A Bond That Should Never Be Broken:

Adhesion and Other Failures in Hot Fluid-Applied Rubberized-Asphalt Membranes

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INTRODUCTION

This paper presents case studies of failures in the application of hot fluid-applied rubberized asphalt in new construction, discusses possible causes of failure, and discusses how the design and construction teams on each project overcame the challenges they encountered. The authors will demonstrate that a combination of thorough field observation, construction of mock-ups, and application of available ASTM testing methods to determine acceptability of the substrate will provide the best chance at successful application of hot fluid-applied rubberized-asphalt membranes.

A BRIEF HISTORY

Hot fluid-applied rubberized-asphalt membranes have been used in the roofing and waterproofing industries for decades. Their failure is not a new phenomenon in the waterproofing industry but is uncommon when compared to the failure rates of other waterproofing membranes. The industry has adjusted the membrane over time to accommodate failures observed in the overall system. Excess moisture vapor in concrete substrates can adversely affect fluid-applied waterproofing membranes due to their initial application, and this phenomenon has influenced the evolution of hot fluid-applied rubberized asphalt.

Initially, hot fluid-applied rubberized-asphalt roofing was commonly installed in a single, 180-mil layer over concrete decks. A slew of failures in the mid-1980s—particularly on projects that utilized lightweight structural concrete as a substrate—led manufacturers to reevaluate their assembly. Lightweight concrete typically requires a longer drying time in comparison with normal-weight concrete, due to the increased absorption properties of the lightweight aggregates. At the projects that experienced failures during installation, the applicators observed extensive pinholing after application of the single layer of hot fluid-applied rubberized asphalt. The pinholing was caused when moisture in the concrete deck vaporized and moved to the exterior through the freshly applied hot fluid-applied rubberized-asphalt membrane.

The industry responded to the failures with the addition of reinforcement into the hot fluid-applied rubberized-asphalt system to overcome the pinholing enhanced the overall system and reliability as a waterproofing membrane. However, despite the evolution of hot fluid-applied rubberized asphalt into a thicker reinforced system, the industry still observes failures, including delamination and pinholing. These modes of failure are described in greater detail below.

MODES OF FAILURE

Failure to Initially Adhere to Substrate

Low-permeability roofing systems (e.g., hot fluid-applied rubberized asphalt) can blister or delaminate at the concrete deck substrate due to a vapor drive toward the roofing or waterproofing assembly, improper surface preparation, or other sources. Delamination can occur when the internal pressure exerted by a water vapor or solvent vapor (result of primer application) exceeds the bond forces between the membrane and the substrate. The membrane can also fail to initially bond to the substrate, causing delamination if the substrate is too smooth or includes a bond inhibitor (e.g., concrete additive or curing compound; see additional discussion below). When heated by the sun, hot fluid-applied rubberized asphalt can...
become soft and pliable. If the membrane is not fully adhered, it will delaminate from the substrate. Upon cooling, the blistered or delaminated area remains plastically deformed and, on reheating, can expand further. If left uncorrected, the delamination can lead to building leakage.

**Pinholing**

When the vapor drive through the membrane is strong enough during initial application of the membrane, fluid-applied waterproofing membranes develop small discontinuities that resemble pinholes prior to curing. The areas of discontinuity are gaps in the membrane and are often circular in shape. The gaps then become potential water-entry locations after the membrane sets. Hot fluid-applied rubberized asphalt also develops pinholes due to excess moisture within the concrete substrate as it vaporizes and drives through the uncured membrane. As discussed above, the industry addressed this issue with the addition of reinforcement and a second layer of membrane.

**Interlayer Adhesive Failure**

Some blisters in the membrane can form between the reinforcing sheet and the second layer of hot-applied asphalt membrane. These blisters can form if an unknown substance or moisture is present on the surface of the reinforcing sheet at the time of application.

