# Testing of Impact-Resistant Asphalt Shingles

By Steven R. Smith, PE;
Timothy P. Marshall, PE;
and Jonathan S. Goode, PhD, PE

*Figure 2 – Bottom side of shingle opposite the bruise shown in Figure 1 (note fracture).*

*Figure 1 – Example of a hail-caused bruise looking down at the top of an asphalt shingle.*

## INTRODUCTION

Hailstorms cause billions of dollars in property damage annually in the United States,[1] and much of that damage is to roof coverings. Asphalt shingles (also known as composition shingles) are the most popular residential roofing product on the market for new construction and reroofing.[2] The popularity of asphalt shingles is largely due to their relatively low cost compared to other roofing products, ease of installation, and desirable appearance.[3] Asphalt shingles are manufactured in two common designs: multi-tab (typically 3-tab) or laminated (sometimes called architectural). Premium shingle designs are also becoming popular. Although asphalt shingles are common and popular, they are among the least hail-resistant roofing products available.[4]

Manufacturers have made improvements to asphalt shingles to increase their hail impact resistance. These improvements sometimes include modifying the asphalt with rubber compounds to increase shingle durability and flexibility. Some manufacturers have also increased shingle thicknesses and/or used stronger reinforcements to add strength. Some shingle designs have additional reinforcement on the bottom of the shingles to help resist high tensile stresses from hail impacts.

Test standards are available to demonstrate the impact resistance of roofing products. These test standards require the use of steel ball bearings or frozen solid ice spheres as projectiles. Both tests are designed to simulate the effects of impact forces from hail; however, the physical differences between impacting with steel balls versus ice balls can be significant. Both test methods are described in greater detail in the following sections.

An increasing number of impact-resistant roofing products are being marketed in hail-prone regions of the country. Tests performed on products are typically noted in product literature or on the packaging, including the hail impact test standards mentioned previously. Haag Research & Testing Co. (HRT) initiated a study of shingles with impact resistance ratings to gain additional information about these products and better understand their performance.

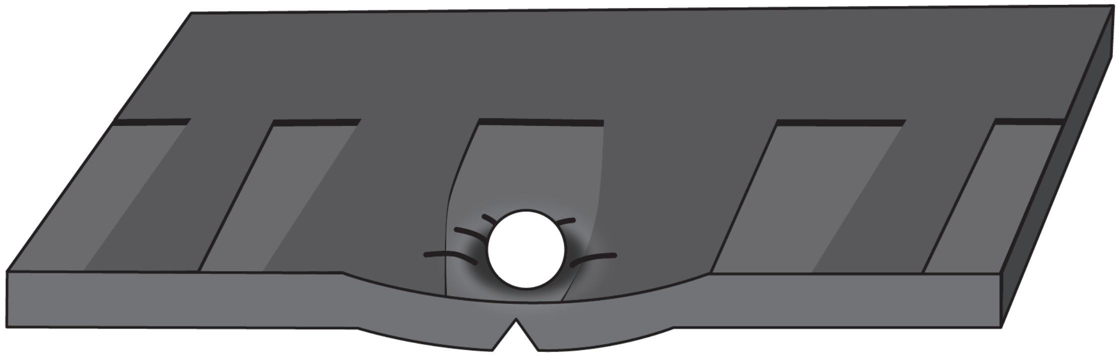


*Figure 3 – Illustration depicting the formation of a hail-caused bruise/fracture in an asphalt shingle.*

## HAIL-CAUSED DAMAGE

Hail damage to roofing is generally understood as a condition caused by hail that either reduces the water-shedding capability or the remaining service life of the roofing material.[4],[5],[6] These criteria do not address cosmetic effects, which are beyond the scope of this paper. Regarding asphalt shingles, hail-caused damage is typically a rupture in the mat material (reinforcement). Hail-caused ruptures in asphalt shingles are often described using other terms, including fractures, tears, or bruises. These terms are synonymous when discussing hail-caused damage and should not be confused as separate conditions. The term "bruise" came about because once the reinforcement is compromised by a hail impact, a relatively soft spot (similar to a soft bruise in an apple) can be felt manually during a roof inspection. Bruises in shingles not only can be felt by tactile examination, but they can also be observed visually on the bottom sides of shingles. Even slight bruises can allow water seepage and, over time, can lead to premature weathering at the bruise. Consequently, hail-caused bruises in shingles are considered damage because they compromise the ability of the shingle to shed water. A hail-caused bruise viewed on the top of an asphalt shingle is depicted in *Figure 1* and the bottom of the same shingle at the bruise in *Figure 2*.

Hail-caused fractures develop on the bottom sides of shingles because the shingles flex on impact. The flexure imparts a tensile stress on the bottom of the shingle, which can tear the reinforcement. Because most of the shingle strength is provided by the reinforcement, a bruise in a shingle means the reinforcement is fractured or substantially strained. *Figure 3* illustrates a hailstone impacting a shingle, causing a bruise/fracture.

## STEEL BALL IMPACT TESTING

In 1996, Underwriters Laboratories (UL) developed an impact testing protocol using four sizes of steel ball bearings dropped from various heights to develop kinetic energies of similar-sized hailstones at their free-fall velocities. The test protocol is called UL-2218,[7] and it is commonly used by roofing manufacturers to describe the hail resistance of their products. Products tested to UL-2218 are given impact resistance classifications from Class 1 to Class 4. A summary of the impact parameters is provided in *Table 1*.

