Simulated Hail Damage and Impact Resistance Test Procedures For Roof Coverings and Membranes

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As a result of hail damage to roof coverings and membranes, insurance companies and property owners spend millions of replacement dollars annually. Over the years, several organizations have attempted to classify the impact or hail resistance of roofing systems. The intent in all cases was to provide some method of testing to quantify the relative hail resistance of roofing systems. Who could have imagined the resulting controversy surrounding finding a test method that would be satisfactory for all systems and meet the industry's needs?

Keywords: impact energy, impact resistance, hail resistance, kinetic energy, velocity, mass, steel, ice, plastic, roof membrane.

Introduction

Roofing related building code issues traditionally focused on fire resistance and structural loading of snow, wind, and drainage. As building codes evolved, numerous other construction issues came to the forefront including items such as ADA compliance. Historically, neither impact nor hail resistance were of significant concern.

Now, four major codes include provisions requiring roofing systems to meet minimum impact resistance requirements. Specifically, these codes include the *BOCA National Building Code* (BOCA)[1]; the *International Building Code* (IBC)[2]; the *Standard Building Code* (SBCCI)[3]; and the *South Florida Building Code* (SFBC)[4].

One assumes the intent of the code is for a building to be constructed with a roof covering or membrane offering some minimal level of resistance to impact or hail.

Technical Organizations

Technical organizations that have been involved with impact or hail testing procedures include:

American Society for Testing and Materials (ASTM)
Canadian General Standards Board (CGSB)
European General Agreement Board (EGAB)
Factory Mutual Research Corporation (FMRC)
National Institute of Science and Technology (NIST)
Underwriters Laboratories (UL)

The impact methods developed by these organizations utilize projectiles made of steel, plastic or ice. In the case of steel projectiles, darts or spheres of various impacting diameters are dropped from predetermined heights to produce an impact with the same kinetic energy possessed by the same diameter hail.

The European plastic sphere[5] and National Bureau of Standards NBS/NIST ice sphere projectiles[6] are pneumatically propelled. The projectile produces a kinetic energy equal to that of free falling hail.

Part of the problem lies in defining the terms "impact resistant" and "hail resistant". A secondary issue involves discerning whether the two terms are fully interchangeable. Additional challenges involve testing of various roofing products and determining whether impacting a roof system with a steel or plastic projectile produces damage that is comparable to hail.

Surprisingly, many of the test methods focus only on new or newly installed material tested only at room temperature. The effect of lower surface temperature often encountered during actual hailstorms and the effect of aging are not considered in most test methods. In fact, Koontz reported in 1991 that surface temperature at the point of impact could be a factor in hail damage.[7] William Cullen subsequently stated in 1992 "the results of testing new materials may not be valid since the hail impact resistance of many roofing materials changes upon exposure to weather."[8]

Impact and Hail Resistance Test Procedures

Depending on the test method, simulated hailstones of steel, plastic or ice are propelled or dropped onto test targets with predetermined impact energies. These values are derived from the impact energy of hailstones graphed by J.A.P. Laurie in 1960. Laurie graphed the relationship between terminal velocity, hail diameter and the approximate kinetic (impact) energy (Table 1).[9]

Diameter		Terminal Velocity			Approximate Impact Energy	
inches	*cm*	*ft/s*	*mi/hr*	*(m/sec)*	*ft lbs*	*Joules*
1	(2.5)	73	50	(22.3)	<1	(<1.36)
1-1/4	(3.2)	82	56	(25.0)	4	(5.42)
1-1/2	(3.8)	90	61	(27.4)	8	(10.85)
1-3/4	(4.5)	97	66	(29.6)	14	(18.96)
2	(5.1)	105	72	(32.0)	22	(29.80)
2-1/2	(6.4)	117	80	(35.7)	53	(71.9)
2-3/4	(7.0)	124	85	(37.8)	81	(109.8)
3	(7.6)	130	88	(39.6)	120	(162.7)

***Table 1**. Terminal velocities and energies of hailstones*

Standard Test Methods

The American Society of Testing and Materials (ASTM) Factory Mutual Research Corporation (FMRC) and Underwriters Laboratories (UL) each have standards for impact resistance or hail resistance.

