IBHS
Impact Resistance Test Protocol for Asphalt Shingles

CONTENTS

INTRODUCTION

1. Purpose

1.1. The purpose of this test method is to provide a methodology using best-available science to allow for differentiation of product performance for the hail impact-resistance of new asphalt shingles.

2. Scope

2.1. This test method provides a laboratory procedure to evaluate the impact resistance of prepared assemblies of asphalt shingles as small units in overlapping rows normally on inclines of 2:12 pitch or greater. The purpose of this method is to determine relative performance of the subject asphalt shingles, and their potential performance when exposed to hailstorms. It is not intended to be used in adjusting claims, underwriting, or to establish legal standards of care or performance.

2.2. This test method evaluates the performance of new asphalt shingles that have been processed through the relevant distribution chain.

2.3. This test method defines construction, application, storage, and testing requirements for test sample assemblies for flat field application of shingles. Testing for hip and ridge shingles, vents, or non-flat roof surfaces such as valleys are outside the scope of this test method.

2.4. This test method defines a procedure for evaluating and reporting the performance of the samples.

2.5. This test method evaluates the effect of impacts from specific types of ice spheres at specific locations on the test sample assemblies.

2.6. The characteristics of ice spheres (density, strength) used in this test method shall match ranges of natural hailstone characteristics as outlined in Section 7.1. Tolerances of variation are prescribed for each value.

Ice spheres shall be propelled at the velocities necessary to achieve average kinetic energies for a natural hailstone of the same maximum diameter. This protocol requires higher mass spheres be propelled at lower impact velocities to achieve proper impact kinetic energies.

2.7. This test method evaluates physical damage to the subject asphalt shingles including, but not limited to, granule loss as a result of hail impact.

2.8. The requirements of this test protocol are based on experimental testing, field data, and research and development initiatives. Many components and specifications from existing test standards of other organizations were adapted and followed. Information provided by insurance professionals, testing laboratories, and roofing professionals has also been considered.

2.9. Effects of weathering, temperature, aging, product variability, roof system configuration and application, or similar effects are outside the scope of this test method.

2.10. Impact performance tested under this method will not guarantee the same performance results when field-installed asphalt shingle roofs are impacted by hailstones. Consequently, this test method does not provide a direct basis to compare expected performance under all hail conditions but does provide a basis for relative comparison of the response of asphalt shingles when subjected to the impact energies and ice sphere characteristics described herein.

2.11. This test method, the damage states, quantities, or categories described herein, are not appropriate for use outside of the laboratory method and analysis, meaning they are not intended for use in the adjustment of insurance claims or inspection operations.

3. Definitions

3.1. Mass—a measure of the amount of matter in an object. Mass (*m*) is measured in grams (g) using a scale or balance.

3.2. Diameter—a straight line passing through the center of a circle or sphere and meeting the circumference at each end. Diameter (*d*) is measured in millimeters (mm) using calipers and converted to centimeters (cm).

3.3. Peak compressive force—the measured compressive load at the time the ice sphere fractured (F_o) such that no portion of the sphere could support a higher compressive load. F_o is measured in Newtons using a Universal Test Machine (UTM) at a sampling rate of 25 Hz.

3.4. Compressive stress (σ_c)—uniaxial compressive strength of an ice sphere at a defined compression strain rate of 10^{-1} s^{-1} calculated by: $\sigma_c = \frac{F_o}{A}$, where F_o is the maximum compressive force and A is the cross-sectional area of the ice sphere along the plane in which the compression force is applied. The compressive stress is required for comparisons to natural hailstones, to ensure ice spheres simulate the impact mechanics of natural hailstones.

3.5. Impact kinetic energy (KE)—the energy of the propelled ice sphere at impact, where $KE = \frac{1}{2} mv^2$, where m is the mass and v is the propulsion velocity (speed) of the ice sphere. Kinetic energy is calculated in Joules. Care shall be taken to ensure the propulsion velocity is adjusted when mass values differ between ice spheres, to ensure the proper impact kinetic energy is achieved.

3.6. Freezer—a controllable appliance that can reach temperatures below 0°C and is used to store ice spheres needed for testing.

3.7. Balance—device used for measuring the mass of ice spheres, accurate within 0.01 g.

3.8. Caliper—device used for measuring the diameter of the ice spheres, accurate within 0.01 mm.

3.9. Universal Test Machine (UTM)—machine used for testing the tensile strength and compressive strength of materials, using standard or custom test methods.

3.10. Test decks—the lumber frame and plywood substrate, built from typical materials using typical installation methods, to which the roofing materials are applied. This term refers to the unprepared (no shingles or underlayment applied) lumber components.

3.11. Test sample assemblies—the completed application where the underlayment and asphalt shingle material has been applied to the test deck per the manufacturer's installation instructions.

3.12. Propulsion system—device or system that propels ice spheres at speeds necessary to achieve the required kinetic energy. Targeting accuracy of the system must be sufficient to ensure the ice spheres strike the required impact areas.

3.13. Radar gun—the device to measure the velocity of the projected ice spheres within ± 1.3 m/s.

3.14. Chronograph—photogate-based device to measure the velocity of projected ice spheres within ± 1.3 m/s.

3.15. LIDAR—laser-based detection system that uses light to measure velocity of projected ice spheres within ± 1.3 m/s.

3.16. Impact Mode—a description of the visually determined physical response of the ice sphere upon impact with the test sample assembly. These Impact Modes influence the Damage Modes and Severities.

3.16.1. Soft—Impact Mode whereby the ice sphere breaks into a few or many fragments (Figure 3.16.1-1) and leaves a slushy residue (Figure 3.16.1-2) on the test sample assembly larger than 18 mm for class 1.5 impacts and larger than 24 mm for class 2.0 impacts.

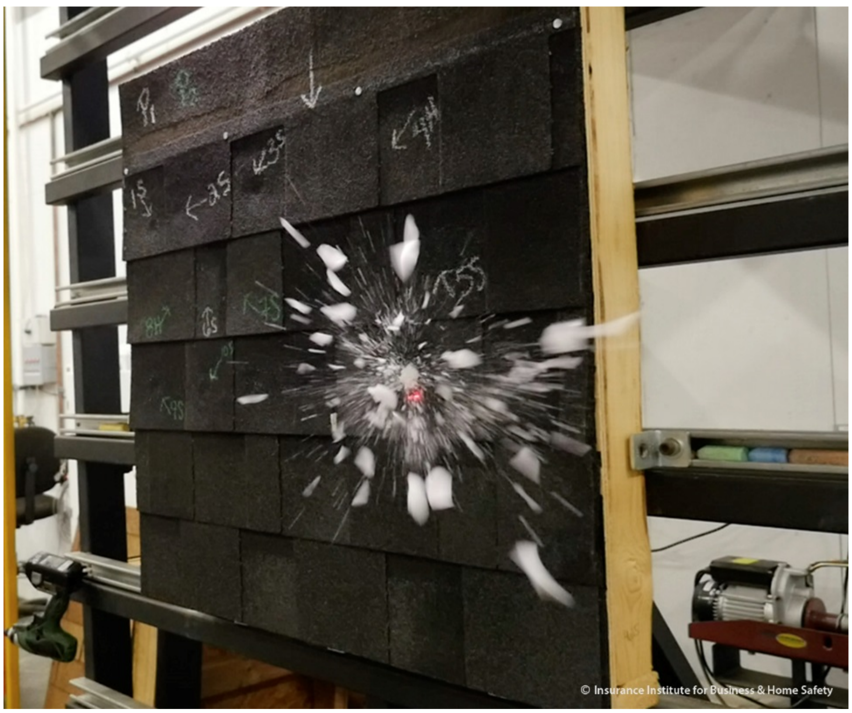

Figure 3.16.1-1. Soft Impact Mode ice spheres will break into many fragments upon impact with the test sample assembly.

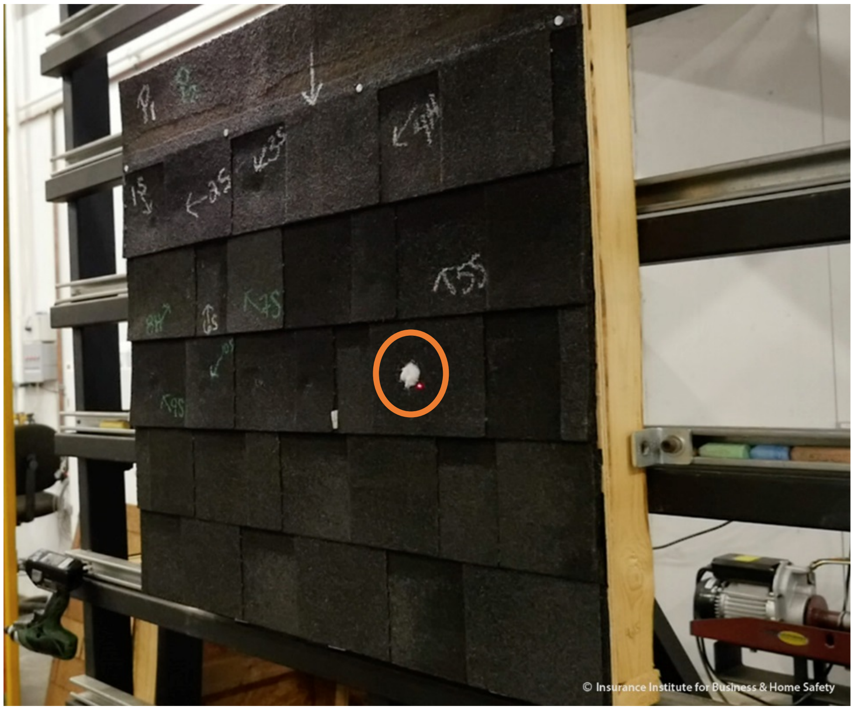

Figure 3.16.1-2. Soft Impact Mode ice spheres will leave a slushy residue (larger than 18 mm for class 1.5 impacts and larger than 24 mm for class 2.0 impacts) on the test sample assembly upon impact.

3.16.2. Hard shatter—Impact Mode whereby the ice sphere breaks into many fragments (Figure 3.16.2-1) and may or may not leave a slushy residue (Figure 3.16.2-2) on the test sample assembly. Slushy residue shall be smaller than 18 mm for class 1.5 impacts and smaller than 24 mm for class 2.0 impacts.