The purpose of the testing is to determine the impact resistance of the product; thus, impacts are made at vulnerable regions, including corners, edges, unsupported areas, as well as at the well-supported regions of the shingle. The protocol also calls for two coincident impacts (defined as both impacts within ½ in. of each other) before the products are determined to have passed the test.

To pass the UL-2218 protocol and achieve a Class rating, roofing products cannot develop any tears, fractures, or cracks that extend through the product and are visible under 5X magnification. Cosmetic conditions resulting from the impacts, such as crushed granules or dents in the material, are permitted. For flexible roofing products able to be bent over a 4-in.-diameter mandrel (pipe), damage assessment is made by bending the product with the top surface in contact with the mandrel at each impact location with the product oriented in the machine and cross-machine directions.

| | Steel Ball Diameter | | Drop Height | | Kinetic Energy at Impact | |
|---|---|---|---|---|---|---|
| Class | (in) | (mm) | (ft) | (m) | (ft·lbf) | (J) |
| 1 | 1¼ | 31.8 | 12 | 3.7 | 3.53 | 4.78 |
| 2 | 1½ | 38.1 | 15 | 4.6 | 7.35 | 9.95 |
| 3 | 1¾ | 44.5 | 17 | 5.2 | 13.56 | 18.37 |
| 4 | 2 | 50.8 | 20 | 6.1 | 23.71 | 32.12 |

*Table 1 – UL-2218 impact parameters.*

## ICE BALL IMPACT TESTING

In 1998, insurance companies in Texas[8] started to provide discounts on insurance premiums if impact-resistant roofing products were installed. Products bearing the Class 4 UL-2218 rating were considered to be impact resistant, and these products qualified for monetary discounts. Other states have followed, offering discounts for installing impact-resistant shingles.[3]

One adverse effect of the UL-2218 steel ball testing protocol was that asphalt shingles appeared more hail resistant than other roofing products because some touted Class 4 ratings. Many rigid roofing products, such as concrete roofing tiles, heavy clay tiles, and roofing slates, for example, typically perform better than asphalt shingles in actual hailstorms, but they often cannot pass the UL-2218 test. Asphalt shingles have the ability to flex upon impact, which distributes the impact forces from a steel ball impact over a larger area, reducing the material stresses within the shingle. Rigid roofing materials cannot flex and, instead, tend to break when struck by a dropped steel ball bearing because the impact forces are concentrated over a very small area (a point load). High stresses generated within rigid materials associated with the point load cause them to break. For this reason, rigid roofing products rarely achieved better than a Class 1 or Class 2 UL-2218 rating.

For these reasons, an ice ball impact test protocol was developed by Factory Mutual called ANSI FM-4473.[9] The protocol was closely modeled after the UL-2218 standard, but it substituted propelled ice balls at free-fall speeds of like-sized hailstones instead of dropping steel ball bearings. Like UL-2218, vulnerable regions of roofing products are impacted twice within ½ in. of each other. Roofing products that do not develop damage can achieve a Class rating. Class ratings in ANSI FM-4473 mirror those in the UL-2218 protocol to minimize confusion. A summary of the target impact parameters for the ANSI FM-4473 protocol is provided in *Table 2*.

| | Ice Ball Diameter | | Mass | | Kinetic Energy at Impact | |
|---|---|---|---|---|---|---|
| **Class** | **(in)** | **(mm)** | **(lb)** | **(g)** | **(ft·lbf)** | **(J)** |
| 1 | 1¼ | 31.8 | 0.0338 | 15.3 | 3.72 | 5.0 |
| 2 | 1½ | 38.1 | 0.0584 | 26.5 | 7.77 | 10.4 |
| 3 | 1¾ | 44.5 | 0.0928 | 42.1 | 14.00 | 19.0 |
| 4 | 2 | 50.8 | 0.1385 | 62.9 | 26.13 | 32.2 |

*Table 2 – ANSI FM-4473 impact parameters.*

Note impact energies listed in *Tables 1* and *2* are very similar.

Ice ball impact testing more closely replicates the effects of hail than impacts from testing with steel ball bearings. This is because the momentum of a steel ball is substantially greater than that of an ice ball having the same kinetic energy. See *Equations 1 and 2.*

$$p = mv \text{ and } Ke = \tfrac{1}{2} mv^2$$

where
$p$ = momentum, $m$ = mass,
$v$ = velocity, and $Ke$ = kinetic energy

*Equations 1 and 2*

Steel balls weigh substantially more than ice balls of the same size. To achieve the kinetic energy of similar-sized hailstones, the steel balls dropped in UL-2218 testing, which are much heavier than hail, impact shingle test panels at significantly lower speeds than actual hail or the ice


