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Testing Built-up and Modified Bitumen Roofs for Hail Damage

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ABSTRACT

Although there is currently no ASTM method specifically for testing built-up and modified bitumen (bituminous) roof systems for hail-caused damage, laboratories routinely test bituminous roof systems for hail-caused damage. This presentation discusses the ASTM test methods that are commonly referenced in these laboratory testing reports. This presentation also includes findings from research the author's company has performed using ASTM D3746, *Standard Test Method for Impact Resistance of Bituminous Roofing Systems*, to illustrate what hail-caused damage of bituminous roofs looks like and to compare our ASTM D3746 test results to actual hail-caused damage to bituminous roofs. The intent is to provide exemplar photographic examples for visual comparative purposes.

SPEAKER

Stephen L. Patterson, RRC, PE

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Stephen L. Patterson has been in the roofing industry for almost 50 years. He founded Roof Technical Services Inc. (ROOFTECH) in 1983 and has been an active consulting engineer and roof consultant ever since. ROOFTECH has provided laboratory testing, including testing for hail damage, since the late 1980s. Patterson has been technical director/director of engineering for two roofing manufacturers and managed a roof contracting company for four years.

Nonpresenting Coauthor

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Testing Built-up and Modified Bitumen Roofs for Hail Damage

There are numerous testing laboratories across the country that test built-up and modified bitumen roof (bituminous roof) samples for evidence of hail damage. The problem is that there is no specific ASTM International standard test method for performing these tests. As a result, testing labs are using a variety of test methods for testing bituminous roof samples for hail damage. Roof Technical Services Inc. (Rooftech) has been testing bituminous roof samples for evidence of hail damage since the 1980s. Most of the testing from different laboratories that we have reviewed has adapted test protocols from ASTM D2829, *Standard Practice for Sampling and Analysis of Existing Built-Up Roof Systems*,[1] and/or ASTM D3746, *Standard Test Method for Impact Resistance of Bituminous Roofing Systems*.[2] Additionally, there are acceptance criteria that are sometimes referenced in the laboratory reports included in Factory Mutual (FM) Class Number 4470, *Single-Ply, Polymer-Modified Bitumen Sheet, Built-up Roof (BUR) and Liquid Applied Roof Assemblies for Use in Class 1 and Noncombustible Roof Deck Construction*[3,4] (Appendix F: Susceptibility to Hail Damage Test Standard), ANSI FM 4473, *Impact Resistance Testing of Rigid Roofing Materials by Impacting with Freezer Ice Balls*,[5] and Underwriters Laboratory (UL) 2218, *Standard for Safety—Impact Resistance of Prepared Roof Covering Materials*.[6]

This paper has two broad objectives. The first is to provide an understanding of the test methods in ASTM D2829 and ASTM D3746 and how they relate to testing bituminous roofs for hail-caused impact damage, as well as the acceptance criteria in UL 2218, FM 4470, and FM 4473. The second is to provide a method for evaluating test samples for evidence of hail damage based on laboratory testing. To accomplish these objectives, we performed ASTM D3746 tests on insulated and noninsulated bituminous roofs. The purpose of this testing was to simulate hail-caused impact damage on these samples, to document the resulting hail-caused impact damage, and to provide a comparative visual standard to evaluate bituminous test samples for hail damage. This is an ongoing project, which will be expanded to more varieties of bituminous roof systems.

ASTM D3746

ASTM D3746[2] is a test protocol used to assess the hail resistance of bituminous roofing, such as built-up and modified bitumen roofing. This test procedure utilizes a free-falling steel missile to replicate the impact energy of a 2 in. (50 mm) hailstone. This test method provides a standard protocol for analyzing the bituminous roofing for resistance to hail-caused impact damage to bituminous roofs.

ASTM D3746 Section 10.7, "Damage Assessment," establishes a test protocol for evaluating the roof for impact damage as follows. Section 10.7 establishes a standard for desaturating felts for evaluation. The process uses a solvent bath to remove the bituminous material from the reinforcement. Reinforcements typically include fiberglass felts; polyester mats; combination fiberglass and polyester; and, in the case of older roofs, organic or asbestos felts. The desaturation process makes it easier to evaluate the felts for evidence of hail-caused damage.

> ***Section 10.7 Damage Assessment***
>
> *10.7.1 Remove any slag or gravel surfacing from the specimen carefully with a hot scraper, such as a putty knife.*
>
> *10.7.2 Record the extent of obvious damage to the membrane, such as dents or fractures, by photograph or sketch and written description.*
>
> *10.7.3 Cut the four Impact Areas from the specimen using a hot knife. Staple the felts in each area together and extract the bitumen by immersing in warm 1,1,1 trichloroethane in a fume hood. Do not heat the trichloroethane to boiling. (For tarred felt and pitch membranes, use xylene in place of trichloroethane.)*

ASTM D3746 Section 10.8, "Rating of Impact Damage," establishes a protocol for rating the impact damage as follows. There is only a protocol for rating the samples based upon the evidence of dents and cracks or splits. There is nothing in the protocol that establishes a pass or fail rating, so the interpretation is left to the reader of the report.

> ***Section 10.8 Rating of Impact Damage***
>
> *10.8.1 Rate the impact damage which occurs in each ply in each of the four quadrants by assigning the number which most accurately describes the impact damage, as follows:*

There are numerous testing laboratories across the country that test built-up and modified bitumen roof (bituminous roof) samples for evidence of hail damage. The problem is that there is no specific ASTM International standard test method for performing these tests.

0 = no damage;
2 = dents, indentations only;
4 = any cracks or splits

10.8.2 After assigning the numbers to all plies within each quadrant, add up all the numbers and divide by four times the number of plies to obtain an average for the membrane. (Note: No passing or failing criteria are provided.)

ASTM D2829

ASTM D2829[1] is a test for the analysis of existing built-up roofs to determine whether the roof sample contained the appropriate number of plies, the appropriate amount of asphalt or coal tar pitch (bitumen), an appropriate flood coat, and an appropriate gravel surfacing, and whether there are excessive installation voids in the interply. The following section from ASTM D2829 describes the test. There is nothing in the scope of this test method that deals with hail-caused impact damage. It is a test protocol for "determining *approximate* quantities of the various components."

> ***1. Scope***
>
> *1.1 This practice is a guide for removing test specimens from existing built-up roofing systems in the field and for determining the "approximate" quantities of the components of that specimen (Note 1). Components determined may be: 1.1.1 Insulation components when they are part of the roof membrane system, 1.1.2 Plies of roofing felt, 1.1.3 Interply layers of bituminous material,1.1.4 Top coating, and 1.1.5 Surfacing.*
>
> *NOTE 1—This procedure is for the investigation of existing roofs and is not intended for new construction inspection.*
>
> *1.2 This practice is applicable to both 914-mm (36-in.) and 1000-mm (39⅜-in.) wide felt rolls.*
>
> *1.3 The values stated in SI (metric) units are to be regarded as standard.*
>
> *1.4 <u>This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.</u> For specific precautionary information, see 6.3.2.1*

The test protocol includes methods for extracting samples from the field and for delaminating the felts, both of which are commonly used in testing bituminous roofs for hail-caused impact damage. Section 8, "Report," describes the reporting protocol as follows. Again, the report is based on analyzing the roof components and is not related to testing for hail-caused impact damage.

> ***8. Report***
>
> *8.1 Describe the built-up roof, including the type and class of bituminous material, type of surfacing, type of insulation, type of roof decking, and the type and number of felts or roofing sheets.*
>
> *8.2 Fully identify the origin and roof location of each specimen.*
>
> *8.3 Report the mass per unit area of surfacing, average interply bituminous material, top coating bituminous material, total applied bituminous material, and the total specimen (minus insulation). See Table 3 for summary of results and conversion to conventional units of measurement.*
>
> *8.4 Diagram the felt lapping to show the number of plies and the lap relationship, if determined (6.8).*

FM 4470

The requirements for hail damage resistance are included in FM 4470 Section 4.4, "Hail Damage Resistance Test."[3] The test is included in Appendix F, "Susceptibility to Hail Damage Test Standard," which was included in the older standard[4] and is only referred to as "Susceptibility to Hail Damage Test Standard" in the newer standard. The FM test is similar to ASTM D3746[2] in that the test method includes dropping steel balls to simulate hail. The acceptance criteria are included in FM 4420 Section 4.4.1, "Conditions for Hail Damage Resistance," as follows.