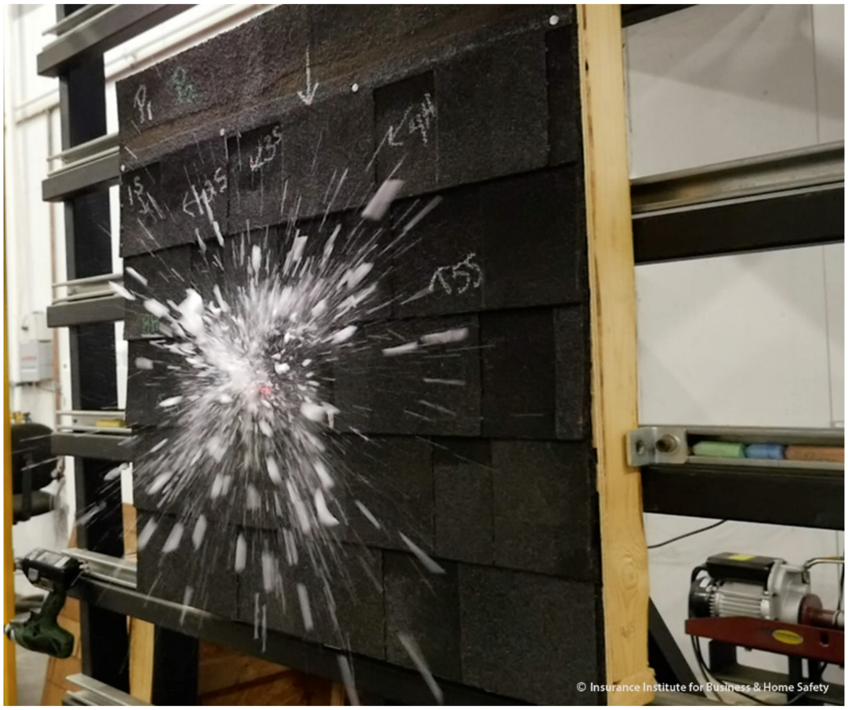

Figure 3.16.2-1. Hard shatter Impact Mode ice spheres will break into many fragments upon impact with the test sample assembly.

Figure 3.16.2-2. Hard shatter Impact Mode ice spheres may or may not leave a slushy residue (smaller than 18 mm for class 1.5 impacts and smaller than 24 mm for class 2.0 impacts) on the test assembly upon impact.

3.16.3. Hard bounce—Impact Mode whereby the ice sphere remains whole, does not shatter (Figure 3.16.3-1), and does not leave a slushy residue (Figure 3.16.3-2) on the test sample assembly. A sufficient portion of the sphere shall remain intact such that it could be tested under compression using standard laboratory equipment (i.e., UTM).

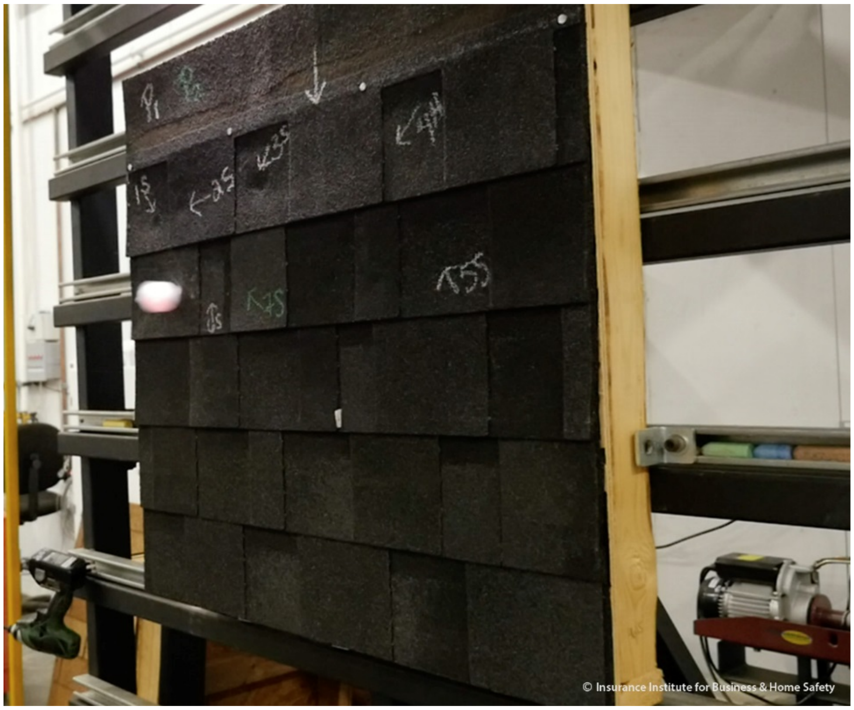

Figure 3.16.3-1. Hard bounce Impact Mode ice spheres will not break upon impact with the test sample assembly and will bounce back as a single piece.

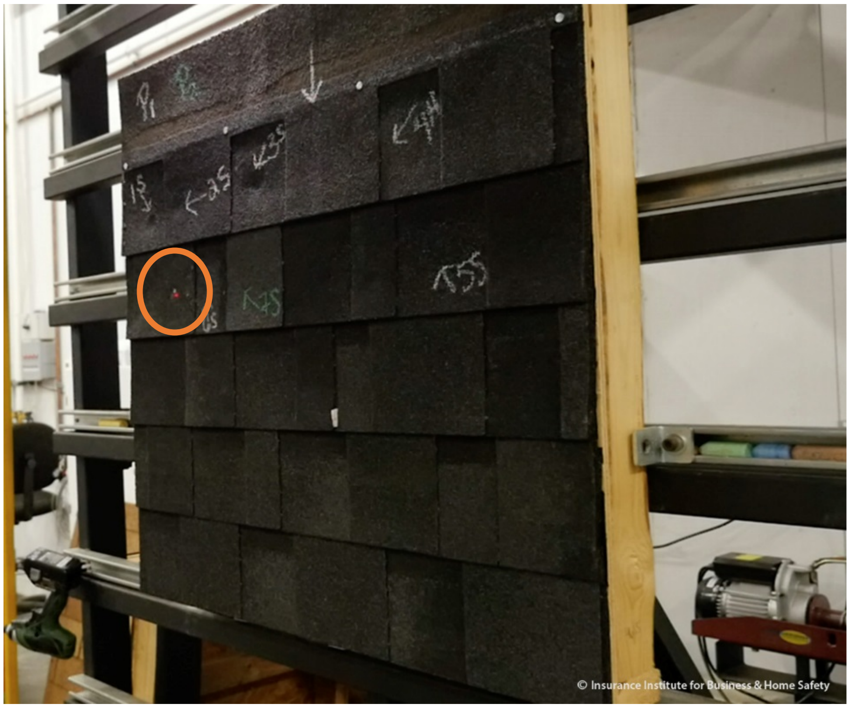

Figure 3.16.3-2. Hard bounce Impact Mode ice spheres will not leave a slushy residue on the test assembly upon impact.

3.17. IBHS-Nemesis Impact Damage Evaluation Tool—an image-processing-based web application that uses custom algorithms to measure quantities of specific damage types based on 3-dimensional (3D) representations.

3.18. Damage Mode—the nature of the physical changes that occur to the shingle following impact. There are five defined Damage Modes.

3.18.1. Deformation (DN)—3D alterations of the shape of the shingle, quantified by volume, measured by the IBHS-Nemesis Impact Damage Evaluation Tool.

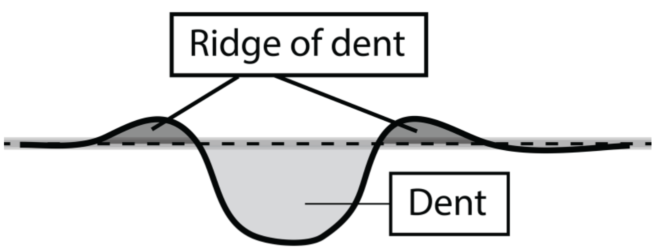

Figure 3.18-1. The negative local deformation caused by a dent and the positive local deformation at the ridge of dent.

3.18.1.1. Dent (DT)—negative local deformation where volume is compressed below the flat shingle plane (displaces downward from shingle surface; Figure 3.18-1).

3.18.1.2. Ridge of Dent (RD)—positive local deformation where volume is raised above the flat shingle plane (displaces upward from shingle surface; Figure 3.18-1).

3.18.2. Granule Loss (GL)—2-dimensional (2D) loss of one or more granules covering the shingle, quantified by area measured by the IBHS-Nemesis Impact Damage Evaluation Tool.

3.18.2.1. Patch Granule Loss (PGL)—clusters of granules missing that result in exposed asphalt and/or fibers (Figure 3.18.2.1-1).

Figure 3.18.2.1-1. Example photograph of patch granule loss.

3.18.2.2. Individual Granule Loss (IGL)—single or many granules missing that are not clustered (Figure 3.18.2.2-1).

Figure 3.18.2.2-1. Example photograph of individual granule loss.

3.18.3. Breach (BH)—1-dimensional (1D) damage caused by a tear, rupture, or crack (Figure 3.18.3-1); quantified by expert judgement by Severity Level.

Figure 3.18.3-1. Example photograph of breach.

3.19. Severity Level—a 0–3 numerical classification of each Damage Mode for each individual impact, based on specific quantities outlined in Table 9.3.

3.20. Severity Score—a 0–3 numerical classification, which represents deformations and granule loss for each individual impact as outlined in Table 9.3 and Sections 9.4.2 and 9.4.3. For breach, the Severity Score is equal to the Severity Level for each individual impact as outlined in Table 9.3 and Section 9.4.1.

3.21. Individual Impact Severity Score—the average condition for an individual impact, determined by averaging the Severity Score for deformations, granule loss, and breach.

3.22. Performance Evaluation Rating—a performance rating in accordance with this test method that is determined from all impacts in the full test sample, as outlined in Section 9.6 and Table 9.6.

PERFORMANCE

4. Procurement of Shingle Samples

4.1. Representative samples of asphalt shingles shall be obtained through the normal distribution chain for that product and fastened to test decks as described in Section 5.4

In accordance with ASTM D228 Section 7, samples selected for installation and testing shall be free from visual indications of damage due to shipping and handling of the material in the distribution chain. This shall include, but not be limited to: torn shingles, removed packaging, large indentations, and scrapes.

4.2. Date codes and other identifying information shall be checked and recorded to ensure products are less than 24 months from the date of manufacture at the time they are tested.

5. Preparation of Test Sample Assemblies

5.1. Fastening—all fasteners used to assemble test decks, or to apply underlayment or shingles, shall be driven straight and flush, not under- or over-driven or driven at an angle.

5.2. Preparation of test decks

5.2.1. The test decks shall be 3 ft by 3 ft and fabricated as shown in Figures 5.2.1-1 and 5.2.1-2. The center vertical support piece which is midspan of the deck is referred to as the “midspan support brace.” A/C grade plywood shall be installed with the “A” side facing up. The plywood shall be cut and installed such that the edges are flush with the frame. The plywood shall be fastened using nails or screws with spacing at a maximum of 6 in. on center (o.c.), equally spaced along the outer frame and midspan support brace.

