FAILURE INVESTIGATION AND TESTING OF SINGLE-PLY ROOFING MEMBRANES

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For many years the United States roofing industry has had its share of built-up bituminous roofing problems caused by design, workmanship and materials. The roofing industry has started changing from built-up bituminous roofing to a simpler, more "foolproof" technology that uses a single ply of polymeric material, in hopes of developing roof systems that have fewer failures. As a result of the industry's change, new types of roofing failures have developed with the use of single-ply membranes. Traditional analysis techniques are unsuitable for single-ply roof investigations. This paper describes new methods for analysis of roof failures of polymeric materials.

The indication of failure in single ply membranes can be:

- loss of bond at laps,
- tensile failure,
- shear failure,
- elongation of holes made for mechanical fasteners,
- mechanical damage,
- dimensional instability and embrittlement,
- deterioration from incompatible materials, chemical or aging deterioration.

PROCEDURES FOR FIELD INVESTIGATION

Field investigation requires careful observation of a roof to determine areas of leakage, the condition of the workmanship and design, and the weathering characteristics of the material. The following procedures can be employed in the field when investigating a single-ply roof to determine the cause for failure and leakage.

As in the case of built-up roofing, inspect the building interior and determine where the leakage occurs, its frequency and severity. Record the areas of leakage on a building plan for reference on the roof. Select roof samples at areas of suspected leaks. Cut and remove samples completely, down to the structural deck. Seal all samples in plastic bags labeled with identification. Note sample locations on a roof plan. Record sample observations in the field and take photos. Determine the path of water leakage through the roofing membrane, insulation, and deck. In multiple layer roofs or practically impervious decks, this may be difficult. Water tests can prove very effective in tracing leaks. The most severe leakage may occur in ponded areas, at flashings, or from roof drains. Walls or other building components not associated with the roof also can cause problems, such as water entering behind flashings from leaky walls adjacent to the roof.

Identify signs of membrane shrinkage or fluttering and inspect the membrane attachment for damage or movement where the fasteners penetrate through the membrane, where the membrane is attached to the perimeter, at penetrations and at fastening strips. Remove the fastener and plate washers. Check for fastener plumbness, elongation of the hole in the membrane, insulation or deck and the tightness of the fastener. Observe the pattern of the direction and extent of movement. Determine a pattern of material behavior. The movement pattern of the roof may lead to the cause for leakage.

Inspect the edges of the laps of the single-ply membrane by tracing the edges of the lap with a probe. Look for unbonded areas or pinholes. Pull apart the laps and note dirt stains, position of debonding or delamination, position of any adhesives, solvents, sealants and the width of the thermal welds or adhesive bonds.

Identify open voids in laps by covering laps with a film of soapy water, applying pressure and watching for air bubbles or squirting water. This is particularly helpful when tracing the edge lap with a probe is impractical, such as when large amounts of sealant are smeared over the lap edge. This method is also useful for finding unbonded lap areas which may exist behind porous edge-lap sealant or under poorly bonded edge-lap sealant. This method of void location can be conducted during water testing.

Press the roof to feel for concealed lap edges to determine the overlap width, fastener spacing, and the reason for any patches. Roof patches may have been applied over an original leaky seam or over a split or imperfection in the sheet. Select samples to confirm these conditions. Patched areas describe the history and maintenance of the roof. Determine any pattern to the patches.

Select a few large samples, 25 to 100 square feet, of the membrane for testing in the laboratory. Sample areas should include areas containing splits, good laps, bad laps, random areas and any areas of deterioration. Large scale laboratory testing programs can be conducted using these large samples.

Obtain samples of unexposed materials for comparative laboratory testing. Note the age, method of storage of the materials, the date of delivery, and manufacturer's identification and stock number. Make sure that the unexposed material can be compared legitimately to the material used in the roof.

Select samples of roof insulation to determine method of attachment and for moisture testing in the lab. If the roof is punctured, select a sample of insulation under the puncture for lab determination of the size and depth of the penetration. Take samples of insulation or substrate under areas of impact damage because lab impact testing should be duplicated on the same substrate.

Dissecting samples in place can lead to observations which may not be observable in the laboratory. For instance, if it is shrinking, the roof may pull back from the edge of the sample while it is being cut. Measure the pull back dimension. Look for effects of long-term membrane shrinkage, such as the top lap pulling away from the edge-lap sealant or the membrane tearing at fasteners. Look for any voids in the membrane or laps which may close up when the sample is removed. Record the direction of membrane shrinkage, such as orientation with respect to the machine direction of the sheet. Trace voids in ridges or wrinkles to potential external causes, such as debris under the roof or raised insulation joints, or wrinkles from changes in the plane of the roof, such as drain sumps or raised flashings. Tracing indications of movement also may lead to discovering splits or tears, displaced flashings or open laps.

PROCEDURES FOR LABORATORY INVESTIGATION

Laboratory testing can confirm leakage paths, material aging, dimensional instability, embrittlement, incompatibility, shrinkage and swelling. Laboratory test results can be compared with the manufacturer's specifications or they can determine if workmanship was in accordance with design requirements. Laboratory procedures for testing polymeric roofing materials are presented below.

Water testing of roof samples can show leakage paths unnoticed in the field. Spread large samples out flat with perimeters raised and fill with 1 to 2 inches of water for up to 12 hours. If leakage occurs, reduce the sample size to concentrate on the leakage area. When the sample size is a few square feet, use methylene blue dye colored water to produce a permanent trace of the leakage path. Do not peel the sample apart until the dye has dried. This method has proven particularly useful in tracing hidden leakage paths. This test will determine leakage paths through porous sealant joints, through laps which may look adequately adhered and through the scrim layer of reinforcement in a membrane ply. The dye permanently traces a path that may have been otherwise unnoticeable.