> ***4.4.1 Conditions for Hail Damage Resistance***
>
> *Both unconditioned (unweathered) and conditioned (weathered) samples of roof cover are inspected for damage. Neither the roof cover nor the field seam (if present) shall show any signs of cracking or splitting. The field seam shall not show any signs of cracking, splitting, separation, or rupture when examined closely under 10X magnification. Under adhered conditions, minor separations of the roof cover from the substrate (directly under the Impact Areas) is acceptable for monolithic decks only (i.e. structural concrete or gypsum) or lightweight insulating concrete insulation.*

ANSI FM 4473

ANSI FM 4473[5] standard utilizes ice balls to simulate hail impact. The ice balls are propelled at a velocity that simulates the kinetic energy established for the various sizes of hail. Ice ball testing is generally more representative of actual hail impact than steel balls. Steel balls are a simple way of simulating impact energy—for example, drop a 1 lb (0.5 kg) steel ball 1 ft (0.305 m) and one gets 1 ft-lb (0.14 kg-m) of impact energy. A good example is clay and concrete tile roofing. Steel balls that generate the same impact energy as hail will break tile, while ice balls with the same impact energy will not, as ice shatters upon impact and steel does not. The difference is related to the difference in momentum between ice balls and steel balls. The acceptance criteria are included in Section 4, "Pass/Fail Criteria," as follows:

> *4.1.1 The test specimen shall show no evidence of visible cracking or breakage or any damage such as splits, punctures, fractures, disengagement of lap elements or exposure of materials not so intended.*
>
> *4.1.2 When a test specimen fails to meet the acceptance criteria for a tested classification, two consecutive test specimens must successfully meet the acceptance criteria to qualify for the given classification*

UL 2218

UL 2218[6] is similar to ASTM D3746[2] in that steel balls are dropped to simulate hail impact. UL 2218 utilizes 1.25-in.- (32-mm-), 1.5-in.- (38-mm-), 1.75-in.- (44-mm-), and 2.00-in.- (50-mm-) diameter steel balls that are dropped from 12.0 ft (3.7 m), 15.0 ft (4.6 m), 17 ft (5.2 m), and 20.0 ft (6.1 m), respectively, to simulate the impact energy of 1.25-in-., 1.50-in.-, 1.75-in.-, and 2.00-in.-diameter hail. The acceptance criteria are included in Section 7, "Acceptance Criteria," as follows:

7.1 The prepared roof covering material is to be examined after being subjected to the test procedure described in Section 6. The prepared roof covering material exposed surface, back surface and underneath layers shall show not evidence of tearing, fracturing, splitting, rupture, crazing or other evidence of opening through any prepared roof covering layer.

7.2 For asphalt shingles, a visible crack of the asphalt on the back of the shingles shall be determined to be a failure.

7.3 For wood, tile, concrete, fiber-cement, plastic and metal roof coverings, a surface crack shall not be determined to be a failure. A crack that extends through the cross-section of the roof covering material layer shall be determined to be a failure.

7.4 Cosmetic damage in and of itself shall not be determined to be a failure. Cosmetic damage such as denting, damage not extending through the cross-sectional area of a roof covering material layer, crack of any paint finish, etc. shall not be determined to be a failure.

TESTING PROTOCOL

We utilize a modified version of ASTM D3746[2] for analyzing hail-caused impact damage and the methodology for delamination and desaturating the felts to evaluate the samples to determine whether there is damage. In general, the protocol includes the following:

1. Visually examining the top and bottom of the samples for evidence of impact damage to the surface of the roof. This would include evidence of spatter marks, denting, displaced granules or gravel, and evidence of crushed or cracked bitumen.
2. Delaminating the samples in general accordance with ASTM D2829[1] and visually examining the interply bitumen for evidence of denting, crushed interply, and/or fracturing of the reinforcement.
3. Desaturating the samples in general accordance with ASTM D3746[2] and visually examining the desaturated reinforcements for evidence of denting and fracturing of the reinforcement. It should be noted that some labs do not desaturate the samples and rely on the examination of the delaminated plies for evidence of fracturing. However, desaturation is part of the ASTM D3746 protocol and provides for a more reliable assessment of the reinforcement.
4. The samples are also examined under various magnifications, including 10-power magnification, at each step of the testing in general accordance with Susceptibility to Hail Damage Test Standard, Section 4.4.1.[7]

The following is an excerpt from a typical report describing our testing protocol.

Each of the six mineral granule surfaced modified bitumen roof membrane samples was logged, visually inspected under various magnifications and photographed top and bottom. The roof membrane samples were then delaminated, inspected, and photographed. The roof membrane samples were desaturated and evaluated in general accordance with ASTM D3746, Impact Resistance Analysis of Bituminous Roofing Systems. *Each individual ply was photographed top and bottom and visually inspected. Plies were examined under microscope at various magnifications. Any anomalies detected were photographed and recorded.*

Our intent is to visually document each step of the testing to provide transparency in our reporting. Each step of the testing protocol is photographed, including photographs of the front and back of the sample upon arrival, the individual plies after delamination, and the individual plies after desaturation, along with magnified views of points of interest. A diagram of the sample configuration in general accordance with ASTM D2829[1] is also provided.

ANALYSIS AND INTERPRETATION OF THE DATA

The next step is to analyze and interpret the data, which can be subjective. As noted earlier, the general guidelines included in ASTM D3746[2] are as follows:

Rate the impact damage which occurs in each ply in each of the four quadrants by assigning the number which most accurately describes the impact damage, as follows:

0 = no damage;
2 = dents, indentations only;
4 = any cracks or splits

We do not provide a rating analysis as described. Our reports document evidence of granule or gravel loss, denting of the surface and/or the reinforcement, cracks or splits in the reinforcement, and crushed bitumen at the point or points of interest. ASTM D3746 provides an unambiguous description of impact damage. Are the desaturated felts dented or fractured? No dents or fractures receive a rating of 0; dents receive a 2, and fractures receive a 4. The test method does not consider the surfacing or the interply bitumen for damage. The issues of what constitutes damage may become subjective, depending on the various definitions of damage—for example, the definition of damage included in an insurance policy.

It is important to consider that ASTM D3746 is designed to test and rate a bituminous roof sample for resistance to hail. Typically, the test samples used are from new construction and often prepared for the purpose of testing. In the case of these samples, the area of impact is known, and the impacted area can be analyzed and compared with the nonimpacted areas. This is not the case of test samples taken from existing roofs.

Existing bituminous roofs have been subjected to construction traffic; maintenance traffic; and, in many cases, years of weathering. Bituminous roofs are typically installed with heat (hot asphalt and torches) and are susceptible to foot and general construction traffic during the installation of the roof, particularly when the roof is hot. Anomalies from installation traffic are common to virtually all bituminous roofs, and these anomalies are often confused with impact damage from hail.

The intent of our ASTM D3746[2] testing was to provide clear visual examples of impact damage to bituminous roofs—that is, what hail-caused impact damage looks like on bituminous roofs.

ASTM D3746 TESTING

We performed ASTM D3746[2] testing on aged aggregate-surfaced fiberglass asphalt built-up roof samples and on new and aged granule-surfaced SBS modified bitumen roof samples. The built-up roofing samples were tested on insulated (relatively soft) and noninsulated (firm) substrates. The new granule-surfaced modified bitumen samples were tested on a firm substrate of 0.5 in. (13 mm) gypsum cover board and an insulated (relatively soft)

Figure 1. A test sample positioned on the platform.

Figure 2. A missile was dropped onto the approximate center of each of the four quadrants.

substrate. The aged granule-surfaced modified bitumen samples were tested on insulated and noninsulated substrates. ASTM D3746 uses a 2.0 in. (50 mm) diameter missile to replicate the impact energy of 2.0 in. hail. Many bituminous roof systems are resistant to 2.0 in. hail. The fundamental purpose of our testing was to replicate hail-caused damage. Therefore, we modified the missile size to replicate 2.5 in. (64 mm) hail and to develop 57.48 ft-lb of impact energy as defined by the National Bureau of Standards.[3]

The modified missile was 2.5 in. (64 mm) in diameter and 6 in. (152 mm) long, and weighed 7.67 lb (3.48 kg). A 24 × 24 in. (610 × 610 mm. testing table was constructed using two-by-fours placed on edge and bolted together in accordance with ASTM D3746. The test sample was placed on the testing table, and the missile was dropped from 87⅞ in. (2232 mm) onto the approximate center of each of the four quadrants. A test sample positioned on the platform is shown in **Fig. 1**.

