Hail Evaluation of Bituminous Roofing Membranes: Understanding Interply Mopping Voids

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Abstract

Forensic evaluation of roofing membranes for hail damage is a large and growing industry throughout the United States, especially in the Midwest and across the South where hailstorms are prevalent throughout the year. For these evaluations, accurate assessment of the roof membrane and the causation of damage is an imperative. An accurate assessment requires knowledge of the potential causes of damage for the roof system, including determination of damage related to hail impact. Laboratory testing of membrane samples is often an important component of such an evaluation.

Damage resulting from interply mopping voids, which are as-built conditions, is often misidentified as hail damage in multi-ply bituminous roof membranes. This misidentification frequently occurs because the characteristics of distress to the membrane surface caused by interply mopping voids can be similar to the characteristics of membrane surface distress caused by hailstone impacts.

The purpose of this paper is to educate readers about interply mopping voids and the type of distress that they can cause. Examples involving roofing membrane samples cut from various structures and analyzed in a laboratory will be used to illustrate interply mopping voids and the damage that results from their presence. Finally, this paper will outline ways to better distinguish hail impact distress from interply mopping void distress when performing a forensic roof evaluation in the field.

Background Information on Bituminous Roofing Membranes

Bituminous roofing membranes are commonly used on commercial low-slope roofs (typically less than a 2 on 12 pitch) throughout the United States. Bituminous roofing membranes include built-up roofing (BUR) membranes and polymer-modified bitumen (mod-bit) membranes. Both of these types of membranes can be further sub-classified based on surfacing and material type.

BUR membranes are assembled with either asphalt or coal tar moppings between felt reinforcement layers and can be either smooth-surfaced or gravel-ballasted. Smooth surfaced BURs are typically coated with a reflective coating such as an aluminum coating. Asphalt-based BUR membranes are the most commonly found BUR membranes. Coal tar BUR membrane systems are outside the scope of this research, and throughout this paper any mention of BUR membranes is intended to refer to asphalt-based BUR membranes.

Mod-bit membranes are composed of asphalt that has been modified with polymers, either atactic polypropylene (APP) or styrene-butadiene-styrene (SBS), and typically are either smooth-surfaced or granule-surfaced. A variety of application methods exist for installing mod-bit membranes, including using hot moppings of asphalt between the membrane layers, using torch-down membranes, and using self-adhering membranes (i.e., peel and stick).

Installing a hot-mopped bituminous roof membrane is a labor-intensive process, requiring multiple layers of application. The installation process utilizes asphalt that is kept in a viscous state in a hot kettle, a mop or other spreading tool/equipment to apply the hot asphalt, and the reinforcement layers of roofing felts and/or mod-bit membrane sheets used to make the membrane. The kettle must keep the asphalt within a specified temperature range based on the type of asphalt being used. The specified temperature range will typically fall somewhere between 400 degrees Fahrenheit and 475 degrees Fahrenheit (NRCA 2015). The first (bottom) reinforcement layer of the membrane that is installed is the base sheet, which is typically heavier (i.e., thicker) than the other reinforcing felts. Depending on the type of roof deck and insulation, the base sheet will either be mechanically fastened to the deck (through any insulation) or hot-mopped to its substrate. After the base sheet is installed, a layer of hot asphalt is spread over it and the next reinforcement layer is set into the asphalt. The hot moppings and reinforcement layers are then alternated until the total number of reinforcement layers or plies is achieved (typically 3 to 5 plies). Throughout this paper the reinforcement layers of bituminous membranes will be referred to as plies. The layers of hot mopped asphalt between the reinforcement layers will be referred to as interply moppings.

Discussion of Research Basis

The authors of this paper have directly observed as-built mopping voids in bituminous roof membrane samples that have been evaluated in a laboratory. The samples consisted of various types/configurations of hot-mopped bituminous membranes that typically measured approximately 12" by 12" in area. The samples were collected from a variety of structures, primarily located in Texas, Oklahoma, Colorado, New Mexico, and Arizona. The sample evaluation process included freezing the samples with liquid nitrogen and then carefully separating the membrane plies by hand (commonly referred to as "delamination" testing). The plies typically separate near the thickness midpoint of the interply moppings, leaving portions of the interply moppings adhered to the topside and underside of each ply. The information presented in this paper is based on the authors' collective observance of delaminated membrane samples and of mopping voids observed within those samples.

