SPECIAL Report
NATIONAL ROOFING CONTRACTORS ASSOCIATION

EPDM Membrane Shrinkage

May 1996

The purpose of this report is to inform the membership of issues related to EPDM membrane shrinkage. Following the "Recommendations," this report discusses the shrinkage phenomenon and presents conclusions. *(Note: In many instances, this report refers to the designer. On jobs where there is no third-party designer, the roofing contractor typically also functions as the designer.)*

At the 11th Conference on Roofing Technology (September 1995), a paper was presented on EPDM membrane shrinkage. It was coauthored by researchers from the National Research Council of Canada and NRCA staff. The majority of the information in this Special Report was derived from that paper. (A complete copy of the paper can be obtained by purchasing the *Proceedings of the 11th Conference on Roofing Technology* from NRCA.)

Terminology

- Shrinkage is the irreversible (i.e., permanent) dimensional shortening of the roof membrane.

  Note: Shrinkage has been referred to as contraction, tenting, bridging, normalization and volume change.

- Contraction refers to membrane tightening, which may be caused by shrinkage and/or other induced loads.

Recommendations

- Existing Roofs

  It is recommended that existing roofs be inspected semiannually. If the base securement has been compromised (e.g., the batten has been displaced, or the field sheet has begun to pull out from under the batten), the building owner should have corrective action performed (providing that the remainder of the roof is in reasonably good condition):

  —If the batten has been *slightly* displaced, it may be possible to return it to approximately its original position with the installation of new fasteners (which are then flashed). If this option is chosen, the condition of the substrate should be checked to verify that it has not deteriorated.

  Note: The more conservative approach, and the one that will likely be applicable on most roofs, requires more extensive repairs.

  —If the batten is more than slightly displaced or no longer holds the field sheet securely, more extensive repairs are recommended. Consult the manufacturer, if known, for repair guidance.

  If significantly deteriorated originally uncured flashings are observed, it is recommended that the building owner have corrective action performed. (This recommendation is unrelated to contraction issues.)

- New Roofs

  It is recommended that EPDM sheet manufacturers reevaluate their details. Base securement details should be conservatively engineered, with incorporation of suitable safety factors and consideration of the variety of substrates that commonly occur.

  It is recommended that compression securement not be relied upon for non-reinforced sheets. Either use a reinforced EPDM fastening strip (see Figure 1-E), or use a reinforced field sheet behind the batten (which may then be seamed to a non-reinforced field sheet in the plane of the roof). Fasteners which are capable of pulling the fastening strip snugly to the substrate and maintaining it there (e.g., screws) are recommended. It is recommended that base securement fasteners be capable of resisting an ultimate design contraction and wind load of at least 400 lbf/lineal ft (5.8 kN/m). (Mechanically attached membrane systems may require a substantially higher load capacity, depending upon the wind environment and the location of the first row of membrane fasteners.)

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For metal edge flashings, refer to the discussion under "Base Securement Details." These details should be considered as requiring periodic repair.

It is recommended that designers also consider the substrates into which the batten or EPDM fastening strip fasteners are being installed—a suitable substrate (e.g., 15/32 in. [12 mm] plywood) should be specified. Additionally, the substrate should be firm (if the fastening strip is in the horizontal plane, rather than placing it over the insulation, a wood nailer is recommended.) It is also recommended that EPDM sheet complying with the latest edition of ASTM D 4637 be specified.

To avoid building in membrane stress, allow the EPDM sheet to relax a minimum of 30 minutes prior to securement. During cold weather application, a longer relaxation time may be required (consult with the sheet manufacturer).

- Reroofing

  In addition to the recommendations noted for new roofs, it is recommended that the designer determine the type of substrate and its condition. Where weak or deteriorated conditions exist, replacement/strengthening should be specified.

  Rather than re-cover over a membrane that may be susceptible to further shrinkage (e.g., an unreinforced PVC membrane), consider removal of the old membrane prior to the installation of the new EPDM membrane.

  During application, mechanics should be alert to fastener conditions that may indicate the substrate is inadequate. If an inadequate substrate is encountered, the designer should be consulted for direction.

- Reroofing an Existing EPDM Membrane

  If an existing EPDM membrane is to be removed, it is recommended that the roofing contractor be alert to taut conditions. When ballast is removed, the membrane may contract. When cut, a long tear may result, which could leave a larger area of the roof vulnerable to infiltration than anticipated.

