P 3.2 HAIL DAMAGE THRESHOLD SIZES FOR COMMON ROOFING MATERIALS

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1. INTRODUCTION

The hail size necessary to inflict property damage was the subject of a recent NWS (National Weather Service) committee meeting on re-evaluating the national severe thunderstorm warning criteria. The lead author served on this committee. The authors' firm had impacted common roofing materials with simulated hailstones to determine threshold sizes needed to initiate damage. A mechanical launcher was developed to propel freezer ice stones at desired velocities. This paper will present the methodology and findings of our impact tests. Further, test results compared favorably with field observations of roof damage in natural hailstorms.

2. HAIL DAMAGE

Hail causes billions of dollars in property damage each year in the United States (Smith, 1994). Changnon (1996) indicated that more than 75 percent of the cities in the continental U.S. experience one or more hailstorms per year. Hail damages property including roofs and automobiles as well as agricultural crops. Hail also poses a significant danger to the public. It is the duty of National Weather Service to issue severe thunderstorm warnings when dangerous storms threaten life and property. The definition as to what constitutes a severe thunderstorm has been hotly debated.

In 1999, the NWS established a committee to re-examine the criteria on what constitutes a severe thunderstorm. Currently, a severe thunderstorm is defined as having hail ¾ of an inch in diameter or greater, wind gusts of 50 knots or greater, a funnel cloud or tornado. The lead author served on this committee and provided expertise about hail damage to roofing materials. The authors' firm has performed ice stone impact tests on common roofing materials since 1963 and inspected damage in the wake of hailstorms. Hailstone sizes necessary to damage roofing materials have been determined.

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As expected, there is considerable variation in the size hail necessary to damage a specific roofing product. These variations involve the physical parameters of the hail as well as the roofing products. Hail variations include the stone size, shape, hardness or density, free-fall velocity, and angle of impact. Roof material variations include product type, age, support condition, impact location, and temperature (Fig. 1).

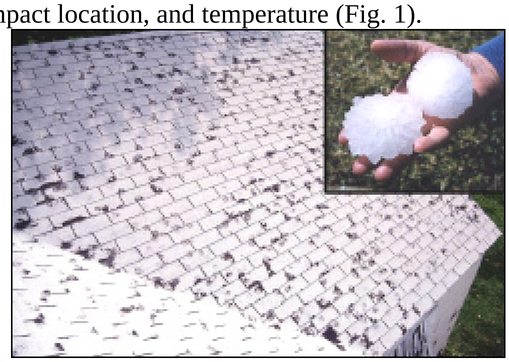

Figure 1. Hail damaged asphalt shingle roof from the Fort Worth, Texas hailstorm on May 5, 1995. Large hailstones are shown in the inset photograph.

Huge annual insurance losses from hail have led to a roof classification system in Texas where roofing products are rated on a scale from 1 to 4 depending on their impact resistance to steel balls. Class 1 provides the least impact resistance whereas as Class 4 provides the most. Impact testing is based on criteria developed by Underwriters Laboratories (1996) entitled UL 2218. In response to the need for better impact resistance, certain roofing manufacturers have developed shingles made with polymer-based modifiers that can meet Class 4 criteria.

3. HISTORY OF ICE IMPACT TESTING

Ice impact testing of roofing products began in South Africa during 1952. Rigby and Steyn (1952) were the first researchers to publish experimental procedures and test results from launching ice stones at various roofing products. General interest and subsequent requests for impact testing of roofing materials and wall cladding prompted a series of hail resistance investigations conducted by Laurie (1960). In 1963, Haag Engineering Co. began a testing program in the U.S. by launching ice stones at various grades of new wood shingles. Test panels were constructed and impacted, then set outside in the weather for ten years. The test panels were examined periodically. Haag

(1975) summarized their research and presented a methodology for inspecting and quantifying the extent of hail damage to roofing. Meanwhile, Greenfeld (1969) published his test results on ice stone impacts on various roofing products while working at the National Bureau of Standards.

In 1983, Haag's testing program was expanded to include impacts on asphalt shingles, fire-retardant-treated wood shingles and shakes, wood fiberboard panels, and aluminum panels. At the same time, Haag refined the procedures for assessing hail damage to a roof to include examining test squares in order to quantify the damage and applying a repair difficulty factor. These procedures were later published formally by Marshall and Herzog (1999).