A missile was dropped onto the approximate center of each of the four quadrants, as shown in **Fig. 2**.

Testing was performed on test samples taken from an aged aggregate-surfaced asphalt fiberglass built-up samples and from new and aged granule-surfaced SBS-modified bitumen samples. Each sample was examined and photographed in accordance with the our protocol described previously.

TEST RESULTS FROM AGGREGATE-SURFACED BUILT-UP ROOF SAMPLES

Evaluation of Surfacing at Impact Area

The test results related to surface damage were consistent. The impact from a 2.5 in. (64 mm) missile resulted in surface damage to the samples on both the insulated and noninsulated substrates. The results of the laboratory impact damage to the surface were compared with test samples of roofs that had been damaged by hail and to examples included in Haag Engineering's *Built-up Roofing: A Pictorial Guide*.[8] The test sample before the missile drop in shown in **Fig. 3**. The test sample after the missile drop and after the loose gravel was removed is shown in **Fig. 4**. The red arrows identify the area of impact in Fig. 4.

Figure 4. The test sample after the missile drop and after the loose gravel was removed.

Figure 3. The test sample before the missile drop.

Figure 5. The test sample after the missile drop showing crushed gravel at point of impact.

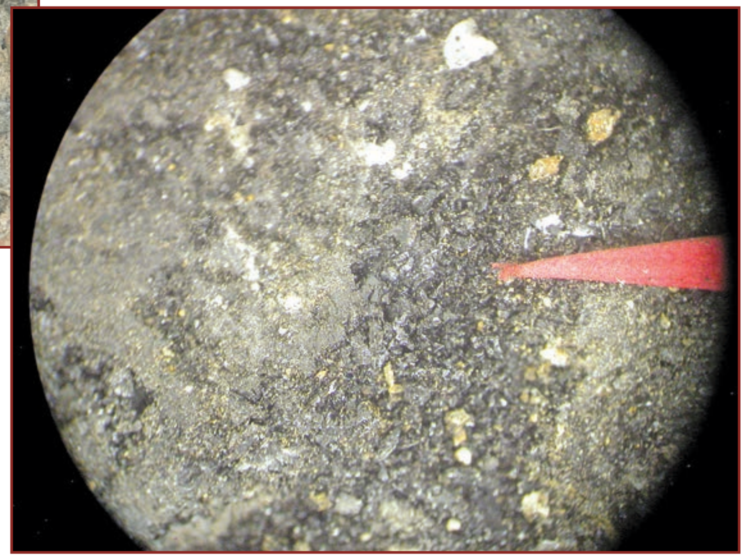


Figure 6. Localized crushing of the asphalt flood coating at the point of impact is shown in this 10-power photograph.

The areas of impact were very similar on all tests. There was a general displacement of the imbedded aggregate and exposure of the asphalt flood coat. The aggregate at the point of impact was crushed at some of the impacts (**Fig. 5**). In no case did the impact result in aggregate being driven into the sample, affecting the felts below. The crushed aggregate was likely the result of using a steel missile rather than an ice ball for testing, as hail typically shatters on impact and steel does not.

There was localized crushing of the asphalt flood coat at the point of impact, as shown in **Fig. 6**.

The area of impact in our simulated testing is also consistent with roof samples that we have tested from roofs damaged by hail. **Figure 7** shows a test sample taken from a roof that was damaged by hail. The meteorological and physical evidence indicated that the hail was in the 2.5 in. (64 mm) and larger range.

The surface damage occurring at each of the impact areas from our testing was consistent in appearance, was consistent with surface damage from actual hail observed in the field and in the laboratory, and was consistent with the photographs included in *Built-up Roofing: A Pictorial Guide*.[8] Our conclusion is that these illustrations of surface damage to aggregate-surfaced built-up roofs are representative of actual hail damage and can be used for comparative analysis.

Evaluation of Interply Bitumen—Insulated and Noninsulated Samples

There is no protocol for the evaluation of the interply bitumen in ASTM D3746.[2] The rating system protocol for evaluation of damage is limited to the desaturated felts. Therefore, crushed or disturbed interply is not a factor in the evaluation process of ASTM D3746. In the case of the noninsulated samples, there was no denting or cracking of the desaturated felts, so, based upon ASTM D3746, this roof would have been rated as having no hail-caused impact damage.

The sample was desaturated and the felts were evaluated using the rating protocol in ASTM D3746. Early on, the vast majority of our testing focused on ASTM D2829[1] and ASTM D3617.[9] Both standards were used to determine whether the roof system was installed in accordance with industry standards. These testing standards consisted of weighing and measuring the components of the roof and comparing the results to a recommendation or guideline, either a manufacturer's or the National Roofing Contractors

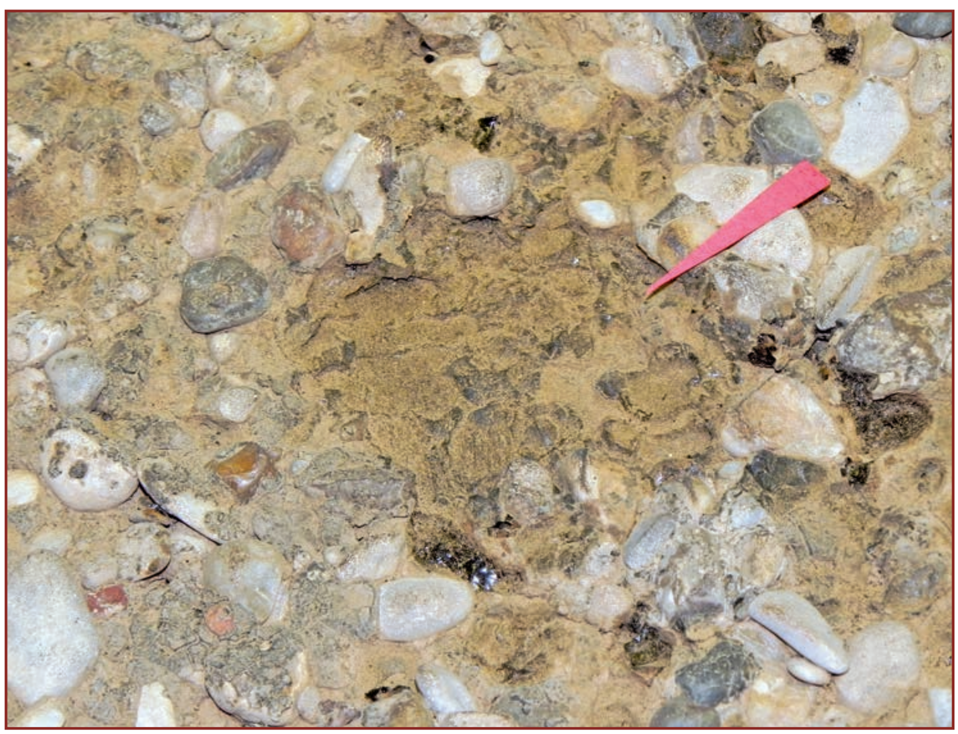
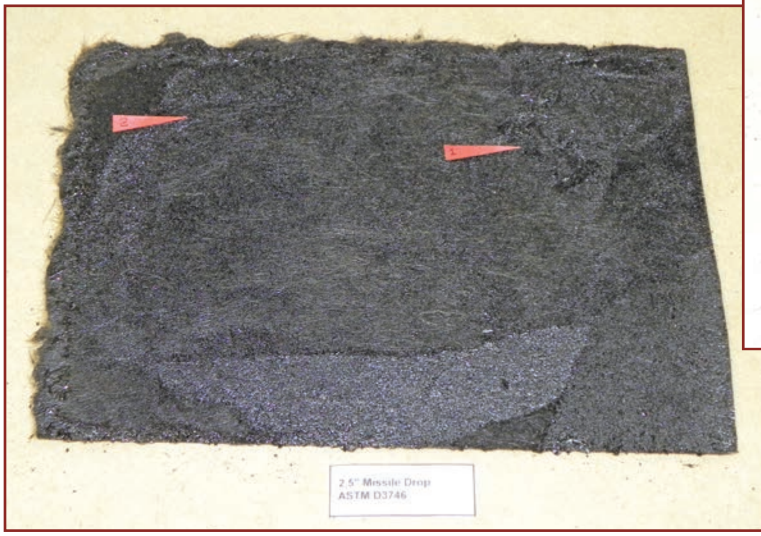


Figure 7. A test sample taken from a roof that was damaged by hail.