*Figure 4 – Laminated shingle test panel.*

*Figure 5 – High-profile shingle test panel.*

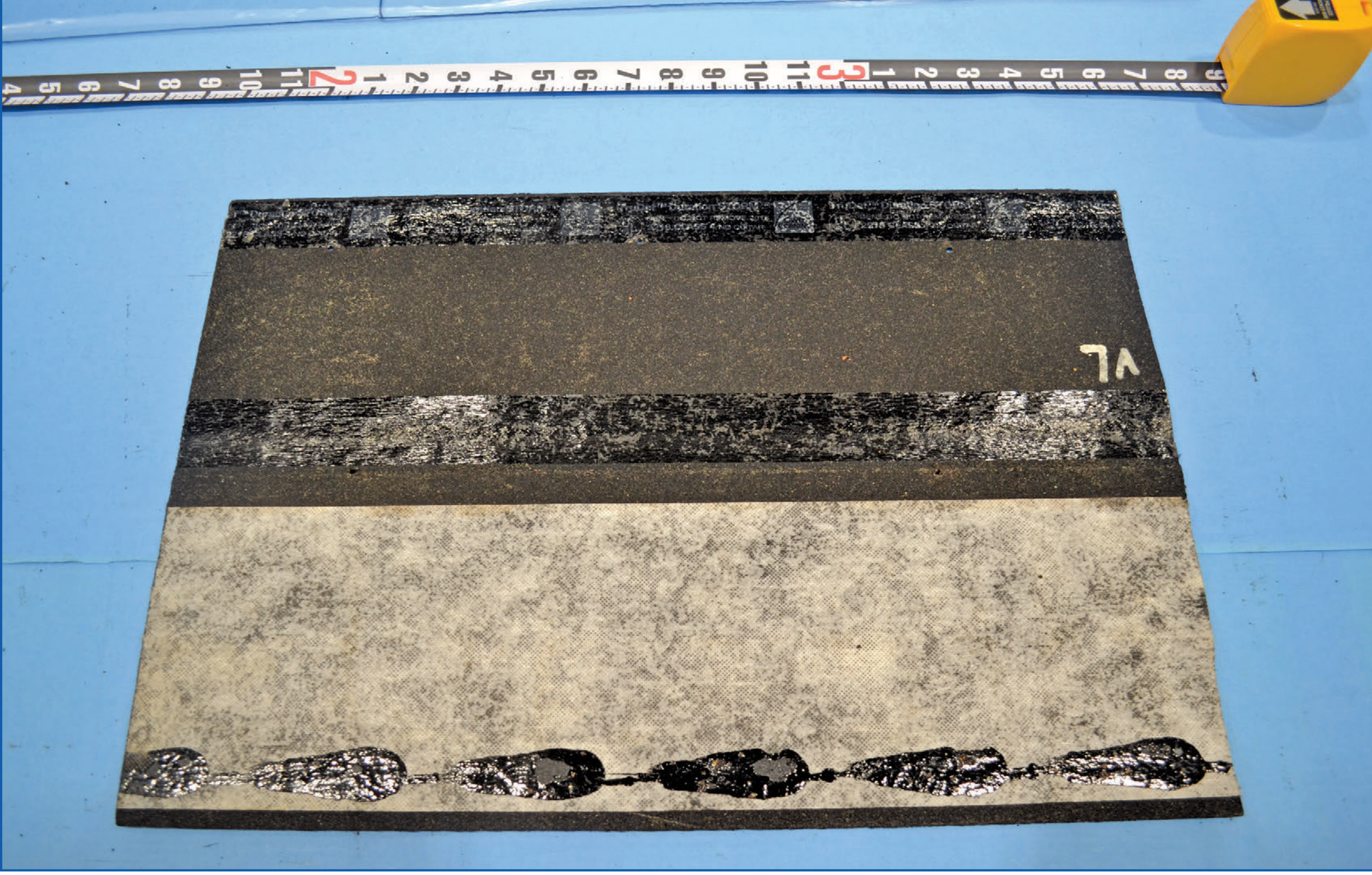


*Figure 6 – Reinforced backing on an impact-resistant asphalt shingle.*

balls propelled during ANSI FM-4473 testing. Thus, the UL-2218 test is considered an indexing test as it does not correspond to the same physics as a comparably sized hailstone.

## STUDY PARAMETERS

To study the impact resistance of heavyweight asphalt shingles, test panels were constructed for five different shingle designs from four different shingle manufacturers. All of the shingles were advertised as having UL-2218 class ratings, including four Class 4-rated shingles and one Class 3-rated shingle. None of the shingles were advertised as having been tested to ANSI FM-4473. Shingles on test panels were subjected to steel ball bearing drops in accordance with UL-2218, and duplicate panels were subjected to ice ball impacts following ANSI FM-4473. HRT is accredited by the International Accreditation Service (IAS) to perform both testing protocols and is listed as Testing Lab-656 by IAS.[10]

Upon completion of the impact testing, the shingles were examined for the pass/fail criteria listed in the standards. The reinforcements were also extracted via desaturation, which is not prescribed by either standard, but provides additional insight regarding the actual performance of the shingles. Extraction of reinforcements by use of solvent is prescribed in ASTM D3746, *Standard Test Method for Impact Resistance of Bituminous Roofing Systems,*[11] which uses a 2-in.-diameter, 5-lb. missile, dropped from a height of 53 in., onto asphalt built-up roofing, to determine the impact resistance. Desaturation in ASTM D3746 is prescribed to absolutely determine the condition of reinforcements at the tested locations. This is because the reinforcements can be examined for fractures or strains that may not be visible using surface examination techniques alone.