**TESTS AND PRACTICES TO PREVENT FAILURE**

Our experience shows that successful application of hot-applied rubberized asphalt is highly dependent on the age and moisture content of the concrete substrate, well-timed application of the membrane, and a project-specific series of adhesion tests to determine proper primer coverage.

**Moisture in Concrete**

Manufacturers of hot fluid-applied rubberized asphalt typically recommend applying the membrane to a substrate that is clean, dry, and free of water, ice, snow, dust, curing compound, or any foreign matter. Concrete should be allowed to cure for a minimum of 14 days (21 for lightweight concrete). Cure time is essential to allow water to dissipate from the concrete. Several test methods are available to address moisture in concrete decks prior to the application of a hot fluid-applied rubberized-asphalt membrane. Each test method described below measures moisture content of the concrete substrate. If used properly, these tests can indicate whether a concrete deck is too moist to support the application of a hot fluid-applied asphalt system.

- **ASTM D4263 – Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method.** This test consists of sealing a piece of plastic sheeting (approximately 18 in. by 18 in.) to the concrete surface (Figure 1). After approximately 16 hours, the sheet is removed, and both the sheet and concrete surface are inspected. Moisture on either the plastic or concrete surface indicates wet concrete, which requires additional drying time prior to installation of a hot fluid-applied rubberized-asphalt membrane. ASTM D4263 requires testing of one area per 500 sq. ft. maximum. This test has several limitations; the exterior environment (i.e., temperature, amount of direct sunlight or shade, etc.) can greatly impact the results of this test.
- **ASTM F2170 – Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes.** The test includes two methods of placing probes in a concrete slab; the first involves drilling a hole in the concrete slab after placement and inserting a plastic sleeve, while the other involves forming a hollow sleeve in the slab and placing the concrete around it. The sleeve allows for placement of probes that measure relative humidity at a specific depth within the concrete slab. The plastic sleeves are covered and sealed to the concrete deck throughout the entire test to prevent any changes to the air in the sleeve. By measuring the relative humidity of the slab, the user can predict the success or failure of a coating applied to the surface of the concrete due to excessive moisture content.
- **ASTM F2420 – Standard Test Method for Determining Relative Humidity on the Surface of Concrete Floor Slab Using Relative Humidity Probe Measurement and Insulated Hood.** Similar to ASTM F2170, this test method measures the percent of relative humidity above the surface of a concrete slab. By placing an insulated hood that contains humidity-measuring apparatus, the user can predict whether the moisture in the concrete will allow for the placement of a coating on the surface of the concrete. This test, however, does not predict moisture movement or overall moisture content of the slab, since it measures surface relative humidity only. Moisture within concrete is dynamic and can cause
failures of a waterproofing membrane under conditions that differ from what the moisture probe measures.

**Primer Application**

In addition to gauging the moisture in the concrete substrate, manufacturers have long used asphalt-based primers to enhance the bond between the concrete surface and hot fluid-applied rubberized-asphalt membranes. These primers must conform to ASTM D41-11 – *Standard Specification for Asphalt Primer Used in Roofing, Dampproofing, and Waterproofing*, and are applied in a thin layer over the concrete substrate using a brush, roller, or spray equipment. Coverage rates can vary between 100 and 600 sq. ft./gal., depending on porosity and surface texture of the substrate and the selected primer. When applied too thickly, primers can experience increased drying times or not cure by the time the membrane is applied; when applied too thinly, primers may not adequately cover the substrate. Additionally, primers can feel dry to touch but the solvent in the primer might not have fully flashed off. In all cases, the membrane may experience reduced adhesion to the deck.

Applicators must also pay careful attention to duration of exposure of the primer to weather and construction traffic. Primers left overnight can accumulate moisture in the form of dew or pick up dirt and debris from construction traffic. In addition to the challenges associated with application of the primer, manufacturers have reformulated primers to produce fewer volatile organic compounds (VOCs) to make them greener and comply with legislation. These alternative primers have a short track record and therefore cannot be directly correlated to adhesion failures in the membrane. Therefore, the designer should require careful evaluation of the primer, preferably through mock-ups, to evaluate the effectiveness and suitability prior to selection and wholesale installation.