Figure 9. Close-up of impact 2 with no evidence of crushed or disturbed interply.

Figure 8. The back side of the top ply of felt, which was partial lap-ply.



Association's. These tests were used for quality assurance or forensic purposes. Part of the protocol included the delaminating the felts to determine the lap-ply configuration. In addition, we examined the interply for evidence of voids or dry spots.

We began testing roof samples for evidence of hail damage in the 1980s. Our standard test protocol for evaluating hail damage utilized ASTM D2829 testing standards for removal of the samples, for preparation of the samples, and for delamination of the felts. The delaminated felts were then desaturated and evaluated using the ASTM D3746 protocol for assessment. On rare occasions, in the case of very large hail, we observed crushed interply asphalt between the plies and began including these observations in our reports. It should be noted that crushed interply was never observed in coal tar pitch samples, which is likely the result of the self-healing properties of coal tar pitch.

Observations regarding crushed or disturbed interply bitumen were included in our study. Our study was based on evaluating damage from 2.5 in. (64 mm) missiles representing very large hail. Crushed interply bitumen was observed at each area of impact on the insulated samples. Crushed interply was observed at some of the impact areas on the noninsulated samples. **Figure 8** shows the back side of the top ply of felt, which was partial lap-ply. The sample was only impacted by test drops 1 and 2. There was no evidence of crushed interply at this level within the sample.

Figure 9 shows a close up of impact 2 with no evidence of crushed or disturbed interply.

Figure 10 shows the impact area at 10-power with no evidence of crushed asphalt.

There was evidence of crushed interply in the lower layers of felt. **Figure 11** shows impact area 4 on the back of the first full ply.

Figure 12 shows impact area 4 at 10-power and the crushed interply asphalt at the point of impact.

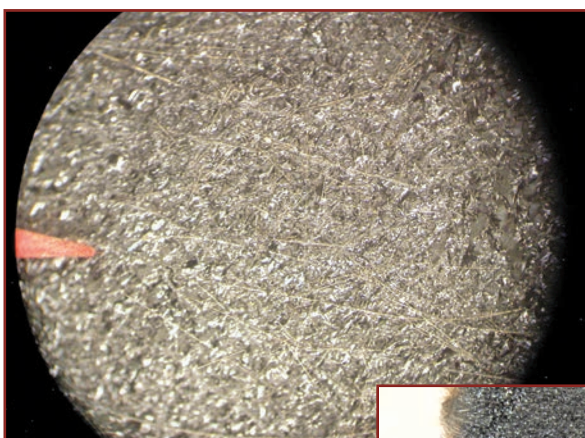


Figure 10. Impact area at 10-power with no evidence of crushed asphalt.

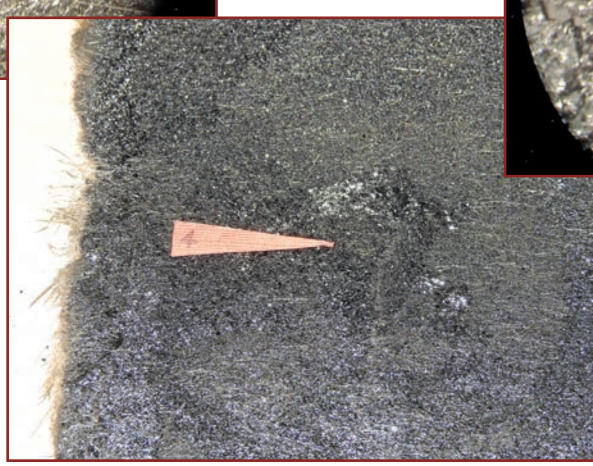


Figure 11. Impact area 4 on the back of the first full ply.

Figure 12. Impact area 4 at 10-power and the crushed interply asphalt at the point of impact.

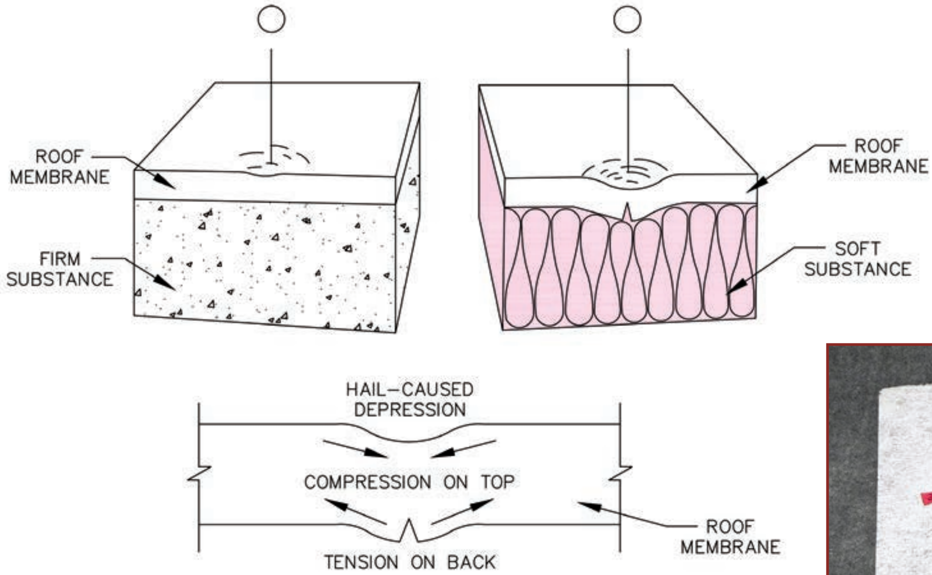


Figure 13. The softer substrate allows for more deflection in the membrane, resulting in tension in the bottom layers of the felts. Figure: Adapted from Haag Engineering's **Built-up Roofing: A Pictorial Guide.**

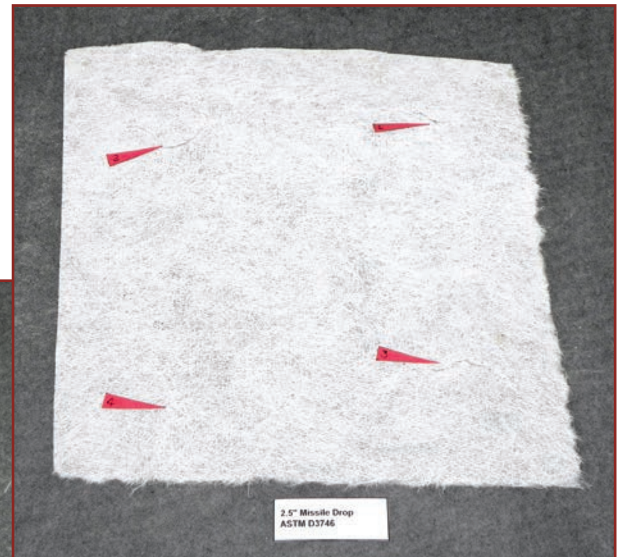


Figure 15. Bottom full ply with impact fractures identified by red arrows.

Figure 14. Desaturated bottom ply of felt in the noninsulated (firm substrate) sample.

The crushed interply in our simulated testing was also consistent with roof samples we have tested from roofs damaged by hail. One example is a roof designed by us that was approximately 15 years old at the time of the event. The hail was in the 2.5 in. (64 mm) and larger range.

There was evidence of crushed interply in all of the areas of impact on the insulated samples. There was evidence of crushed interply in some of the areas of impact on the noninsulated samples. In general, the softer the substrate (typically insulated), the more susceptible the roof is to hail damage. Crushing of the interply may also be a function of the thickness of the asphalt. The crushed interply bitumen occurring at each of the impact areas from our testing was consistent in appearance and was also consistent with crushed interply bitumen from actual hail observed in the field and laboratory.

