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HAIL DAMAGE TO BUILT-UP ROOFING

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1. INTRODUCTION

Built-up roofs account for a large percentage of the commercial roofing systems in the United States. Such systems are comprised of asphalt-coated glass-fiber reinforcements or asphalt-saturated organic paper reinforcements that are sandwiched and flooded with asphalt or coal tar pitch. The finished surface can be covered with gravel, left bare, or topped with a variety of coatings. The hail resistance of built-up roofs has been known to be substantial especially when covered with loose and embedded gravel in an asphalt flood coat. However, occasional disputes arise in the settlement of insurance claims over the size hail needed to cause damage to a built-up roof and what those characteristics are.

The authors have inspected thousands of built-up roofs after hailstorms and have identified consistent damage characteristics. In addition, the authors' firm has conducted a series of ice impact tests on various built-up roofing samples to determine damage thresholds and have compared these results with field observations. In this paper, we will define the characteristics of hail damage to built-up roofs, describe our inspection and testing procedures, and present the results of our ice impact tests. We also will identify and explain various anomalies with built-up roofs that frequently are mistaken for as hail damage.

2. GREENFELD'S STUDY

Greenfeld (1969) was among the first to conduct ice impact testing on built-up roofs in the U.S. and publish his results at the National Bureau of Standards. He utilized a compressed air gun to launch various size ice balls at a "target" at certain terminal velocities (Table 1). Liquid water was frozen in molds comprised of a silicone casting resin. For built-up roof impact tests, ice balls varied in size from 1.5 in. (3.8 cm) in diameter to 2.5 in. (6.4 cm) in diameter. Built-up roof samples, one-foot square, were placed over various surfaces and impacted at room temperature. Roof membranes were asphalt-saturated organic paper, asphalt-coated glass-fiber, or asbestos-fiber. The roof samples were placed over plywood, metal, asbestos-cement, fiberboard insulation or foam board insulation and held together with large C-clamps. The vast majority of his built-up roof samples were unballasted (not covered with gravel). He defined failure or functional damage as a fracture in the coating or membrane.

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Diameter In.	Diameter cm.	Terminal Velocity mi./hr.	Terminal Velocity m/sec.	Impact Energy ft.-lbs.	Impact Energy Joules
1.00	2.5	50	22.3	<1	1.36
1.25	3.2	56	25.0	4	5.42
1.50	3.8	61	27.4	8	10.85
1.75	4.5	66	29.6	14	18.96
2.00	5.1	72	32.0	22	29.80
2.25	5.8	76	34.0	34	46.01
2.50	6.4	80	35.7	53	71.90
2.75	7.0	84	37.6	81	109.8
3.00	7.6	88	39.6	120	162.7

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

Greenfeld was able to damage certain unballasted samples with the 1.5 in. (3.8 cm) diameter ice balls. However, in no instance was he able to damage the roof samples covered by gravel even with 2.5 in. (6.4 cm) diameter ice balls. He concluded that the built-up roof samples performed better on dense or hard substrates. He also concluded that glass-fiber reinforcements had greater impact resistance than the organic paper reinforcements.

3. HAAG'S 1988 STUDY

In 1988, Haag Engineering performed a series of ice impact tests on built-up roof samples obtained from a 14-year old roof in Dallas, Texas (Figure 1). The roof samples contained three-plies of asphaltic-pitch impregnated organic reinforcement, with perforated base sheet. There was ample loose and embedded gravel in the asphalt flood coat. Roof samples were placed over poured gypsum, concrete block, or 2.0 in. (5.1 cm) thick bead board insulation prior to impact testing.

Figure 1. Roof samples being removed for impact testing in the laboratory from a 14-year-old roof in Dallas, Texas.

Ice balls were produced in synthetic rubber molds (Figure 2). Round ice balls were produced in 1, 1.25, 1.5, 1.75, and 2 in. (2.5, 3.2, 3.8, 4.5 and 5.1 cm) diameters and cubical stones were produced with 1.625-in. (4.1 cm) sides. The ice was solid with specific gravities of about 0.9.

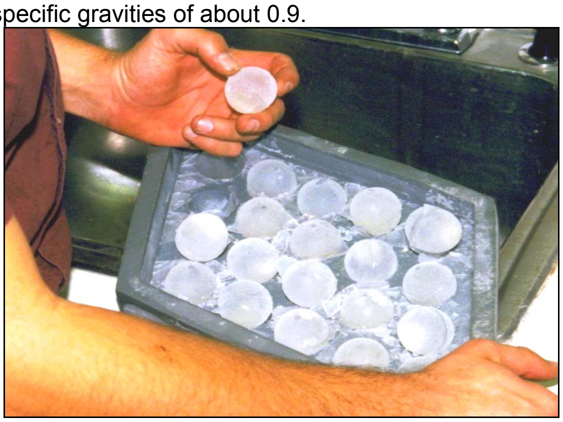

Figure 2. Ice ball mold.

