperature for 5 days before testing in the Westher-Ometer (twin-enclosed violet carbon arc). The weathering ability of the cold-process adhesive, as measured by cycles to cracking failure, exceeds that of other typical roofing asphalts. This increase of stability is attributed to the adhesive's reinforcing fibers.

The foregoing discussion is not intended to prove that the subject system does or does not "pass" the NBS criteria. As the Bureau has repeatedly stressed, its criteria are preliminary. On the other hand, the NBS attributes do represent, as stated earlier, an important new laboratory tool for those involved in the development of new roofing systems.

FIELD INVESTIGATION

Pending test standarization and expansion of the criteria to include other known requirements, one must continue to rely on full-scale field trials.

For this evaluation, 25 projects with felt-based and glass-based systems were examined. The majority of these roofs were located in the midwest or south. They varied in age from one year or less to seven years; in size, from 25 to 3000 squares. Substrates were primarily perlite or fiber glass insulation, but included lightweight concrete decks, urethane board stock and reroofing over smooth-surfaced asbestos felts. Roof slopes were generally less than 1 in. per ft., but jobs with slopes of 2 in. and 5 in. were included. These roofs were flashed either with combination flashing or roofing membrane, with the cold-process adhesive.

These twenty-five jobs were examined for general condition, plus the following specific problems:

- Blistering
- Shrinkage
- Fishmouthing and Edge Sealing
- Buckling
- Slippage
- Aging

Blistering, specifically balloon-type blistering, was found to be essentially non-existent. This may be attributable to the high heat reflectivity of the white granule surfacing.

Shrinkage and the related problems of splitting have also not been observed.

Fishmouths sometimes occur during application of the felt-based or glass-based membranes. Fishmouthing is the term given to describe the lifting of the top felt edges from the ones beneath, usually in a parabolic shape. It usually results from twisting the sheet, as it unrolls, so that it continues in a straight line over deck imperfections or slope changes. When these fishmouths occur in the felt-based system, they generally disappear within hours, and do not cause any permanent harm or affect the appearance of the roof. However, when a three-ply fiber glass membrane roof is installed over certain decks, such as a wet-mix deck, fishmouths tend to remain in place. The solution to this problem was the use of a composite roof system containg a base sheet of fiberglass felt and two top plies of coated organic felts. The fiberglass base sheet provides a moisture resistant layer and the felt-based membranes lie flat even if the substrate is uneven.

Buckling of the felt-based system has been observed on poured-in-place lightweight aggregate decks. Investigations based on roof cut samples taken at the time of application, and again after three months' service, revealed that the moisture content of the bottom ply increases from less than 1 to about 3 percent. Organic felts expand as they absorb moisture, and it is indicated that the buckling observed is due to this membrane expansion. Buckling occurs with cold-applied systems, since the felts of the cold-process are not rigidly fastened to each other initially, and stresses can be relieved by felt movement.

Most buckling occurs as a result of with-machine direction (WMD) expansion because of the longer distance between breaks in the felt (36 to 54 feet WMD vs. 3 feet CMD). Figure 6 shows the effect of moisture on both felt-based and glass-based membranes. The glass-based membrane exhibited no expansion in either the with or cross-machine direction. There has been no problem with buckling of the glass-based membrane systems in the field. The dry, felt-based membrane exhibited hygroexpansion in the WMD, as shown in the top curve. In an effort to reduce the amount of hygroexpansion, and thereby eliminate the buckling problem the felt-based membranes are now being pre-expanded by remoisturization to about the 1% level at the time of manufacture. In addition, 4-mil-polyethylene sheets are specified for use over wet-mix decks, for added moisture protection.