Evaluation of Desaturated Felts—Insulated and Noninsulated Samples

The protocol for evaluating hail-caused impact damage to desaturated felts is clearly defined as dents or cracks or splits (fractures) in ASTM D3746.[2] The desaturated felts were examined for evidence of damage at each of the four impact areas. The results of the laboratory impact damage to the surface were compared with our test samples of roofs that had been damaged by hail and to examples included in Haag Engineering's *Built-up Roofing: A Pictorial Guide.*[8]

Our study showed that there were fractures in the felts at each of the impact areas on the insulated samples, but there were no fractures in the felts at each of the impact areas on the noninsulated samples. There were no dents or indentations in the felts in any of the impact areas. The denting criterion is probably a holdover from testing on organic or asbestos felts, as it has been our experience that hail impact does not typically result in dents in fiberglass felts. Dents and other anomalies in the top layer of felt commonly occur as a result of construction traffic during installation, particularly from loose aggregate stepped on during construction before the flood coat has been applied.

Our test results confirm the importance of the substrate in the hail resistance of bituminous roofs. In general, the softer the substrate (typically insulated), the more susceptible the roof is to hail damage. Impact from very large hail can cause localized deflection in the membrane at the point of impact. **Figure 13** illustrates how the softer substrate allows for more deflection in the membrane, resulting in tension in the bottom layers of the felts.

Figure 14 shows the desaturated bottom ply of felt in the noninsulated (firm substrate) sample. The tension is greatest in the bottom ply, so the bottom ply is the most likely ply to fracture. The tension in the felt was limited by the firm substrate, and there was no fracturing. Also, there was no denting in the fiberglass felts on the insulated and noninsulated sample.

There were fractures at all impact areas in the insulated sample. **Figure 15** shows the bottom full ply with impact fractures identified with the red arrows.

Figure 16 shows a magnified view of the fracture in the felt at impact area 3.

The fractures at the areas of impact in our simulated testing are also consistent with roof

Figure 16. Magnified view of the fracture in the felt at impact area 3.

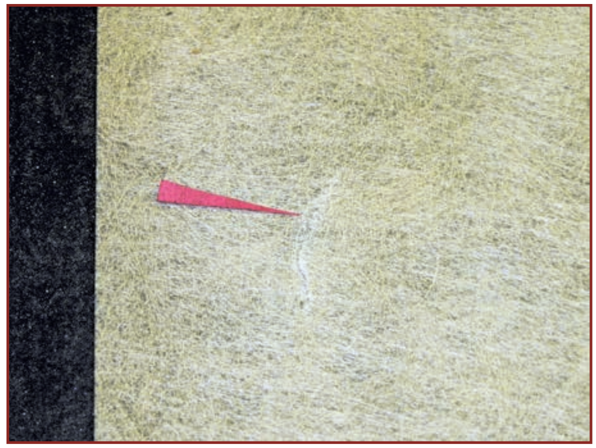


Figure 17. Fractured felts in a test sample from a roof that was damaged by hail.

samples we have tested from roofs damaged by hail. **Figure 17** shows fractured felts in a test sample from a roof that was damaged by hail. This was a roof that was designed by us and was approximately 15 years at the time of the hail event. The hail was in the 2.5 in. (64 mm) and larger range.

The area of impact in our simulated testing is also consistent with the hail-caused impacts illustrated in reference 8.

There was no evidence of fracturing in the desaturated felts in the noninsulated sample. The was evidence of fractured felts at all of the areas of impact on the insulated samples. There was no evidence of denting in the insulated or noninsulated samples. The fractured felts occurring at the impact areas from our testing were consistent with fractures occurring as a result of actual hail and consistent with published literature.[8]

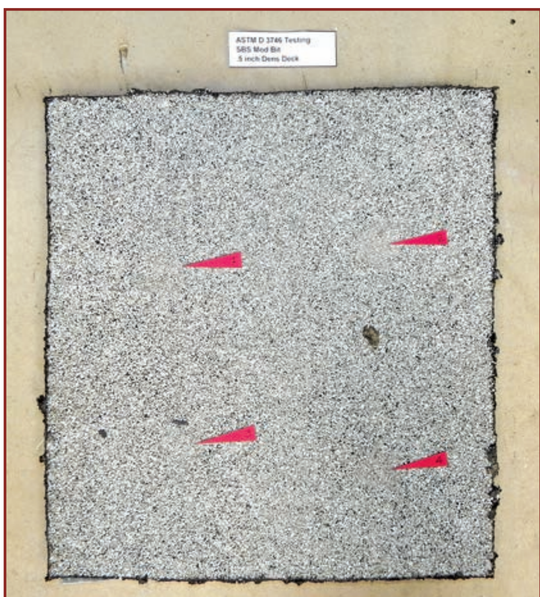


Figure 18. The new modified bitumen sample on noninsulated substrate after the sample was impacted by the four missile drops.

TEST RESULTS FROM NEW GRANULE-SURFACED SBS MODIFIED BITUMEN ROOF SAMPLES

Evaluation of Surfacing at Impact Area

The test results related to surface damage to the granule-surfaced modified bitumen samples varied. There was very little evidence of displaced granules on the new samples on insulated or noninsulated substrates. It should be noted that the noninsulated samples were supported by 0.50 in. (13 mm) gypsum cover board, which was not as firm as the wood test table but is considered to be a firm substrate. The insulated samples were supported by 0.75 in. (19 mm) perlite, which is considered to be a soft substrate. The samples were positioned and impacted as described in the protocol for the aggregate-covered built-up roofs.

Figure 18 shows the new modified bitumen sample on noninsulated substrate after the sample was impacted by the four missile drops.

Figure 19 shows a closer view of impact area 1. There is a slight difference in the color of the granules.

Figure 20 shows a 10-power view of impact area 1. There are no discernible displaced granules. The change in color is the result of localized crushing of the granules at the point of impact.

Figure 21 shows a 10-power view of a typical

Figure 20. 10-power view of impact area 1. There are no discernible displaced granules. The change in color is the result of localized crushing of the granules at the point of impact.

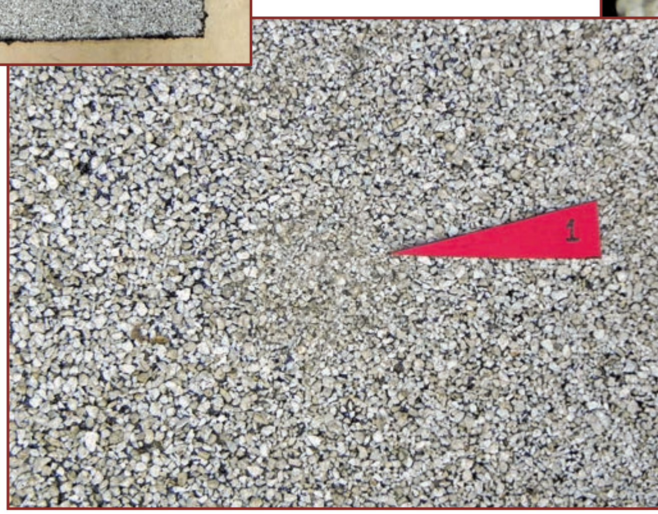


Figure 19. A closer view of impact area 1. There is a slight difference in the color of the granules.

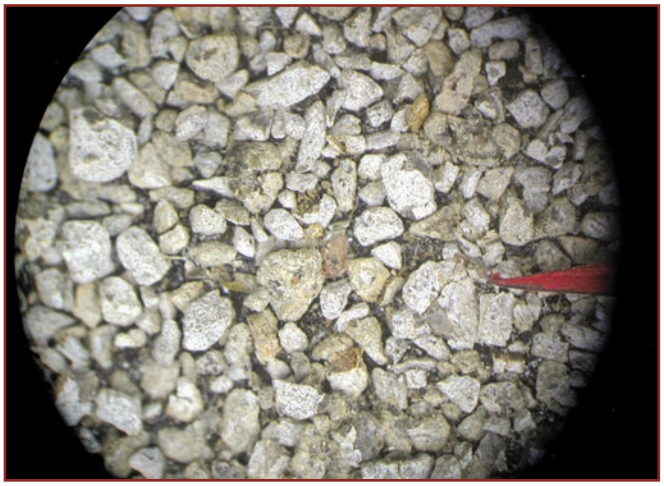


Figure 21. 10-power view of a typical impact area on the insulated sample. There are no discernaile displaced granules. There is no evidence of localized crushed granules on the insulated samples.