Two types of mechanical launchers were utilized in the study. Small ice balls 1 in. (2.5 cm) and 1.25 in. (3.2 cm) in diameter were propelled with a specially built mechanical device similar to a diver's speargun that utilized rubber tubing (Figure 3). The tubing was secured to each end of a crossbar that was oriented perpendicular to length of the gun. The crossbar could be adjusted at different positions along the length of the gun to allow adjustment of the degree to which the rubber tubing was stretched when the gun was cocked. Stored energy, and thus the ice ball velocity, was proportional to the amount of tubing stretched. Ice balls rode in a carrier made to fit an aluminum rail that ran the length of the gun. A locking mechanism at the rear end of the gun secured the carrier that could be released via a trigger. When the trigger was depressed, the carrier released and accelerated forward, propelled by the contracting rubber tubing. When the carrier reached the crossbar, it began to decelerate and the ice ball traveled forward unimpeded. A chronograph fixed to the front end of the gun measured the speed of the airborne ice ball.

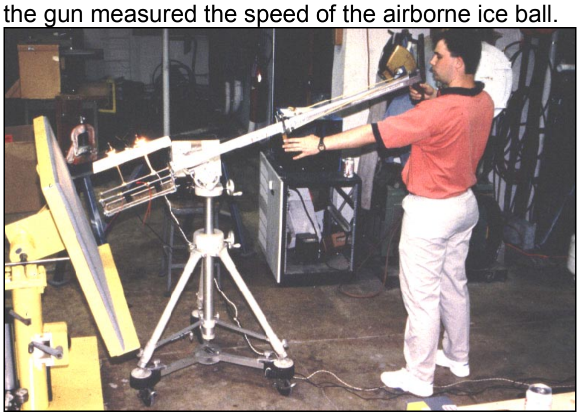

Figure 3. Mechanical launcher used to propel smaller ice balls.

The remaining ice balls were propelled using a piston driven, pneumatic gun (Figure 4). A piston-operated valve assembly was installed within an aluminum tube that was approximately 8 ft. (2.4 m) long with a 3.5 in. (8.9 cm) inside diameter. Prior to firing, the ice ball was loaded into the carrier through the front end of the barrel. To fire the gun, high-pressure air was injected via a valve behind the piston to initiate movement of the piston and carrier. After initial acceleration to the desired speed, the carrier decelerated and stopped, releasing the ice ball to travel unimpeded past a chronograph fixed to the front end of the barrel. Target velocities of the ice ball were the same as in the Greenfeld study.

Figure 4. Pneumatic air launcher used to propel larger ice balls.

The chronograph was comprised of a pair of photoelectric detectors. These sensed the passage of the ice balls and sent signals to the chronograph that displayed the velocities of the ice balls.

Each roof sample was gridded off into 16 impact zones, each measuring 4 in. by 4 in. (10 cm x 10 cm). Loose and embedded gravel was removed (spudded) on one of the roof samples. Impacts were 90 degrees (perpendicular) to the roofing samples except in one instance where the impact was 80 degrees. All testing was done at room temperature, about 72 degrees F (22 C). Following each impact, test areas were carefully examined for evidence of hail-caused damage.

A total of 94 impacts were made against the built-up roof samples of which 18 samples had the loose and embedded gravel removed prior to testing. Typically, the ice ball broke apart or shattered upon impact and removed the loose gravel, forming a divot (crater) in the roof surface (Figures 5 and 6). Larger and faster ice balls created larger and deeper divots in the loose gravel. The largest ice ball impacts removed pieces of the asphalt flood coat, leaving the exposed asphalt surface fragmented and shiny. There were no instances where gravel had been driven downward into the roofing membranes.

Figure 5. Ice ball breaks apart on impact removing some of the surface gravel and flood coat.

Figure 6. Roof surface after ice ball impact. Some of the gravel and asphalt flood coat had been removed. However, gravel was not driven into the plies.

The impacted roof samples were examined visually before they were subjected to an asphalt solvent. The roofing reinforcements then were extracted, dried, and examined for cuts, tears, dents, or any other evidence of hailstone impact. Fractures in the roof reinforcements appeared star- or crescent-shaped (Figure 7).