The asphalt-saturating step in the manufacturing process results in an essentially bone-dry membrane. This unnatural state does not last long, and if remoisturization takes place after application, expansion, and hence buckling occurs. Remoisturization at the time of manufacture causes this expansion to occur before application to the roof. The result can be seen as the middle curve on the graph. Moisturizing reduces the amount of expansion that will be exhibited by the roof system by shifting the hygroexpansion curve downward, so that dimensional change occurs: (1) at higher moisture content and (2) at a lower rate. For example, if a sample of each membrane was brought to a 3% moisture content, the approximate amount of expansion exhibited by the membrane in the WMD would be (1) glass = 0%, (2) moisturized felt-based = 0.04% and (3) dry felt-base = 0.23%. The unmoisturized sample would expand over 5 times as much as the moisturized. Since these results have been reproduced in the field, we believe the buckling problem has been solved. If high moisture exposure is expected, use glass-based felts.

Slippage has not been observed in the field, and resistance to slippage can be demonstrated in the laboratory.

Aging affects all roofing, and the effect of aging on the strength and flexibility of roofing is a subject requiring continued study. (4) As cold-process roofing ages the adhesive volatiles gradually dissipate, resulting in measurable changes in physical characteristics. Figure 7 shows the change in volatile content for the felt-based systems over a five-year aging period. These data were obtained from the same roofs, primarily in the mid-west, that were inspected for blistering and shrinkage. Volatile content is about 5% after five years' exposure. Also shown is the glass-based system's volatiles loss which proceeds at a faster rate than in the organic felt systems.

Based on these findings, lab conditioning tests were run to provide a basis for sample aging prior to testing.

For the felt-based systems, five months in a forced draft oven at 133°F is required to bring the volatile content down to about 5% (see Fig. 8). The more rapid loss of volatiles for the glass system is confirmed in the laboratory.

DISCUSSION

Over seven-years' field experience has been acquired using the current felt-based system, which is now widely accepted by contractors and owners. The fiber glass system is relatively new. Field experiences and laboratory data indicate it will also be an acceptable, long-service roof system.

For the cold-process systems described, it has been shown that values such as tensile strength and flexibility change with aging, and that three months' accelerated aging of the felt-based system in a laboratory oven at 133°F is about equivalent to five years of actual exposure in the midwest. The aging process results in increasing strength and decreasing flexibility for the cold process system, and it can be hypothesized, based on successful field experience, that this is a fortunate combination of properties, allowing for movement and stress relief during the first few years of the roof's existence. It further appears that the residual volatiles are, in effect, a long-term plasticizer helping to maintain flexibility. Additional data is required to establish field aging characteristics of the glass-based system, as well as field aging characteristics of the felt-based system beyond the five-year period examined to date.

CONCLUSION

On the basis of this evaluation, viewed against available laboratory and field data, we believe the cold-process membranes described herein are functional roofing systems that will provide in-service performance comparable to acceptable conventional systems.

The fiber glass membrane is especially useful over poured-in-place lightweight concrete or gypsum decks due to its resistance to hygroexpansion. These glass membranes are currently released for use only in the southern market on decks where moisture is of concern. In the future, we expect to release this product for use throughout the country.

REFERENCES

(1) Mathey, R. G., and Cullen, W. C., *Preliminary Performance Criteria for Bituminous Membrane Roofing,* National Bureau of Standards (U.S.) Bldg. Science, Ser. 55

(2) Davis, D. A., and Krenick, M. P., *"A New Cold Process Roofing System: Description and Performance,"* Roofing Systems, ASTM STP 603, American Society for Testing and Materials, 1976, pp. 3-12

(3) Griffin, C. W., Jr., *Manual of Built-Up Roof Systems,* The American Institute of Architects (McGraw-Hill Book Company) 1970.