ITEM NO.	DESCRIPTION	LENGTH	QTY.
1	2"x4"	33"	3
2	2"x4"	36"	2
3	15/32" A/C plywood	36" x 36"	1

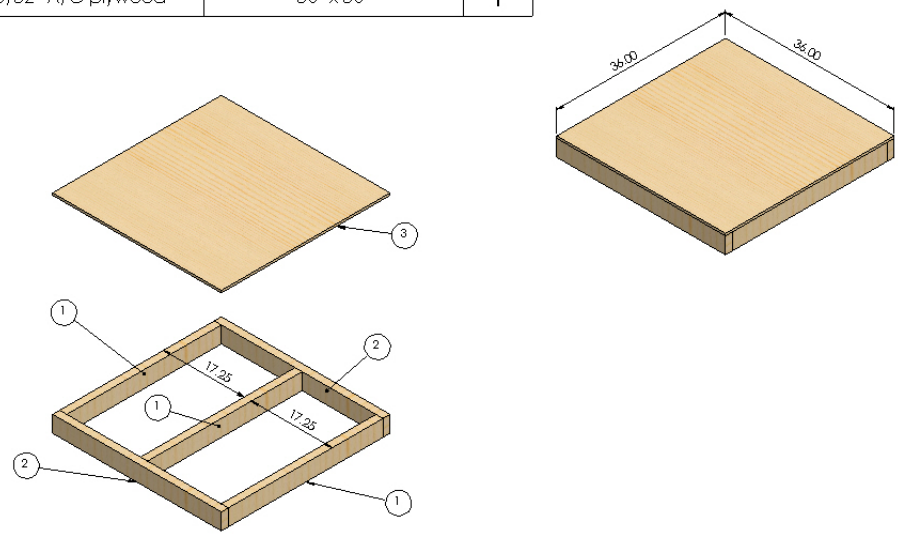

Figure 5.2.1-1. Assembly requirements for test decks.

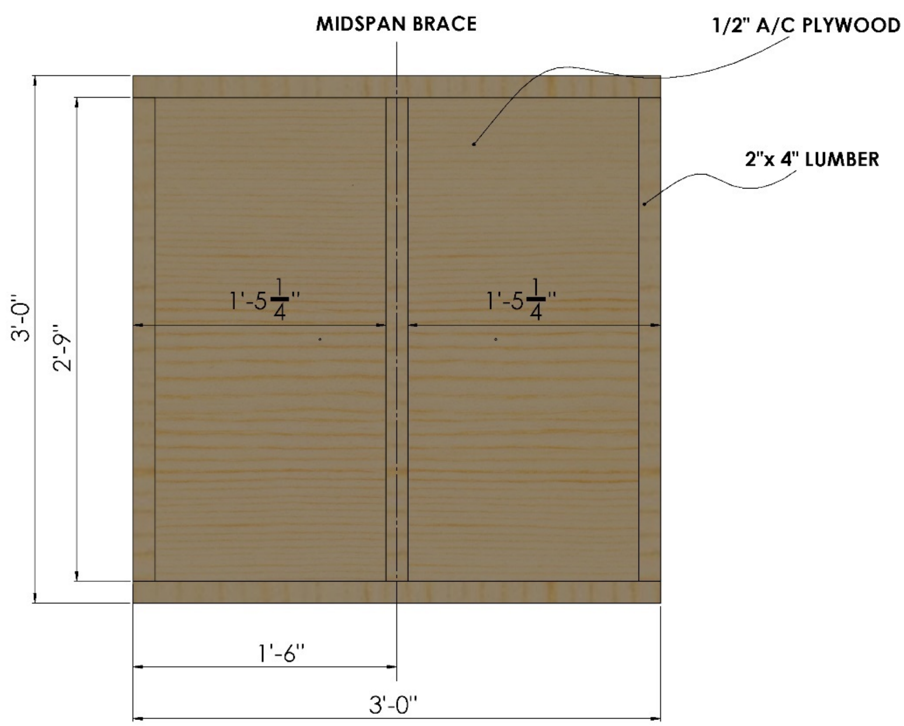

Figure 5.2.1-2. Bottom view of the test desk to illustrate the midspan support brace.

5.3. Application of underlayment

5.3.1. The underlayment shall be ASTM D226 Type I or ASTM D4869 Type II. The underlayment shall be applied such that the nail line markings are perpendicular to the midspan support brace.

The underlayment shall be fastened using button-cap nails along the outer frame at each corner and the center of each edge such that fasteners shall penetrate through the plywood and into the frame. Underlayment shall be applied as a single piece with no overlap and shall be trimmed flush with the outer edges of the deck. See Figure 5.3.1-1.

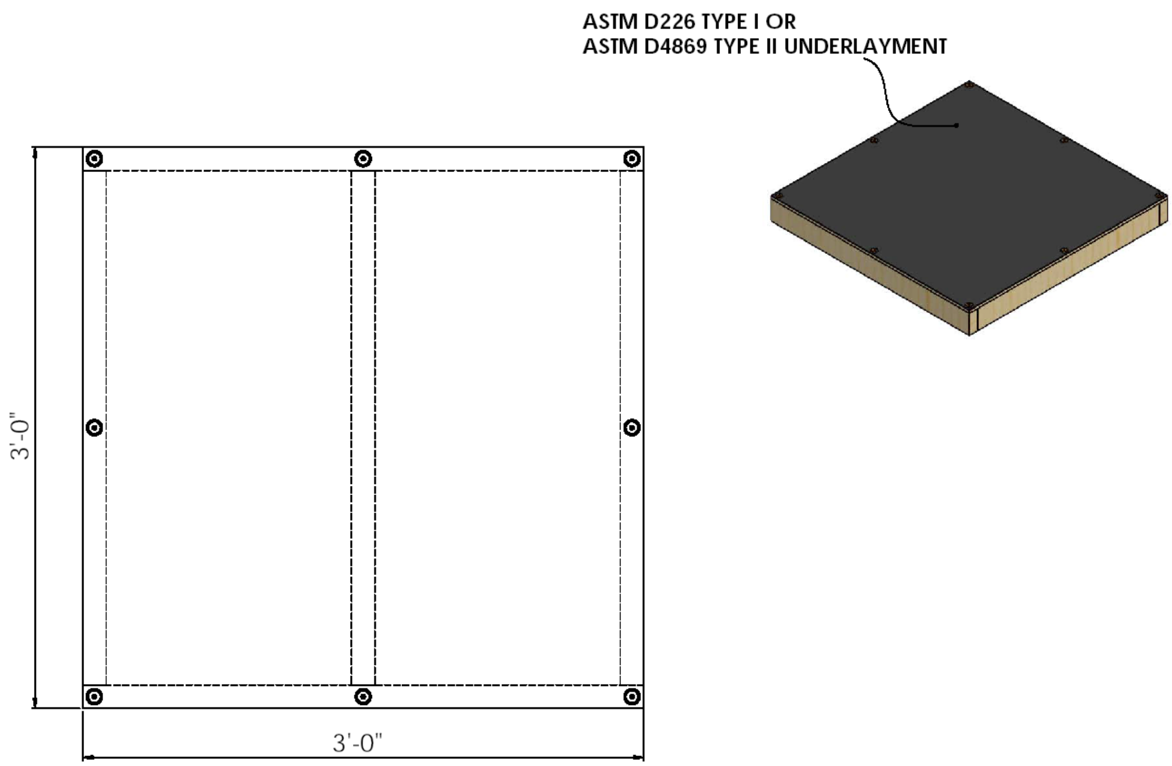

Figure 5.3.1-1. The underlayment is applied to the test deck with button-cap nails driven straight and flush and spaced along the outer frame at each corner and the center of each edge.

5.4. Application of shingles

5.4.1. A starter strip and shingles shall be applied to the test deck in accordance with the manufacturer's installation instructions. The specified fastener type and spacing shall be used. The material shall extend to, and be flush with, the outer edges of the test deck.

5.5. Conditioning

5.5.1. The test sample assemblies shall be assembled and stored such that the shingle material is facing up.

5.5.2. The test sample assemblies shall be assembled and stored indoors at a temperature between 18°–27°C (65°–80°F) for the period of time necessary to achieve thermal equilibrium. Test sample assemblies shall not be stacked on one another and shall be stored in such a manner that does not restrict airflow between samples.

5.5.3. The moisture content of the lumber for the test sample assembles shall not exceed 12%, as measured by a moisture meter.

5.5.4. The completed test sample assemblies shall be conditioned for 16 continuous hours at a temperature of 57°–60°C (135°–140°F). The self-seal adhesive shall be prevented from adhering by covering it with tape.

5.5.5. Care shall be taken to avoid scraping, scuffing, bending, or creasing of the shingles prior to testing. Care shall also be taken to avoid twisting or distortion of the test sample assemblies during handling.

6. Test Apparatus

6.1. The test apparatus shall consist of the propulsion system and the selected velocity measurement device. The test apparatus shall also consist of a frame or support to hold the test sample assembly in place. Any design of these systems is allowed, such that the desired test parameters outlined in Section 8 are met.

The test apparatus shall also consist of the system to manufacture and store ice spheres used for testing. Any design of this system is allowed, such that the desired ice sphere characteristics outlined in Table 7.1 are met.

7. Test Parameters

7.1. The ice spheres used in this test protocol shall meet the characteristics outlined in Table 7.1, within the acceptable variability ranges. Because the compressive force test is destructive in nature, a distribution of 30 ice spheres for each size and impact mode, meeting the mass and diameter specifications of Table 7.1, shall be tested a minimum of once per month for peak compressive force with a UTM using the parameters defined in Section 2.3, to ensure the ice sphere manufacturing and storage procedures and equipment produce satisfactory ice spheres.

Table 7.1. Ice Sphere Characteristics and Acceptable Variability Ranges

Impact Mode	Class	Diameter (cm)	Mass (g)	Peak Compressive Force (F_o) (N)	Impact Kinetic Energy (J)
Soft	1.5	3.81 ± 2%	22.0 ± 2	400 ± 10%	6.9 ± 15%
	2.0	5.08 ± 2%	51.5 ± 3	653 ± 10%	24.0 ± 15%
Hard shatter	1.5	3.81 ± 2%	24.5 ± 2	622 ± 10%	6.9 ± 15%
	2.0	5.08 ± 2%	60.0 ± 3	930 ± 10%	24.0 ± 15%
Hard bounce	1.5	3.81 ± 2%	24.5 ± 2	622 ± 10%	6.9 ± 15%
	2.0	5.08 ± 2%	60.0 ± 3	930 ± 10%	24.0 ± 15%

7.2. Ice spheres meeting the criteria in Table 7.1 shall be stored between impacts and test series such that the required characteristics are not compromised.

8. Test Procedure

8.1. Tests shall be conducted indoors at a temperature of 18°–27°C (65°–80°F).

8.2. Propulsion velocity shall be calculated for each ice sphere per the equation in the definition of impact kinetic energy in Section 2.4, and such that the target impact kinetic energy from Table 7.1 is achieved. A slight variation in measured mass of an ice sphere will require a slight adjustment in propulsion velocity to achieve the correct impact kinetic energy required by Table 7.1.

8.2.1. The propulsion system shall be calibrated at the beginning of each day, when room conditions change throughout the testing period, and when switching between different ice sphere sizes or Impact Mode characteristics, to determine the system settings that will ensure the correct propulsion velocity to achieve the necessary impact kinetic energy.

8.3. The test sample assembly shall be positioned such that it is securely seated and will not move or tip during the test. The propulsion apparatus shall be positioned such that the trajectory of the ice sphere shall be perpendicular (± 5°) to the test sample assembly. The selected velocity measurement device shall be positioned such that its beam width will sample the ice sphere speed when it is launched. The ice spheres shall exit the propulsion system 91.4 cm (3 ft) from the target impact location. The test area shall be set up such that the operator is protected.