Contraction Problems

Dimension change caused by shrinkage or other induced loads creates extra forces on lap joints (seams) and flashing/base securement details. Rupture of the flashing/base securement (i.e., perimeter/curb) detail may occur as the tensile forces within the membrane increase. When the membrane or flashing is ruptured, the waterproofing ability of the roof can be greatly affected. However, typically this is not catastrophic, compared to a problem such as a wind blow-off which leaves a large area of the roof vulnerable to water infiltration.

Problems resulting from contraction may be associated with material, design, workmanship or a combination of these factors. They can also be related to substrate deterioration. For example:

- Material—The EPDM membrane contains oils added during the manufacturing of the sheet. The oil facilitates mixing and processing of the ingredients and is used in conjunction with the EPDM polymer and carbon black to achieve the desired physical properties for the membrane. Consequently, loss of oil may lead to lower flexibility and shrinkage. In addition, crosslinking (i.e., a chemical bond joining two polymer chains together) or other molecular changes could play a role.

- Design—The design of the base securement details at perimeters and equipment curbs is important. If the detail's design lacks sufficient strength to resist shrinkage forces and other induced loads, leakage can occur as the flashing detail is pulled apart.

- Workmanship—If the execution of well designed base securement details is poor (e.g., the actual fastener spacing is far in excess of the specified spacing), contraction can pull the details apart.

  During application, stresses may also be inadvertently built into the membrane. Although unrelated to shrinkage, the effect of these application-induced loads may be mistaken as shrinkage, since they can cause the membrane to become taut. Fortunately, these induced loads are quite low. However, particularly when combined with high-shrinkage loads, the combined loading can over-stress weak base securement details and cause problems. *These application-induced loads should be taken into account by manufacturers when designing various termination details.*

- Substrate deterioration—If the base securement fasteners were initially installed into a sound substrate, but that substrate subsequently deteriorates (e.g., plywood dry rot due to condensation within the parapet), the base securement fasteners can pull out and cause problems.

Laboratory Evaluation

Nineteen roofs were sampled by contractor members or NRCA staff from various parts of the U.S. These roofs ranged in age from 1.5 to 18 years. Some of the roofs exhibited contraction problems at the time of sampling, while others did not. In addition to these field samples, four unaged control samples were obtained from contractor members.

The field and control samples were analyzed by a variety of test methods. For those jobs exhibiting flashing/base securement problems, it was difficult to attribute the cause of the problems to changes in material property of the membrane.

Well formulated membranes can be expected to exert a minor amount of shrinkage-induced load on flashings/base securements. However, if the membrane is poorly formulated, the shrinkage-induced load could be relatively large and not within the resistance capacity of well designed and installed flashing/base securement details, as discussed below.

Base Securement Details

Base securement details at the roof perimeter and at equipment curbs need to have sufficient strength to resist design contraction forces that are induced by shrinkage and temperature change, as well as loads contributed by wind uplift. Ultimate design load information on shrinkage and temperature-induced forces has not been made readily available by the sheet manufacturers. Accordingly, designers have had to rely primarily on manufacturers to provide base securement requirements.

Since the introduction of EPDM roofing sheets, the various manufacturers/suppliers have recommended a variety of base securement details, and individual manufacturers have typically changed their requirements over the years. Some manufacturers did not recommend mechanical attachment near the base of the parapets or curbs, but rather relied upon the bonding adhesive to resist the contraction load. However, because of the bonding adhesive's low peel-strength, the membrane could be pulled off the parapet or curb with very little force.

Early base securement details relied on roofing nails, which typically proved to be ineffective. A variety of base securement devices followed, including wood, metal and polymer battens (see Figure 1). Metal and polymer edge flashings of various designs have also been used. The latest base securement detail uses a strip of reinforced EPDM, which is fastened with screws and plates (see Figure 1-E).