## TESTED SHINGLES

Two of the tested shingles were thick, high-profile designs. The other three were standard laminated shingle profiles. Four of the tested shingles had additional reinforcement backing on the bottom surfaces of the shingles to increase tensile strength. *Figures 4* through *6* depict typical test panels and typical reinforcement backing. One of the high-profile designs also featured asphalt modified with styrene-butadiene-styrene (SBS), a rubber compound that adds flexibility to the shingle. *Table 3* summarizes characteristics of the tested shingles. The identities of the products and shingle manufacturers were withheld from this paper.

| Shingle | Profile | Reinforced Backing | Modified Asphalt | Class Rating |
|---|---|---|---|---|
| 1 | High-profile | Yes | No | 4 |
| 2 | High-profile | Yes | Yes | 4 |
| 3 | Laminated | Yes | No | 4 |
| 4 | Laminated | Yes | No | 4 |
| 5 | Laminated | No | No | 3 |

*Table 3 – Tested shingle descriptions.*

Figure 7 – UL-2218 Class 4 double impact. Note crushed granules on top of the shingle.

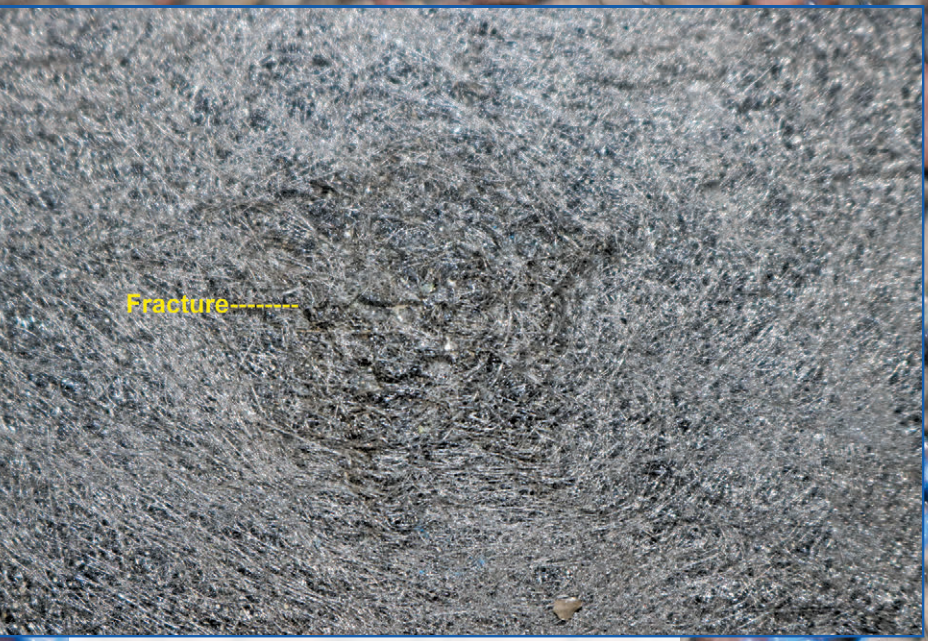



Figure 8 – Dent and apparent fracture on bottom of shingle at impact location. Note asphalt bleed-through.

## IMPACT TEST RESULTS

Initially, HRT planned to test each shingle listed in *Table 3* to the UL-2218 class rating noted by the manufacturer and perform ANSI FM-4473 ice ball impacts of the same ratings and then compare differences between the steel ball and ice ball impact test results. The impacted shingles were desaturated to determine the effects of the impacts on the reinforcements. The UL-2218 test results are provided in *Table 4*. Visual results were made in accordance with the UL-2218 and ANSI FM-4473 pass/fail criteria.

Shingles 2, 4, and 5 exhibited dents after UL-2218 testing. Although the UL-2218 discusses dents as “cosmetic damage,” hail-caused dents in asphalt shingles typically indicate fractures or substantial strains in the shingle reinforcements. The ANSI FM-4473 protocol does not discuss dents. In addition to dents, impacts against shingles with reinforced backing often exhibited asphalt bleed-through at impact locations (*Figure 8*). In many cases, the backing obstructed the view of the impacted area, making visual confirmation of fractures subjective. The shingles were desaturated after impact procedures to discern any fractures or strains in the reinforcements.

*Figures 7* through *10* depict a Class 4 shingle after a set of Class 4 UL-2218 tests. Recall that the test procedure requires double impacts. Note the crushed granules are a cosmetic condition of the testing and are not considered in the test results. Any fracture visible on the bottom of the shingle constitutes a test failure; however, many of the

| Shingle | Class Tested | Visual Result | Reinforcement |
|---|---|---|---|
| 1 | 4 | Fractured | Fractured |
| 2 | 4 | Dented [A] | Fractured |
| 3 | 4 | Fractured | Fractured |
| 4 | 4 | Dented [A] | Fractured |
| 5 | 3 | Dented [A] | Fractured |

Note: [A] = dents but no visually confirmed fractures.

