# HAIL DAMAGE TO ROOFING: ASSESSMENT AND CLASSIFICATION

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Storm damage complaints and large insurance payouts in the Southwestern and Midwestern United States have generated a renewed interest in hail as a destructive force to roofing. There is an inventory of hail damage information resulting from field investigations and many insurance claims. However, information about the assessment and classification of damage to roofs by falling hailstones is lacking. Part I of this paper suggests procedures for on-the-roof assessment of hail damage. It assigns damage susceptibility factors for eight generic roof systems with respect to damage types.

Part II proposes a classification system for rating the resistance of roofing products to hailstones. Hail testing has been carried out in laboratories using simulated hailstones to impact roofing products for many years. The results have been reported in the technical literature. Using these results, kinetic energy is proposed as the criterion for quantifying hail resistance of roofing products. This allows for making reasonable comparisons between the results of the many different test methods used to measure the hail resistance. Such a system can be useful to standard developers, insurance companies, contractors, manufacturers, owners, regulators, researchers and other interested parties.

## KEYWORDS

Assessment, classification, criteria, damage, hail, kinetic energy, resistance, roofing, test methods.

## INTRODUCTION

Hailstorms cause considerable damage to residential and commercial roofing each year. Smith[1] reported that, since 1989, the insurance industry estimates that hail damage to buildings averages $1.94 billion per year. Hailstorm damage in the Southwestern and Midwestern United States has generated a renewed interest in hail as a destructive force to roofing. This is reflected in escalating insurance settlements, increasing owner complaints, and requests for information about evaluating and repairing hail damage. Although information on hail tests is reported in technical literature, little deals with the assessment or classification of hail damage to roofing. This paper addresses these subjects.

Part I offers guidelines for the assessment of hail damage to commercial and residential roof systems. It asserts that testing may be required to supplement visual observations to identify concealed damage that can adversely affect the waterproofing integrity and the service life of the roofing membrane.

Part II proposes a classification system for rating the hail resistance of roof systems. Kinetic energy is used as a quantitative measure to classify the hail resistance of roofs as proposed by Mathey.[2] The threshold criteria used are interpreted from data reported in the technical literature. Several benefits from the establishment of a reasonable classification system are described.

## HAIL AND HAILSTORMS

It is beyond the scope of this paper to review the theories of hail formation, storm types, storm development, and other theoretical and practical information regarding hailstones and their characteristics. This information can be found in the literature. Hailstorms rarely produce hailstones of uniform size, shape or density. In most cases, these storms produce hailstones that are relatively small and render little danger to roofing materials. However, each year there are rare storms that yield hailstones in the range of 13 to 75 or even 100 mm (½ to 3 or even 4 in) in diameter.

U.S. Weather Bureau data[3] show that the most likely areas of the United States to encounter hailstorms lie between the Appalachian and Rocky mountains. A method for predicting the frequency and probability of hail size in the Midwestern states was reported by Friedman.[4] Figure 1 illustrates the annual frequency of the number of days on which hail falls that he estimated for the Midwestern states. Using several