**Surface Preparation**

Construction of mock-ups will demonstrate whether any concrete admixtures, curing compounds, or concrete finishes will affect the bond of the hot fluid-applied rubberized-asphalt membrane to the concrete deck. Many admixtures have no effect, but some curing agents may prevent...
a strong bond from forming between the waterproofing membrane and the surface of the concrete. Manufacturers require concrete substrate to have a wood or broom finish. The finish can also affect the bond between the membrane and the substrate. A steel-troweled finish or a smooth finish from formwork can inhibit the bond, whereas a broom or wood-float finish will enhance the bond. A lack of bond between the waterproofing membrane and concrete deck due to the presence of a concrete admixture can be easily fixed by using an etching agent or other chemical agent on the surface of the concrete deck. Mechanical abrasion (i.e., sandblasting, shotblasting, diamond grinding, etc.) will enhance the bond in areas with poor adhesion due to the presence of a curing compound or smooth finish.

**Construction Mock-ups**

By building mock-ups, a construction team can evaluate which combination of products and coverage rates creates the best adhesion on a case-by-case basis. Without determining which balance of materials is correct for a particular application, the result could be widespread adhesive failure of the waterproofing membrane.

The moisture content and the condition of the concrete deck can vary based on the area and exposure of the project. Constructing mock-ups at each area of application will best predict success or failure of the membrane and indicate whether primer rates should vary from area to area. A hot fluid-applied rubberized-asphalt mock-up must meet the following criteria to confirm adequate adhesion:

- The mock-up must produce little to no pinholing (Figure 2). If the project team first conducts moisture tests on the concrete, such as those described above, pinholing of the mock-up will be less likely.
- The mock-up must demonstrate cohesive failure of the waterproofing membrane. A cohesive failure means the membrane, when placed under stresses great enough to cause tearing, will debond from itself rather than the substrate. An adhesive failure, where the membrane tears away from the substrate rather than itself, is less desirable and is indicative of a higher risk of delamination.

To perform an adhesion test, a small area of hot fluid-applied rubberized asphalt is placed with a reinforcing strip of fabric or neoprene embedded in it and a pull tab left exposed on the end (Figure 3). The fabric or neoprene is pulled until the membrane fails by tearing. A cohesive failure indicates the bond to the concrete deck is stronger than the internal bond between layers of membrane, while an adhesive failure indicates insufficient bond between the membrane and the deck. Different test methods can measure numerical adhesion values for comparison purposes, but the main objective of the test is to determine mode of failure.

**CASE STUDIES**

The following case studies provide greater detail on a few projects that demonstrated adhesion issues with the hot fluid-applied rubberized-asphalt system.

**CASE STUDY NO. 1: CURING AGENTS**

**Background**

A biosciences building located in Northern California featured application of a hot fluid-applied rubberized-asphalt membrane on a large podium area at grade and multiple levels of vegetative roof in a protected membrane configuration (Figure 4).
Problem 1
Initial application of the hot fluid-applied rubberized-asphalt system began at the podium level. To meet the project schedule, the construction team used a concrete curing agent prior to application of the hot fluid-applied rubberized-asphalt membrane. Despite meeting the concrete admixture manufacturer’s curing requirements, the initial application of primer and membrane easily delaminated from the surface of the concrete deck. In response, the construction team used a concrete surface treatment to negate the effects of the concrete admixture. Adhesion problems persisted.

Solution 1
The team discerned that the membrane delaminated under certain coverage rates of primer. The team devised a series of mock-ups to determine the optimal primer coverage, utilizing varying coverage rates and adhesion tests. Through the mock-up process, it became apparent a super-thin film of primer allowed the hot fluid-applied rubberized-asphalt membrane to fully bond to the concrete substrate.

