WJE

HAIL IMPACT TESTING OF MODIFIED BITUMEN ROOF MEMBRANES

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Introduction

Wiss, Janney, Elstner Associates, Inc. (WJE) and the Midwest Roofing Contractors Association (MRCA) Technical and Research (T&R) Committee have a history of collaborating to develop research and testing programs that focus on expanding knowledge of commonly used roofing materials. In 2023, the focus of the research and testing was on granule-surfaced, modified bitumen roofing membranes. WJE, in collaboration with the MRCA T&R Committee, developed a testing program to evaluate the influence of hail impact on granule-surfaced modified bitumen roof membranes installed in a low-slope roof assembly. The objective of the test program was to determine the extent of damage to these membranes from a single manufacturer of various ages through physical testing and laboratory review and analysis.

Test Program Description

Testing was conducted in accordance with ASTM D3746, *Standard Test Method for Impact Resistance of Bituminous Roofing Systems*. Per the standard, "*this test method subjects 305 by 305 mm [12 by 12-in.] specimens of a roofing system (insulation and membrane complete with top surfacing) to a series of four impacts, one in each quadrant, from a standard missile falling freely from a predetermined height with an impact energy of 30.0 J [22 lbf-ft]. Damage to the membrane is assessed by visual examination of the felts after solvent extraction of the bitumen*."

Eighteen 12-inch by 12-inch samples were divided into four 6-inch by 6-inch quadrants. A 5-pound, 2-inch diameter steel missile was released from a height of 53-inches and impacted the samples one time in each quadrant. The steel missile equates to a 2-inch diameter hailstone, as both have an impact energy of 30.0 J [22 lbf-ft].

Sample weights, granule counts, and exposed bitumen measurements were taken both before and after the impact to capture any changes the impact caused. Desaturation of the membrane samples was then conducted to remove the bitumen and make visual observations of the membrane reinforcement. Additionally, microscopy of the cross sections was performed on portions of each sample at the areas of impact.

Sample Procurement

All samples were provided by MRCA T&R Committee members and consisted of two-ply modified bitumen membranes applied in cold adhesive, all from a single manufacturer. The samples contained two cover board types: ½-inch thick gypsum and ½-inch thick wood fiber, along with polyisocyanurate insulation. The ages of the samples varied, consisting of new, approximately five years old, and approximately ten years old. All the samples came from in-service roofs from Midwest environments (in lieu of artificial weathering), with the exception of the new samples which were fabricated for the purposes of this testing.

Testing Procedure

The testing procedure consisted of the following seven steps:

1. **Initial Documentation.** A total of 18 samples were received and consisted of the following:
   a. (3) 16"x16" modified bitumen with gypsum cover board – 10 years old
   b. (3) 16"x16" modified bitumen with wood fiber cover board – 10 years old
   c. (3) 16"x16" modified bitumen with gypsum cover board – 5 years old
   d. (3) 16"x16" modified bitumen with wood fiber cover board – 5 years old
   e. (3) 16"x16" modified bitumen with gypsum cover board – new
   f. (3) 16"x16" modified bitumen with wood fiber cover board – new

   All samples were labeled, using a sample naming convention consisting of sample age, membrane type, cover board type, and sample number (i.e. 5-MB-G-2), and then photographed.

2. **Test Sample Preparation.** All samples were neatly trimmed to a size of 12-inch x12-inch in the laboratory and graphically divided into (4) 6-inch x 6-inch quadrants with 3-inch-diameter circles as impact zones (Figure 1). The as-received samples were larger than the test sample size to eliminate any negative edge effects from the removal process. Each zone was used for a different purpose throughout the testing process. Zone 1 (upper left) was used for image analysis and manual granule counts, Zone 2 (upper right) for image analysis, Zone 3 (lower left) for image analysis and desaturation, and Zone 4 (lower right) for image analysis and cross-section microscopy, all of which as described in the following steps.

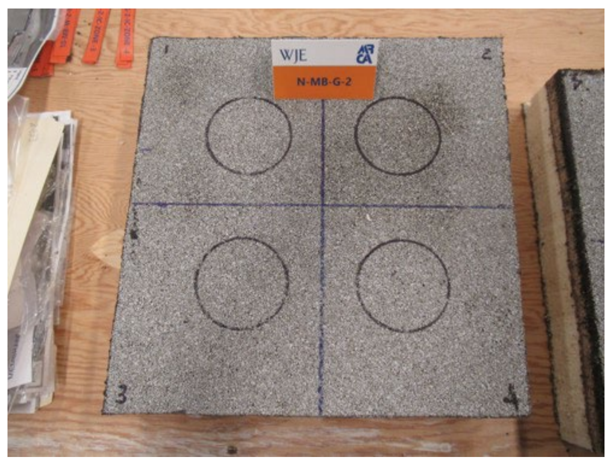

Figure 1. Sample trimmed and divided into four quadrants with 3-inch diameter impact zones.