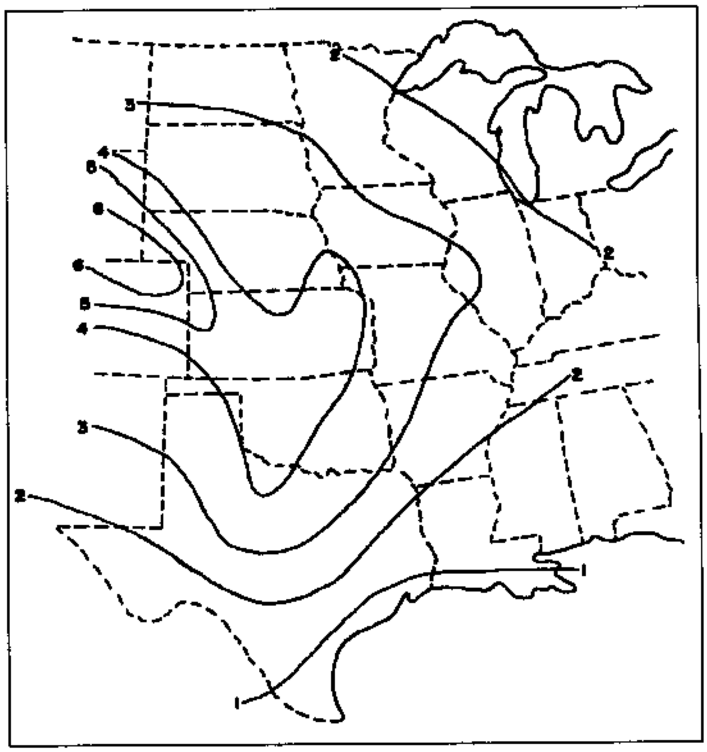

*Figure 1. Average annual number of days with hail in the Midwestern states.*[5]

| Average Annual No. of Days | Hail Stone Size, mm | | | | | | |
|---|---|---|---|---|---|---|---|
| with Hail | <13 | 13-25 | 25-38 | 28-50 | 50-63 | 63-75 | + 75 |
| 2 | 61% | 28% | 4% | 3% | 2% | 1% | 1% |
| 4 | 44% | 43% | 4% | 4% | 3% | 2% | 1% |
| 6 | 25% | 58% | 6% | 5% | 3% | 1% | <1% |

*Table 1. Probability of hail size when a hail day occurs.*[5]

sources of data, Friedman also calculated the probability that hail will be of a certain size on a day that hail occurs as exemplified in Table 1. Information on hailstorm frequency is also reported in a Factory Mutual Data Sheet.

## PART I—HAIL DAMAGE ASSESSMENT

### Foreword

Most roof systems are susceptible to damage resulting from the impact of large hailstones falling at high velocities. The extent of damage depends on the nature of the roof system, i.e., materials and design as well as the force produced by the impact of falling hailstones. Other factors, such as age and surface temperature at time of impact, may also come into play.

Hail damage can be cosmetic or substantial. The effects of hail damage often can be readily seen. But, visual observation of roof surfaces often does not reveal serious damage. This may include weakening of granular adhesion, fractures, punctures and the like. Damage to the substrate also can occur. In such cases, testing is required to help determine the extent of the damage to the roof system's components. Unfortunately, some damage may not be apparent until after months or years of exposure. If substantial damage has occurred, the roof system's waterproofing integrity is at risk and its service life threatened.

### Inspection and Testing

A thorough inspection for damage is recommended after exposure to large hailstones. Initially, a "walk over" of the roof is made noting the extent, type and intensity of visible damage. Particular attention should be given to the more vulnerable roof areas including flashings, seams, material edges and unsupported areas. Probe questionable areas to decide if further study is warranted. If substantial damage is suspected, testing may be required.

Samples should be taken from the damaged areas. The samples and the exposed substrates are examined for defects caused by the hailstones impact. The components or plies of bituminous-based materials can be separated by solvent extraction or other suitable means to establish the full extent of concealed damage. This can be accomplished on-site with proper equipment, but it is more conveniently done in a laboratory. Specific testing techniques are required to detect hidden damage to other materials such as single-ply membranes, shingles, metal and inorganic materials.

### Damage Grouping

Various generic roof systems are susceptible to distinctive types of hail damage. It is beneficial to become familiar with the types of damage associated with generic systems for inspection and testing purposes. Some examples follow:

| Roof System | Type of Damage | | | | | | |
|---|---|---|---|---|---|---|---|
| | GRL | IND | FRC | SHR | PCT | PLS | SBS |
| Asphalt Shingles | X | X | X | | | X | X |
| Prepared Roofing | X | X | X | | X | X | X |
| Bituminous BUR | | X | | | X | X | X |
| Single-ply Membranes | | X | X | X | X | | X |
| Wood Shingles | | X | X | | X | | X |
| Inorganic Tiles, Slates, etc. | | | X | X | | | X |
| Metal | | X | | | X | | X |
| Modified Bitumen | X | X | | | X | X | X |
| Spray. Poly. Foam | X | X | X | | | | |

Key: GRL - Granule loss; IND - Indentation; FRC - Frct/Crack; SHR - Shatter; PCT - Puncture; PLS - Ply sep.; SBS - Substrate Related Problems

*Table 2. Susceptibility of generic roof system to hail damage class.*

Bituminous BUR: Membrane fracture, flashing puncture and cracking, interior ply fracture or separation, interface separation between membrane and substrate, and substrate damage.