(4) Bonafont, R. L., *Research Into Mechanical Behavior of Waterproofing Membrane Systems,* International Symposium on Roofs and Roofing, Brighton, England, September 1974, Paper No. 9

TABLE 1 – TYPICAL MEMBRANE CHARACTERISTICS

	Felt-Based	Fiber-Glass Based
Material	Asphalt-saturated and coated felt	Asphalt-coated fiber glass mat
Weight	45 lb./100 ft.^{2} (2.2 kg/m^2)	20 lb./100 ft.^{2} (0.98 kg/m^2)
Tensile	27 lb./in. width (min.) (4.73 N/mm)	30 lb./in. width (min.) (5.26 N/mm)
Saturation	140% (min.)	Coating saturated
Dry Mat	32 lb./480 ft.^{2} (0.33 kg/m^2)	1.85 lb./100 ft.^{2} (0.09 kg/m^2) reinforced

TABLE 2 – RELATIONSHIP OF COMPONENTS IN ROOF SYSTEM

	Weight/Lb./Sq.	
Component	Felt-Based	Glass-Based
Adhesive	72	72
Membrane	144	65
Surfacing	50	50
TOTAL	266	187

TABLE 3 – PUNCHING SHEAR AND IMPACT RESISTANCE

	Punching Shear	Impact (9.3 ft.)
Felt Based		
31.6% Volatiles	177 psi (1.2 x 10^6 Pa)	Mod. Cracking
12.6% Volatiles	256 psi (1.7 x 10^6 Pa)	Slight Cracking
Glass Based		
30.2% Volatiles	191 psi (1.3 x 10^6 Pa)	Severe Cracking
0.5% Volatiles	300 psi (2.0 x 10^6 Pa)	Slight Cracking
4 x 15 Lb.	451 psi (2.8 x 10^6 Pa)	Trace Cracking
NBS Minimum	250 psi (1.7 x 10^6 Pa)	----

Test	Conditions
NBS Punching Shear	73°F. (23°C.), ¾ in. probe (19.1 mm)
Impact Resistance (Modified)	73°F. (23°C.), 2 in. ball (50.8 mm)

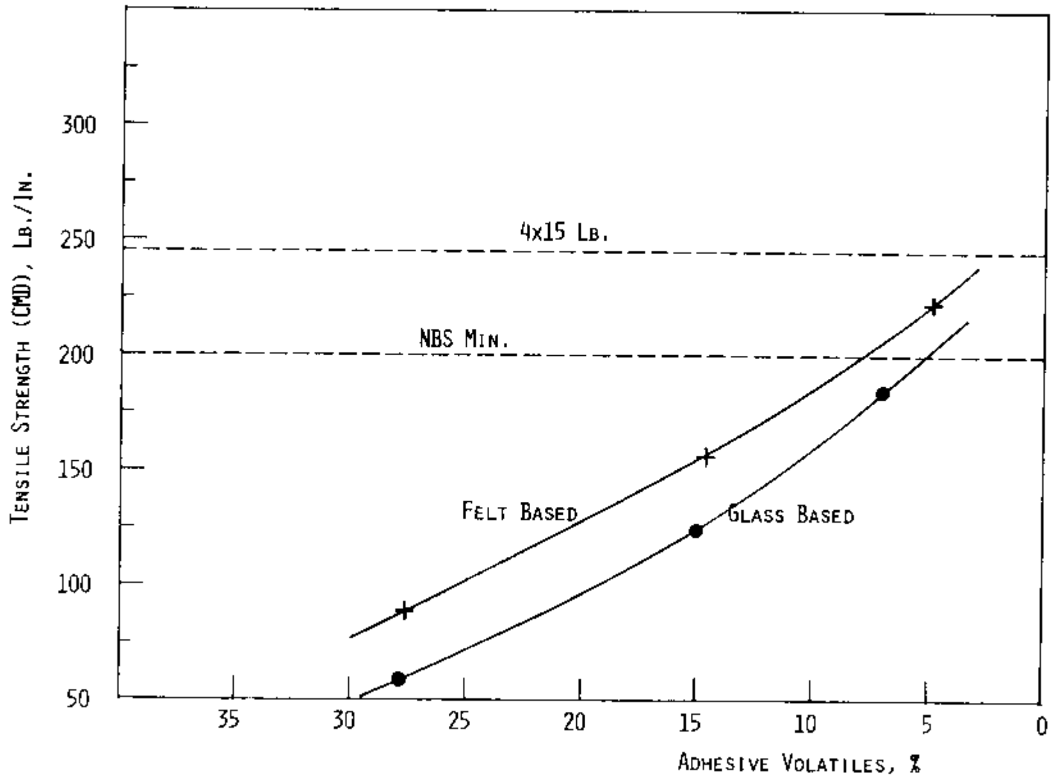

Fig. 1 - Tensile Strength of Cold Process Systems at 0°F.

