Shrinkage of bituminous roofing membranes
Turenne, R. G.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000689
Canadian Building Digest, 1976-07

Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 181

Shrinkage of Bituminous Roofing Membranes

Originally published July 1976.

R.G. Turenne

Please note

Serious problems can result if bituminous roofing membranes are allowed to shrink. Base flashings can be torn, metal counterflashings displaced, improperly secured wood blockings pulled out and masonry work along the roof edge damaged. Membrane shrinkage, which often results in roof leakage, appears to be on the increase despite the technical information available on the subject. It may be that the relevant information has not always reached the design and specifying authorities or roofing contractors. It is the purpose of this Digest, therefore, to outline the factors involved in membrane shrinkage and to suggest methods for controlling them.

What is Membrane Shrinkage?

All materials react to temperature changes by contracting and expanding. For solid materials this movement is usually reversible, and expansion joints, flexible connections or compressible filler materials incorporated in a structure or building component can accommodate it. Bituminous membranes, though relatively strong in tension, are weak in compression and this difference in behaviour is further magnified by the system itself, which uses adhesives to bond various materials together. Where adhesion is inadequate, the contractive stresses induced in a membrane by falling temperatures may be sufficiently large to break the bond between certain components, allowing the membrane to contract. Compressive forces, on the other hand, (because of the flexibility of the membrane) may dissipate without producing expansion and a gradual shrinkage can take place. Membrane shrinkage can therefore be defined as the reduction in size of a membrane as a result of thermal cycling at cold temperatures. It is manifested by inward displacement at the edges.

Main Causes of Shrinkage

Membranes in the conventional roofing system are exposed to high temperature fluctuations ranging from daytime temperatures 30 to 40 C deg above ambient air temperature to night temperatures 4 to 8 C deg below ambient. Such changes, in excess of 55 C deg, induce stresses in a membrane that can produce expansion and contraction, the main causes of shrinkage.

To understand the problem one should consider the physical properties of a built-up membrane and examine the assembly of conventional roofing. The coefficient of thermal expansion of membranes varies considerably with temperature, increasing as temperature decreases. Table I gives the coefficient of expansion of various types of membrane for different temperature ranges. The coefficients listed for asphalt and organic felt membranes would result in a 1.8-in. (46-mm) contraction if a 100-ft (30.48-m) wide membrane were exposed to a 33 C deg drop in temperature (from -1 to -34°C) while unrestrained. A membrane, however, is seldom completely free of its support because a conventional roofing system is based on uniform adhesion of all components. Under these circumstances contraction will take place only if the adhesive component fails and there is no peripheral attachment.

Table I. Coefficients of Thermal Expantion for Roof Membranes[2]

Type of Membrane	Coefficent of Thermal Expansion per °F x 10^{-6}			
	30 to 0°F		0 to -30°F	
	L	T	L	T
Organic Felt & Coal Tar Pitch	22.3	36.0	19.3	29.5
Organic Felt & Asphalt	2.7	12.6	13.9	37.4
Asbestos Felt & Asphalt	4.8	18.1	19.5	37.5
Glass Felt (Type 1) & Asphalt	8.9	10.1	35.1	46.4

L Denotes longitudinal or machine direction of felts
T Denotes transverse or cross-machine direction of felts

Tensile stresses are induced in a membrane by rapidly falling temperatures. It was reported some years ago that a sample membrane subjected in the space of 2 hours to a temperature drop of 61 C deg (from 21 to -40°C) developed stresses of 20 and 30 lb per inch of width (2.26 to 3.4 N/m) measured at temperatures of -18 and -23°C, respectively. These stresses increased as the temperature decreased. The actual values are not important because too many factors are involved under service conditions, but they do demonstrate the existence of such stresses. Even their magnitude appears to be consistent with the type of damage observed on a number of buildings. On the other hand, experiments show that the tensile strength of a 4-ply organic felt and asphalt membrane can be as high as 240 lb per in. of width (27 N/m) in the cross-direction of the felts at -29°C. This suggests that temperature-induced stresses tend to be smaller than the tensile strength of the material itself, and that membranes should be immune to splitting if other factors are not involved.