Problem 2
During later installation of the same hot fluid-applied rubberized-asphalt membrane on the vegetative roof assembly, the membrane experienced extensive pinhole failures.

Solution 2
After reviewing the installer’s primer application procedures and determining that they matched the successful application at the podium deck below, it became clear that another mechanism of failure was causing the pinholing. Upon closer examination, the construction team discovered that the pinholes occurred only in the top coat of the membrane (Figure 5). In reviewing its application procedures, the team realized that the installers allowed the bottom coat and reinforcing to sit overnight. Upon cooling during the nighttime hours, the reinforcement collected moisture from the air. The moisture on the surface of the reinforcement vaporized and drove through the second layer of hot fluid-applied rubberized asphalt upon its application the next morning. The construction team concluded that a well-timed application of the complete waterproofing assembly is critical to adhesion and overall performance of the membrane. At areas of concern, the team allowed the second layer to thoroughly dry and then applied a third coat over the area with extensive pinholing. For the remainder of the project, the waterproofing contractor installed only as much material as could be covered with the second layer of membrane in a single day.

CASE STUDY NO. 2: BLISTERS IN MEMBRANE

Background
The second case study occurred during the construction of a new hospital in Southern California. The project included a 60,000-sq.-ft. vegetative roof over the operating rooms (Figure 6). The concrete deck is a 5-in.-thick, normal-weight concrete over a vented steel deck. The concrete cured for approximately four months prior to application of the hot fluid-applied rubberized-asphalt membrane. The installer reviewed the curing compounds, form-release agents, and substrate preparation with the hot fluid-applied rubberized asphalt manufacturer prior to the start.

As outlined in the specifications, the installer prepared a mock-up of the installation, including all unique conditions, per-

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Figure 5 – Pinholing through the top layer of fluid-applied rubberized asphalt.

Figure 6 – A hot fluid-applied rubberized-asphalt vegetative roof in Southern California.
formed moisture tests using the plastic sheet method, and later performed ten adhesion tests approximately halfway through the installation of the hot fluid-applied rubberized-asphalt membrane. The project team observed good adhesion (cohesive failure) at all adhesion tests in the field of the roof.

Problem 1

Adhesive failure occurred between the membrane and the concrete substrate at the two test cuts performed at the parapets (Figures 7A and 7B).

Solution 1

After reviewing the application process and the differences between the deck and the parapet walls, the team attributed the poor adhesion to surface preparation. The parapet walls were finished smooth (not the recommended broom or wood-trowel finish). The team constructed a mock-up with varying degrees of surface preparation, including light application of surface primer, wire wheel, and bead blasting. The wire wheel provided the best adhesion. To remediate the areas already completed, the contractor removed the protection sheet, scraped off the membrane, wire-wheeled the concrete, and then wire-wheeled the concrete again with a clean wheel. The contractor then installed the reinforced hot fluid-applied rubberized-asphalt membrane over a primed concrete wall.

Problem 2

Shortly after the contractor completed installation of the second half of the roof, the project team performed random adhesion tests throughout the installation. At the two areas selected, we observed large blisters in the hot fluid-applied rubberized-asphalt membrane. The delamination
occurred between the hot fluid-applied rubberized asphalt and the concrete deck and between layers of hot fluid-applied asphalt (Figures 8A and 8B).

Solution 2
To confirm the levels of moisture in the concrete deck, the project team performed relative humidity tests using in situ probes. The team drilled ten holes at random locations in the concrete deck at varying depths and measured the moisture content. In each location, the moisture content was below 76.9%, with an average of 72.7% relative humidity. Typically, an average relative humidity of 75%, and below indicates that moisture in the concrete deck is not the source of failure.