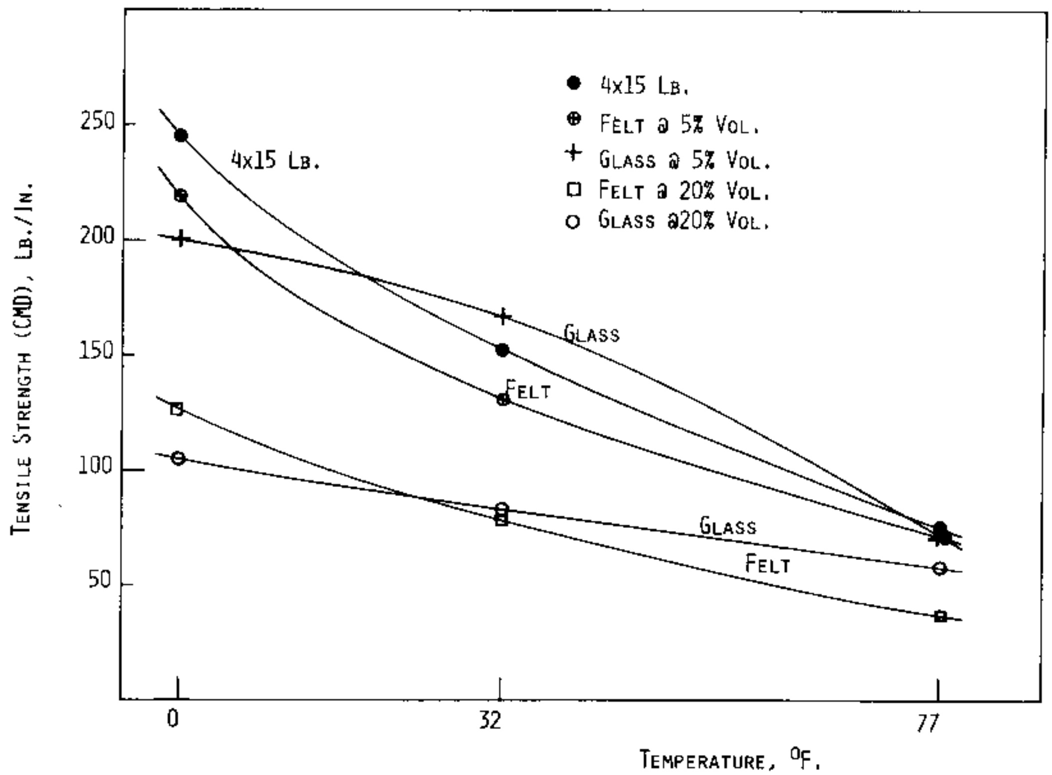

Fig. 2 - Tensile Strengths of Roof Systems at Various Temperatures