*Table 4 – UL-2218 test results.*

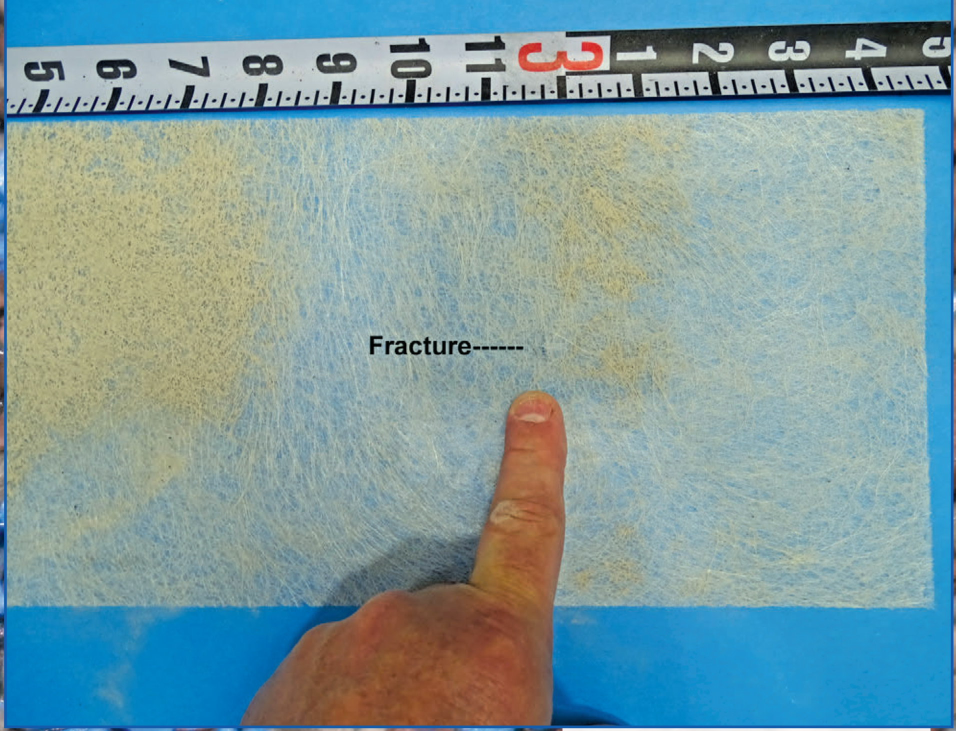



*Figure 9 – Desaturated shingle pointing to the impact location.*

*Figure 10 – Close-up of the fracture in reinforcement at the impact location.*

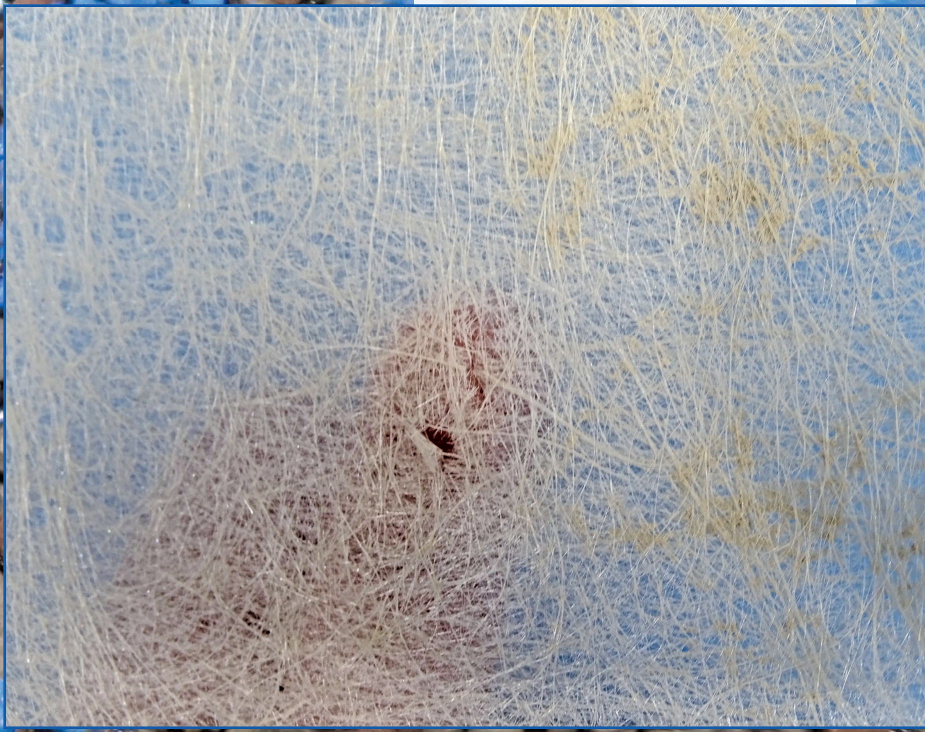


*Figure 12 – Fracture visible on bottom of shingle at impact shown in Figure 11.*

*Figure 11 – ANSI FM-4473 Class 2 double impact on a Class 3 shingle.*

shingles exhibited conditions that appeared to be fractures but could not be visually confirmed. Desaturation of the shingle revealed a fracture in the reinforcement, which would constitute hail damage in field inspection/evaluation.

*Figures 11* through *14* depict the Class 3 shingle after a set of Class 2 double impacts per the ANSI FM-4473 standard. Note the granules did not crush, but a clear fracture was detected on the bottom side of the shingle. Desaturation of the shingle revealed a fracture in the reinforcement at the impact location.