A built-up membrane, composed as it is of felts and asphalt or tar, exhibits the viscoelastic properties of the bitumen and does not behave elastically except when loaded at high speed. At the rates of loading generated by service exposure, plastic or viscous flow takes place when tensile stresses are induced in a restrained membrane; if the strain is maintained long enough, the stress subsides until the membrane becomes completely relaxed. This flow characteristic is greatly influenced by temperature (being greater at higher temperatures) and to a lesser extent by rate of loading.

How do most membranes perform so well despite their behaviour patterns and the adverse conditions to which they are exposed? There are a number of reasons: 1) Viscoelasticity imparts to the membrane the ability to absorb tensile stresses without contracting. 2)

Membrane breaking strain, even at low temperatures, far exceeds the strain a membrane is expected to withstand in service. 3) Stresses that could build up in membrane with time are dissipated through cold flow. 4) Membranes generally have adequate tensile strength.

Methods of Restraining a Membrane

To a large extent the method of supporting and assembling roofing determines its behaviour. A membrane neither attached to its support nor restrained along its edges can expand and contract without developing stresses, which generally appear only when resistance has to be overcome. This might well be the ideal system if the threat presented to flashings by a membrane whose size varies continually in response to climatic conditions could be resolved. In practice it is necessary to restrain the membrane by one of two methods.

In the first, a loosely laid membrane is restrained along its perimeter so that this attachment transmits all tensile stresses to the structural deck. Although it is often recommended for single-ply membranes of synthetic materials, it is not used in Canada with conventional built-up membranes. Wind blow-off protection generally requires spot attachment to the substrate or adequate ballasting.

The second method, in common use in Canada, depends on uniform adhesion of all components of the roofing system, including deck, to achieve restraint. All stresses are thus transmitted from the membrane to the deck by the intervening materials. These insulation, felts, adhesives must have adequate shear resistance and the deck itself must possess good lateral stability. Complete adhesion, however, is not always achieved, nor is it always desirable. Most roofing installations therefore offer a combination of loosely laid and adhered areas side by side. Stresses induced in a membrane located over an area with poor or no adhesion are transferred to the deck in areas where good adhesion occurs, so that a complex stress distribution pattern can exist. Such non-uniformity of adhesion probably contributes to splitting failures, especially where marginal adhesion may fail, causing a sudden lateral redistribution of the membrane stresses. Uniform adhesion should therefore be the aim in a conventional roofing system, although complete adhesion is not required. In fact, it is common practice to nail insulation to a wood deck, and to attach roofing to steel decks by ribbons of adhesive, or to concrete decks by spot, strip or solid mopping. These methods are quite acceptable if good wind blow-off and shrinkage resistance are provided.

Attaching membranes to a stable substrate and restraining them at their edges is a safe practice to follow. For years, before it became common to place insulation between deck and membrane, roofing membranes were mopped directly to concrete decks with good results. It is true that heat losses from the building (if no insulation was used under the deck) protected the membrane from temperature extremes during both winter and summer; it is also true that many membranes installed over vented lofts (without the benefit of heat losses from the buildings) performed well. It appears, therefore, that a membrane attached to a stable substrate has the required viscoelasticity to adjust to changing ambient temperatures without being damaged.

Although the practice of placing insulation between the membrane and the deck has in most cases increased considerably the temperature range that a membrane has to endure, it is believed that other factors such as instability of the insulating substrate (caused by poor adhesion, poor cohesion or dimensional changes due to moisture absorption or temperature cycling) may be responsible for some premature failures.

Investigation of Failures

A study of a number of roofs in which membrane shrinkage had been observed revealed that movement had taken place at one of two planes: at the membrane-insulation interface or at the insulation-deck interface. In certain cases both appeared to have been involved. Examples of the first type consisted of installations where coated base sheets had been placed dry (without asphalt) over polystyrene insulation without adhering. Movement at the insulation-deck interface resulted from improper attachment of the roofing to the deck because of lack of nailing to wooden decks or inadequate adhesion to most others. Steel decks appeared to be specially vulnerable because of unevenness or concavity of their top flanges or poor workmanship on the part of the roofing contractor.