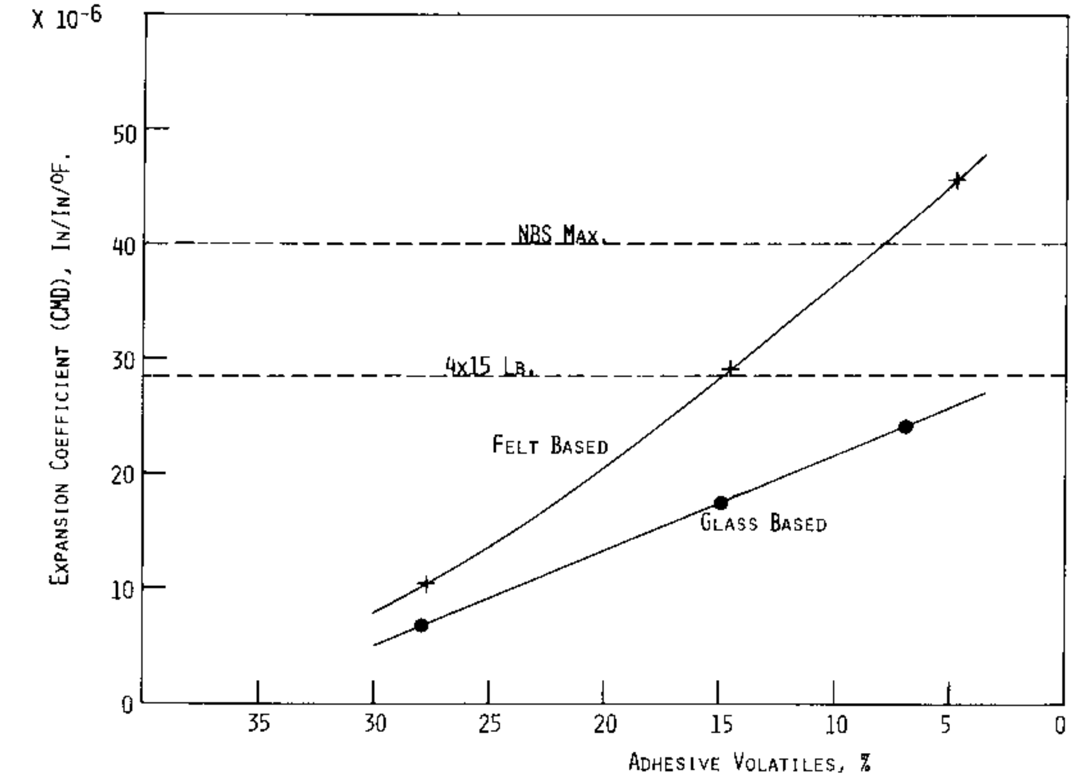

Fig. 3 - Linear Thermal Expansion Coefficient Over Temperature Range of -30 to 0°F.