All of the tested shingles exhibited at least some visible dents or fractures after impact testing following both testing protocols, and all exhibited fractures in their reinforcements after desaturation. For this reason, the scope of testing was expanded such that each shingle was tested at lower class levels until a rating could be achieved. It is important to note the energy level of a Class 3 impact is nearly two-thirds that of a Class 4 impact, and a Class 2 impact has about half the energy of a Class 3 impact. Consequently, there is a significant difference between each class level, and slight differences between testing laboratories should not result in significantly different outcomes.

*Table 5* lists the highest class levels that each of the shingles passed after additional UL-2218 testing, and *Table 6* lists the highest class levels that each of the shingles passed after ANSI FM-4473 testing. Note, due to the design of the high-profile and laminated shingles tested in this study, the shingles could not be bent over the mandrel as prescribed by UL-2218 without damaging shingles during examination.

Only two of the tested shingles achieved UL-2218 class ratings, and one shingle achieved an ANSI FM-4473 class rating; however, the shingle reinforcements were found to be ruptured after desaturation at all classes on both tests. Shingles 2 and 3 only passed because dents in shingles are not addressed as failures in the testing protocols. Impact fractures in the bottom surfaces of most shingle designs are readily visible, but the presence of the reinforcement backing on most of the shingles tested in this study obstructed the view of the impact locations. The pass/fail criteria in the standards address only visual conditions, and the reinforcement backing on the bottom prevented visual detection of the fractures, giving misleading indications of their actual performance.

| Shingle | Highest Class Passed | Reinforcement |
|---|---|---|
| 1 | DNP | DNP |
| 2 | 4 [A] | DNP |
| 3 | 4 [A] | DNP |
| 4 | DNP | DNP |
| 5 | DNP | DNP |

Note: DNP = Did not pass any class. [A] = dents but no visually confirmed fractures.

*Table 5 – UL-2218 Class determinations.*

| Shingle | Highest Class Passed | Reinforcement |
|---|---|---|
| 1 | DNP | DNP |
| 2 | 3 [A] | DNP |
| 3 | DNP | DNP |
| 4 | DNP | DNP |
| 5 | DNP | DNP |

Note: DNP = Did not pass any class. [A] = dents but no visually confirmed fractures.

*Table 6 – ANSI FM-4473 Class determinations.*

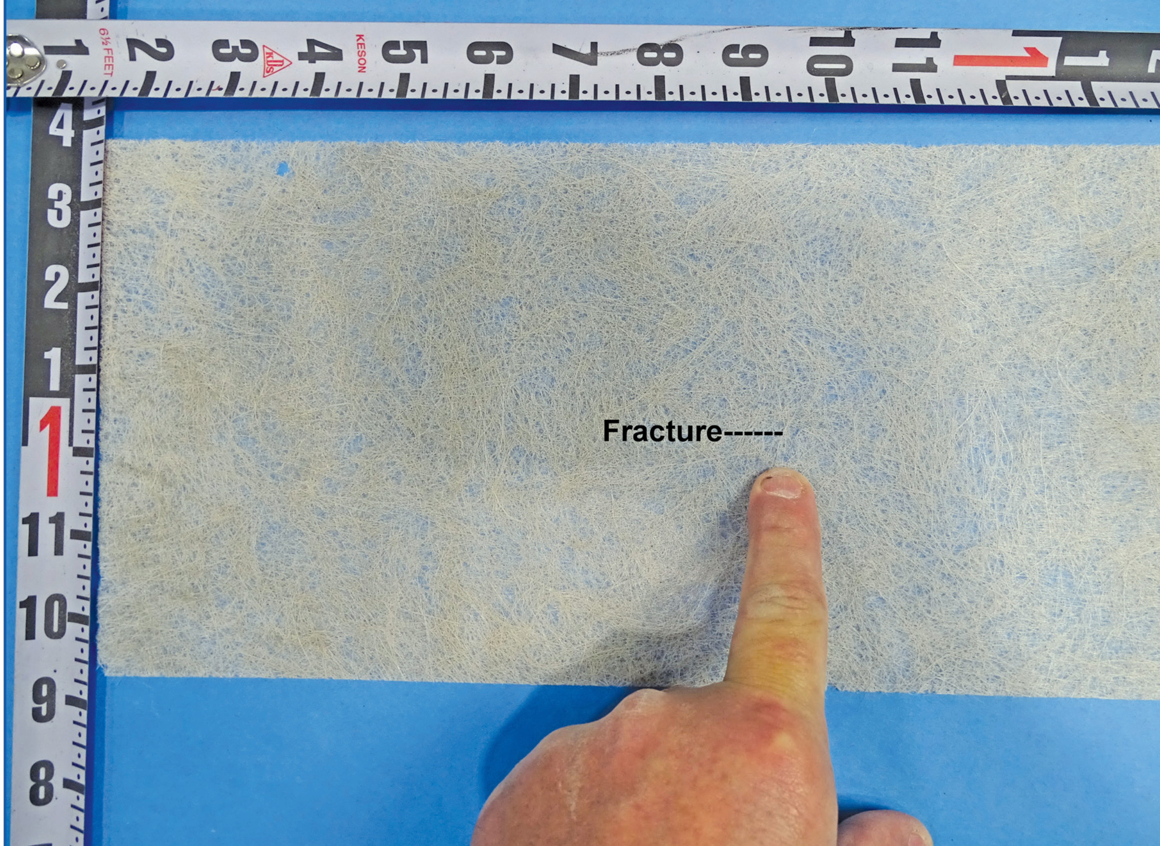
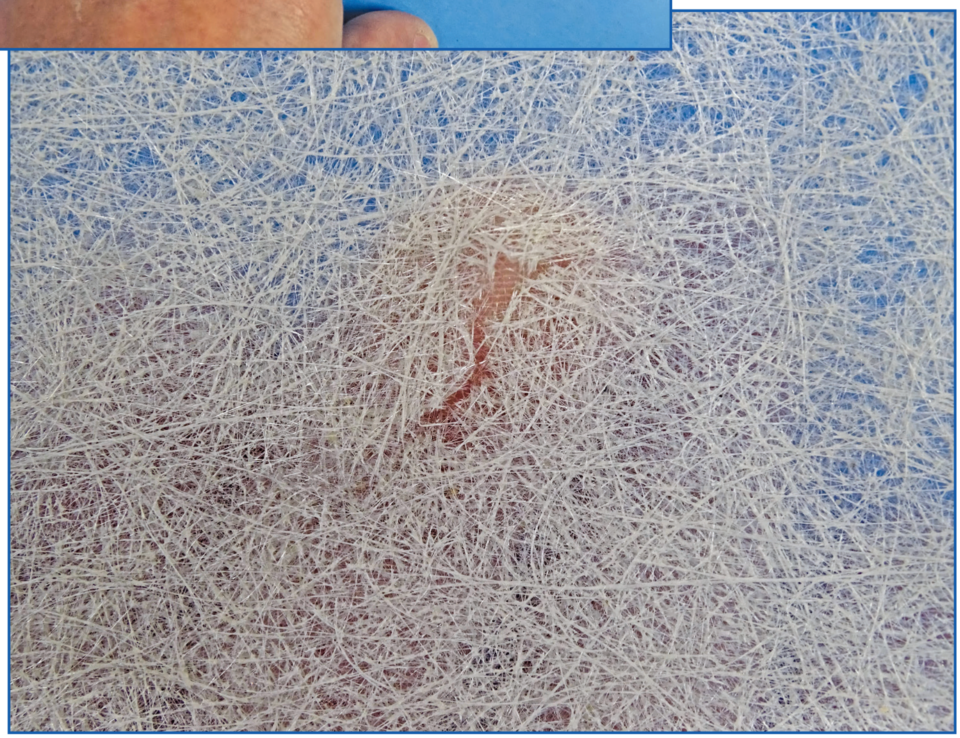