ASTM D 3746: ***"Standard Test Method for Impact Resistance of Bituminous Roofing Systems"[10]***
FM 4470: ***"Susceptibility to Hail Damage, Test Standard for Class 1 Roof Covers"[11]***
UL 2218: ***"Impact Resistance of Prepared Roof Coverings"[12]***

Additional standards include: CGSB 37-GP-56M Canadian General Standards Board *"Standard for Membrane, Modified, Bituminous, Prefabricated and Reinforced for Roofing (Dynamic Impact (Puncturing)) Test"[13] and ASTM D 4272 "Standard Test Method for Total Energy Impact of Plastic Films by Dart Drop".[14]*

A closer look into a few of these methods reveals significant variations, not only in the procedures utilized, but also in the resultant data and subsequent certification attained. With the ASTM D 3746 method, a steel dart drops from a predetermined height impacting bituminous test targets with impact energy 22-ft. lbs. (30 J). A standard provision allows the test to be performed at any desired temperature and on new or insitu membranes. ASTM recognizes the importance of temperature and aging with this standard.

FMRC certifies roof coverings for hail resistance. This test method utilizes steel balls dropped onto test targets from various heights. Two FMRC certifications are available: Class 1 - SH (Severe Hail Resistance); and Class 2 - MH (Moderate Hail Resistance).

UL certifies roof coverings or membranes for impact resistance. The method utilizes four sizes of steel balls dropped at various heights onto a roofing system test target. The impact resistance is based on four classes with Class 4 the most resistant. Testing is performed on new roof coverings at room temperature.

Several notable differences exist between the test methods utilized by FMRC and UL. For instance, artificial weathering is employed in the FMRC test procedure but not in the UL. FMRC procedures address new roof coverings (or membranes on test decks) and similar ones exposed to 1,000 hours of weathering. UL procedures test new material only.

Further review of the procedures used by FMRC and UL indicates that UL requires separation of bituminous or multi-layer samples into individual components to determine internal damage from impact. In some cases, as with SBS membranes, the membrane may pass the impact test with slight granule loss. However, separation of the sample may reveal interply mopping asphalts have been fractured as shown in Figure A. The FMRC procedure does not require separation of the sample; instead, visual examination of the top and bottom of the sample is considered adequate.

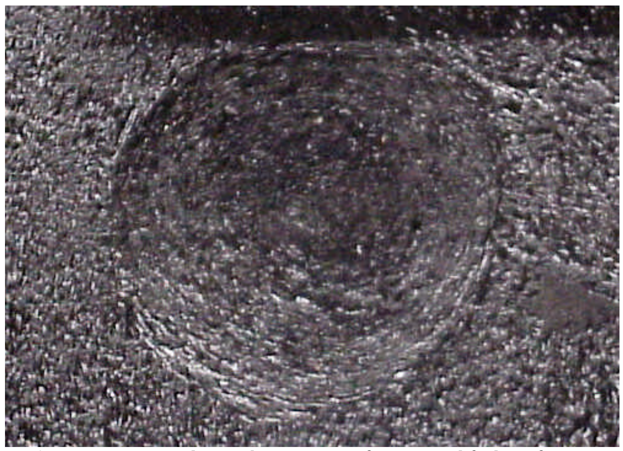

***Figure A.** Fractured Interply Moppings of a SBS Modified Roof System*

It should be noted that both FMRC and UL test procedures are performed at room temperature, without taking into account the temperature drop usually experienced during a hail event.

The testing inconsistencies between FMRC and UL may result in one roofing system passing a hail test, but failing the impact test of the other organization.

For comparison, Table 2 summarizes the respective test standards, parameter and impact energies of the ASTM, FMRC and UL methods.