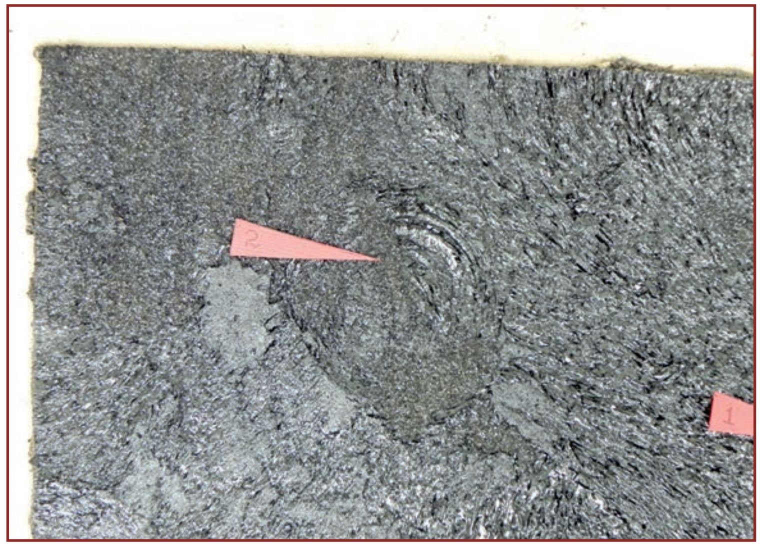


Figure 22. Example of crushed interply on the insulated sample.

impact area on the insulated sample. There are no discernible displaced granules. There is no evidence of localized crushed granules on the insulated samples.

The area of impacts on the new modified bitumen exhibited no displaced granules. The crushed granules were likely the result of the steel missile and were unlikely to occur on simulated ice balls or natural hail. We have observed similar results on newer installations that were impacted by large hail. The adhesion of the granules on new SBS modified bitumen roofs is generally very good and limited or no granule loss may occur on newer installations of modified bitumen roofs. The crushed granules may weather away over time and result in an area of localized granule loss, but this was not verified.

Evaluation of Interply Bitumen—Insulated and Noninsulated Samples

As stated previously, there is no protocol for the evaluation of the interply bitumen in ASTM D3746.[2] However, the interply bitumen was examined on the modified bitumen samples. Crushed interply bitumen was observed on the insulated sample but not on the noninsulated sample. The lack of crushed interply is possibly the result of the quantity of interply asphalt. It has been our experience that thicker applications of interply asphalt are more prone to crushed interply. **Figure 22** shows an example of crushed interply on the insulated sample.

There was evidence of crushed interply in all of the areas of impact on the insulated samples. There was no evidence of crushed interply in the areas of impact on the noninsulated samples. In general, the softer the substrate (typically insulated), the more susceptible the roof is to hail damage. Crushing of the interply may also a function of the thickness of the asphalt. The crushed interply bitumen occurring at each of the impact areas from our testing was consistent with crushed interply bitumen from actual hail observed in the field and laboratory.

Evaluation of Reinforcement—Insulated and Noninsulated Samples

The modified bitumen membrane had a dual-carrier mat with a combination of polyester and fiberglass reinforcement. **Figure 23** shows the dual-carrier mat with no fractures or denting.

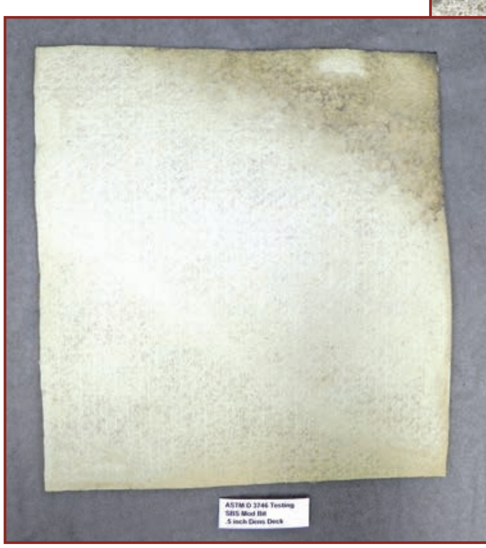


Figure 23. Dual-carrier mat with no fractures or denting.

The second ply was fiberglass asphalt felt. There were fractures in the fiberglass felt at all four missile drops on both the insulated and noninsulated samples. In should be noted that there was a depression at the area of impact in the gypsum cover board, which resulted in more tension in the bottom ply than the built-up samples on the wood testing table. **Figure 24** shows a fracture in the bottom ply (fiberglass felt) on the noninsulated sample. The fractures on the insulated samples were more pronounced than on the noninsulated samples.

The fractured felts occurring at the impact

Figure 24. Fracture in the bottom ply (fiberglass felt) on the noninsulated sample.

areas from our testing were with fractures occurring as a result of actual hail, and consistent with published literature.[8]

TEST RESULTS FROM AGED GRANULE-SURFACED SBS MODIFIED BITUMEN ROOF SAMPLE

Evaluation of Surfacing at Impact Area—Noninsulated Substrate

The aged modified bitumen sample was only tested over a noninsulated (wood) substrate. The exact age of the sample is unknown but is believed to be at least 10 years old. The test results related to surface damage to the granule-surfaced modified bitumen samples were similar to results for the noninsulated new modified bitumen sample, with the exception that there was some granule displacement at the point of impact on the aged sample. **Figure 25** shows the aged modified bitumen roof on the noninsulated substrate after the sample was impacted by the four missile drops.

Figure 25. Aged modified bitumen roof on the noninsulated substrate after the sample was impacted by the four missile drops.

Figure 26 shows a close-up of impact area 3. There are crushed granules similar to the crushed granules on the new modified bitumen sample on the firm substrate as well as some granule displacement not evident in the sample of the new roof.

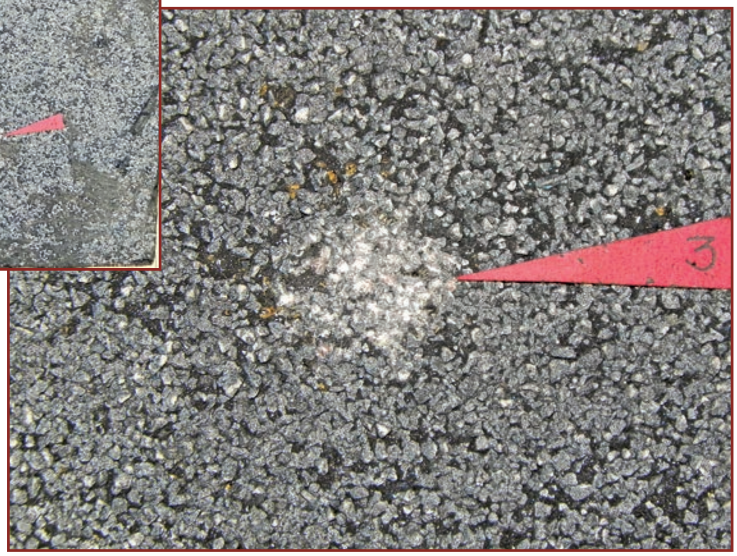


Figure 26. Close-up of impact area 3.

Figure 27 shows a 10-power view of impact area 3.

Figure 27. 10-power view of impact area 3.

Figure 28 shows a close up of impact area 4. There are crushed and displaced granules. Exposed reinforcement is also visible.

Figure 29 shows impact area 4 at 10-power. The area of impacts on the aged modified bitumen exhibited crushed granules and some displaced granules. It is possible that additional granule loss would occur over time if the sample were exposed to normal weathering.

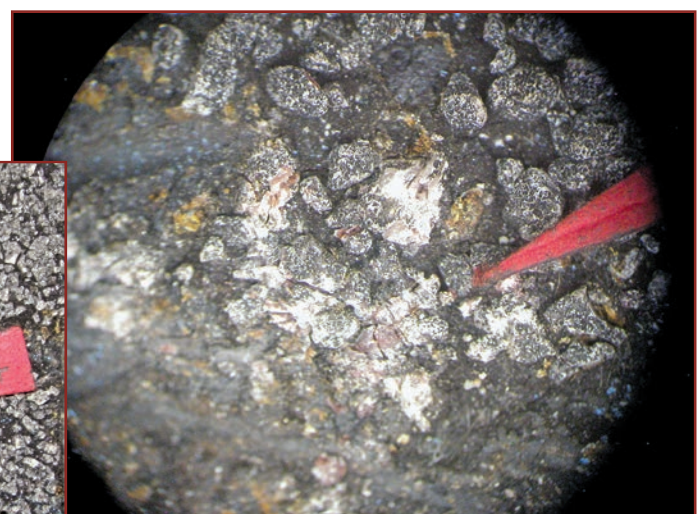


Figure 29. Impact area 4 at 10-power.