8.3.1. Chronograph: the chronograph shall be positioned at least 30.5 cm (1 ft) from the exit of the propulsion system such that the ice sphere will pass through the photogates. Lighting requirements, per the chronograph manufacturer, shall be met.

8.3.2. Radar or LIDAR: the radar or LIDAR shall be positioned behind the propulsion system or directly behind the specimen with an unobstructed line of sight to the ice projectile.

8.4. The mass and diameter of each ice sphere shall be measured and recorded to the nearest 0.01 unit (g, mm, respectively) before it is loaded into the propulsion system; any spheres that do not meet the specifications of Table 7.1 shall be discarded and shall not be used. The time to remove the ice sphere from the freezer, collect the diameter and mass measurements, and load and propel the ice sphere, shall not exceed 60 seconds.

8.5. Impact locations—the test sample assemblies shall be subjected to a single impact at locations outlined in Table 8.5. All impacts shall be made at least 7.6 cm (3 in.) away from other impacts, the outer edge of the test sample assembly, and from the midspan support brace. See Figures 8.5-1 and 8.5-2.

Table 8.5. Shingle Impact Locations

3-Tab Shingles	Architectural (Laminate) Shingles
At least 2.5 cm (1 in.) from edge of tab	Single- and multi-ply: at least 2.5 cm (1 in.) from edge of shingle and from transition from single- to multi-ply portion

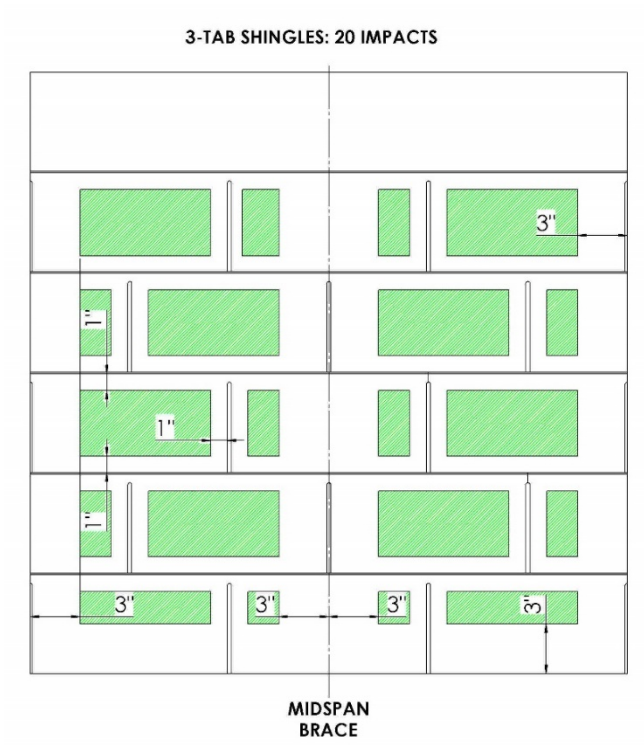

Figure 8.5-1. Impact location options for 3-tab shingles following the requirements of Table 8.5 and Section 8.5.1. (1 in. = 2.54 cm; 3 in. = 7.62 cm.)

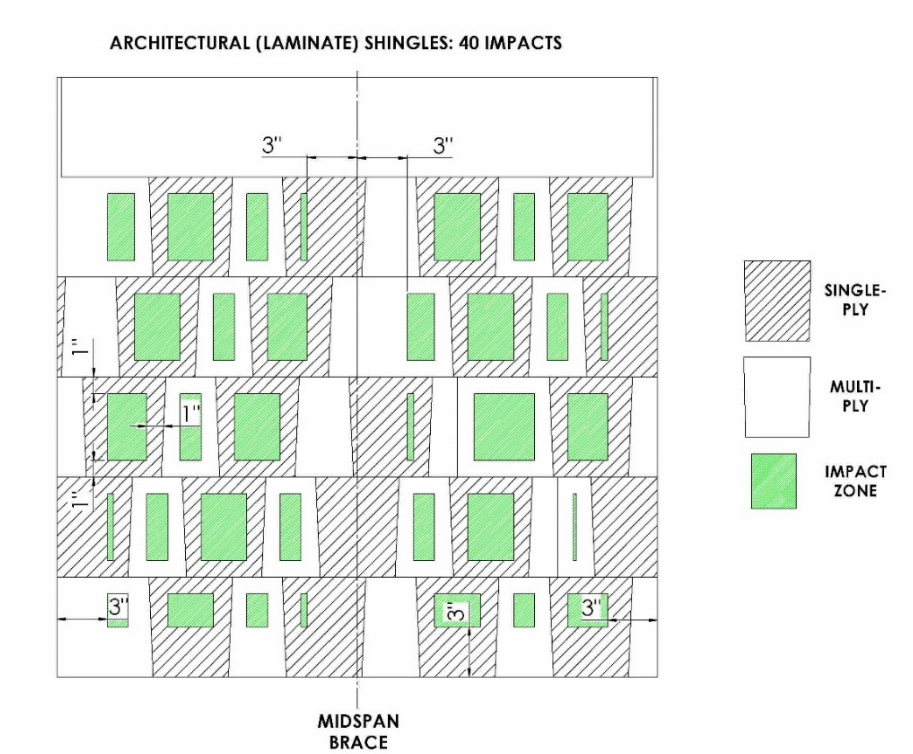

Figure 8.5-2. Impact location options for architectural shingles following the requirements of Table 8.5 and Section 8.5.1. (1 in. = 2.54 cm; 3 in. = 7.62 cm.)

8.5.1. Impact number on field of shingles

8.5.1.1. For 3-tab shingles, the number of impacts in the field of the shingle shall be 10 “hard mode” impacts, made up of at least 4 “hard shatter” and 4 “hard bounce” impacts; as well as 10 “soft mode” impacts; for each class tested. Therefore, the total number of impacts in the field of the shingle shall be 20 for each class tested.

While attempting to target specific Impact Modes, others may occasionally occur. These shall be discarded.

8.5.1.2. For architectural (laminate) shingles, the number of impacts in the field of the shingle shall be 10 “hard mode” impacts, with a minimum of 4 “hard shatter” and 4 “hard bounce” impacts; as well as 10 “soft mode” impacts, for both single- and multi-ply portions of the shingle; for each class tested. Therefore, the total number of impacts in the field of the shingle shall be 40 impacts for each class tested. If all impacts will not fit on a single test sample assembly while maintaining the appropriate distances outlined in Table 8.5, additional test sample assemblies may be used, provided the shingles come from the same batch.

While attempting to target specific Impact Modes, others may occasionally occur. These shall be discarded.

8.6. The mode of each impact shall be recorded and marked on the test sample assembly using a user-defined code (i.e., different colors or symbols to differentiate mode) to facilitate damage assessment after testing is completed.

8.7. The propulsion velocity shall be recorded to the nearest 0.1 m/s. Should a velocity not be recorded, or if the velocity is such that when combined with the mass will not result in an acceptable impact kinetic energy per Table 7.1, that impact shall be disregarded and will not count toward the impact requirements outlined in Section 8.5. These impacts shall not be recorded in the results and performance report as described in Section 10.

9. Performance Evaluation

9.1. A minimum of 24 hours shall be allowed to elapse between the time of impact and the time in which the damage assessment is conducted.

9.2. Each individual impact location, as specified in Section 8.5, shall be evaluated on the top surface utilizing image processing techniques of the IBHS-Nemesis Impact Damage Evaluation Tool to quantify deformations and granule loss; and using expert judgement to assign a 0–3 Severity Level for breach. These data fields shall be recorded following Table 10.1 for each impact.

9.3. For each impact, each Damage Mode shall be assigned a Severity Level for the quantities determined by the IBHS-Nemesis Impact Damage Evaluation Tool following Table 9.3. These data fields shall be recorded following Table 10.1 for each impact.

Table 9.3. Criteria for Damage Mode Classification by Severity Level and Severity Score (formatted as a worksheet for each individual impact).

<table>
<tr><th colspan="2" rowspan="2">Damage Mode</th><th colspan="4">Severity Level</th><th rowspan="2">Severity Score (0–3)</th></tr>
<tr><th>0</th><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Breach (BH)</td><td>Expert Judgement (qualitative)</td><td>0</td><td>1</td><td>2</td><td>3</td><td>Breach (BH): evidence of damage caused by a tear, rupture or crack.

BH Severity Score = BH Severity Level</td></tr>
<tr><td rowspan="2">Deformations (DN)</td><td>Dent (DT): Volume (mm³)</td><td>0 to ≥-11 mm³</td><td>>-11 to ≤-31 mm³</td><td>>-31 to ≤-88 mm³</td><td><-88 mm³</td><td rowspan="2">Deformations (DN): alterations of the shape of the shingle.

DN Severity Score = 1/2 DT Severity Level + 1/2 RD Severity Level</td></tr>
<tr><td>Ridge of Dent (RD): Volume (mm³)</td><td>0 to ≤8 mm³</td><td>>8 to ≤23 mm³</td><td>>23 to ≤58 mm³</td><td>>58 mm³</td></tr>
<tr><td rowspan="2">Granule Loss (GL)</td><td>Patch Granule Loss (PGL): Area (mm²)</td><td>0 to ≤11 mm²</td><td>>11 to ≤31 mm²</td><td>>31 to ≤92 mm²</td><td>>92 mm²</td><td rowspan="2">Granule Loss (GL): loss of one or more granules on the shingle.

GL Severity Score = 2/3 PGL Severity Level + 1/3 IGL Severity Level</td></tr>
<tr><td>Individual Granule Loss (IGL): Area (mm²)</td><td>0 to ≤9 mm²</td><td>>9 to ≤22 mm²</td><td>>22 to ≤44 mm²</td><td>>44 mm²</td></tr>
</table>

9.4. Severity Scores shall be determined for each impact as follows, and outlined in Table 9.3:

9.4.1. The Severity Score for breach shall be equivalent to the Severity Level assigned by expert judgement.

$$BH\ Severity\ Score = BH\ Severity\ Level$$

9.4.2. The Severity Score for deformations shall be the average of the Severity Levels for dent and ridge of dent.

$$DN\ Severity\ Score = \left(\frac{1}{2} * DT\ Severity\ Level\right) + \left(\frac{1}{2} * RD\ Severity\ Level\right)$$

9.4.3. The Severity Score for granule loss shall be a weighted average of the Severity Levels for patch granule loss and individual granule loss, where the weights are 2:1, respectively.

$$GL\ Severity\ Score = \left(\frac{2}{3} * PGL\ Severity\ Level\right) + \left(\frac{1}{3} * IGL\ Severity\ Level\right)$$

9.5. The Severity Scores for breach, deformations, and granule loss determined using Table 9.3 shall be numerically averaged to determine an Individual Impact Severity Score for each impact.

$$Individual\ Impact\ Severity\ Score = \left(\frac{1}{3} * BH\ Severity\ Score\right) + \left(\frac{1}{3} * DN\ Severity\ Score\right) + \left(\frac{1}{3} * GL\ Severity\ Score\right)$$

9.6. All Individual Impact Severity Scores shall be numerically averaged to determine the average Severity Score for all impacts and the corresponding Performance Evaluation Rating for the product, following Table 9.6.