Standard	Missile Parameters			
	Diameter, in (mm)	**Mass lbs (kg)**	**Distance, ft (mm)**	**Energy, ft. lbs. (J)**
ASTM D 3746	2” (50)	(2.27)	4’5.0” (1355)	22 (30.0)
FM Class I-SH	1.75” (45)	(.360)	17’9.5” (5400)	14 (19.0)
FM Class I-MH	2” (51)	(.737)	5’ (1500)	8 (10.8)
UL Class 1	1.25” (32)	.28 (.127)	12’ (3700)	3.36 (4.6)
UL Class 2	1.5” (38)	.48 (.218)	15’ (4600)	7.2 (9.8)
UL Class 3	1.75” (46)	.79 (.358)	17’ (5200)	13.43 (18.3)
UL Class 4	2” (51)	1.15 (.521)	20’ (6100)	23 (31.2)

***Table 2**. Kinetic energies produced by ASTM, FM, and UL standard test methods.*

Ice Sphere Method

Another test method involves propelling an ice sphere at a roofing target. The NBS Series 23 (Ice Sphere Method) is based on the early work of Sidney Greenfield. Using ice spheres, Greenfield researched the hail resistance of various roofing materials. Greenfield utilized the terminal velocities and impact energies by Laurie (Table 1) in his research and these continue to be the primary values used today.

In February 2000, FMRC published test standard Class Number 4473 *"Specification Test Protocol for Impact Resistance Testing of Rigid Roofing Materials by Impacting with Freezer Ice Balls"*.[15] This standard lists four classifications with Class 4 as the highest rating available. This test standard was established to meet Texas Department of Insurance and other state jurisdictional requirements for impact resistance by hail. The standard does not qualify products for a Factory Mutual Approval at this time.

FMRC 4473 references NBS Building Science Series 23 by Greenfield and clearly specifies "for new material only". According to the test protocol, one is to "visually scrutinize top and bottom surfaces of test specimen" after impact. Separation and examination of individual layers is not specified. Temperature during testing is to be maintained between 60° and 90°F. Impact energy values are slightly higher as FMRC utilizes increased velocities of the hail spheres.

Research Methodology

Jim D. Koontz & Associates, Inc. (JKA) performed research to explore potential differences in the test methods, focusing on three common test methods: FMRC 4470, UL 2218 and the NBS Ice Sphere Method. Selecting an approximate impact energy of 14 ft-lbs allowed comparison between UL 2218 Class 3, the FM Severe Hail Test, and the NBS 1.75-inch ice sphere test methods.

The testing process included Thermoplastic Olefin (TPO), Styrene Butadiene Styrene (SBS) Modified, Clay Tile, Concrete Tile, Atactic Polypropylene (APP) Modified, Built-Up Roofing (BUR), Shingles, Ethylene Propylene Diene Monomer (EPDM) reinforced and non-reinforced, and Poly-Vinyl Chloride (PVC) reinforced and non-reinforced. In order to compare impact methods, limited product samples were tested. Results should not be seen as a reflection of product group performance.

Test Targets

Deck construction below all test roof systems consisted of 3-foot x 3-foot x 1/2-inch CDX plywood. The single ply impact targets consisted of the membrane and two layers of 1-inch polyisocyanurate insulation. The BUR and Modified Bituminous Membrane target construction consisted of the membrane installed over 1-inch perlite insulation. The shingle and tile test targets consisted of the shingle/tile and underlayment.

Test Variables

Although temperature at the time of impact and membrane aging are not considered in most test methods, both variables were incorporated into the JKA testing process. All roofing systems were first tested at room temperature. To explore the potential effect on impact resistance, the temperature of the roof membranes was lowered to 40^{o} F. This was accomplished by using a manifold or a nozzle system (or both) to distribute chilled water over the test target.

Actual field samples of varying ages were used to address the effect of aging. According to Koontz, most new single ply membranes initially have a high degree of impact resistance.[16]

While some material such as tile and EPDM appeared unaffected by age and temperature, clear differences were observed in shingles and PVC's. Tests on several different new roof membranes at lower temperatures also revealed substantially different results with some of the tested materials.