Modified Bitumen: Weakening of granular adhesion, granule loss, cracking, puncture, insulation facer separation, substrate delamination and substrate damage.

Single-Ply Membranes: Indentation, puncture, cracking, shatter, substrate damage, fracture at fasteners and membrane/substrate delamination.

Asphalt Shingles: Weakening of granular adhesion, granule adhesion loss, fracture, puncture, component delamination, and valley flashing and substrate damage.

Prepared Roofing: Weakening of granular adhesion, indentation, fracture, puncture, component delamination and substrate damage.

Wood Shingles: Fracture, puncture, splitting and substrate damage.

Inorganic Tiles, Slates, etc.: Shatter, cracking, fracture and substrate damage.

Metal Roofing: Indentation, creasing, coating adhesion loss and puncture.

Sprayed Polyurethane Foam: Indentation, fracture, surface cracking and coating damage.

### Maintenance and Repair

Maintenance and repair options for hail damage are very broad. Just as damage is roof-system specific, maintenance and repair alternatives are also roof system specific. Repair decisions must follow after analysis of data from visual observations and test results. The significance and degree of damage will determine the remedial techniques required. These options include spot repair, recoating, recovering the damaged areas and, in extreme cases, reroofing of the damaged system. The economics of repair vs. reroofing should dictate the choice.

**Summary**
Unfortunately, there are a lack of procedures for assessing hail damage both on actual roofs and on hail-damaged samples in the laboratory. These procedures need to be developed. Lacking them, the assessment of hail damage sustained by common roof systems requires system specific analysis. Data and information ensuing from observations and test results are required to carry out the analysis. Maintenance and repair decisions rely on the information available and judgments of qualified professionals based on the analysis of the available data.

## PART II—HAIL RESISTANCE CLASSIFICATION SYSTEM

### Test Methods

Test methods for impacting roofing targets with simulated hailstones are described in the literature. Some methods use compressed air guns to propel projectiles at targets. Timing devices are used to measure projectile velocity either initially or just prior to impact. Other methods use projectiles dropped on targets from predetermined heights. In each case, the impact energy resulting from the projectile impact can be calculated.

The composition of the commonly used projectiles to simulate hailstones include ice, metal and plastic missiles. They vary considerably in density, shape and size. Consequently, there is considerable debate among researchers regarding the dissipation of energy of the various types of missiles when they impact a target. This is a fruitful subject for further research.

A test method, developed at the National Bureau of Standards* (NBS),[5] uses ice spheres varying in diameter from 25 to 75 millimeters in increments of 6 millimeters (1 to 3 inches in increments of ¼ inch). The spheres are propelled at velocities of 23 to 40 m/s (75 to 131 ft/s) to impact the target resulting in impact energies varying from about 1.4 to 63 joules (1 to 46 ft. lbf).

Table 3 relates hailstone size and terminal velocity† to kinetic energy as reported by the National Building Research Institute of South Africa.[6] The table gives the data and Figure 2 illustrates these data in terms of the relation between size, velocity and impact energies achieved by falling hailstones. The data show that the impact energies increase exponentially with the increase in size and velocity of ice spheres. The energy nearly triples from the impact of a 38 mm to a 50 mm (1½ to a 2 inches) hailstone from 11 to 30 joules (J) (8 to 22 ft. lbf).

In 1991, Koontz[7] reported on hail impact tests on residential roofing products. Ice spheres, 19 to 63 mm( ¾ to 2½ inches) in diameter, were projected at roofing targets at velocities of 20 to 36 m/s (65 to 118 ft/s). The resulting impact energies varied from about 1.4 to 72 joules (1 to 53 ft. lbf).

At another laboratory,[8] a pneumatic gun was used to impact targets with ice projectiles of various shapes, sizes and densities. The projectiles, up to 75 mm (3 inches) in diameter, were propelled at speeds in excess of 40 m/s (131 ft/s) resulting in impact energies exceeding 163 joules (120 ft. lbf). Tests were conducted on a variety of roofing products.