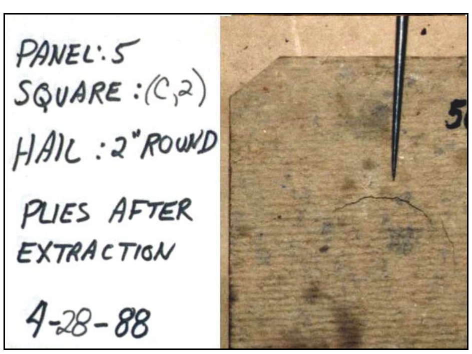

Figure 7. Crescent-shaped fracture in organic reinforcement after desaturation.

A summary of our impact test results is shown in Table 2 at the end of this paper. Examination of impact zones on roofing samples covered with gravel revealed no impact damage using either 2.0 in. (5.1 cm) spherical or 1.625 in. (4.1 cm) cubical ice stones. This result was independent of the base material used (poured gypsum concrete, concrete block, or 2.0 in. (5.1 cm) thick bead board insulation. Similarly, no impact damage occurred to roofing samples where all the gravel was removed (spudded) and placed on top of a poured gypsum deck. However, one of the three impacts by 2.0 in. (5.1 cm) diameter ice balls did cause a slight indentation and tear in the top ply of the spudded sample resting on a concrete block base. The ice ball that produced this damage was timed at a velocity of 114-ft/sec (78 mph). Similarly, one of three impacts produced by the 1.625 in. (4.1 cm) cubical ice stones damaged the spudded sample resting atop 2.0 in. (5.1 cm) bead board insulation. Tears occurred in all plies.

Finally, all three impacts of the 2.0 in. (5.1 cm) ice balls damaged the spudded samples resting atop bead board insulation. This indicated that softer substrates make the overlying built-up roof more susceptible to impact damage. However, the characteristics of hail damage were the same regardless of support conditions. Impact-caused damage was surface based (i.e. visible at the roof surface).

Test results indicated the gravel surfacing provided significant impact protection to the built-up samples. No damage occurred to the gravel-covered built-up roof samples with ice balls up to 2.0 in. (5.1 cm) in diameter. Therefore, the gravel surface was removed (spudded) from remaining samples. The largest ice balls fractured the roofing plies, base sheet, and dented the insulation on samples when the gravel was removed.

4. HAAG'S 1993 STUDY

In 1993, Haag conducted a series of ice impact tests on an eight-year old, three-ply built-up roof with glass-fiber reinforcements. Roof samples contained approximately 3 lbs. (1350g) per sq. ft. of loose and embedded gravel. The built-up roof had been installed over glass-fiber insulation board on a plywood deck. Ice balls of 1.5 in. (3.8 cm) and 2.0 in. (5.1 cm) were launched at standard velocities against ballasted and unballasted (where the ballast had been removed) samples. Each sample was struck at least three times. Samples were visually examined for damage, desaturated, and the glass-fiber reinforcements were examined.

No damage occurred to the built-up roof samples whether ballasted or unballasted when impacted with 1.5 in. (2.4 cm) diameter ice balls. However, some spalling of the asphalt flood coat occurred with 2.0 in. (5.1 cm) diameter ice ball impacts against the ballasted samples, but no damage was found to the glass-fiber reinforcements. Glass-fiber reinforcements were fractured when unballasted samples were struck with 2.0 in. (5.1 cm) diameter ice balls (Figure 8). The fractures appeared star-shaped and occurred in all layers beneath the center of the impact. The underlying glass-fiber insulation board also was dented beneath the impact points. Occasionally, gravel-sized indentations were found in the upper plies but this was not coincident with any impacted areas. Such anomalies were created when the gravel was pressed into the plies before the asphalt had cooled. This likely occurred during the initial installation of the roof.

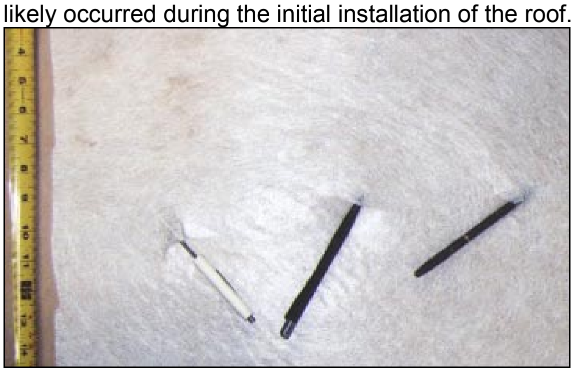

Figure 8. Star-shaped fractures in the glass-fiber reinforcements after asphalt removal.