Roofing Materials Tested

1. *TPO*: New material, **Passed** UL Class 3, FM-SH, and NBS 1.75-inch ice sphere at room temperature and 40° F.
2. *SBS*: New material, Fractured interply asphalt at room temperature and 40°F, all methods. This would be considered **Failed** under UL Class 3 and **Passed** on FM-SH since with FMRC the membrane components are not individually examined. **Failed** NBS 1.75-inch ice sphere method @ 40°F, membrane fracture.
3. *SBS*: Aged material (14 yrs), Fractured interply asphalt at room temperature and 40°F all methods. This would be **Failed** under UL Class 3 and **Passed** under FM-SH. **Failed** NBS 1.75-inch ice sphere method @ 40°F, membrane fracture.
4. *Clay Tile*: Aged material, **Failed** UL Class 3 and FM-SH at room temperature and 40°F. **Passed** NBS 1.75-inch ice sphere method at room temperature and 40° F.
5. *Concrete Tile*: Aged material, **Failed** UL Class 3 and FM-SH at room temperature and 40° F.

Passed NBS 1.75-inch ice sphere method at room temperature and 40° F.

6. *APP*: New material, **Passed** UL Class 3, FM-SH and NBS 1.75-inch ice sphere at room temperature and 40°F. Slight granule loss at impact point when tested at 40°F.
7. *BUR*: New material, **Passed** UL Class 3, FM-SH and NBS 1.75-inch ice sphere at room temperature and 40°F. Note interply fracture of asphalt observed at 40°F with FM-SH Test. The FM test does not require separation; therefore, this damage would not be detected.
8. *Shingles*: New material, (180 wt.), **Failed** UL Class 3, FM-SH and 1.75-inch ice sphere method at room temperature and 40°F. The fiberglass mat fractured during NBS 1.75-inch ice sphere method at 40°F.
9. *EPDM Non-Reinforced*: Aged material (15 yrs.), **Passed** UL Class 3, FM-SH and NBS 1.75-inch ice sphere method at room temperature and 40°F.
10. *EPDM Reinforced*: New material, **Passed** UL-Class 3, FM-SH and NBS 1.75-inch ice sphere method at room temperature and 40°F.
11. *PVC Non-Reinforced*: New material, (5 mos.), **Passed** UL Class 3, FM-SH, NBS 1.75-inch ice sphere method at room temperature. **Passed** UL Class 3 and FM-SH at 40°F. F**ailed** 1.75-inch ice sphere method at 40°F. This product had a FM Class 1-SH rating.
12. *PVC Non-Reinforced*: Aged material, (8 yrs.), **Passed** UL Class 3 at room temperature. **Failed** FM-SH and NBS 1.75-inch ice sphere method at room temperature. **Failed** UL Class 3, FM-SH and 1.75-inch ice sphere at 40°F.
13. *PVC Reinforced*: New material, **Passed** UL Class 3, FM-SH and NBS 1.75-inch ice sphere method at room temperature and 40°F.
14. *PVC Reinforced*: Aged material, (6 yrs.), **Failed** UL Class 3, FM-SH, and NBS 1.75-inch ice sphere method at room temperature and 40°F.

Steel or Ice

Obviously the impact energy from dropping a steel ball can be calculated to equate to the kinetic energy of ice in the form of hail. However, as the research has shown, test methods employing a steel ball do not always reflect an accurate accounting of a roof coverings hail resistance capability.

Consider the controversy which arose when the Texas Department of Insurance (TDI) adopted a program of discounts or reductions in residential insurance premiums that relied on the finding produced using the UL 2218 test method. JKA research indicates that roof coverings such as slate, concrete or clay tile will withstand impact from an NBS 1.75-inch ice sphere, but can fail even under the minimum UL Class 1 rating (1.25-inch steel ball dropped at a height of 12-feet).

The answer to the technical question of why some roofing systems fail when impacted with steel versus ice is relatively simple. The ice spheres will compress or crush upon impact with a very hard surface such as concrete tile. Figure B depicts an ice sphere at the moment of impact with a concrete tile. A slight crushing of the ice is seen to occur at the surface of the sphere.

***Figure B**. Ice Sphere at Moment of Impact with Concrete Tile.*

When steel projectiles are used, however, the fact that the steel is much harder than the concrete and does not compress can result in a tile failure. The moment of impact of a steel projectile upon a concrete tile is captured in Figure C.