*Now the National Institute of Standards and Technology (NIST).
†Terminal velocity is the limiting uniform velocity attained by a falling body when the resistance of the air has become equal to the force of gravity.

| Diameter (mm) | Terminal Velocity* (m/s) | Kinetic Energy Joules (J) |
|---|---|---|
| 25 | 22 | 1 |
| 31 | 25 | 6 |
| 38 | 28 | 11 |
| 44 | 30 | 19 |
| 50 | 33 | 30 |
| 56 | 36 | 72 |
| 69 | 38 | 110 |
| 75 | 40 | 163 |

* *Terminal velocity is the limiting uniform velocity attained by a falling body when the resistance of the air has become equal to the force of gravity.*

*Table 3. Size, terminal velocities, and energies of hailstones.*[8]

In contrast to using ice spheres to impact samples, the Swiss Federal Laboratory for Materials and Research[9] (EMPA) impacted various building envelope products with plastic spheres, 40 mm (1½ inches) in diameter with a mass of 38.8 grams(0.09 lbm). The velocity of the plastic spheres propelled by compressed air was varied from 2 m/s (6 ft/s) to over 30 m/s (98 ft/s) resulting in kinetic impact energies from 1 to about 20 joules(1 to about 15 ft. lbf). In this procedure, the surface of the samples are cooled with crushed ice prior to impact of the plastic missiles.

*Standard test methods*
ASTM, Underwriters Laboratories (UL) and Factory Mutual Research Corporation (FMRC) promulgate standards for measuring the impact resistance of roof coverings. The three test methods are similar in concept in that each measures the resistance of roof systems to the impact of metal missiles of weight, size and shape as specified in each method.

The ASTM method[10] subjects samples of bituminous roof systems to the impact of a missile (steel cylinder) falling from a predetermined height imparting an impact energy of 30 joules(22 ft. lbf). Damage is assessed by visual examination of the reinforcing felts after solvent extraction. The method suggests a resistance rating be assigned as follows: 0 = no

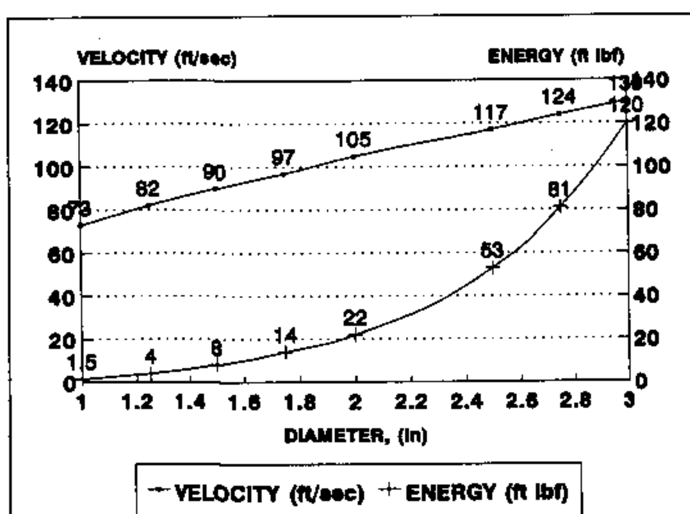


*Figure 2.*

damage, 2 = indentations only and 4 = cracks or splits.

The FMRC method[11] determines the potential for hail damage of roof covers adhered to insulation and various concrete, metal, gypsum and wood decks. Test surfaces are artificially cooled prior to testing. Two separate hail damage tests are used. One test measures the resistance to severe hail damage (Class I-SH) by subjecting the sample to an impact energy of 19 joules (14 ft. lbf). The second measures hail resistance of roof coverings to moderate hail damage (Class I MH) by delivering an impact energy of 10.8 joules(8 ft. lbf).

The UL method12 provides impact resistance data for the evaluation of several different roofing materials and roof coverings. The performance is predicated on the materials and coverings resistance to falling steel balls dropped from predetermined heights thus generating energies consistent with hailstones falling at terminal velocities. Various techniques are used to assess the resulting damage.

Table 4 provides the test parameters and the energies produced by the impacting missiles in the ASTM, UL and FMRC test methods.