Then determine the average of the BH Severity Scores for all impacts. Repeat the process for DN Severity Scores and GL Severity Scores. Products may only achieve the Excellent Performance Rating if each of these three average scores are 1.2 or less. Any products for which the average Severity Score meets the Excellent Performance Rating criteria, but the averages in the three Severity Score categories are greater than 1.2, shall receive a Good Performance Rating.

Table 9.6. Performance Evaluation Ratings

Average Severity Score	Performance Evaluation Rating
0–0.3	**EXCELLENT PERFORMANCE***
>0.3–1.2	**GOOD PERFORMANCE**
>1.2–1.8	**MARGINAL PERFORMANCE**
>1.8	**POOR PERFORMANCE**

*Excellent Performance can only be achieved if the average BH Severity Score, average DN Severity Score, and Average GL Severity Score are all 1.2 or less.

REPORT

10. Report Requirements

10.1. The report shall include the following:

- Asphalt shingle product name, color, and any other identifying labels found on the packaging, which may include plant, date, batch.
- List of impact classes conducted.
- A table of mass, impact velocity, resulting impact kinetic energy, Impact Mode, and impact location for all impacts conducted. The table must also include the Damage Modes quantities in Table 9.3, as well as the Severity Levels and Scores for the damage categories, and the Individual Impact Severity Score for each impact. The average of the Individual Impact Severity Scores shall also be included, to determine the Performance Evaluation Rating in Table 9.6. The table shall follow the format of Table 10.1.
- Results shall be reported and evaluated in the context of and subject to the hail impact test results disclaimers. The disclaimers are available at: https://ibhs.org/hail-impact-test-results-disclosures/

Table 10.1. Performance Data Table for Individual Impacts

							DN Volume (mm^3)		DN Severity Level			GL Area (mm^2)		GL Severity Level				
Impact #	Class	Mass (g)	Impact velocity (m/s)	Impact kinetic energy (J)	Impact Mode	Ply	DT	RD	DT	RD	DN Severity Score	PGL	IGL	PGL	IGL	GL Severity Score	BH Severity Level (Score)	Individual Impact Severity Score
1																		
2																		
3																		
Average																		

COMMENTARY

INTRODUCTION

1. Purpose

1.1. Releasing performance results provides a benefit to consumers during the building or rebuilding process and illustrates performance for manufacturers and other stakeholders. Consumers deserve to have confidence that products labeled as resilient live up to expectations. Shining a light to distinguish top performers with strong reliability in the hail peril raises expectations of performance and drives innovation and improvement.

2. Scope

2.1. At this time, the test method has only been used on asphalt shingles. While it may be possible to test other products using this method or variations of it, this has not been attempted or evaluated, and is therefore outside of the scope of this test method.

2.2. Material properties of shingles may change with time and exposure to elements after the time of manufacture. This test method evaluates products that have traveled through what is believed to be typical distribution and handling and are therefore considered most representative of what ultimately gets installed on a building and ensures samples that are free from bias. The material properties of these samples may not be identical to products in pristine condition from the factory floor, nor identical to those that have been installed on roofs and exposed to the elements, and thus performances may be different.

2.3. Although the ice sphere characteristics and test methodology outlined in this protocol would be appropriate for testing other shingle roof systems such as hip and ridge shingles, or in valleys, construction and assembly specifications are not outlined, and are therefore outside the scope of this test method.

2.4. Intentionally left blank

2.5. Specific ice sphere characteristics, as well as data sources for these values, are further explained in Commentary Section 7.1 and in Appendix B.

Target impact locations are outlined in Section 8.5 and are based on initial testing conducted by IBHS to aid in development of this test method. The impact locations required by existing test methods for asphalt shingles and other roofing products (UL 2218, FM 4473) were considered.

2.6. Ice characteristics used in this test method were derived from characteristics of actual hailstones. The IBHS hail field research program has collected data on hailstones with different characteristics, such as shape, density, and strength (Appendix B; Heymsfield et al. 2014; Giammanco et al. 2015; Giammanco et al. 2017). Characteristics of natural hailstones vary and are not identical stone-to-stone even within a small geographical area of a single hail-producing thunderstorm. Therefore, a range of natural characteristics are captured within the manufactured ice spheres used for testing. Density and compressive strength are accounted for in this test method, to account for the material response (of both ice and shingle) to the impact force. Although hailstone shape data have been collected, testing of different shape ice projectiles has not been attempted or evaluated, and is therefore outside of the scope of this test method. This method requires ranges of the natural characteristics to be captured within the manufactured ice spheres used for testing, to ensure proper combinations of Impact Mode, and ice sphere density and strength.

The impact kinetic energies used in this test method were derived from impact energies of actual hailstones. The IBHS hail field research program has also contributed data to research collaborators for use in calculating impact kinetic energies of hailstone distributions. Impact kinetic energies, as well as data sources for these values, are further explained in Appendix A. Because natural hailstones exhibit complex shapes, an ice sphere having the same density as a natural hailstone of the same maximum diameter, will have more mass than the natural hailstone. Thus, the higher mass sphere must be propelled at a lower impact velocity to achieve the correct impact energy for the natural hailstone. Further explanation is provided in Commentary Section 8.2.1. Therefore, the impact velocities do not represent natural hailstone theoretical terminal velocities.

2.7. Initial testing conducted by IBHS to aid in development of this test method highlighted different Damage Modes, all of which could be important for real-world performance of shingles. Physical damage to the structure of the shingle such as cracks, fractures, dents, and tears, some of which may be identified as failures by existing impact test methods (UL 2218, FM 4473), may reduce the water-shedding nature of the shingle, while loss of granules may result in exposure and therefore more rapid oxidation and embrittlement of the underlying asphalt, resulting in reduced product lifetime. Therefore, both damage types are considered within this test method.

Both top and bottom surfaces of shingles may display visible damage upon testing, but only the bottom side is evaluated in one existing test method (UL 2218), while both surfaces are evaluated in another existing test method (FM 4473). In a real-world setting following a hailstorm, only the top surface of the shingle would likely be visible to an inspector and includes granule damage, so while both surfaces were evaluated in the development of this method, only the damage visible on the top surface is considered for evaluation purposes under this test method. The testing conducted in the development of this method evaluated the relationship between top and bottom surface damage to set performance criteria for this test method.

2.8. This test method uses state-of-the-science knowledge to derive test parameters such that product performances can be best compared and evaluated for potential suitability in hail-prone regions.

In addition to using state-of-the-science knowledge and data to derive test parameters, the advice and opinions of other experts were sought, to ensure the prescribed protocol evaluated the ice and damage properties that most influence losses. In addition, many characteristics of existing test methods UL 2218 and FM 4473 were carried over to this protocol, as they either represented best practices or accurate scientific assumptions, and there was no evidence-based reason to deviate from their specifications.

2.9. This test method is not applicable for evaluating the performance of aged or weathered products, whose properties and responses may have changed from their original, new state. The importance of long-term natural weathering of shingle products, as well as the temperature and conditions at the time of impact, are acknowledged as variables which may affect how shingles respond to hailstone impacts. However, no testing has been attempted or evaluated to address these variables, and therefore they are outside of the scope of this test method. This test method is also not applicable for evaluating damaged or defectively manufactured products, per ASTM D228 Section 7. See Section 4.9 of this test method.

2.10. No impact test will be able to fully replicate all factors of hailstone and hailstorm characteristics, environmental conditions, and shingle properties to account for all possible real-world scenarios. The limitations outlined in Section 2.9 and Commentary Section 2.9, mean that impact performance tested under this method will not guarantee the same performance results when field-installed asphalt shingle roofs are impacted by hailstones.

Despite best efforts to replicate important hailstone properties, product variability and exposure length and conditions will affect real-world performance, and these are not currently accounted for in this test protocol. Therefore, products tested under this protocol can be compared to one another, but direct correlation to hail performance in any one location or individual event cannot be derived based on test results. Acceptable performance under this test method will not guarantee indestructible materials in all types of exposures. Considerations outside of scope are listed as appropriate.

2.11. The damage states, quantities, and categories produced by this test method are not intended for use beyond laboratory performance testing and evaluation. They are not intended for use in the adjustment of insurance claims or other insurance operations, or other real-world inspection activities, because of the limitations outlined in Sections 2.6, 2.9, and 2.10, and Commentary Sections 2.6, 2.9, and 2.10.

3. Definitions

3.1. Intentionally left blank

3.2. Intentionally left blank

3.3. See Giammanco et al. 2014.

3.4. See Giammanco et al. 2014.

3.5. Intentionally left blank

3.6. Freezer—time and condition of storage of ice spheres can affect the strength of ice spheres and the Impact Mode. Tuning should be conducted by each lab to determine the storage conditions and lengths that are appropriate for the given equipment to produce specified ice characteristics and reliable Impact Modes.

3.7. Intentionally left blank

3.8. Intentionally left blank

3.9. Intentionally left blank

3.10. Intentionally left blank

3.11. Intentionally left blank

3.12. Propulsion system—any launching mechanism is allowed, such that it can be controlled and calibrated to achieve the correct propulsion velocity for the various ice sphere sizes and characteristics to reach the target impact kinetic energy. The system needs to be accurate enough to aim to nominally strike the center part of shingles and avoid areas such as the outer frame and midspan support brace (see Section 8.5) and provide perpendicular impacts.

Although not specifically required, it is recommended that the propulsion system be adjustable in both height and angle of impact, such as to reduce the need to reposition the test sample assembly for each impact.

3.13. Intentionally left blank

3.14. Chronograph—testing to aid in the development of this test method revealed that a chronograph was not always reliable for capturing velocity, as ice is a harder medium to measure than the traditional ballistics for which chronographs are designed. Additionally, chronographs are sensitive to lighting conditions which may affect the instrument's ability to measure velocity in a lab as compared to outdoor conditions.

3.15. Intentionally left blank

3.16. Impact Mode—based on IBHS research to aid in the development of this test method, the Impact Mode is not perfectly predictable for each ice sphere, but reasonable reliability has been found for soft, hard shatter, and hard bounce Impact Modes, using specific manufacturing processes and storage times and conditions for each mode, to match specific mass, diameter, and peak compressive force specifications. See Commentary Section 3.6 for further details.

3.16.1. Intentionally left blank

3.16.2. Intentionally left blank

3.16.3. Intentionally left blank

3.17. IBHS-Nemesis Impact Damage Evaluation Tool—users take a series of photographs which are programmatically stitched together to create a 3D rendering of each impact. Targets of a specific size and color are used to provide a scale and reference points for the photographs. Custom computer algorithms are then executed to quantify the five defined Damage Modes by calculating the number of pixels affected and relating those to the target scale to determine the size of the damage.