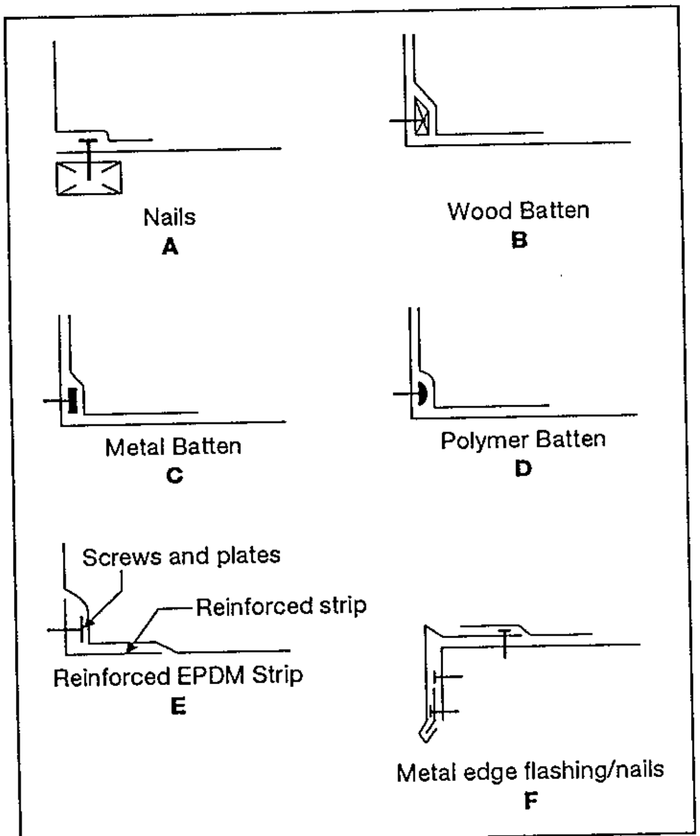

Figure 1. Common base securement details that have been or are still being used. (Typically, fastening strips may be installed on the vertical or horizontal plane.)

For non-reinforced membranes, all of the base securement details that use battens rely upon the batten to provide an adequate amount of compression to the membrane to prevent it from moving. If the batten does not provide sufficient compression and if the non-reinforced membrane contracts, then the membrane begins to tear around the strip's fasteners. As the field sheet becomes unrestrained, the originally uncured flashing is stretched. If stretched sufficiently, the flashing can tear. (When stretched, originally uncured flashing can tear more easily than stretched field sheet.)

To enhance the probability of maintaining sufficient compression during the design service life of the roof, batten fasteners could be specified to be spaced more closely together (e.g., 6 in. [152 mm]), rather than the common 12 in. (305 mm). Also, it is of critical importance to specify a fastener, such as a screw, that is capable of pulling the batten snugly to the substrate and maintaining it there. Attention by the sheet manufacturer to the type of batten fasteners that they recommend for various substrates is also vital. The substrate under the EPDM should be firm and capable of maintaining the compression load. Bending characteristics of the battens are also important, although the batten needs to be flexible enough to conform to common substrate irregularities.

Considering the variabilities of construction, relying on compression securement of non-reinforced sheets is problematic, particularly when the battens are fastened at 12 in. (305 mm) on center or greater. This difficulty is minimized when the batten fasteners are securing a reinforced sheet. In this case, if compression is lost, the sheet's reinforcement can resist progressive tearing around the fastener hole. Alternatively, rather than relying upon batten attachment, a reinforced EPDM strip (see Figure 1-E) may be used.

For metal edge flashings, securement of non-reinforced sheets may be successful if the sheet is turned down at the outside face of the wall and fastened with galvanized roofing or galvanized capped-head nails and the membrane is additionally secured with a continuous metal cleat. It is recommended that a spacing of approximately 6 in. (152 mm) on center maximum be provided by the combination of the membrane and cleat fasteners. The 90° angle change reduces the tearing stresses at the holes around the fasteners. However, some tearing/elongation of holes around the fasteners securing the horizontal flange of the edge flashing may still occur. Periodic observation and repair of the flashing may be required, as is commonly the case with similar details in built-up roofs.

In addition to base securement problems associated with loss of compression, the batten fasteners can be pulled out of the substrate, the batten can be pulled over the heads of the batten fasteners, or weak parapets can be displaced. When battens are displaced, the ends of the battens can puncture the flashing.

Contraction Loads

Information on the contraction load induced by the combination of shrinkage and temperature change has previously been published. However, the amount of the load contributed by shrinkage and the amount contributed by temperature changes was not determined. These loads were derived from sheets that had been artificially aged. More recently, in 1994, NRCA was advised by two manufacturers that 24 lbf/ft (0.35 kN/m) would be a reasonable ultimate design load (i.e., this would be the expected load if the membrane shrank 2 percent, as permitted in the ASTM D 4637 material standard).

In addition to the 24 lbf/ft (0.35 kN/m) shrinkage load, an allowance should be made for thermally-induced loads. These loads are quite small until the membrane reaches the glass- transition temperature. Below the glass-transition temperature the loads substantially increase. However, assuming that the membrane remains chemically stable, the glass-transition temperature, which appears to occur at approximately –58°F (–50°C) or colder, will not be reached on most roofs in North America.