5. HAIL DAMAGE ASSESSMENT

There normally are many items on and around a building that can give an inspector a better understanding of the size and direction of hailfall. Metal and wood items can record hail-caused scuff and spatter marks. These marks are formed when hail removes some of the oxidation from these surfaces. The marks appear similar to a bug smear on a windshield and widen or fan outward from the point of impact. The width of the mark near its narrow end has been found to be close to the diameter of the hailstone. Areas where algae, microorganisms or grime are cleaned away by impacting hailstones also can be good indicators of hailstone size and direction. However, these marks are temporary and will fade within about a year or two after the hailstorm.

Soft metals, such as lead and aluminum, are susceptible to denting even by small hailstones that have insufficient energy to damage the roof covering. Air conditioners with exposed aluminum fins are particularly good indicators of hailstone sizes and fall directions. However, because dents in metals do not weather away, the metal becomes a record of all previous storms. Therefore, care needs to be taken to determine which dents are from previous hailstorms and which are from the most recent. Air conditioners usually have nameplates with the date of manufacture listed or contained within the serial number. Thus, a history of hail occurrences can be derived from analyzing the dates of manufacture on air conditioners.

Hail damage to a built-up roof takes on many forms depending on the age and condition of the roof surface. Concentric fractures can occur in the asphalt flood coat around the impact points on newer built-up roofs whereas, the asphalt flood coat can be spalled or fractured on older and more brittle roofs. With ballasted roofs, hail can remove some of the loose gravel forming a crater or divot in the roof surface. The larger, harder, and faster the hailstone, the deeper and wider the crater or divot. Large hailstones can leave a "doughnut-shaped" fracture pattern in the roof surface where gravel and/or flood coat remains at the center of the impact. Only the largest and hardest hailstones can remove enough of the ballast to break apart the asphalt flood coat and penetrate the roofing reinforcements (Figures 9 and 10).

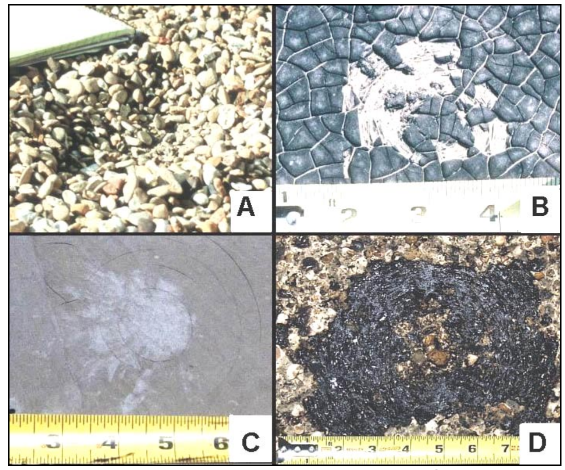

Figure 9. Hail impacts on built-up roofs: a) divot in loose gravel (no damage), b) spalling of the asphalt flood coat, c) concentric fractures in coating associated with a spatter mark, and d) "doughnut-shaped" area of spalled asphalt flood coat with large impact.

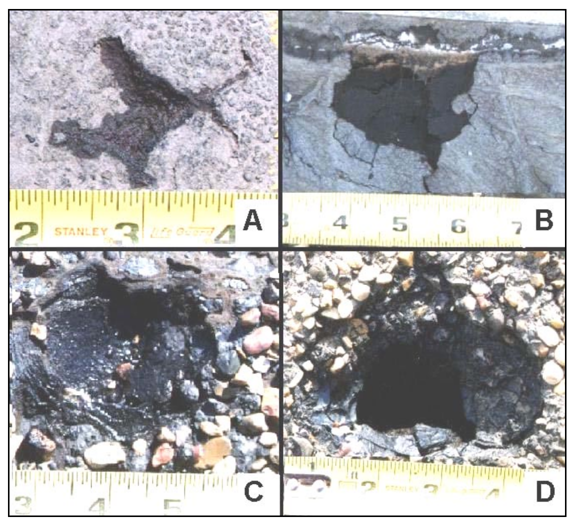

Figure 10. Hail damage forms on built-up roofs: a) star-shaped fracture in bare area, b) punctured flashing, c) punctured blister, and d) puncture in field of roof that went through the wood roof deck.

Exposed asphalt oxidizes as it ages turning from black to grey in about one year. Some times loose gravel can cover hail damaged areas and a broom is needed to sweep aside the loose gravel. Hail damage to a roof can still be found years after the event (Figure 11).