3. **Pre-Impact Weights and Granule Counts.** Weights and granule counts were obtained for each sample prior to impact. Weights were obtained using a scale (Figure 2). Granule counts were obtained through a process called "image analysis" which uses a computer program to analyze a high-resolution photograph to identify features of interest (granules) within a 3-inch diameter circle (Figure 3). A black and white image was created from the original color image, a process called color thresholding. This enabled the computer program to determine quantitative information regarding the image (granule counts and exposed bitumen area). In addition to image analysis, manual counts of the granules were also conducted.

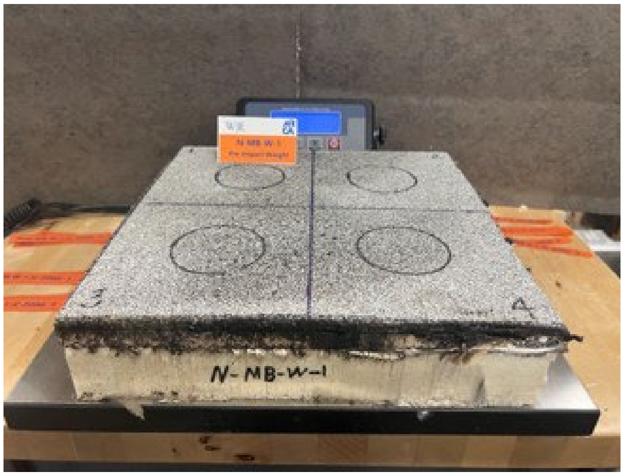

Figure 2. Weighing of sample.

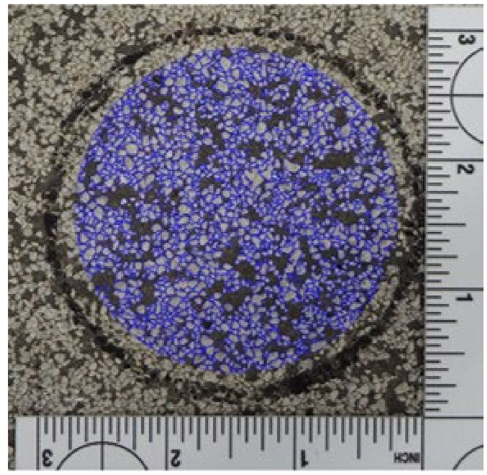

Figure 3. Granule identification through image analysis.

4. **Impact Testing.** A 5-pound steel missile released from a height of 53-inches impacted each quadrant of the sample per ASTM D3746. The steel missile was held at the top of the drop tube with a pin until the sample was ready to be impacted. A laser guide was used to align the missile with the center of the impact zone. See Figure 4.