Accelerated water testing of small samples in a vacuum chamber filled with methylene blue-colored water identifies voids in laps, blisters, pinholes, and delaminations in membrane plies or laps. Place the sample in a vacuum filled with the colored water, immerse the sample in water, draw a vacuum until all air bubbles stop, remove the sample, dry thoroughly, and then dissect it. The dye shows physically where water penetrates small voids in materials which may look waterproof.

Using ASTM and other test methods, one can compare the test results of the products with the products as described by the roofing manufacturer. Nondestructive physical tests include thickness, unit weight, sheet width, continuity of interply adhesion, water absorption, water vapor permeability, and inspection for pinholes. Destructive testing includes tensile strength, elongation at rupture, lap strength, lamination strength and impact testing. Any destructive physical test should include control samples of unexposed materials because comparative tests between unexposed and aged samples may show that the weathered material has lost important physical properties and is failing, or that the original unexposed material is defective. A more in-depth destructive test program includes testing at low and high temperatures. At cold temperatures products become brittle; they elongate less when ruptured. At hot temperatures, a stretched material may fail from creep deformation. Little research has been published about creep failures and long-term behavior of single-ply roofs.

Heat aging of some polymeric materials will produce permanent shrinkage. Many manufacturers refer to ASTM Test Method D1204 which requires a 12×12-inch sample. I was unable to measure adequately the shrinkage of a polymeric membrane using ASTM Test Method D1204 at a temperature of 158F (70C) for 28 days. My data were statistically inconclusive because of scatter. To improve measurement accuracy, 9-foot-long samples were used with a small preload for alignment purposes, in the same heat aging environment. Measurements of one per cent shrinkage in both exposed and unexposed materials in the machine direction were obtained with a high degree of statistical confidence. With a larger sample measurement accuracy improved. ASTM D1204 may be appropriate for measuring shrinkage in a semi-rigid material, but it did not prove useful for measuring small shrinkage in flexible materials.

Heat aging samples in the laboratory in contact with asphalt or coal tar pitch roofing or other materials may cause harmful physical or chemical change. For instance, some sheet membranes aged in contact with coal tar pitch roofing show weight change, discoloration, shrinkage, and embrittlement.

Infrared analysis and solvent extractions of exposed and unexposed samples after accelerated aging may show a pattern of chemical changes that explain such physical changes as embrittlement, cracking and shrinkage. Materials analyzed by infrared spectrometry are commonly first extracted with solvents or broken down by pyrolysis. For instance, a drop in the quantity of plasticizer in some polymer membranes is confirmed by solvent extractions of exposed, unexposed and heat-aged roof samples in a Soxhlet extractor using diethyl ether solvent. Results from solvent extraction can show changes in extractable quantities. The extracts then are analyzed by infrared analysis to identify the type of plasticizer. Infrared analysis also can define base polymers, fillers and additives. Polymer materials also may be identified by differential scanning calorimetry (DSC) which identifies materials by thermal analysis. This method of analysis is new and not well established. However, further DSC testing may develop more complete reference data on the aging characteristics of single-ply roofing membranes. Quantitative analysis and chemical identification can determine why and how the material is changing physically. For instance, a drop in plasticizer content causes a volumetric change in the roofing sheet which is observed as shrinkage on the roof.

Laboratory preparation of samples of exposed and unexposed materials may show that adequate sealing is difficult, that some materials are too sensitive to heat or pressure, or that some materials develop inadequate lap peel strength in cold environments, even under laboratory conditions. Working with the materials in the laboratory and preparing samples can show how sensitive the materials are to changes in environment, surface preparation, adjustments to automatic welding machines, adhesive application, substrate evenness or compatibility with other materials. Test procedures can be developed to evaluate variations in construction conditions by changing the workmanship quality, design or material quantities.

CONCLUSIONS

Combining observations from field investigations and laboratory testing can determine how and why roofing systems fail. For instance, field investigations may determine that leakage occurs through splits in the polymeric membrane, and that the splits are caused by shrinkage of the sheet as evidenced by torn membrane at fasteners and a pattern of bent fasteners. Tensile tests of unexposed and exposed samples show a small decrease in tensile strength. Heat aging of unexposed and exposed samples of the polymeric sheet in the laboratory produce permanent shrinkage. Solvent extractions of samples of the polymeric sheet before and after heat aging show a drop in the extractable quantities. The solvent extractions also show that the polymeric samples from the roof contain less solvent extractables than unexposed polymeric samples. Infrared analysis identifies the solvent extractables as plasticizers. In this scenario, the use of a plasticizer which is not stabilized for the temperatures expected is responsible for membrane roofing shrinkage and failure.

Field investigation and laboratory testing of polymeric and elastomeric/rubber materials can also show that workmanship problems have caused roof failures, such as where surfaces were improperly prepared or when bonding pressure was inadequate when mating laps together. Tests in a vacuum chamber with dye colored water will produce a permanent trace of poorly bonded lap areas.

This can be confirmed by duplicating both good and poor quality workmanship in the laboratory, using the same products as applied in the field.

Field and laboratory investigations can distinguish between workmanship deficiency and material deficiency. For example, a thermally welded seam is blistering at the level of interply scrim reinforcement. Methylene blue dye tests in a vacuum and immersion tests show water wicks into the scrim reinforcement layer. Samples thermally welded in the lab produce blistered laps because the water in the scrim reinforcement layer expands when heated and causes the softened polymeric materials to delaminate. This is not an application problem but either a material deficiency or a material storage problem.

From the results of field investigations and laboratory testing the cause of the roof leakage can be established by weighing all the merits of workmanship quality, roof design, and material adequacy. If necessary, the system can be duplicated to reproduce the failure.

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