A combined ultimate design load of 40 lbf/ft (0.58 kN/m) for shrinkage and temperature- induced forces appears to be a reasonable value for most EPDM membrane roofs. In addition to resisting shrinkage and temperature-induced forces, the base securement detail also needs to resist wind-induced forces. SPRI recommends that base securement details provide a minimum design holding power of 100 lbf/ft (1.46 kN/m). This load includes an allowance for shrinkage, temperature and wind, however, the amount of load assigned to each load category was not determined. If 40 lbf/ft (0.58 kN/m) is subtracted from SPRI's recommendation of 100 lbf/ft (1.46 kN/m), then 60 lbf/ft (0.88 kN/m) is left to account for wind loads. This appears very conservative for fully adhered and ballasted systems (assuming the membrane does not balloon). *However, for mechanically attached systems, depending upon the wind environment and the location of the first row of membrane fasteners from the perimeter, this load allowance appears inadequate.*

SPRI's recommended load should have a safety factor applied to the base securement fasteners. Incorporating a safety factor of 4 (which is suitable for masonry) gives an ultimate design load of 400 lbf/lineal ft (5.8 kN/m) for the base securement fasteners. Mechanically attached single-ply systems may require a substantially higher load capacity, as discussed above.

Note: Fastening into masonry substrates (brick or concrete masonry units [CMU]) is challenging. Some types of fasteners are very applicator-sensitive (e.g., slightly enlarged or elongated holes can greatly minimize their withdrawal strength). The EPDM manufacturer should consider the load capacity of the fasteners as well as their application sensitivity prior to fastener approval for these types of substrates.

Lap Problems

Based on strength values determined from lap-shear tests, well-constructed laps should have sufficient strength to resist ultimate design shrinkage forces coupled with expected temperature-induced loads, provided that the lap is loaded in shear.

Laps loaded in shear are significantly stronger than laps loaded in T-peel. Therefore, based on strength values from T-peel tests, if a lap becomes loaded in peel, shrinkage-induced loads may become high enough to cause a creep-rupture failure of the lap.

System Influences

It appears that the following factors do not influence EPDM shrinkage: deck type, insulation type or presence (or absence) of a vapor retarder. However, it does appear that the type of system attachment can influence shrinkage problems (i.e., ballasted and mechanically attached systems appear more prone to contraction problems). It is believed that with fully adhered systems, the shrinkage forces are essentially uniformly distributed through the bonding adhesive to the insulation substrate. This greatly minimizes the pulling force on the field sheets at their base securement.

Climatic Influences

From available data, it is not possible to correlate shrinkage problems with climatic influences. Shrinkage problem jobs have occurred in areas with substantially different climates, but the significance (if any) of climatic influence is unknown. (A minor amount of temperature-induced stress can result when application occurs during very cold or warm sunny weather, as previously discussed.)

Flashing Degradation

Many of the roofs that NRCA investigated had severely deteriorated originally uncured flashings. These roofs ranged in age from nine to 14 years. All of the flashings were probably neoprene. In some areas, the tautness of the flashing appeared to exacerbate the deterioration. However, the poor performance of the flashing did not appear to be related to shrinkage of the field sheets.

Conclusions

- Based on the information available, it appears that the occurrence of shrinkage-induced taut EPDM roof membranes may occur in any geographical location. Furthermore, it appears that the taut condition of many of these roofs has resulted in flashings that are susceptible to water infiltration, or could soon become susceptible. However, in many instances the building owner may be unaware of the leakage condition because the amount of water infiltration is slight, or in the case of re-covers, the previous membrane has prevented water from migrating inside.

  Although significant water infiltration can occur, fortunately contraction-related problems are typically not catastrophic. (An exception would be a long tear extending from an equipment curb into a ponded area, or a wind blow-off that was caused by loose or torn base flashings).

  In many instances, if flashings have become damaged, the roof life can be extended by their replacement/repair.

- In the past, many of the base securement details recommended by manufacturers have had very limited resistance to damage by membrane contraction. *Many of the current details (i.e., those that do not use reinforced field sheets or reinforced sheet fastening strips) are still non-conservative.* Non-conservative base securement details should be of particular concern to roofing contractors, because the quality of the installation will probably be questioned if flashing problems develop.

- During very cold or warm sunny weather, it is difficult for the roofing contractor to avoid an installation that builds in temperature-induced stress. Since these loads typically will be quite small, problems should not be anticipated with details that are well designed and installed. However, temperature-induced loads may cause flashing problems where base securements are poorly designed or installed.