Koontz (1991), conducted ice stone impact tests on asphalt shingles, wood shingles, and concrete tiles. He also experimented with varying the angle of impact as well as launching ice stones at new and old roofing materials. Impact tests also were conducted on roofing products at different temperatures.

In the above tests, hard ice stones were launched at target free-fall velocities as shown in Table 1. Generally, the ice stones were made by freezing tap water in molds and were harder and denser than natural hailstones (Fig. 2). Changnon (1996) reported that natural hailstones are slightly less dense than freezer ice since natural hailstones are composed of alternating layers of clear and rime ice as well as air cavities. Thus, the use of freezer ice in impact testing presents a worst case scenario. In addition, many of the impact tests involved striking the roofing samples perpendicularly imparting maximum impact energy to the samples.

Diameter		Terminal Velocity		Impact Energy	
in.	cm	mi./hr.	m/sec.	ft.-lbs.	Joules
1	2.5	50	22.3	<1	1.36
1.25	3.2	56	25.0	4	5.42
1.5	3.8	61	27.4	8	10.85
1.75	4.5	66	29.6	14	18.96
2	5.1	72	32.0	22	29.80
2.25	5.8	76	34.0	34	46.01
2.5	6.4	80	35.7	53	71.90
2.75	7.0	84	37.6	81	109.8
3	7.6	88	39.6	120	162.7

Table 1. Terminal velocities and energies of hailstones (after Greenfeld, 1969).

Figure 2. Solid ice stones made in rubber molds utilized for impact testing on roofing products.

Early researchers launched ice stones with pneumatic guns triggered by compressed air. Problems with compressed air-type guns included inconsistency in the ice stone velocity and imprecise targeting. In 1997, Haag Engineers developed a mechanical device dubbed the IBL-7 (Ice Ball Launcher – 7th generation) that launched ice stones on a track employing multiple bands of latex tubing (Fig. 3). The tubing ensured consistency in launch velocity and the track guided each ice stone to the desired target point. An ice stone was placed into a plastic holder that kept the stone in place while it accelerated forward. The holder was stopped at the end of the track allowing the ice stone to propel forward. Velocities of the ice stone were obtained by controlling the tension on the latex tubing. The velocities of the ice stones were measured by a chronograph mounted on a tripod at the end of the launcher and connected to a computer. Target launch velocities are shown in Table 1.

Figure 3. Ice ball launching (IBL) device with light sensors (chronograph) developed for impact testing.

4. STUDY PARAMETERS

Test panels were constructed for various roofing products. The products tested were: 1) three-tab asphalt shingles with glass fiber mats, 2) three-tab asphalt shingles with organic mats, 3) laminated glass fiber asphalt shingles, 4) cedar shingles, 5) "heavy" cedar shakes, 6) flat concrete tiles, 7) S-shaped concrete tiles, 8) fiber-cement tiles, and 9) built-up gravel covered roofing. The asphalt shingles and cedar shingles were weathered naturally about 11 years; the built-up roofing samples were eight years old. The other roofing products were new. Test panels were constructed in accordance with manufacturer specifications. The panels were covered with plywood decking and/or wooden lath boards or battens and had an asphalt-saturated underlayment if required. The built-up roofing samples also had one-inch thick perlite insulation board on top of the wooden roof deck. The IBL-7 was utilized to propel solid ice stones that were 1, 1.25, 1.5, 1.75, and 2 inches in diameter at free-fall velocities listed in Table 1. Ice stones of .75 inch in diameter also were utilized for impacting the organic three-tab asphalt shingles. All impacts were made perpendicular to the product at ambient room temperature. A total of ten impacts were made for each size ice stone on each roofing product (usually one impact per unit) until eight of ten (80%) impacts or more, damaged the roofing product. Impact velocities were within ten percent of nominal freefall velocities as shown in Table 1.

4a. *Definition of damage*

Morrison (1999) defined damage to roofing as a diminution of water-shedding capability or a reduction in the expected long-term life of the roofing material. Damage to asphalt shingles included punctures, tears, or fractures (bruises) in the shingle mats as well as the displacement of granules to visibly expose the underlying bitumen. Damage to wood shingles and shakes consisted of hairline fractures in the wood caused by the impacts. The fractures had uniform cleavage through the wood grain and could be closed tight. In addition, the interior surfaces of the wood fractures were unweathered (orange). Damage to tile roofing involved breaking or shattering of the product. Multiple fractures occurred in the concrete tiles and fracture surfaces were irregular, emanating from the impact point. Fiber-cement tiles were indented and fractured. Damage to built-up roofing was breaking of the surface coating (asphalt) along with fracturing the roofing membrane.