What Is A Mopping Void?

A mopping void is an anomaly that can occur within the interply moppings of hot-mopped bituminous roof membranes. The void is a confined volume of space within an interply mopping that is occupied by air, not asphalt. In other words, a mopping void is a pocket of air, or possibly water vapor, that gets trapped within an interply mopping during installation. For the purpose of this paper, mopping voids are volumes of air large enough to be easily seen by the unaided eye. These mopping voids can be as large as several inches across or in diameter. Voids that are of a microscopic nature are not included in this discussion of mopping voids.

Mopping voids have distinctive features that can be easily identified after delamination. Delamination of membrane plies provides a detailed view of any mopping voids between those plies. A schematic magnified example of an interply mopping void between two membrane plies, shown in cross-section, is provided in **Figure 1**. To help visualize how delamination provides a view of a mopping void, the figure also shows a representation of where an interply mopping will typically split during delamination.

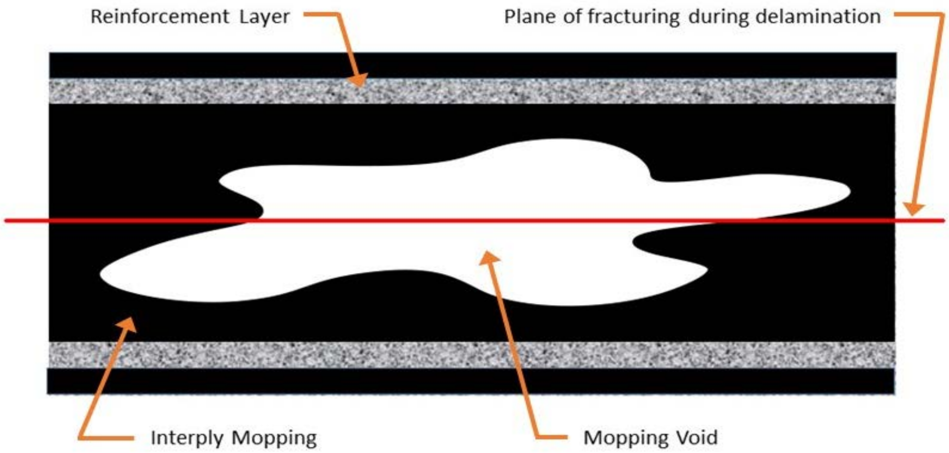

Figure 1 – Schematic magnified view of a mopping void

Mopping voids are typically irregular in shape, but can also be circular or semi-circular. Each mopping void is finite in size and therefore confined by a distinct boundary. The boundary typically has a smooth and/or curvy shape. Additionally, the void will have a concave appearance on the faces of the delaminated plies. Therefore, the surface profile of the observed interply mopping changes at the void boundary. Within the void boundary the residual asphalt on the plies appears smooth and lustrous. This is because this portion of the interply mopping cooled and hardened around an air bubble and the plane of fracturing that occurs during delamination does not disturb this portion of the mopping. Outside of the mopping void, the interply mopping will be heavily faceted and/or jagged due to the random fracturing of the frozen bitumen that occurs along the plane of delamination. Furthermore, the residual asphalt on the delaminated plies is often thin enough that individual fibers of the reinforcement plies are visible within the void boundary. In some instances there may actually be no residual mopped asphalt of the surface of the plies within the mopping void boundary. Examples of mopping voids that were discovered after membrane sample delamination are provided in **Figure 2** and **Figure 3**.