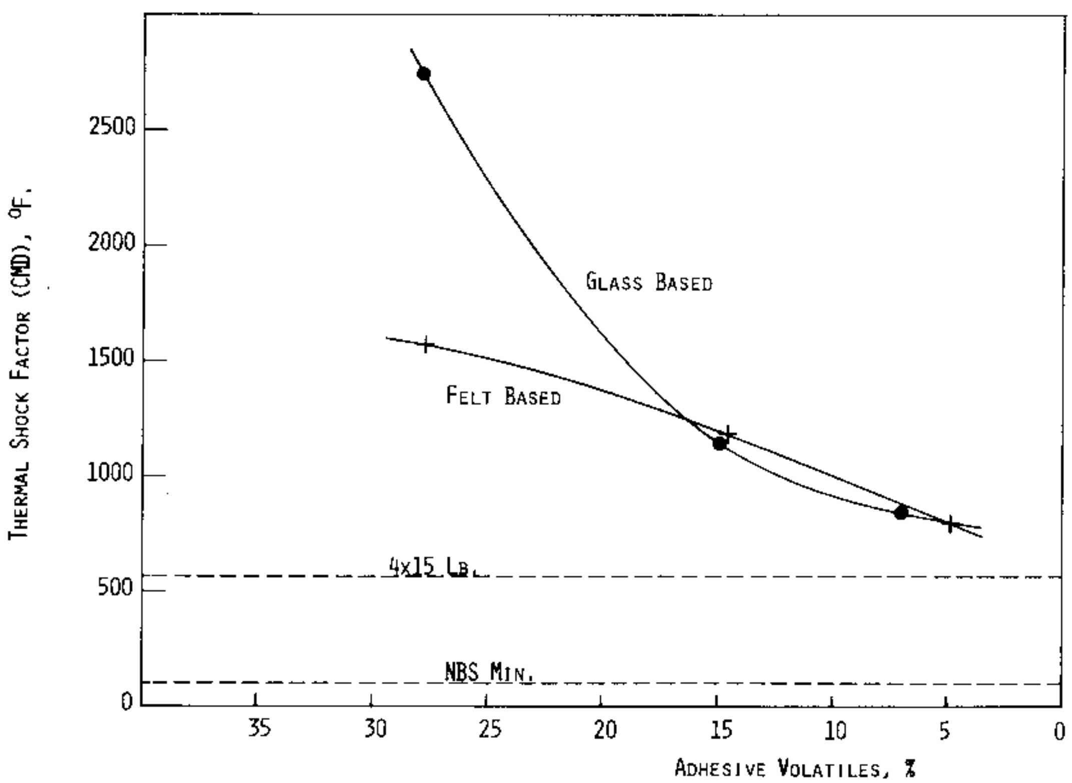

Fig. 4 - Thermal Shock Factors

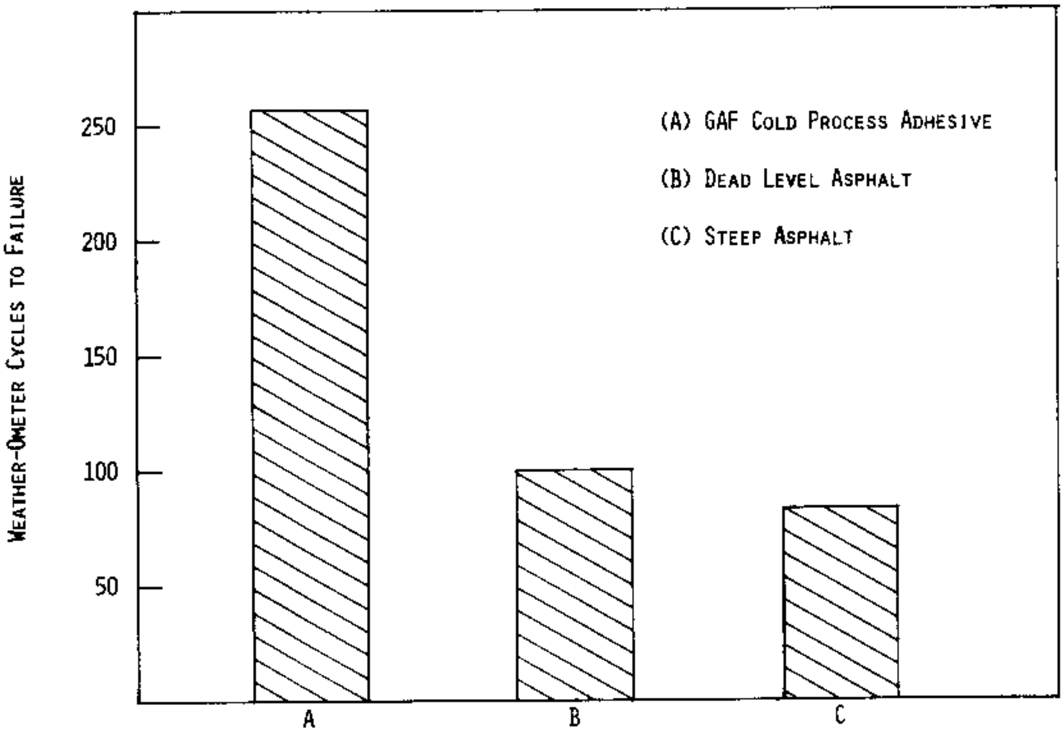

Fig. 5 - Weathering Ability of Cold Process Adhesive Compared to Typical Roofing Asphalts