The tool was developed to improve upon the binary pass/fail criteria based on expert judgement in the existing test methods (UL 2218 and FM 4473), but also because it would allow precise quantities of multiple Damage Modes to be extracted for analysis. Multiple Damage Modes allow for an evaluation of the many factors that occur in real-world hail events. The quantitative nature of the tool's output allows for severities of damage to be evaluated to determine performance, rather than treating all damage severities as equal, as is done in the existing test methods through the binary pass/fail determination.

Validation of the algorithms was conducted through expert judgement of the reasonableness of the output quantities for a test sample. It should be noted that a computer is more precise and accurate in determining quantities than a human can be using hand tools such as a depth gauge or calipers.

3.18. Intentionally left blank

3.18.1. Intentionally left blank

3.18.1.1. Intentionally left blank

3.18.1.2. Intentionally left blank

3.18.2. Granule Loss (GL)—one of the most frequent results of hail impact damage to asphalt shingles. There are no set criteria for how much granule loss is considered to be acceptable for the roof to still function, but it is important to make progress in that area. Some manufacturers apply excess granules during manufacturing, so some loss is considered a normal part of natural weathering. The granules serve to protect the underlying asphalt from UV degradation (which may cause a reduced lifespan) so products that retain their granules during natural weathering, and even hail events, are desirable.

3.18.2.1. Intentionally left blank

3.18.2.2. Intentionally left blank

3.18.3. Intentionally left blank

3.19. Intentionally left blank

3.20. Intentionally left blank

3.21. Intentionally left blank

3.22. Intentionally left blank

3.23. Bulk density—defined as: $\rho_{bulk} = \frac{m}{V_{sphere}}$ where *m* is the mass of the ice sphere and V_{sphere} is the total volume of the sphere calculated using: $V = \frac{4}{3}\pi r^3$ where r is the radius determined from the maximum nominal diameter (*d*), where $r = \frac{d}{2}$.

Although density requirements are not explicitly stated in Section 7.1, the values for diameter and mass outlined in Table 7.1 ensure that bulk densities fit within the range stated in historical literature and in the IBHS hail field research program hailstone database, which range from 0.2–0.9 g cm^{-3}. The results of Giammanco et al. (2017) have shown evidence that in general, hailstone density increases with diameter. The density values used in this protocol reflect those values for the projectile sizes specified and fall within the range of their natural hailstone counterparts.

PERFORMANCE

4. Procurement of Shingle Samples

4.1. See Commentary Section 2.2. This protocol assumes the distributor is appropriately handling the material, per the manufacturer’s precautions regarding stacking and exposure. Additional details are recommended by ARMA (2015).

Products with obvious damage or defects from manufacturing or shipping and handling should be discarded and not used for testing purposes.

4.2. Intentionally left blank

5. Preparation of Test Sample Assemblies

5.1. Fasteners installed flush with the material they are securing are important so as to reduce enhanced damage that may occur as a result of striking a fastener that is under-driven or driven at an angle. Similarly, a void created by an over-driven fastener could result in enhanced damage and should be avoided.

5.2. Preparation of test decks

5.2.1. Existing test methods have utilized test decks of identical construction, and there is no scientific reason to deviate from these details, as they represent common building materials and installation methods. Although shingles may be installed on different kinds of substrates in the field, the selection of A/C plywood of a fixed thickness ensures that direct comparisons can be made between tests. Testing of assemblies with OSB or plank sheathing, and varying thicknesses has not been attempted or evaluated, and is therefore outside of the scope of this test method.

5.3. Application of underlayment

5.3.1. Underlayment application instructions include the use of common building materials and installation methods. Although shingles may be installed on different types of underlayments in the field, this is a fixed variable in this testing protocol and likely does not substantially contribute to damageability due to hail impacts in the field. However, underlayment quality may affect the water-shedding performance of a roof that has sustained hail damage and should be considered at the time of design or installation in the field.

5.4. Application of shingles

5.4.1. Intentionally left blank

5.5. Conditioning

5.5.1. Intentionally left blank

5.5.2. Existing test methods require storage and/or testing at 21°–25°C (70°–76.4°F) (UL 2218) or 16°–32°C (60°–90°F) (FM 4473). The temperature and conditions at the time of impact are acknowledged as variables which may affect how shingles respond to hailstone impacts, where it is expected that shingles at colder temperatures would be more stiff, rigid, and brittle than those at warmer temperatures, and these characteristics may affect a shingle's susceptibility to impact damage. However, it is hypothesized that this effect is likely minimized except for at very cold or very hot temperatures. The range of temperatures selected here (18°–27°C; 65°–80°F) represent values that are typically present in an HVAC-controlled work space, are comfortable for the operator, and are between the values of existing test methods. Conditioning and testing at temperatures outside the range stated in Sections 5.5.2 and 8.1 has not been attempted or evaluated and is therefore outside the scope of this test method.

5.5.3. Moisture absorption of the test sample assemblies could affect the impact performance, particularly for test decks with very high moisture contents, where they may be softer and more flexible or yielding. Existing test methods recommend curing, storing, or conditioning to assure no more than 12% moisture content in the test deck lumber, and there is no scientific reason to deviate from this, as the effects of higher moisture contents have not been evaluated.

5.5.4. Existing test methods require conditioning in a chamber at an ambient air temperature of 57°–60°C (135°–140°F) for a continuous period of 16 hours for products with a self-seal adhesive, such as asphalt shingles. While the conditioning length and temperature is likely not long enough or high enough to significantly affect the material properties, other than to activate the adhesive, it may allow for settling of distortions of the shingles caused by shipping and handling. Taping the adhesive strip, specifically to prevent it from adhering, will avoid any damage that may be caused should it be desirable to pry it loose to examine the impacts after testing, although this is not required by this test method.

5.5.5. Scraping, scuffing, bending or creasing of shingles, and twisting of panels during handling may cause distortions that may affect the condition of the shingle, and should thus be avoided. If any visible damage occurs between the time of installation and the time of testing, those zones should be marked out and eliminated from the test.

6. Test Apparatus

6.1. The propulsion system and/or the support frame should be adjustable in position, angle and/or height to allow for smooth transition to target specified impact locations.

Although several velocity measurement devices are allowed, initial testing conducted by IBHS to aid in the development of this test method found a radar gun to be the most widely available and consistently performing device to use for measuring ice sphere impact velocity. Chronographs are widely available, but sometimes struggle to sense ice spheres as opposed to the less-reflective ballistics projectiles for which they are designed. Chronographs are also more sensitive to ambient lighting conditions and some indoor lighting conditions, such as overhead fluorescent lights, can cause inconsistent performance of the chronograph. LIDARs are an acceptable device for measuring impact velocity, but they are more cost-prohibitive and not widely available, so they were not tested by IBHS during the development testing for this method.

The system required to manufacture and store the ice spheres used in this test should be tested to determine the specific settings needed to achieve the desired ice sphere characteristics with a set of given equipment.

7. Test Parameters

7.1. During initial testing conducted by IBHS to aid in development of this test method, laboratory ice production methods were tested to identify necessary production and storage settings for the specific laboratory equipment used, to generate the desired ice sphere characteristics. The calculated bulk densities that result from the prescribed diameter and mass values for all Impact Mode categories fall within the observed range for natural hailstones specifically at sizes greater than 2 cm (Giammanco et al. 2017). The range of allowable kinetic energy captures existing natural hailstone variability and represents expected average values for the specified diameters. See Commentary Section 8.2 for further details.

The allowable variabilities in ice sphere characteristics from Table 8.1 are based on the following:

7.1.1. Diameter—approximately ± one standard deviation for values collected during laboratory testing at IBHS during the development of this test method. Sample sizes exceeded 100 ice spheres for each category.

7.1.2. Mass—approximately ± one standard deviation for values collected during laboratory testing at IBHS during the development of this test method. Sample sizes exceeded 100 ice spheres for each category. The ice sphere masses specified in Table 8.1 represent average values determined to ensure a proper match of the compressive strength and desired Impact Mode.

7.1.3. Peak compressive force (F_o)—approximately ± one standard deviation for the peak compressive force distribution determined from UTM maximum load measurements sampling at 25 kHz using displacement rates of 0.381 cm s^{-1} for 3.81 cm (1.50 in) ice spheres and 0.508 cm s^{-1} for 5.08 cm (2.00 in) ice spheres.

The peak compressive force values, specified in Table 7.1, used to calculate a uniaxial compressive stress for comparison with field observations, represent the typical compressive stress found in natural hailstones. Similar to the diameter and mass values, the peak compressive force values represent average values found during laboratory ice testing for development of this test method. It is noted that compressive strength is dependent upon the rate of compressive strain. The method in which natural hailstones were measured is described in detail by Giammanco et al. (2015). Laboratory testing was conducted on ice spheres during development of this test method utilizing the same field measurement device as used by Giammanco et al. (2015) to allow for direct comparison with field data. Laboratory testing was also conducted using a UTM, to quantify measurement differences and develop adjustment factors for the field measurement device. The specified peak compressive force values in Table 7.1 and the calculated compressive stress values represent measurements made using a UTM at a strain rate of 10^{-1} s^{-1} sampling at 25 kHz and fall near the median compressive stress of adjusted observations of natural hailstones. The adjustment factors account for sampling differences and variability in strain rates from the field measurement system. It is noted that neither system can duplicate the very high strain rates observed during a hailstone or ice sphere impact. The methodology and laboratory testing results are provided in greater detail in Appendix B. A Split-Hopkinson pressure bar (also known as a Holsky bar) to capture compressive strength information for the specified ice spheres at strain rates associated with impacts would help refine the characteristics presented here, but this has not been attempted or evaluated, and is therefore outside the scope of this test method.

Because a single ice sphere cannot be used for both compression testing and impact testing, as both result in destruction of the ice sphere, the peak compressive force of a sample of ice spheres must be evaluated at regular intervals to instill reasonable confidence that ice spheres produced by the specific manufacturing method and stored in specific equipment and conditions will meet the specified peak compressive force requirements.

7.1.4. Impact kinetic energy—based on the diameter to kinetic energy relationship for the 25th and 75th percentiles of the total distribution presented in Heymsfield et al. (2014).

The target kinetic energies outlined in Table 7.1 are representative of the results of Heymsfield and Wright (2013) and Heymsfield et al. (2014), which established the following mean relationship between kinetic energy and maximum diameter:

$$KE = 0.271\, D_{max}^{4.31}$$

at a pressure level of 1000 hPa (approximating sea-level), where D_{max} is measured in centimeters (per Heymsfield et al. 2014), and KE is measured in Joules. The equation is applicable for natural hailstones larger than 1.5 cm (0.59 in) in maximum diameter. See Appendix A for further details.

7.2. Laboratory testing conducted during development of this test method revealed that freezer storage conditions can alter ice sphere characteristics, and the deviations in those characteristics became larger as storage length is increased. Thus, care should be taken to ensure that the ice spheres are not stored in conditions or for lengths of time that will affect the desired properties outlined in Table 7.1. The conditions and length of time appropriate for storage will be affected by the specific laboratory conditions and equipment used, thus experiments will need to be conducted by each laboratory for the appropriate equipment to determine the storage condition limits.