Figure 2 – Example of mopping void from a delaminated membrane sample

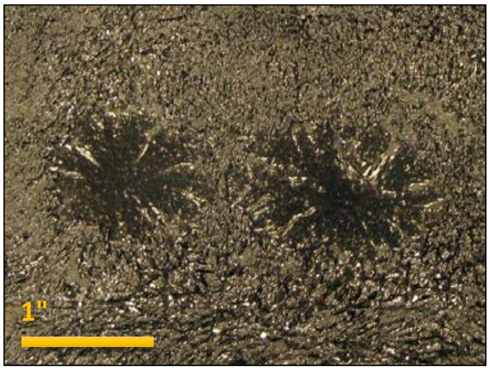

Figure 3 – Example of mopping voids from a delaminated membrane sample

Laboratory Observational Data

The authors of this paper have collectively evaluated over 1,200 delaminated membrane samples and observed and documented hundreds of examples of mopping voids within various types/configurations of hot-mopped bituminous membrane systems. These samples were typically submitted to the authors' laboratory for the evaluation of hail impact distress, and featured some form of anomaly at the surface such as loss of granules, dark/light colorations, and/or soft spots. While it was determined that some of the samples featured surface distress consistent with an impact force, the samples that were used in this study are those that were determined as not having damage consistent with impact forces, such as from hail impact.

In total, 51.5% of all the evaluated samples contained at least one mopping void. In observing and documenting these samples, patterns have emerged. Specifically, the authors have noted a strong correlation between the presence of mopping voids and the presence of discrete distress to the surface of the membrane over the location of the mopping void. In the observed samples, 25.3% of the samples with one or more mopping voids also had surface distress directly located over a mopping void. Multiple factors appear to influence the development of surface distress over a mopping void, including the following:

- *The Size of the Void*: The larger the void is, the more likely it is that a discrete area of surface distress will form over the void. **Figure 4** shows the relationship of void size to the presence of surface distress. When voids matched the location of surface distress, the void size was equivalent to 2" in diameter or larger approximately 81% of the time. The void was between 1-1/2" and 2" in diameter 8.6% of the time, between 1" and 1-1/2" in diameter 5.5% of the time, between 1/2" and 1" in diameter 4.3% of the time, and smaller than 1/2" in diameter 0.6% of the time.
- *The Depth of the Void within the Sample*: The closer the void is to the membrane surface, the more likely it is that a discrete area of surface distress will form over the void. Voids directly under the top ply are much more likely to result in surface distress than voids in lower layers. In samples where surface distress was located directly over a void, the void was located directly under the top ply 85% of the time.
- *Age/Wear of Membrane*: While the ages of the membranes were typically not known, surface distress over voids was more common in samples with more advanced wear and general surface deterioration (generally indicative of aging).