The team narrowed the source of blistering to either improper drying time of the primer or an unknown substance on the concrete deck (e.g., perhaps a substance spilled on the deck during construction or someone tracked something on their shoes across the deck). Through additional adhesion testing, the team identified the area of blisters to an approximately 2,400-sq.-ft. area—a much smaller area than the entire application of membrane on the project. The installer then removed the protection sheet, cut open the blisters down to the concrete deck, and patched them with the hot fluid-applied rubberized-asphalt system (215-mil reinforced system), extending the repair 6 inches in all directions. The waterproofing contractor installed the protection layer set in an additional 90-mil layer of hot fluid-applied rubberized asphalt over the entire area. The waterproofing contractor allowed the primer to dry for a minimum of 24 hours on the remaining portions of the project. Manufacturers typically require application of the hot fluid-applied rubberized asphalt over the primer during the same day (within four to six hours), but the project team learned in this instance that variance from this rule produced a better result. In addition, the cut-and-patch method successfully solved the blistering encountered during the first portion of application.

CASE STUDY NO. 3: PRIMER APPLICATION RATE
Background
On a project in Northern California, a 20-year-old hot fluid-applied rubberized-asphalt membrane was experiencing failures due to a combination of root growth and aging materials. The project consists of multiple residences united by a large podium deck in the center of the structure on the third floor. The podium deck is covered with vegetative materials over a protected hot fluid-applied rubberized-asphalt membrane.
Problem

The owner observed leakage through the concrete slab below the podium deck into the parking garage below. To remediate the leakage, the owner sought wholesale replacement of the waterproofing membrane above areas experiencing leakage (Figure 9). After removal of the overburden and existing waterproofing, the construction team prepared several mock-ups with varying primer coverage rates to determine the amount that would yield the best adhesion to the concrete deck. Surprisingly, even the old concrete deck, which after 20 years should demonstrate a moisture content at equilibrium, yielded a variety of results dependent on the coverage of primer.

Figure 9 – Wholesale replacement of an existing hot fluid-applied rubberized-asphalt membrane still required attention to concrete moisture content and primer application rates.

Figure 10 – The team used mock-ups to find the best primer application rates to cause adhesion of the membrane.
Solution

The construction team selected a primer coverage rate associated with the mock-up that had the best adhesion and successfully used the hot fluid-applied rubberized asphalt to the repair areas (Figure 10). The team learned from these mock-ups, though, that moisture content alone does not dictate the success or failure of the waterproofing assembly. Optimal primer coverage rates vary on a project-by-project basis, and performing mock-ups to determine the amount of primer is critical to successful application.

These case studies demonstrate that failures of hot fluid-applied rubberized asphalt applied to concrete can be overcome with forethought and diligence. On each project, the team recognized the need for adjustments to the application process and utilized quality control methods to create a successful application.

RECOMMENDATIONS

Several tools are available to prevent the failure of hot-applied rubberized asphalt to concrete decks. Each tool will help the user better understand the characteristics of deck adhesion on a project-by-project basis. Successful application will involve the following:

• Allowing the concrete substrate adequate time to cure
• Measuring the relative humidity of the deck using one of the available ASTM test methods
• Properly cleaning the deck, including surface treatment if concrete additives are present, and mechanical abrasion to remove curing compounds and provide the desired surface texture
• Constructing several mock-ups at each area of hot fluid-applied rubberized asphalt application to establish the appropriate amount of primer application, required drying time, and surface preparation

To prevent future failures, the most reliable approach is to incorporate the recommendations outlined above into the specification. Specifications should include the following: requirements to perform a specific number of relative humidity tests on the concrete substrate prior to application of the membrane, quantification of the acceptable moisture content of the concrete substrate, inclusion of surface treatment for concrete additives and mechanical abrasion to remove curing compounds, and construction of several mock-ups. During construction, mock-up testing and enhanced quality control procedures will provide the best chance for a successful application of hot fluid-applied rubberized-asphalt membranes.

FOOTNOTE

1. Delamination can also occur when water works against exposed edges of membrane until the membrane separates from the deck. Delamination of this nature is less likely to occur in the field of membrane application but is common at edge or transition locations due to poor detailing. For the purposes of this article, only delamination due to vapor drive is considered.

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