*Figure 13 – Desaturated Class 3 shingle showing fractured reinforcement.*

*Figure 14 – Close-up of fracture in reinforcement shown in Figure 13.*



Laboratory testing and countless field inspections have shown that non-impact-resistant laminated shingles can be damaged by hard hailstones measuring at least 1¼ inches in diameter.[4] Since shingle reinforcements were found to be ruptured after desaturation at all classes on both tests, none of the five shingle designs tested in this study exceeded the typical performance of standard laminated asphalt shingles. For reference, frozen solid hailstones are more damaging to roofing than softer, lower-density hailstones. The ice balls specified by ANSI FM-4473 replicate hard, frozen solid hail by maintaining the ice balls at 0 ± 7°F and ensuring the ice balls are free of cracks and air bubbles.

## SUMMARY

Two of the five tested shingles performed as well as their product literature stated, but only because the pass/fail criteria in the standards do not require examination of the shingle reinforcements using solvent desaturation procedures. Some fractures in the bottom sides of shingles at impact locations were hidden from view due to the reinforced backing applied to the shingles. The presence of the reinforced backing gave the shingles artificially high impact ratings because the shingle damage was hidden by the backing layer.

Extraction of shingle reinforcements using solvent desaturation procedures will allow the testing laboratory to determine whether the shingle reinforcements were fractured during impact testing. This procedure is commonly performed by roofing test laboratories in response to actual hail events because industry professionals—including contractors, insurance adjusters, engineers, and roof consultants—need to know whether the roofing in question was damaged by hail to accurately assess the roof condition that is the subject of a hail claim or litigation. The authors of this report are engineers who frequently perform hail damage evaluations of residential and commercial roofs; as part of their examinations, they often provide roofing samples to HRT for this analysis in order to develop fully informed opinions. Since these procedures are well established for hail damage analysis on in-service roofing, the procedures can also be performed on product testing, including UL-2218 and ANSI FM-4473.

This research project was limited in scope to five impact-resistant shingle designs produced by four different manufacturers. The results are not intended to reflect every impact-resistant shingle on the market; nevertheless, the shingles studied in this paper were selected to cover a wide range of designs, including designs with and without reinforced backing, high-profile and traditional designs, and standard asphalt or modified asphalt.

Ice ball impact testing per ANSI FM-4473 replicates hail impacts to roof coverings better than steel ball impact testing due to the physical differences between steel and ice. Although this paper did not delve into the sizes of the fractures in sample reinforcements, the products tested in this study exhibited larger and more frequent fractures when impacted by ice balls than the same class size steel balls. Consequently, impact ratings achieved during steel ball testing can artificially make asphalt shingles appear more hail-resistant.