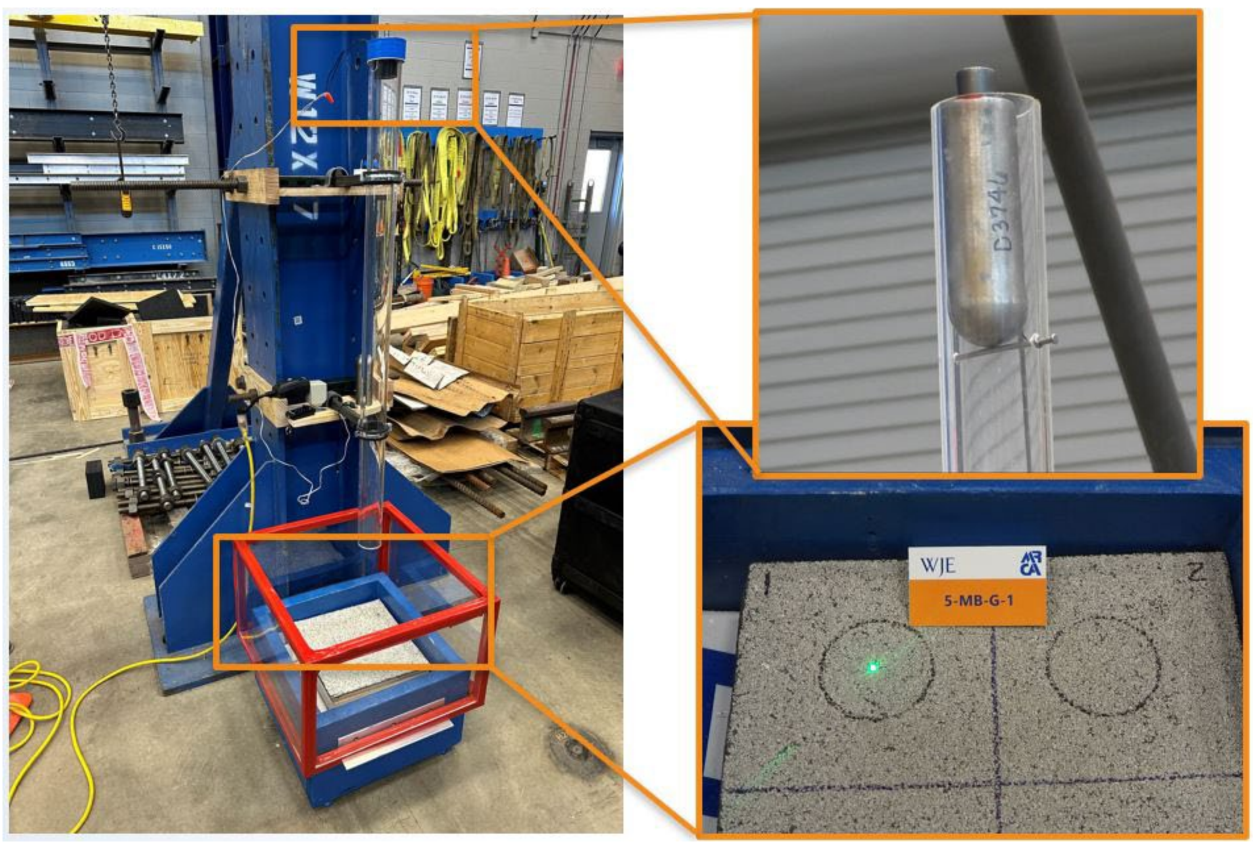

Figure 4. Testing apparatus at left; steel missile within drop tube at upper right; and laser spot alignment for missile drop within a typical 3-inch diameter circle at lower right.

5. **Post-Impact Weights and Granule Counts.** Weights of the samples and granule counts at each impacted zone were obtained a second time for each sample following impact. In addition to weighing the full samples using a precise scale, granules equal in number to those lost during impact were also weighed. Comparisons were made between pre- and post-impact images (Figures 5 and 6).

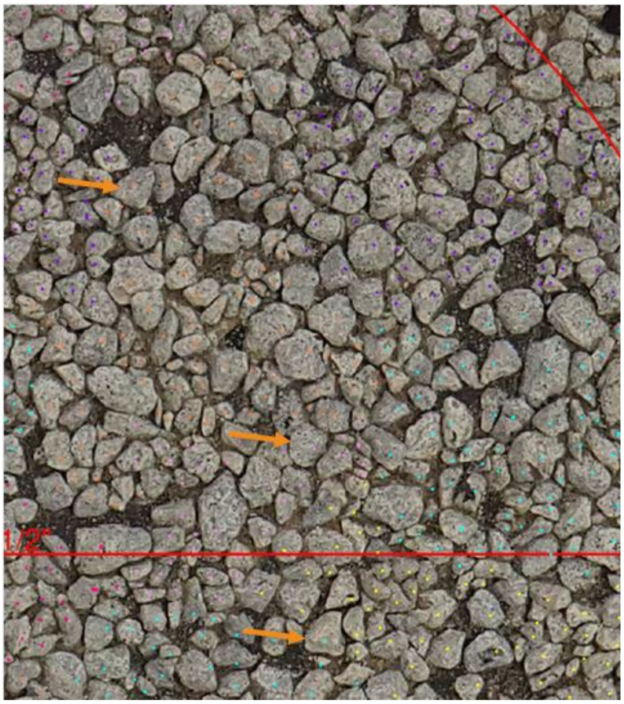

Figure 5. Sample 5-MB-G-1 pre-impact. Orange arrows indicate some differences between the pre-impact and post-impact images.