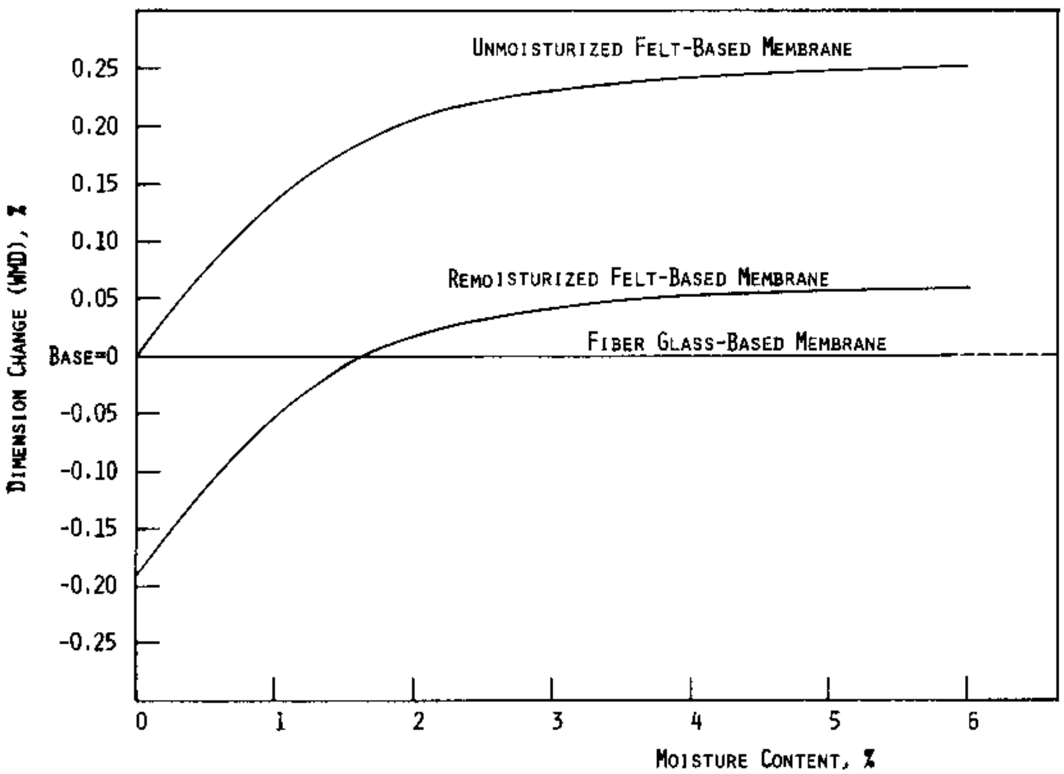

Fig. 6 - Effect of Moisture on Membrane Dimension

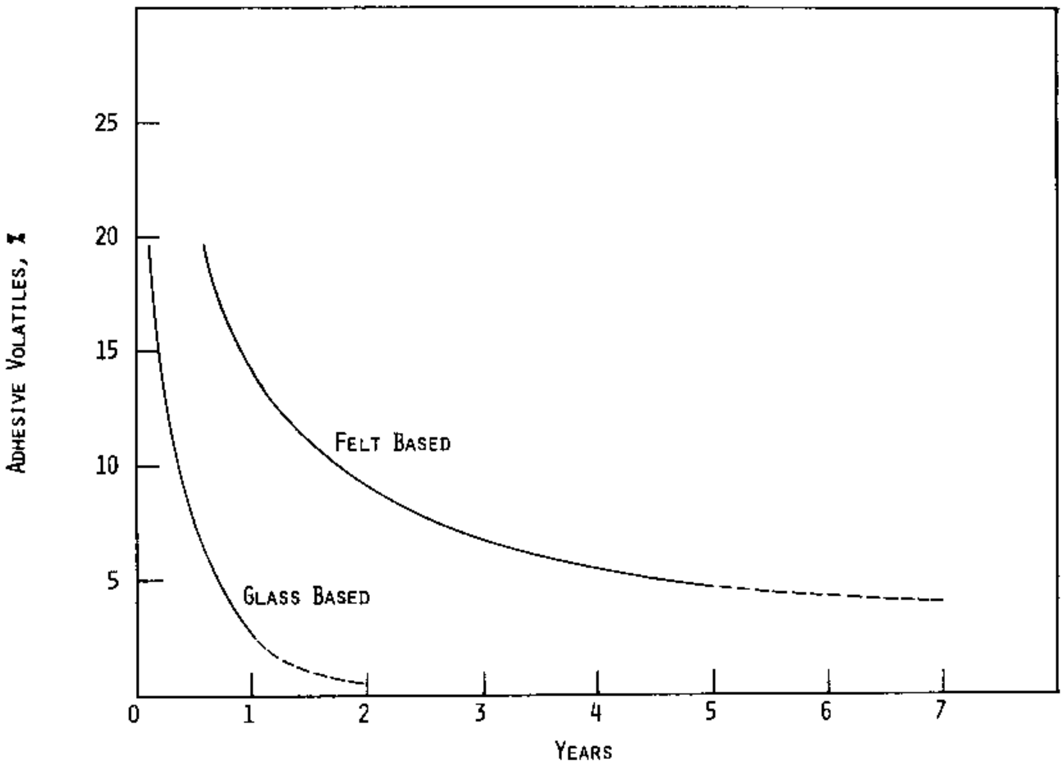

Fig. 7 - Adhesive Volatiles