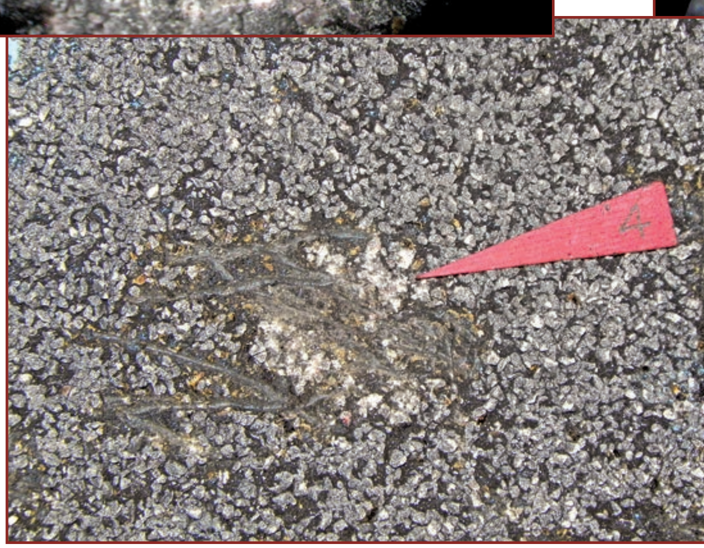


Figure 28. Close-up of impact area 4.

Figure 30. An example of localized granule loss on an aged modified bitumen roof.

Figure 31. A closer view of the hail-caused granule loss on the same project as Fig. 30.

We have observed localized granule loss at impacts from actual hail on aged modified bitumen roofs. **Figure 30** shows an example of localized granule loss on an aged modified bitumen roof. The pattern of granule loss was consistent with the random distribution of the large hail that fell and matched the pattern of the larger hail-caused impacts on the air-conditioning units and larger spatter marks.

Figure 31 shows a closer view of the hail-caused granule loss on the same project.

Figure 32 shows the impact at 10-power. There are visible fractures in the surface at the point of impact. Also, note that the surface of the exposed modified bitumen is relatively smooth. There is no evidence of shrinkage cracking or oxidized bitumen typically seen on older modified bitumen roofs.

Figure 33 shows a test sample from a modified bitumen roof with an area of localized granule loss at the point of interest noted. This type localized granule loss is also often confused with localized granule loss from hail impact. In some cases, a close examination of the area of granule loss will exhibit signs of weathering, as shown in Fig. 33, indicating that the granules loss occurred prior of the hail event.

Figure 34 shows a closer view of the point of interest. There is evidence of shrinkage cracking in the surface. There is localized granule loss in areas where the shrinkage cracking has converged. The point of interest is the largest area of localized granule loss visible on the sample.

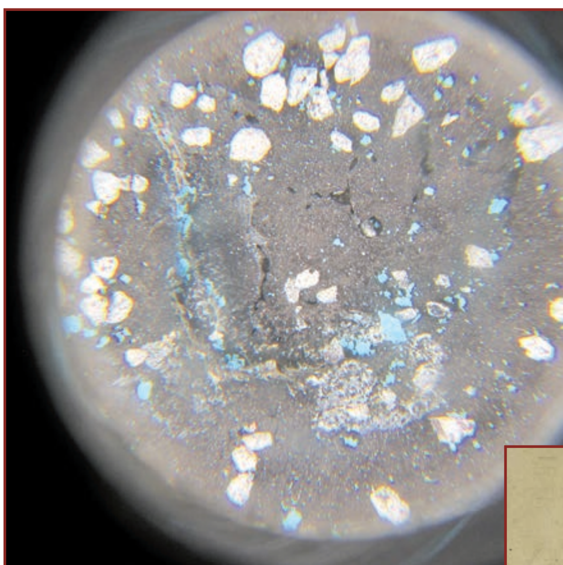


Figure 32. Impact at 10-power.

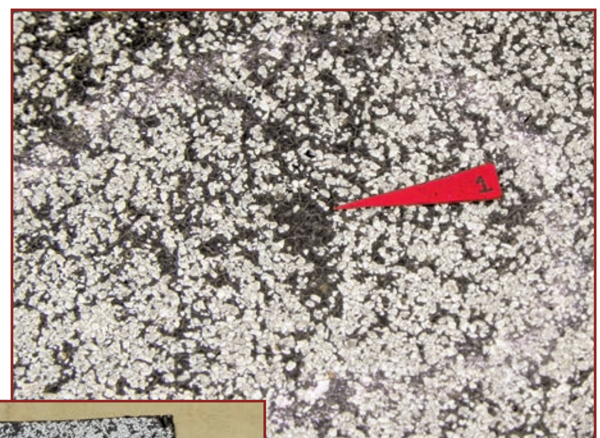


Figure 34. A closer view of the point of interest.

Figure 33. Test sample from a modified bitumen roof with an area of localized granule loss at the point of interest noted.

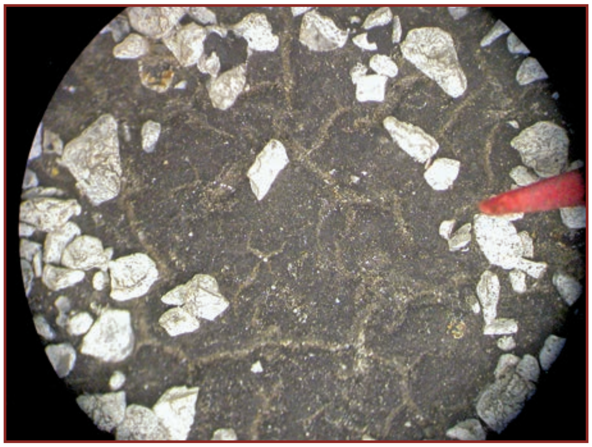


Figure 35. Point of interest at 10-power.

Figure 35 shows the point of interest at 10-power. The oxidized modified bitumen and shrinkage cracking in the modified bitumen surfacing are visible. There is no evidence of impact damage to the surface, and there were no fractures of crushed interply below the point of impact. There was no evidence of any other damage to the sample consistent with hail-caused impact. This type localized granule loss is often confused with granule loss from hail-caused impact.

Another type of localized granule loss is related to contaminants such as bird droppings. This type of localized area of granule loss tends to be in specific areas where birds congregate, as shown in **Fig. 36**. This type of localized granule loss is often confused with granule loss from hail-caused impact.

Figure 37 shows a closer view of granule loss of localized granule loss occurring as a result of contaminants from bird droppings.

Figure 38 shows the progression of granule loss occurring as a result of the bird droppings. Remnants of the bird droppings are visible. The granules typically continue to come off over time.

Figure 39 shows the progression of granule loss from small semicircular areas of granule loss to complete circular granule loss.

The surface damage occurring as a result of our impact testing of the granule-surfaced modified bitumen ranged from no displaced or crushed granules on the new modified bitumen on insulated (soft) substrate to crushed granules on firm substrates with no discernible granule loss. This is consistent with field observations on relatively new modified bitumen roofs that were impacted by large hail.

The aged modified bitumen sample tested on a firm substrate resulted in crushed granules and some displaced granules. The displaced granule loss observed on the aged sample tested was not as pronounced as observations of granule loss on aged modified bitumen roofs impacted by large hail. The age and degree of surface deterioration are likely contributing factors, as well as the angle of strike from actual hail.

Figure 36. Localized areas of granule loss tend to be in specific areas where birds congregate.

Figure 37. A closer view of granule loss of localized granule loss occurring as a result of contaminants from bird droppings.

Evaluation of Interply Bitumen—Noninsulated Samples

The interply bitumen was examined on the modified bitumen samples. Crushed interply bitumen was observed on the sample at all four areas of impact.