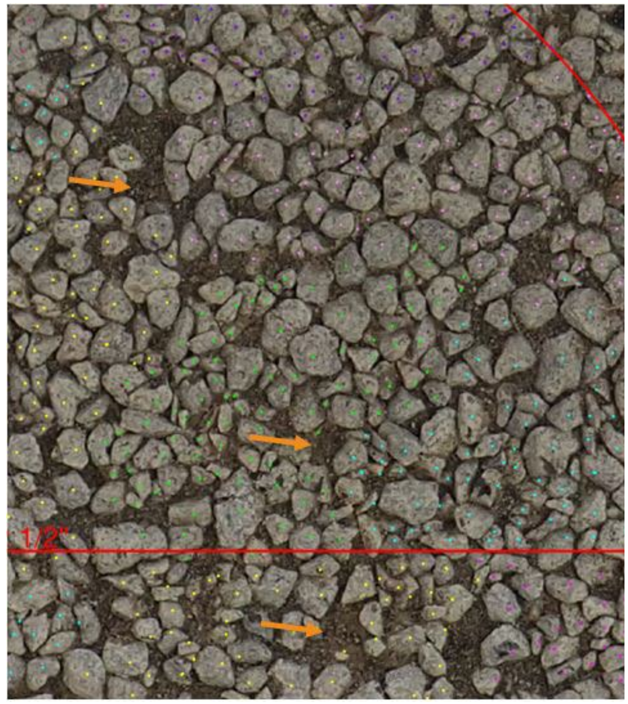

Figure 6. Sample 5-MB-G-1 post-impact. Orange arrows indicate some differences between the pre-impact and post-impact images.

6. **Desaturation.** Desaturation is the process of removing the bitumen from the membrane samples using a solvent to expose the reinforcement. One quadrant of each sample was desaturated to allow the membrane reinforcement to be visually inspected for damage due to the impact (Figures 7 and 8).

Figure 7. Fiberglass reinforcement from a modified bitumen base ply.

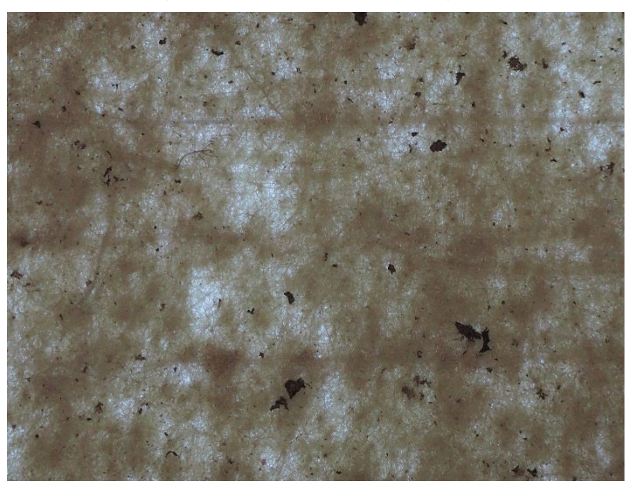

Figure 8. Polyester and fiberglass dual reinforcement from a modified bitumen cap ply.

7. **Microscopy.** One quadrant of each sample was cut through the impact site to view the membrane and cover board in cross-section with the use of a microscope (Figures 9 and 10).

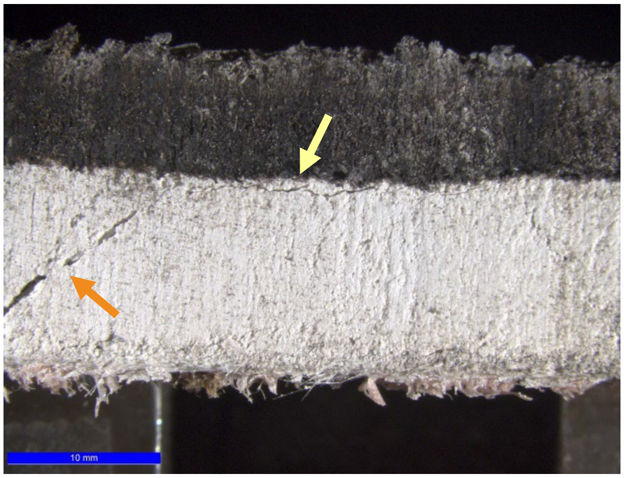

Figure 9. Cross-section of 10-year-old gypsum cover board sample. Note separation of facer from gypsum (yellow arrow) and radial crack throughout thickness of gypsum (orange arrow).