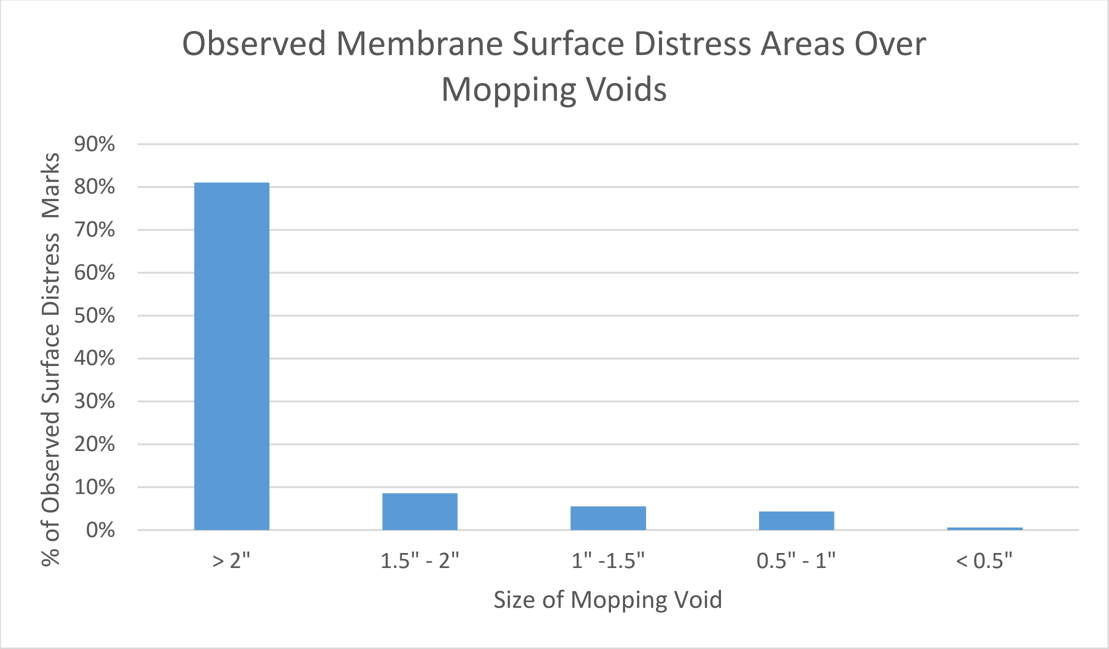

Figure 4 – Relationship of Membrane Surface Distress to Mopping Void Size

In addition to the factors listed above, membrane type influences the characteristics of surface distress that can form over a void. Common forms of surface distress that form over mopping voids include the following:

- *Granule-Surfaced Mod-Bit Membrane*: The surface distress typically manifests as a discrete area of granule loss over the void (**Figure 5**). The area of granule loss will often approximate the shape of the mopping void below, albeit typically smaller in size (**Figure 6**).

- *Smooth-Surfaced BUR*: The surface distress can depend on the nature of the surfacing. Some smooth-surfaced BUR membranes have a thick flood coat of asphalt, whereas others have a thin flood coat and/or a thin aluminized surface coating. For membranes with a thick flood coat of asphalt, the surface distress typically manifests as a discrete area of missing surface bitumen over the mopping void (**Figure 7** and **Figure 8**). For samples with a thin flood coat and/or an aluminized surface coating, the surface distress typically manifests as an area of missing coating and/or a discoloration (lightening) of the coating (**Figure 9**). The missing coating and/or discoloration will often approximate the size and/or shape of the mopping void below (**Figure 10**).

- *Gravel-Ballasted BUR Membrane*: The surface distress typically manifests as loss of the asphalt flood coat and/or loss of embedded gravel over the mopping void.

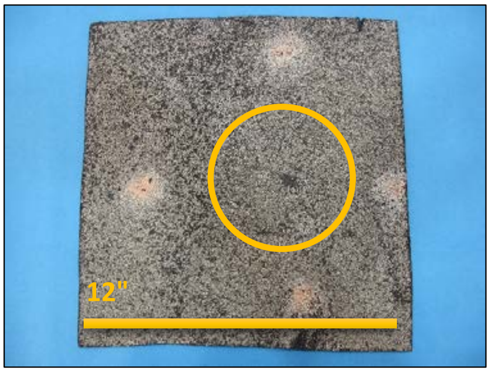

Figure 5 – Area of granule loss over mopping voids in mod-bit membrane.

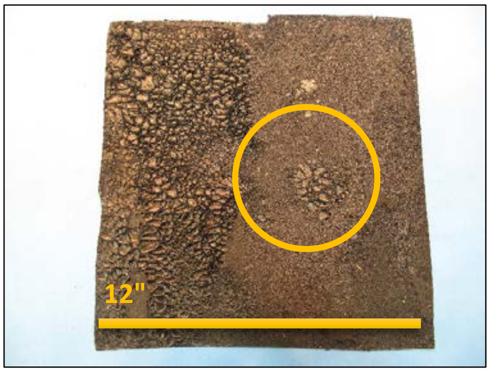

Figure 6 – Mopping voids below granule loss from Figure 5.

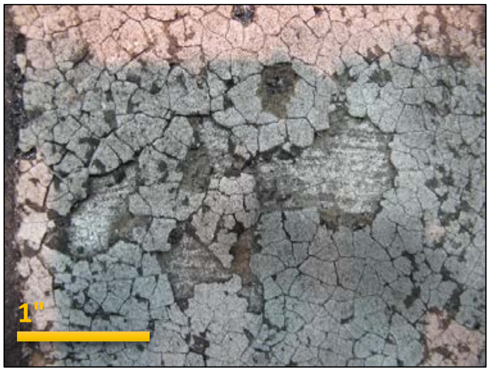

Figure 7 – Loss of flood coat over mopping voids in BUR membrane.