Relative to Time of Exposure in the Field

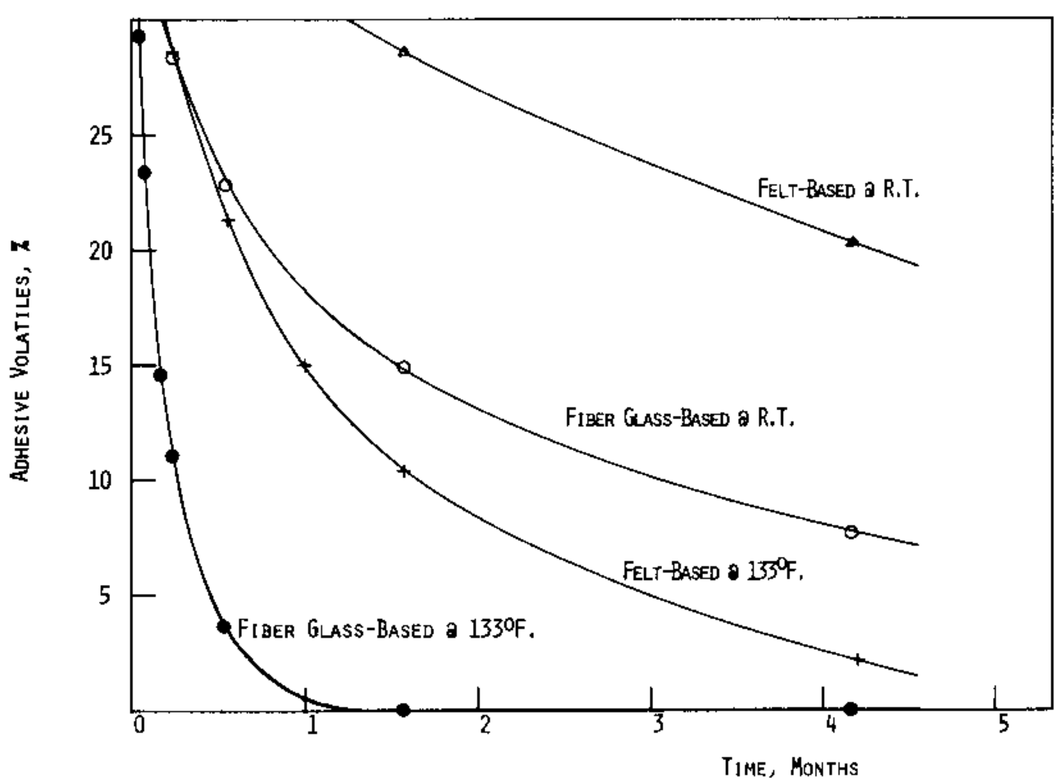

Fig. 8 - Adhesive Volatiles Relative to Time of Conditioning in the Laboratory