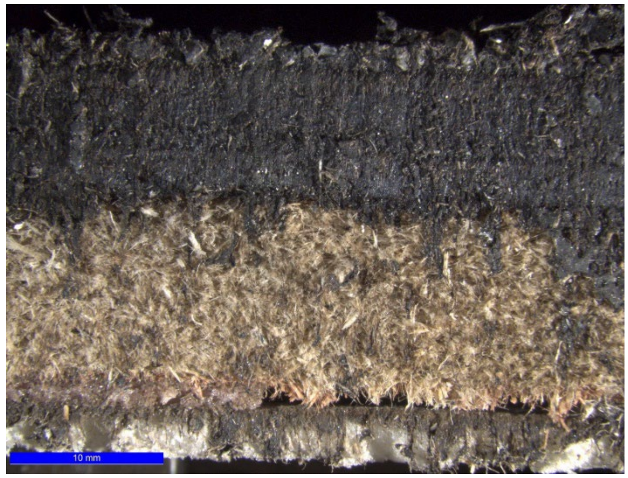

Figure 10. Cross-section of new wood fiber cover board sample. Note that no separations are visible.

Results of Impact Testing

The following table describes the average results of the impact testing in terms of granule counts and exposed bitumen (expressed as a percentage of area) within the 3-inch diameter impact zone for each type of sample tested:

Table 1. Average manual granule counts and exposed asphalt area pre- and post-impact

Cover Board Type	Sample Age (yrs)	Granule Count Pre-Impact	Granule Count Post-Impact	Granule Count Decrease	Exposed Bitumen Pre-Impact	Exposed Bitumen Post-Impact	Exposed Bitumen Increase
Gypsum	New	2761	2743	18	33.9%	34.3%	0.4%
Gypsum	5	2242	2231	11	33.9%	35.2%	1.3%
Gypsum	10	1845	1794	51	40.2%	42.2%	2.0%
Wood Fiber	New	2720	2703	17	36.9%	37.3%	0.4%
Wood Fiber	5	2246	2173	73	34.6%	35.1%	0.5%
Wood Fiber	10	1753	1736	17	55.5%	55.8%	0.3%

Conclusions

The following conclusions were drawn from the results of the impact testing and analysis:

- In general, regardless of cover board type or impact, the quantity of granules on the membranes decreased with age, while the exposed bitumen area generally increased with membrane age. There was a larger increase in exposed bitumen area between five- and ten-year-old membranes than there was between new and five-year-old membranes (Figure 11).

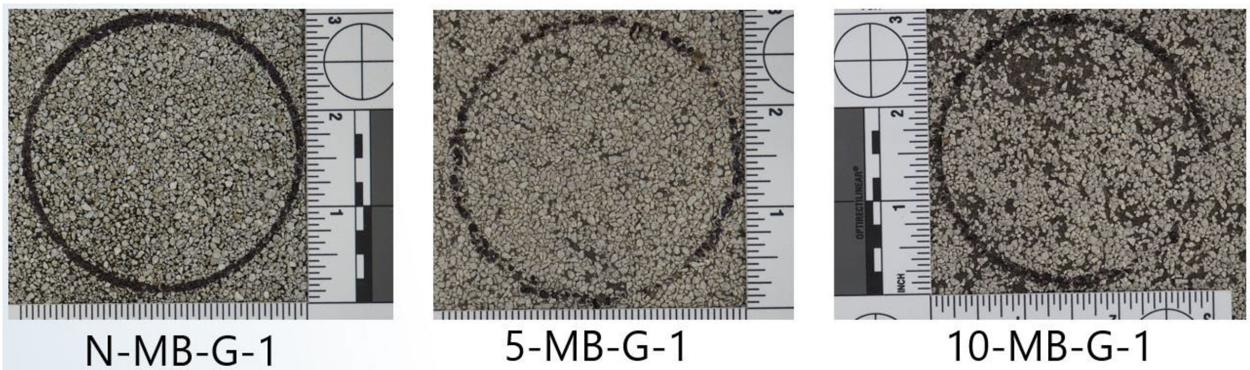

Figure 11. Comparison of new, five, and ten-year-old membranes over gypsum cover board.

- For each membrane age, the simulated hail impact resulted in minor granule loss that yielded slightly more exposed bitumen. The exposed bitumen area generally increased more upon impact with gypsum cover board than it did with wood fiber cover board.
- The impacts did not fracture the membrane reinforcement in any of the samples.
- Cracking of the gypsum cover board was observed at the impact site in all gypsum cover board samples that were tested. The impacts also caused cover board facer separation from the gypsum core at the impact sites in two thirds of the gypsum cover board samples. The wood fiber cover board samples were visually unaffected by the impacts.
- Comparison between image analysis and manual granule counts revealed that image analysis accuracy is variable due to differences in granule shape, color, texture, and size as well as features like granule overlap or fracturing. For this reason, manual counts were found to be more accurate and ultimately what was relied upon for the study. However, image analysis was found to be more useful in identifying exposed bitumen area due to the high color contrast between the granules and the bitumen, a property that image analysis is proficient in detecting.