**Test Results**

*Asphalt shingles*

The NBS research involved the testing of a variety of asphalt shingle products. Type 235 organic reinforced asphalt shingles were impacted with hailstones at three areas of the shingle tab: at the edge, at areas of no support and at areas of triple coverage. Testing was performed on shingles applied to plywood and tongue and groove wood decks with and without organic felt underlayments. The criterion used to define the endpoint was the impact energy required to fracture the shingle reinforcement. Table 5 summarizes the results of hail testing on shingles.

Koontz reported test results on organic and fiberglass reinforced asphalt shingles. The shingles varied in quality from the standard class to the laminated products. The shingles were applied to plywood decks and tested at room temperatures. Table 6 reports minimum energy* sufficient to cause indentation, fracture and puncture.

*Built-up roofing*

Four types of built-up roof constructions used in the 1960s were tested in the NBS hail research program. The samples included: 1) base sheet and 3 plies of #15 felt, 2) base sheet and 3 plies of asbestos felts, 3) two plies of glass reinforced felts covered with coated glass reinforced sheet and 4) base sheet and 3 plies of coal tar felt. The membrane systems were tested over substrates of various densities and, in some cases, were tested with and without a 14 kg/m² (2.9 psf) slag surfacing. The result of the NBS hail tests, as interpreted from Greenfeld's data[7] in terms of minimum energy to cause damage, are reported in Table 7.

More recent hail testing (1991)[10] of a weathered four-ply, organic felt BUR support the NBS test results by demonstrating that spherical hailstones must attain energies in excess of 30 joules (22 ft. lbf ) to cause damage.

**Classification System for the Hail Resistance for Roofing**

Based on hail research and testing results reported in the literature, it is logical to propose a classification system for measuring the hail resistance of roof systems. A performance for-

| Standard | Missile Parameters | | | |
|---|---|---|---|---|
| | Diameter, mm | Mass kg | Distance, mm | Energy, J |
| ASTM D-3746 | 50 | 2.27 | 1355 | 30.0 |
| FM Class I-SH | 45 | .360 | 5400 | 19.0 |
| FM Class I-MH | 51 | .737 | 1500 | 10.8 |
| UL Option 1 | 32 | .127 | 3700 | 4.6 |
| UL Option 2 | 38 | .218 | 4600 | 9.8 |
| UL Option 3 | 46 | .358 | 5200 | 18.3 |
| UL Option 4 | 51 | .521 | 6100 | 31.2 |

*Table 4. Kinetic energies produced by the ASTM, FM, and UL standard test methods.*[12, 13, 14]

| Deck Type | Energy Required to Fracture ReinforcementJoules (J) | | | | | |
|---|---|---|---|---|---|---|
| | No Underlayment | | | #15 Felt Underlayment | | |
| | Edge | No Supt. | Triple Cover | Edge | No Supt. | Triple Cover |
| Plywood (13 Mm) | 19 | 19 | 19 | 11 | 11 | 19 |
| T&G (25x150mm) | 30 | 19 | 72 | 11 | 11 | 30 |

*Table 5. Test results on Type 235 asphalt, organic shingles.*[5]

| Asphalt Shingles | | | Failure Criteria Kinetic Energy (J) | | |
|---|---|---|---|---|---|
| Reinforcement | Type | ASTM Std | Indent. | Ind/fract | Puncture |
| Fiberglass | #210 | D-3018 | 19 | 30 | None |
| Organic | #235 | D-225 | 5 | 19 | None |
| Fiberglass | #260 | D-3018 | 5 | 30 | None |
| Fiberglass | #300 | D-3018 | 5 | 30 | None |
| Organic | #240 | T-lock | 5 | 19 | None |
| Fiberglass | N/A | T-lock | 5 | 19 | None |

*Table 6. Hail test results of asphalt shingle products.*[5]

| Membrane Roofing | | | Kinetic Energy (J) | | |
|---|---|---|---|---|---|
| Type | Substrate | Surface | I[a] | C[b] | P[c] |
| Bur, 4-Ply Organic | Dense | Smooth | 11 | 30 | + 72 |
| " " " | Fbr Board | Smooth | 11 | 30 | + 72 |
| " " " | Fbr Glas | Smooth | 11 | 30 | 72 |
| Bur, 3-Ply, Glass | Dense | Smooth | N/a | + 30 | + 72 |
| " " " | Fbr Board | Smooth | 11 | + 30 | + 72 |
| | Fbr Glas | Smooth | 11 | + 30 | + 72 |
| Bur, 4-Ply Organic | All | Aggregate | + 30 | + 72 | + 72 |