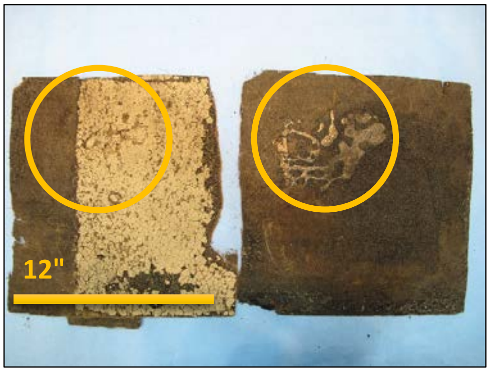

Figure 8 – Mopping void below flood coat loss from Figure 7.

Figure 9 – Discoloration and loss of surface coating over a mopping void in a BUR membrane

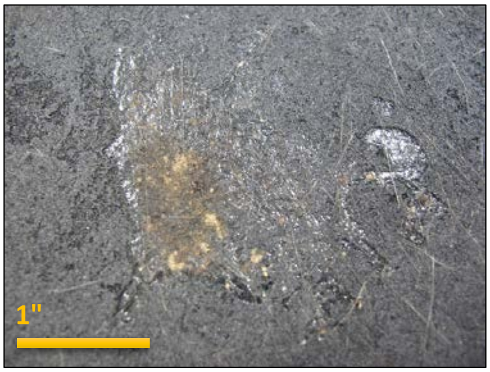

Figure 10 – Mopping void below coating loss from Figure 9.

The numerous examples of surface distress over mopping voids indicate a direct relationship between the voids and the manifestation of discrete surface distress. The most prominent examples of the relationship were observed in smooth-surfaced BUR membranes. In these samples, the discrete areas of surface distress exhibited a clear and defined resemblance to the size and shape of the mopping void below the distress. The patterns indicate that mopping voids can create surface distress, and the likelihood of the manifestation of surface distress increases with the size of the void, the proximity of the void to the top surface of the membrane, and the age/wear of the membrane.

The exact mechanism of manifestation of surface distress over a mopping void was not determined through the observational data, and requires additional research. Based on the known mechanics of void formation in bituminous membrane roofing systems, it is the authors' hypothesis that the membrane surface distress is caused by numerous thermal cycles, which result in cyclical increases and decreases in the pressure of the air trapped inside of the mopping void, and cyclical localized flexure of the membrane plies over the mopping void.

The authors' observational data indicates that mopping voids resulting in surface distress is a widespread issue. In examining over 1,200 hot-mopped bituminous membrane samples, 51.5% of the samples contained one or more mopping voids. Because it was common for multiple samples to have been taken from the same roof, the percentage of hot-mopped roof membranes with mopping voids is estimated to be even higher. In total, 25.3% of the observed samples with mopping voids exhibited distinct surface distress attributed to the presence of the void(s).

Distinguishing Mopping Void Distress from Hail Damage

The membrane samples discussed in this paper were evaluated by the authors in the context of hail distress evaluations. The membrane samples had been extracted at selected areas of interest to determine if they were consistent with impact damage. In instances where the authors observed surface distress directly over a mopping void, the surface distress in question was typically the area of interest that had been selected. One reason for interest in these areas of surface distress was their discrete nature, a characteristic that can be consistent with hail impact distress. In addition, because the mopping void is essentially a small blister in the membrane, the membrane may have felt soft at the area of surface distress, similar to a condition anticipated from an impact bruise or fracture of the membrane. The findings regarding mopping voids and the manifestation of surface distress indicate that mopping voids can create surface distress on a membrane that may be mistaken for hail damage.