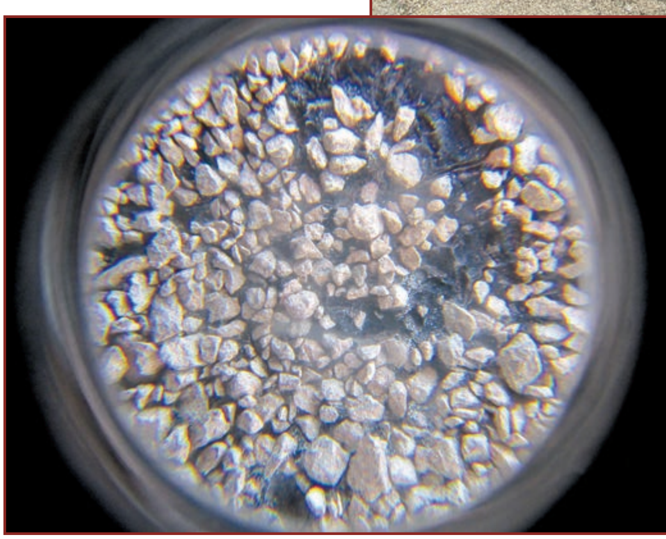


Figure 38. Progression of granule loss occurring as a result of the bird droppings.

Figure 39. Progression of granule loss from small semicircular areas of granule loss to complete circular granule loss.

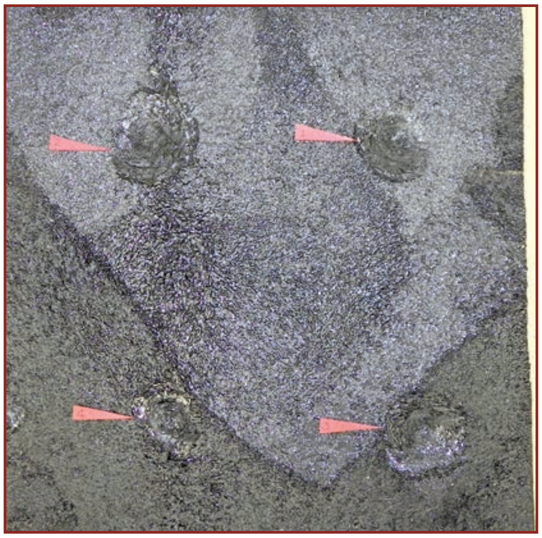


Figure 40. An example of crushed interply on the insulated sample.

Figure 41. Fractured bottom ply of the membrane.

Figure 40 shows an example of crushed interply on the insulated sample.

There was evidence of crushed interply in all of the areas of impact on the samples. The crushed interply bitumen occurring at each of the impact areas from our testing was consistent in appearance and was also consistent with crushed interply bitumen from actual hail observed in the field and laboratory.

Evaluation of Reinforcement—Noninsulated Substrate

The membrane was a fiberglass-reinforced modified bitumen installed over two plies of glass felt. There was no denting or fracturing of the modified bitumen reinforcement. There were fractures in the bottom ply at all four impact areas. **Figure 41** shows the fractured bottom ply of the membrane. The fractures were small and difficult to see without desaturating the felts.

The testing results of the aged modified bitumen sample were consistent with the testing of the new modified bitumen samples, with the exception that there was discernible granule displacement on the aged modified bitumen sample.

DISCUSSION

The use of highly magnified photographs of samples and particularly desaturated felts and reinforcements to demonstrate damage has become increasingly prevalent. By way of demonstration, We performed desaturation on a new roll of Type IV fiberglass felt. A 12 × 12 in. (305 × 305 mm) sample was removed and placed on a light table, illustrating the normal holes in the new felt, as shown in **Fig. 42**.

Figure 43 shows the portion of the felt in the red box (test area) of Fig. 42 at a magnification showing the normal holes in a typical fiberglass felt.

Figure 44 shows the desaturated test area. The individual fibers can be seen. We have seen an increasing number of this type of photograph, which is represented as evidence of hail-caused damage to bituminous roofs. The holes like the one circled in red are often represented as being the result of hail impact. Anomalies resulting from construction or maintenance damage are also often represented as evidence of hail-caused damage. It is important to distinguish normal surface anomalies and normal holes in felts from actual hail-caused impact damage.

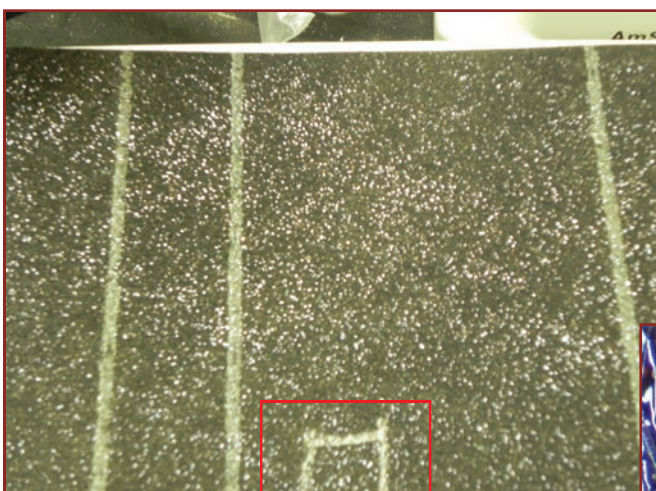


Figure 42. A 12 × 12 in. sample was removed and placed on a light table illustrating the normal holes in the new felt. Note: 1 in. = 25.4 mm.

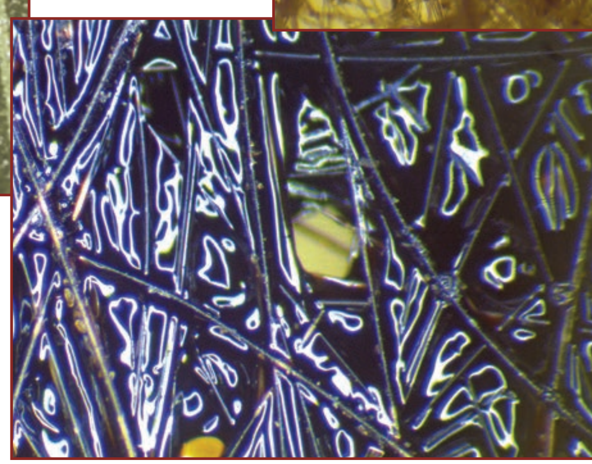


Figure 43. The portion of the felt shown in the red box (test area) of Fig. 42 taken at magnification showing the normal holes in a typical fiberglass felt.

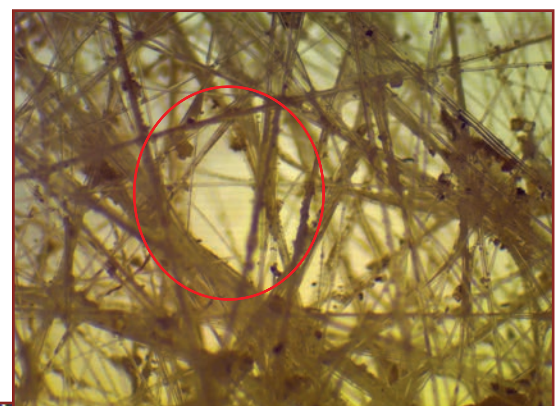


Figure 44. Desaturated test area.

CONCLUSION

The use of the assessment protocol in ASTM D3746[2] is an appropriate method for evaluating impact damage to the reinforcements of bituminous roofs. The assessment protocol in ASTM D3746 does not address impact to the surfacing of the sample or to the interply bitumen. The results of our testing utilizing ASTM D3746 impact testing protocol to simulate hail-caused impact damage provide a graphic example of what hail-caused damage looks like. The results of our testing were consistent with observations and testing of bituminous roofs that have been damaged by hail, are consistent with the research performed by Haag Engineering,[8] and are consistent with testing reports by others that we have reviewed over the years.

Hail-caused impact damage has a specific signature, as demonstrated by this testing, and the results of this testing provide a graphic comparative standard for hail-caused damage to bituminous roofs. The results of this testing provide a way to distinguish actual hail-caused damage to bituminous roofs from normal anomalies common on bituminous roofs, including construction traffic, maintenance traffic, and contaminants. Most bituminous roofs are resistant to 1.5 in. (38 mm) hail, and many are resistant to 2.0 in. (50 mm) or larger hail, so it takes large hail to damage this type of roof. We are continuing to research different types of roofing to provide standards for assessing hail-caused damage on various combinations of roofing.

There are a variety of testing standards that provide protocols for addressing hail-caused impact. Unfortunately, there is no specific ASTM test method for evaluating hail damage to existing roof systems. The lack of a specific standard has led to confusion in the industry and the use of widely varying in test methods for analyzing hail-caused impact damage. A new ASTM test standard that specifically addresses testing for hail-caused impact damage to existing roofs would help eliminate the confusion in the industry and provide more consistent testing and analysis.

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