[a] Surface Indentation
[b] Surface Cracking
[c] Puncture

*Table 7. Minimum hailstone impact energy to damage BUR.*[7]

**Interpreted from reported data.*

mat was selected using impact energy as the criterion to classify the hail resistance of roofing. This permits a reasonable comparison of results between existing test methods and those being developed.

Requirement—Roof systems shall resist the impact of hailstones without impairment to their waterproofing quality or longevity of service life. In some cases, a secondary requirement may need to be stated that addresses the aesthetics of a roofing system.

Criteria*—Table 8 lists the energies produced by the impact of simulated hailstones that roofing materials shall resist without fracture, shatter, puncture, ply separation, component separation, substrate damage and the like. These criteria are based on the test results reported in the literature and referenced in this paper.

Test Method—The following is a sample test procedure only. The test conditions may be varied as necessary to comply with the test objectives.

- Prepare the roofing system sample as specified. A convenient size for testing impact resistance is approximately 900 x 900 mm (3 x 3 feet).
- Condition sample as required to simulate such conditions as temperature, aging (both artificial and natural), repeated impact areas and the like.
- Select several areas of the target for impact, including the more vulnerable areas.
- Impact selected areas with missiles of a size and at a velocity sufficient to attain the impact energies desired.
- Conduct test at the desired temperature. Impact target at the desired angle. Note: During hailstorms, surface temperatures and impact angles my vary considerably. Therefore, researchers may wish to select other variables than those stated above.
- Examine the impacted areas, paying particular attention to the more vulnerable areas for visible signs of damage such as fracture, puncture or other indications of damage as listed in the criteria.
- If needed, conduct additional tests on the impacted area to reveal the type and extent of any hidden damage.
- Classify hail resistance according to the energy criterion reported in Table 8.

Commentary—A word of caution is appropriate for those conducting hail impact tests. Impact energy is determined by the mass of a moving (falling) body multiplied by its velocity multiplied by itself as expressed by the equation, $E = \frac{1}{2} mv^2$.

| Class | Rating | Kinetic Energy, J |
|---|---|---|
| 1 | Superior | 30 |
| 2 | High | 20 to 30 |
| 3 | Medium | 11 to 19 |
| 4 | Low | 11 |

*Table 8. Performance classification for hail damage resistance of roofing products.*

**These criteria are based on the data reported by researchers as listed in Tables 5, 6, and 7.*

A small body falling at a high velocity can impart the same energy as a large body falling at a slower velocity. Consequently, it is important that impact tests on roofing materials be conducted to simulate the energy generated by actual hailstones falling at their terminal velocity.

Severe surface fracture, cracking and puncture damage is quite obvious. Damage to waterproofing integrity or reduction of the intended service life of roofing products often is not readily apparent from visual observation. In such cases, additional testing is required to reveal the extent of the damage.

## SUMMARY AND COMMENT

Part II of the paper proposes a model for classifying roof systems as to their resistance to hail damage. The model, based on the concept of using kinetic energy as the criterion for appraising the hail resistance of roofing materials, is reasonably sound. Several benefits are apparent from utilizing a classification system. First, using energy as the criterion allows reasonable comparisons to be made between the results of current and future methods used to measure the hail resistance of roofing materials.

Next, insuring agencies may wish to adopt comparable systems for defining hail resistance requirements for roof products in hail-prone areas commensurate with hailstone size and frequency experienced. Standard and code bodies could utilize kinetic energy for defining impact resistance of building products. Finally, the implementation of a rational classification system for quantifying the hail resistance requirements for roofing products will benefit the roofing, insurance and allied interests as wind and fire requirements have done in the past.

For the most part, hail tests, like many other test methods, are conducted on new, unweathered materials. The results of testing new materials may not be valid since the hail impact resistance of many roofing materials changes upon exposure to weather. The development of an in situ roof test for hail resistance may be useful.

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