4b. *Impact test results*

Results of our ice stone impact tests are shown in Table 2. As expected, the 11-year old asphalt shingles were most susceptible to damage since they were thin and brittle. Aged organic mat-based asphalt shingles were damaged half of the time by one-inch diameter ice stones, whereas it took 1.25-inch diameter ice stones to damage the aged glass-fiber mat based asphalt shingles. Thicker, aged laminated shingles were damaged by 1.5-inch ice stones. The most impact resistant products were the S-shaped concrete tiles and the built-up gravel roofing where ice stones of two inches in diameter were needed to initiate damage. In general, the majority of the roofing products we tested (5 of 9) sustained impact damage with ice stones of 1.25 inches in diameter and all products tested sustained impact damage with two-inch diameter ice stones.

Type of Roofing Product	Age (yrs)	1 in. (25 mm)	1.25 in. (32mm)	1.5 in. (38mm)	1.75 in. (44mm)	2.0 in. (50mm)
3-tab fiberglass shingles	11	0	60	90	100	100
3-tab organic shingles*	11	50	90	100	100	100
30 yr. Laminated shingles	11	0	0	60	90	100
Cedar shingles	11	0	30	80	100	100
Heavy cedar shakes	0	0	0	50	90	100
Fiber-cement tiles	0	0	20	80	100	100
Flat concrete tiles	0	0	20	50	50	100
S-shaped concrete tiles	0	0	0	0	0	80
Built-up gravel roofing	8	0	0	0	0	30
Number of Products Damaged		1/9	5/9	7/9	7/9	9/9

*no damage at .75 inch.

Table 2. Ice stone impact test results for various roofing products. Percent of damage is indicated.

5. FIELD OBSERVATIONS

The authors have conducted more than one dozen hail damage surveys around the U.S. These surveys have been conducted in such places as Dallas, Denver, Minneapolis, Orlando, and Phoenix. Hundreds of roofs were inspected to document the extent of damage and size hail needed to inflict roof damage. In many instances, we found people who had picked up hailstones after the storm and kept them in their freezers. Similar hail damage surveys have been done by Charlton and Kachman (1996).

Hail damage threshold sizes derived from these surveys are listed in Table 3. The term "threshold" was defined as the onset of damage to the roofing product. Generally, the lighter, thinner, and older roofing products were most susceptible to hail damage and had the lowest damage thresholds. In contrast, built-up roofs protected by gravel on a hard (gypsum or concrete) roof deck exhibited substantial hail resistance. Comparison of our ice stone impact test results in Table 2 with our field observations in Table 3 show good correlation.

Type of Roofing Product (all ages)	Hailstone Size in.	mm.
3-tab asphalt shingles	1.00	25
30 yr. Laminated shingles	1.25	32
Cedar shingles	1.25	32
Medium cedar shakes	1.50	38
Fiber-cement tiles	1.50	38
Concrete tiles	1.75	44
Built-up gravel roofing	2.50	63

Table 3. Threshold sizes for hail-caused damage to roofing - field observations (after Morrison, 1997).

6. SUMMARY

Ice stone impact tests were conducted on common roofing materials to determine threshold sizes necessary to inflict damage. The roofing materials tested consisted of three types of asphalt shingles, cedar shingles and shakes, flat and S-shaped concrete tiles, fiber-cement tiles, and built-up gravel roofing. A mechanical launcher had been developed to launch solid ice stones at desired velocities. As expected, there was considerable variation with regard to the impact resistance of the tested roofing products. Aged three-tab asphalt shingles were most susceptible to damage with ice stones as small as one inch in diameter. In contrast, the S-shaped concrete tiles and built-up gravel roofs were the most impact resistant. Our laboratory test results compared favorably with field observations of roof damage in natural hailstorms. Basically, hailstones one inch in diameter begin causing damage to some of the older, thinner roof products. Therefore, from a roof damage perspective, we believe the hail size threshold for issuing a severe thunderstorm warning can be increased from ¾ of an inch to one inch in diameter. The one-inch hailstone criteria would still be conservative as supported by laboratory tests as well as field observations.

7. REFERENCES

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