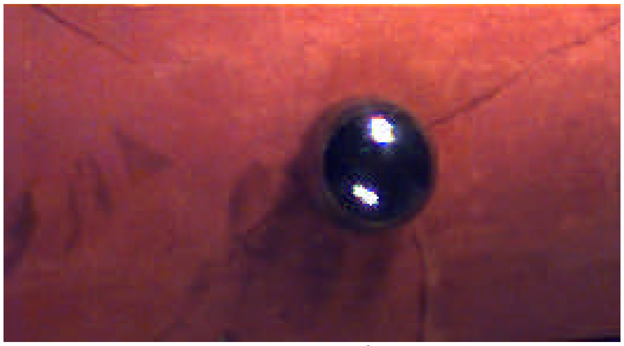

***Figure C**. Steel Projectile at Moment of Impact with Concrete Tile.*

Both projectiles, the ice and steel, struck the concrete tiles with the same impact energy. Therefore the impact failure with steel does not accurately reflect the tile roofing products true hail resistance.

Building Codes

Building codes are an important consideration when discussing roof failures. As previously stated, all four of the model code agencies now address impact resistance. The IBC, SBCCI, and SFBC requirements apply to roof slopes less than 2 in 12. BOCA applies to all roofs and roof coverings.

Each code, with the exception of SFBC which refers to FM 4470 only, lists four test methods for impact resistance: ASTM D 3746, ASTM D 4272, CSGB 37-GP-56M and FM4470. It is important to note that the code requirements provide a choice between test methods.

Choose Wisely

Depending on the test method selected, the impact energy varies from 3.6 ft lbs to 22.0 ft lbs. This equates to approximately a 1-1/4-inch hail for the 3.6 ft-lbs to a 2-inch hail for the 22.0 ft-lbs, a significant difference. As summarized in Table 3, one can quickly determine the inequality of the test methods.

Method	**Impact Energy**	**Projectile**
FM 4470	14 ft-lbs	1.75" Steel Ball
ASTM D 3746	22 ft-lbs	2.00" Dart
CGSB 37-GP-52M	3.6 ft-lbs	0.222" Puncturing Tip
ASTM D 4272	5.42 ft-lbs	1.50" Dart

***Table 3**. Impact Energies of Projectiles*

Since the codes are not specific as to selection of a test method for specific roof coverings or membranes, one assumes if challenged, the test method will be chosen based on best results for a particular material. This is an area for further research, one that the authors are currently undertaking.

Conclusions

It is clear the current test methods available for product hail resistance certifications will not work for all roof coverings. Based on JKA research, several key points became evident.

- Some test methods represent an ineffective measure of a membranes field ability to withstand hail.
- Temperature at the time of impact will affect the results of some membranes.
- Resistance of some membranes changes with aging.
- Internal damage is not always apparent on the surface of bituminous systems. Separation of the membrane may be necessary to evaluate internal product damage.

Manufacturers could face potential liability when products fail as a result of the size of reported hailstones less than the requirements of the code. Graham cautioned manufacturers, roof system designers and contractors not to misrepresent a roof systems performance during hailstorms.[17]

Because building codes are an important consideration when discussing roof failures, it would appear that code organizations need to more clearly define which test method is required for each roof covering or membrane; or list which test methods closely mirror one another in equivalent results so that a more equitable comparison is achieved. Is their intent for "hail resistance" as the FM test is centered on, or for "impact resistance" which would be the UL, ASTM or the CSGB method?

Of the current test methods, FM 4473 and NBS Series 23 are the most realistic as hail resistance testing for all roof coverings. Shortcomings of the two test procedures are temperature at the time of impact and examination methods. Results obtained from steel ball tests as an indicator for hail resistance are not applicable. While ice spheres are currently the closest simulation of hail, one should not consider them an exact replication.

Building owners, consultants and manufacturers should carefully evaluate a products hail resistance prior to considering its use in hail prone areas. Products with certifications may not perform as represented since temperature and, in some cases, aging are not part of the test procedure upon which the certification was based.

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