8. Test Procedure

8.1. See Commentary Section 5.4.2 for more information.

Although not specifically required for storage and/or testing under this method, initial testing conducted to aid in the development of this test method revealed that the manufacture of ice spheres was more consistent and reliable when lab relatively humidity values were 30%–50% and stable throughout the day. Any relative humidity conditions are allowed such that the ice sphere criteria in Table 7.1 is met, but improved production reliability will likely be seen for stable, low humidity conditions.

8.2. Impact kinetic energy is outlined in Section 7.1, for ice sphere tests with desired factors. It is based upon the estimated maximum diameter to kinetic energy relationship of natural hailstones. The propulsion velocity must be determined for the specific ice sphere measured mass and the specific test properties using the following:

$$v = \sqrt{\frac{2KE}{m}}$$

where *m* (mass) and *KE* (kinetic energy) are dictated by the test parameters in Table 7.1.

Natural hailstones exhibit complex shapes that depart from sphericity with increasing size. An ice sphere having the same density and maximum diameter of an observed natural hailstone will have a larger volume and subsequent mass due to the shape differences (Figure C8.2-1). Because spheres are used in this testing protocol, there is a higher amount of mass, which much be compensated for with a lower propulsion velocity to match impact kinetic energies of natural, irregularly shaped hailstones in the absence of strong winds. The calculated velocities that result from the equation above ensure natural hailstone theoretical impact kinetic energies are achieved, but do not represent natural hailstone theoretical terminal velocities. It is noted that Heymsfield et al. (2014) found that shape is a larger factor in hailstone aerodynamics than density (mass) for hailstones with similar maximum diameters.

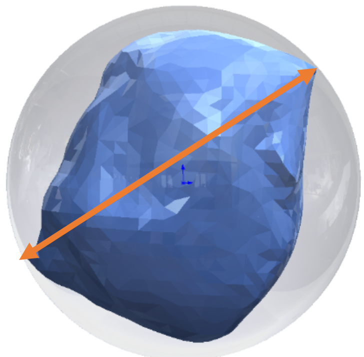

Figure C8.2-1. A natural hailstone (blue) of a given maximum diameter (illustrated by the orange dimension; measured with calipers following Giammanco et al. 2015), such as the one shown in this model produced from a 3D scan of a real hailstone, is less massive than a sphere of the same diameter (assuming density is constant), due to the volume voids (as illustrated by the gray sphere). Thus, this testing protocol relies on higher mass spheres propelled at lower impact velocities to achieve the correct impact kinetic energy to represent natural hailstones of the same maximum diameter.

8.2.1. Slight variations in mass for an individual stone may require a slight adjustment in propulsion system settings to slightly adjust the propulsion velocity. Slight differences in the indoor room conditions at the time of testing (pressure, temperature, relative humidity) can also impact the propulsion system settings necessary to achieve the correct calculated velocity, if a compressed air propulsion system is used. Thus, the propulsion system must be calibrated with representative ice sphere samples identical to those which will be used for the testing series. This should be done at a minimum of once per test day for cases where the desired kinetic energy, density, strength, Impact Mode, and ice sphere size remain the same. If these selected parameters change throughout the day, the system should be recalibrated under the new ice sphere and kinetic energy selections.

The system should be recalibrated when consistent difficulties achieving the desired propulsion velocity and kinetic energy are encountered, as they may indicate a change in pressure, temperature, or relative humidity in the testing environment has occurred.

8.3. The most severe impact energy per square area occurs when the impact is perpendicular to the test sample assembly, and existing test methods (UL 2218 and FM 4473) require perpendicular impacts. The transfer of momentum and energy from the projectile to the test specimen would be spread over a larger surface area if impacted at an angle and may be more prone to causing slightly different Damage Modes or severities. Testing of impact angles other than perpendicular (±5°) has not been attempted or evaluated and is therefore outside of the scope of this test method.

The larger the distance between the propulsion system and the test sample assembly, the more likely it is for a difference to occur between the desired and actual impact locations, as impact accuracy will degrade with distance. Thus, the ice sphere should exit the apparatus within 3 ft of the test panel assembly.

The ice spheres will be traveling at fast speeds and may have unpredictable ricochets. The projectiles themselves, or fragments of ice produced when the ice sphere shatters, could cause a threat to the operator's body and eyes. As a result, the operator should be protected during any testing activities.

8.4. The mass is needed to calculate the impact kinetic energy and must be recorded for each ice sphere. The diameter must also be measured and recorded for each ice sphere to ensure consistency.

The time between removing the ice sphere from the freezer, making the mass and diameter measurements, and loading and propelling the ice sphere is limited to 60 seconds to limit melting. This is reflective of the time allowed by the FM 4473 method.

8.5. Impact locations—the impact locations for the test sample assemblies were selected based on testing by IBHS to aid in development of this test method. Performance differences for single- and multi-ply portions of architectural shingles were seen during development testing. As a result, the test procedure dictates impacts be made at all of these locations.

Substantial performance differences for joints, corners, edges, etc., which are target impact locations in existing test methods (UL 2218, FM 4473), were not observed in ice sphere testing by IBHS to aid in the development of this test method. Therefore, these specific locations are not required to be impacted. When shingles are installed properly per the manufacturer's installation requirements, most of these areas are at the downslope side of the shingles, such that a crack, tear, or other damage at these locations would likely cause water to run to the next course of shingles and shed away at that point, meaning there is no enhanced vulnerability to these zones.

Testing by IBHS to aid in the development of this test method revealed that ice Impact Mode (hard or soft) generally influences the damage patterns (physical damage such as tearing, cracking, or denting of the shingle, versus granule loss damage). Existing test methods require the use of double impacts at each location; however, if the Impact Modes are different from the first impact to the duplicate one, the resulting damage can be obscured, in that it is impossible to know how each ice sphere contributed to the final damage state. Additionally, development testing has indicated that although duplicate impacts work reasonably well for the steel ball impact test method (UL 2218), damages were too severe for duplicate ice impacts (required by FM 4473) on asphalt shingles. As a result of these factors, this test method requires only single impacts to be made at each targeted location.

So as not to cause one impact to influence another, impacts are required to be spaced a minimum of 7.6 cm (3 in.) apart. Impacts are also required to be a minimum of 7.6 cm (3 in.) from the edge of the test sample assembly to reduce influence from the underlying framing lumber. Another requirement is for impacts to be 2.5 cm (1 in.) from the edge of shingles (to ensure the impact does not unintentionally become an edge impact), and for architectural shingles, 2.5 cm (1 in.) away from transitions from single- to multi-ply portions (to reduce effects of impacting an uneven surface).

8.5.1. Impact Number—while targeting a specific Impact Mode, if a different Impact Mode occurs, this impact shall be discarded. The resulting compressive stress will represent that of the desired Impact Mode, while the actual Impact Mode and resulting impact mechanics are different than desired. Conversely, the compressive stress of the actual Impact Mode will not represent the characteristics needed for that Impact Mode.

Any ice spheres that do not meet the impact kinetic energy, should be discarded from the dataset—see section 8.7 and associated commentary.

8.6. Intentionally left blank

8.7. The impact velocity is required to calculate the impact kinetic energy. Thus, it should be recorded for each impact. Any impacts which do not meet the required impact kinetic energy calculated from the mass and impact velocity, must not be included in the impact count or the report. They should be marked on the panel and any associated data files in a way that makes it clear they are to be excluded.

9. Performance Evaluation

9.1. Real-life reports suggest that some materials may be able to "recover" following an impact to return to their approximate initial state. The elapsed time between impact and assessment allows for this process.

Additionally, the elapsed time between impact and evaluation will ensure the shingle is dry so as to not obscure the image processing or expert assessment.

9.2. The performance of the top side of the shingle is evaluated, as this represents the surface that would likely be seen by a building owner or inspector following a suspected real-world hail event.

In support of the development of this test method, IBHS contracted a vendor to develop an image-processing-based tool to quantify four of the five Damage Modes outlined in Table 9.3. Tools with similar capabilities may be developed by others, but at the time of publication of this protocol, the IBHS-Nemesis Impact Damage Evaluation Tool is the only known tool with the required capability. Objective tools capable of quantifying damage states are extremely important and are necessary to improve upon the human judgement-based pass/fail ratings of existing impact test methods (UL 2218, FM 4473). The quantities determined by the tool for each Damage Mode are utilized to assign a Severity Level for dent, ridge of dent, patch and individual granule loss. The breach Damage Mode utilizes expert judgement based on visual assessment to determine the Severity Level, as image-processing-based quantification of breaches has not been developed at this time.

The IBHS-Nemesis Impact Damage Evaluation Tool functions by requiring the user to take a large number of photographs (12 or more) from different angles to generate a 3D point cloud model of the individual impacted areas. The photographs must be taken from a relatively fixed distance and in relatively uniform lighting with no glare. Positioning targets are utilized to provide orientation and scaling for the images. Custom image processing algorithms are then run to extract the Damage Mode quantities.

The granule loss detection algorithm uses the 3D point cloud model by transforming the image into a new gray-scale image, since not all shingles are the same color. This allows color to be eliminated, so tone is used for the analysis. A thresholding operation is applied to the gray-scale image by assigning a value cutoff, such that every pixel less than that value is considered one class, while pixel greater than that value are considered a second class. This defines the background of the shingle (first class) as compared to the granules (second class) and produces a binary (black-white) image. A mean filter is then applied to the binary image to reduce the variation between one pixel and the next, resulting in a gray-scale image that represents the local evaluation of the density of the white pixels. A second thresholding operation is then applied to separate normal conditions from those in which the density of white pixels is abnormally low. This step produces another binary image where the black color represents areas of high probability of granule loss. The final step calculates the surface area of the black areas in the final image. Areas that have a surface area less than 2.58 mm^2 are considered individual granule loss, while those greater are classified as patch granule loss. The resolution of the pixels is 0.01 mm^2.

9.3. The breakpoints between quantities for Severity Levels for dent, ridge of dent, patch and individual granule loss were defined by fitting a curve and distribution of data from the IBHS-Nemesis Impact Damage Evaluation Tool for 40 impacts from seven common impact-resistant shingle products, for a total of 280 datapoints. The data for each Damage Mode were fitted with a log normal distribution. The breakpoints between Severity Levels 0–1, 1–2, and 2–3 were defined as the 25th, 50th, and 75th percentiles for the fitted distributions. These breakpoints are outlined in Table 9.3.

9.4. Intentionally left blank

9.4.1. Intentionally left blank

9.4.2. Intentionally left blank

9.4.3. Patch granule loss is considered more detrimental to the function and life of the shingle, so the Severity Level for patch granule loss is weighted twice that of individual granule loss.

9.5. Under existing impact test methods, a single “failure” rating for one impact location leads to a failure of the entire test. Under the protocol developed here, a more statistical and data-driven approach is taken, whereby the overall Performance Evaluation Rating for a given product and test class is evaluated according to the average performance of the impact locations, and not a single impact. This allows for better ability to compare and evaluate performance between test series, test classes, and products.