In all cases the construction at the edge of the roofs was inadequate as a result of either poor detail or poor workmanship. This suggests that both poor adhesion and lack of edge restraint must be present before shrinkage will take place. Examples of poor edge restraint include failure to cement membranes to cant strips, absence of insulation stops at the roof perimeter, or wooden blockings inadequately fastened to structural decks. Often wooden blockings were also attached to building elements incapable of resisting the tensile force exerted by the membrane, for example to face bricks.

In all cases, proper edge securement would have prevented shrinkage. This is not to suggest that edge restraint should be substituted for uniform adhesion as a means of controlling shrinkage; but it should be provided in case adhesion fails.

Recommendations

To help prevent shrinkage problems the following guidelines should be followed in preparing drawings and specifications and installing built-up roofs:

1. All components must be attached uniformly and securely, including membrane to insulation, insulation to vapour barrier and vapour barrier to deck.
2. All insulation stops and wood blockings required at roof edges, building expansion joints, curbs and walls must be securely fastened to the deck or other structural element. The membrane must be properly attached to these wood members. Blockings should not be fastened to face bricks in cavity wall construction nor to curtain walls for the purpose of attaching the membrane. Apart from the relative weakness of this construction in resisting the tensile forces exerted by the membrane, the possibility would exist of differential movement between the insulated and waterproofed deck and the walls (which are exposed to heating and cooling, wetting and drying) and this could cause the membrane to fail as a result of fatigue.
3. Insulation panels should be butted firmly together. Spaces between insulation and wood blockings along the periphery of a roof can result if insulation boards are pulled together as the membrane shrinks away from the edge of a roof. A tighter installation would permit less freedom of movement for the membrane. As it is generally difficult to obtain satisfactory adhesion between two layers of polystyrene insulation with standard construction practices, only one layer should be specified. If two layers must be used, they should be firmly bonded together by means of special adhesives and techniques.
4. Coated base sheets should not be installed dry over polystyrene insulation but should receive a uniform coating of asphalt before being placed on the insulation. This coating should probably not exceed 10 to 15 lb per square* (4.5 to 6.8 kg per 9.3 sq meters).
5. Interply moppings much heavier than the recommended 20 lb per square for saturated felts may be detrimental to the performance of a membrane, for the extra weight of asphalt may facilitate interply slippage in the cross-direction of the felts. This slippage may result from successive expansion and contraction of felts exposed to cyclical heating and cooling and may promote the formation of ridges as well as increase the susceptibility of the membrane to splitting. Asphalt should be heated to its optimum temperature to facilitate spreading. Mopping with cooled asphalt may require larger quantities than are actually required for good roofing application and performance.
6. Membrane control joints are not effective for controlling tensile forces in a membrane. Such forces result from unit stresses induced by severe temperature variations and are independent of the size of the membrane.
7. Special attention should be given to the adhesion of insulation or vapour barriers to steel decks. Many of the recommendations made by the Factory Mutual Engineering Corporation[1] with regard to wind uplift apply equally well to securing insulation and vapour barriers against shrinkage.

Conclusions

Stresses induced in a membrane result from exposure to ambient air temperature. The practice of placing insulation between membrane and deck has not only increased the severity of the exposure but provided a less stable support for the membrane. These stresses should be transferred from the membrane to the deck by the insulation in shear, but if this is not possible good anchorage at the perimeter will achieve similar results. In the event that neither adhesion nor edge restraint is adequate to prevent contraction of the membrane, it will usually shrink, for its ability to contract is greater than its ability to expand. Shrinkage of a membrane often damages base flashings or the roof edge assembly, leading to water infiltration. Methods recommended for preventing shrinkage include adhesion of the whole roofing system and peripheral attachment of the membrane to the deck.

References

1. Factory Mutual Engineering Corp. Loss prevention Data Sheets 1-28, March 1975.
2. Mathey, R.G. and W.C. Cullen. Preliminary Performance Criteria for Bituminous Membrane Roofing. National Bureau of Standards, Bldg. Sci. Ser. 55, 1974, 19p.

---

* 100 sq ft