When evaluating a roofing membrane in the field, there are some visible characteristics that are indicative of distinct membrane surface distress being caused by mopping voids instead of hail impact distress. The size and shape of the distress are two of the most telling characteristics. The authors' observations from evaluated roof samples revealed that surface distress caused by the presence of a mopping void will often resemble the size and shape of the mopping void. Mopping voids can be circular in shape and result in distress that appears to be consistent with impact from a hailstone; however it is also common for mopping voids to form in highly irregular shapes. Therefore, irregular-shaped areas of surface distress or granule loss may be an indicator of a mopping void. If the size and/or shape of the surface distress is not consistent with the size and/or shape of hail that occurred at a structure, this is an indication that the distress is not related to hail impact and may be related to mopping voids. Additionally, roof evaluators should note that discrete soft spots can actually be due to interply mopping voids and do not necessarily indicate impact bruises or fractures.

For smooth-surfaced BUR membranes with an aluminized surface coating, but little to no flood coat of asphalt, coincident discoloration of the aluminum coating can also be an indicator that an area of surface distress was caused by a mopping void. The authors observed that a discoloration of the aluminum coating is a common phenomenon over mopping voids in these types of membranes. If the coating discoloration is of an irregular shape, there is an even higher likelihood that a mopping void is present. Roof evaluators should be careful to differentiate such general discoloration from burnish markings at a roof surface, which are common indications of hail impact locations.

The location of the distress should also be considered. Hail is typically directional in nature, meaning that certain portions of the roof may have been shielded from hail impacts due to rise walls, parapet walls, mechanical screen walls, mechanical units, etc. Distress marks in these shielded areas that look like hail and/or feel soft are more likely to be mopping voids instead. If the pattern of distress in the shielded areas is consistent throughout the unshielded areas too, this may be an indicator of widespread mopping voids rather than damage from hail impact.

The roof evaluator must also consider other data typically used in roof hail evaluations including weather data and distress to metal roof appurtenances to estimate the size of hail that occurred at a given structure. The estimated size will help determine if membrane surface distress is potentially consistent with hail or mopping voids. Previous research papers have been produced by others dealing with the topic of on-site hail distress evaluation.

Ultimately, the best method of distinguishing mopping void distress from impact distress is to perform laboratory delamination testing and visually evaluate the condition of the interply moppings to determine the presence (or absence) of any mopping voids directly aligning with the discrete surface distress on the membrane surface. It is for this reason that the authors recommend that roof coring and laboratory delamination testing be an integral part of hail distress evaluations when distress potentially consistent with impact damage to the membrane is observed.

Conclusions

The authors of this paper have evaluated over 1,200 delaminated membrane samples and observed and documented hundreds of examples of mopping voids within various types/configurations of hot mopped-bituminous membrane systems. In evaluating these samples, patterns have been observed that indicate that as-built interply mopping voids can result in the manifestation of discrete membrane surface distress over the voids.

The type of membrane surface distress that manifests over the void depends on the type and surfacing of the membrane. The manifestation of surface distress is highly influenced by the size and ply location of the void. Voids of a size equivalent to a 2" diameter circle or larger are much more likely to result in surface distress than smaller voids; however, distress may form over voids smaller than 2". Furthermore, voids that are located directly below the top reinforcement layer are much more likely to result in surface distress than voids located further from the surface. It also appears that time is an influencing factor with distress being more likely to form in aged/worn membranes. The cause of the manifestation of surface distress is hypothesized to result from numerous thermal cycles, resulting in localized flexure of the membrane plies above the mopping void.

When mopping voids result in the manifestation of surface distress, the distress may be mistaken for hail impact damage. This is due to the surface distress being discrete and located over a soft spot with similar characteristics as anticipated from an impact bruise or fracture. When evaluating a roof for hail damage, consideration should be given to the size, shape, location, and coloration of the distress marks of interest. These characteristics may help to differentiate between surface distress related to mopping voids as opposed to hail impact. Furthermore, discrete soft spots should not be assumed to be impact bruises or fractures from an impact because mopping voids can result in discrete soft spots that feel similar to impact damage. The best method of distinguishing mopping void distress from impact or other distress is to perform laboratory delamination testing on membrane samples to physically observe the interply moppings and see if any mopping voids directly align with the surface distress. For this reason, it is recommended that roof coring and laboratory delamination testing be an integral part of hail distress evaluations when distress potentially consistent with impact damage to the membrane is observed.

References

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