9.6. Intentionally left blank

9.7. Evaluation Procedure Example

1. Determine the quantities for dent, ridge of dent, patch granule loss, and individual granule loss Damage Modes for each impact using the IBHS-Nemesis Impact Damage Evaluation Tool (Step 1 in Figure C9.7-1).
2. Determine the Severity Level for dent, ridge of dent, patch granule loss, and individual granule loss Damage Modes for each impact using Table 9.3. Determine the Severity Level for breach by expert judgement (Step 2 in Figure C9.7-1).
3. Determine the Severity Scores (Step 3 in Figure C9.7-1):
    a. The Severity Score for deformations is equivalent to the average of the two Severity Levels for dent and ridge of dent.
    b. The Severity Score for granule loss is equivalent to the weighted average of the two Severity Levels for patch granule loss and individual granule loss (2:1 weight).
    c. The Severity Score for breach is equivalent to the Severity Level for breach.
4. Calculate an Individual Impact Severity Score for each impact (Step 4 in Figure C9.7-1).
5. Calculate the average BH Severity Score for all impacts.

6. Average all Individual Impact Severity Scores together and determine the Performance Evaluation Rating using Table 9.6.

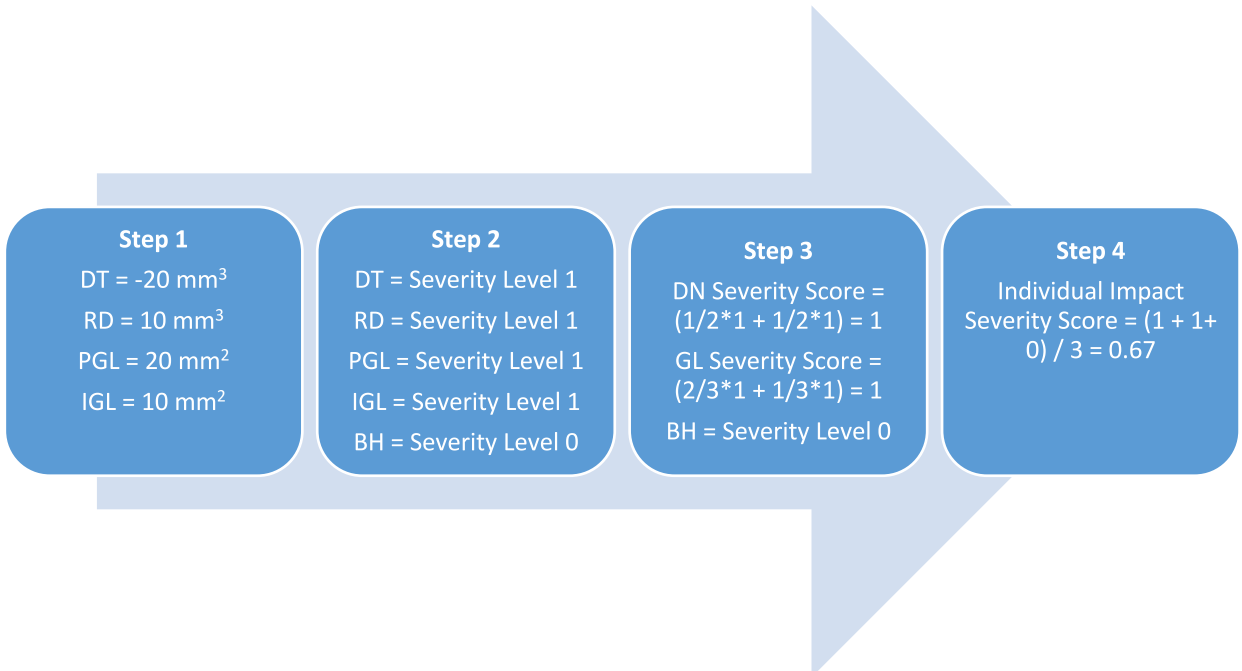

Figure C9.7-1. Example Individual Impact Severity Score.

REPORT

10. Report Requirements

10.1. Test results are derived from the specific product batch tested, and for the specific class tested. The product information and batch code are labeled differently for each manufacturer, thus the information recorded for different products may vary. Examples are included in Figure C10.1-1.

Figure C10.1-1. Examples of different labeling schemes used by shingle manufacturers. All codes should be recorded to ensure test results can be tied back to a specific shingle batch.

Inclusion of a table of impact test measurements is required, will ensure all impacts were within the range of allowable variability for mass and impact kinetic energy, and will ensure the required number of each Impact Mode was achieved. The percentage of Individual Impact Ratings and the final Performance Evaluation Rating will provide an overall single result for the test series.

APPENDIX A: Relationship between hailstone diameter and kinetic energy

The use of detailed measurements of 2,295 natural hailstones allowed the relationship between kinetic energy and maximum diameter to be derived.

This section provides the context for selecting impact kinetic energies applied in the described testing protocol. The relationships shown here are derived through application of improved aerodynamic assumptions described by Heymsfield and Wright (2013). The aerodynamic assumptions used in Laurie (1960), based on Bilhelm and Relf (1937), which formed the basis for previous impact testing protocols, were found using pure ice spheres. The non-homogeneous nature of hailstone shapes renders the aerodynamic properties and the derived diameter to kinetic energy relationships used in previous test protocols obsolete.

The departure from spherical shapes exhibited by natural hailstones is the primary driver of differences between the kinetic energies of Laurie (1960) and those determined through the methodology of Heymsfield and Wright (2013). The method described within Heymsfield and Wright (2013) was applied to a large number of natural hailstones with known measurements of the maximum diameter, minimum diameter, intermediate dimension, and mass. The use of natural hailstone measurements allowed Heymsfield et al. (2014) to derive more detailed relationships between hailstone diameters and their theoretical terminal velocities and kinetic energies. The improved functions account for the departure from spherical shapes and differences in density relative to pure ice. While hailstone densities are typically lower than that of pure ice, this influence is secondary when considering hailstone shapes. The influence of non-sphericity increases as hailstones get larger (Heymsfield et al. 2014, Giammanco et al. 2017). The robust field measurement catalog allowed for the observations to be stratified by percentile groups, enabling functions describing the range of possible kinetic energies. The functions are applicable for maximum diameters 1.5 cm (0.59 in.) or larger and are shown here:

- Mean: $KE = 0.0217\, D_{max}^{4.31}$
- Median: $KE = 0.0189\, D_{max}^{4.49}$
- 10–30th percentile: $KE = 0.014\, D_{max}^{4.05}$
- 30–50th percentile: $KE = 0.026\, D_{max}^{3.82}$
- 50–70th percentile: $KE = 0.032\, D_{max}^{4.11}$
- 70–90th percentile: $KE = 0.041\, D_{max}^{4.3}$

The test parameters outlined in Section 7.1 require the use of kinetic energies determined from the mean hailstone diameter-to-kinetic energy curve. The impact energies represent those expected from typical events. This method for determining impact kinetic energies can be applied to explore the range of possible impact energies for projectile diameters greater than 1.5 cm (0.59 in.). This has not been attempted or evaluated and is therefore outside of the scope of this test method.

APPENDIX B: Required properties of ice sphere projectiles

The test parameters outlined in Section 7.1 provide a testing framework that more accurately accounts for the properties of natural hailstones that influence the Damage Modes. The ice properties specified are based on field measurements and laboratory testing conducted by IBHS to aid in development of this test method. They represent a set of characteristics that were found to be repeatable in a laboratory, are representative of typical characteristics of natural hailstones, and produced Damage Modes consistent with those observed in the field.

B1. Mass and Density

The ice sphere specifications were developed through laboratory testing of manufactured ice at densities below that of pure water. Carbon dioxide gas (CO_2) was diffused into water (filtered by a reverse osmosis system) to introduce bubbles and lower the bulk density to fall within the range of natural hailstones. Ice characteristics needed to generate specific Impact Modes were obtained by changing the pressure and/or length of time in which the gas was diffused into the water, freezing temperatures and/or durations, and storage lengths and/or conditions. The prescribed masses and subsequent densities resulting from this testing were found to be repeatable. It is important to note that laboratory equipment and conditions will affect the controls and configurations that are necessary to obtain the targeted ice characteristics. Therefore, experiments must be conducted by each laboratory for the appropriate equipment to determine the combinations of settings that achieve the desired results.

The density of each specified projectile size and Impact Mode, provided in Table B1.1, is calculated from the prescribed mass and maximum diameter, assuming a spherical shape projectile. It is noted that natural hailstones of the same maximum diameter will have less mass due to their non-spherical shapes, which is accounted for by the specified impact kinetic energy.

Table B1.1. Specified Ice Sphere Impact Mode, Size Class, Nominal Maximum Diameter, Mass, and Density.

Impact Mode	Class	Diameter (cm)	Mass (g)	Calculated Density (g cm^{-3})
Soft	1.5	3.81	22.0	0.77
	2.0	5.08	51.5	0.76
Hard shatter	1.5	3.81	25.6	0.87
	2.0	5.08	60.7	0.87
Hard bounce	1.5	3.81	25.6	0.87
	2.0	5.08	60.7	0.87

B2. Compressive Stress

To analyze field observations and to compare these results to laboratory testing, the uniaxial compressive stress was selected as a proxy for the overall hardness property of natural hailstones. Throughout historical literature, hailstones are often referred to as “hard,” “soft,” or “slushy.” Giammanco et al. (2015) made quantitative in-situ measurements of the compressive stress of a large number of natural hailstones using a custom-designed apparatus. The data obtained from this device were compared to conventional laboratory UTM measurements to ensure the field device was capturing a relative measure of the maximum compressive load and subsequent compressive stress calculation. For more detailed discussion on the field device and its measurement characteristics, refer to Giammanco et al. (2015). Because data on laboratory and natural hailstone compressive strengths were obtained using the same field measurement device, they can be directly compared, such that it is possible to ensure that the laboratory ice spheres match the values obtained for the natural hailstones. Once the desired properties and Impact Modes were achieved for ice spheres that matched the compressive stresses and other properties found in natural hailstones, ice spheres were then tested under a compressive load using a UTM to determine the peak force requirements prescribed in this protocol. This ensures that other laboratories can replicate the necessary quantities using standard laboratory equipment. The peak compressive force values specified in Table 6-1 represent the average for each projectile size and Impact Mode. When used to calculate compressive stress for natural hail comparisons, the values for the "hard" Impact Modes fell near the median (0.5 mPa) of the distribution of natural hailstone measurements made by IBHS (2012–2017). The values prescribed in this protocol are near the 45th percentile of the IBHS hailstone compressive stress database. The compressive stress for the "soft" Impact Mode falls near the 20th percentile of the hailstone compressive stress distribution.

While both the UTM and custom field device provide a way to measure compressive stress to ensure conformity with set test parameters, neither has the capability to produce the high strain rates that occur during hailstone impacts—as compressive stress is dependent on strain rate for a given material. Thus, the stated values in Table 7.1 are not representative of natural hailstone compressive strengths at the time of impact, but rather provide a way to ensure ice sphere characteristics and Impact Modes are reasonably matched for repeatable laboratory testing of products.

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