Inspection techniques in both the UL-2218 steel ball drop protocol and the ANSI FM-4473 ice ball impact protocol do not adequately examine asphalt shingles for impact-caused damage because the reinforcements could sustain damage not visible using the inspection techniques specified in the standards—especially on product designs that include reinforcement backing on the bottom of the shingles. The standards also do not address the fact that dents in asphalt shingles likely indicate strains or ruptures in the product reinforcements.

## RECOMMENDATIONS

Based on the results of this testing, we recommend the UL-2218 and ANSI FM-4473 test standards be modified to include solvent extraction of reinforcements when testing asphalt shingles to absolutely determine whether the products have been damaged during testing. This step would prevent asphalt shingles from appearing more hail-impact-resistant than they actually are.

Based on the results of the testing, shingle manufacturers might consider incorporating stronger reinforcements in the design of impact-resistant asphalt shingles.

## ACKNOWLEDGEMENT

Special thanks to Allen Swan and Cory Hurtubise (HRT technicians) for performing the testing on this project.

## REFERENCES

1. "Facts + Statistics: Hail." Insurance Information Institute. Accessed Dec. 9, 2019. www.iii.org/fact-statistic/facts-statistics-hail.
2. "2015-16 Market Survey." National Roofing Contractors Association (NRCA). 2016. p. 2.
3. Greg Malarkey. "The History of Asphalt Shingles." *Interface*. International Institute of Building Enclosure Consultants (IIBEC). April 2001. pp. 5-9.
4. Timothy Marshall, PE; Richard Herzog, PE; Scott Morrison, PE; and Steven Smith, PE. "Hail Damage Threshold Sizes for Common Roofing Materials." *21st Conference on Severe Local Storms*. San Antonio, TX. August 2002. p. 3.2.
5. Timothy Marshall, PE; Richard Herzog, PE; and Scott Morrison, PE. "Hail Damage to Asphalt Roof Shingles." *Proceedings of the North American Conference on Roofing Technology*. Toronto, Canada. 1999. p. 9.4.

6. Scott Morrison, PE. "Long-Term Effects of Hail Impact on Asphalt Shingles – an Interim Report." *Proceedings of the North American Conference on Roofing Technology*. Toronto, Canada. 1999. pp. 30-39.
7. Underwriters Laboratories. "*UL-2218 Impact Resistance of Prepared Roof Covering Materials - Second Edition*." January 2010.
8. Terry Binion. "Let it Hail, Let it Hail, Let it Hail." *Insurance Journal*. April 7, 2003. https://www.insurancejournal.com/magazines/mag-features/2003/04/07/28144.htm.
9. American National Standards Institute/Factory Mutual Approvals. ANSI FM-4473, *Test Standard for Impact Resistance Testing of Rigid Roofing Materials by Impacting with Freezer Ice Balls - Second Edition*. January 2011.
10. *Testing Laboratories*. International Accreditation Service. IAS. https://www.iasonline.org/services/testing-laboratories.
11. ASTM International. ASTM D3746, *Standard Test Method for Impact Resistance of Bituminous Roofing Systems*. 2015.



Steven R. Smith, PE

*Steven Smith graduated from the University of Texas at Arlington with a BS in mechanical engineering. He is licensed as a professional engineer in six states. Smith has been with Haag Engineering since 1998 and is the director of Haag Research & Testing Co. He has inspected over 1,000 roofs for hail- and wind-caused damage and began his career with Haag in the testing laboratory. He is a member of the American Society of Mechanical Engineers, the National Roofing Contractors Association, and the Asphalt Roofing Manufacturers Association.*

Timothy P. Marshall, PE

*Timothy Marshall graduated from Northern Illinois University with a BS in meteorology and Texas Tech University with master's degrees in atmospheric science and civil engineering. He is a licensed professional engineer who has been employed at Haag Engineering since 1983. An avid speaker and publisher of scientific papers, Marshall is a member of the American Society of Civil Engineers and currently serves as subchair of its Wind Speed Estimation in Tornadoes Committee. He is also a member of the American Meteorological Society and National Weather Association.*

Jonathan S. Goode, PhD, PE

*Jonathan Goode holds BS, MS, and PhD degrees in agricultural and civil engineering from the University of Georgia, the University of Colorado at Boulder, and Colorado State University. He is a licensed professional engineer in 17 states and was an assistant professor at Oklahoma State University prior to coming to Haag Engineering in 2010. Dr. Goode is a member of the American Society of Civil Engineers and serves on its Committee on Forensic Practices.*


## Living Wall as Art

Urban Ecotones, an interior living wall installation in Oakland, CA, in 2019 became the first living wall to meet the requirements of public art status by a U.S. city. The wall, by David Brenner, founder and principal of Habitat Horticulture, is a 19- x 34-ft. living wall at 601 City Center that is now a part of the city's permanent public art collection. It features more than 25 colorful plant species. The 600,000-sq.-ft. commercial building is in the heart of Oakland. Brenner was also officially recognized as an artist by the San Francisco Museum of Modern Art for "The Living Wall," the largest such installation currently in the U.S.

In 2014, the city adopted a requirement that 1 percent of nonresidential private development project costs be allocated "for freely accessible public art on site, or within the public right of way."