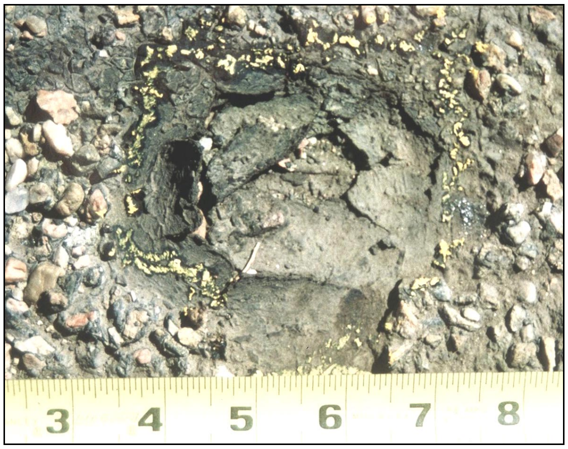

Figure 11. Five-year-old hail damage to a built-up roof.

Experience and testing have shown there are three levels of increasing hail resistance on a built-up roof. Unsupported and unprotected areas of a built-up roof are most prone to hail-caused damage. Such areas are the exposed flashings along curbs and parapets as well as membrane blisters in the field of the roof. Relatively small hail may dent or puncture these areas. Well-supported unballasted areas have moderate hail resistance. Built-up roof areas protected by gravel and an asphalt flood coat have the most hail resistance when supported solidly. Therefore, if unprotected and unsupported areas of the roof are not damaged by hail, then it is unlikely that the ballasted areas were hail damaged.

There are a number of anomalies on built-up roofs that can be mistaken for hail-caused damage such as alligatoring, interply voids, membrane blisters, and asphalt bubbles (Figure 12). Alligatoring occurs as oils within the asphalt separate leaving a harder material that cracks when it shrinks. Interply voids result when not enough asphalt is applied between membrane plies. Membrane blisters develop when air and water vapor are expanded within interply voids. Bubbles form in the asphalt when it is boiled and cools rapidly as it is applied to the roof surface.

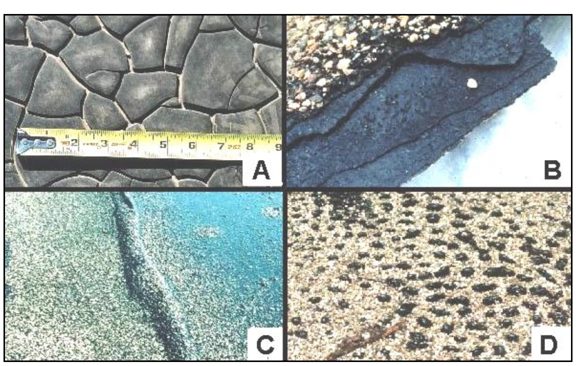

Figure 12. Built-up roof deficiencies not caused by hail: a) alligatoring, b) gaps between plies, c) membrane blister, and d) asphalt bubbles.

6. SUMMARY

This study has shown that built-up roofs are quite resistant to hail-caused damage, especially if the roof surface is covered with loose and embedded gravel in an asphalt flood coat. Impact testing of various built-up roof samples has revealed no damage to the roof membranes with ice balls up to 1.5 in. (3.8 cm) in diameter. Some spalling of the asphalt flood coat occurred with some 2.0 (5.1 cm) ice balls but no damage was found to the roof membrane reinforcements. Not surprisingly, built-up roof samples without gravel were more susceptible to hail-caused damage than those covered with loose and embedded gravel in an asphalt flood coat.

In no instance was the roof gravel driven downward into the roofing membranes by the impact. Instead, gravel was ejected from around the impact point as the ice stone shattered upon impact. The impact energy had dissipated across many pieces of gravel including the asphalt flood coat.

The authors believe the ice impact tests conducted herein represent a "worst-case" scenario as solid, freezer ice spheres were launched perpendicularly against the roof samples. Typically, naturally occurring hail is not as dense as freezer ice and usually falls from a certain direction hitting the roof at an angle. However, characteristics of the impact damage using solid ice balls in the laboratory matched identically with our observations in the field after natural hailstorms. Furthermore, built-up roofs vary considerably in age, thickness, and support conditions. Therefore, these impact test results should not be taken as absolute values for all built-up roofs.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

Greenfeld, Sidney H. 1969: Hail Resistance of Roofing Products, Building Science Series 4/23, National Bureau of Standards, 9 pp.

TABLE 2
SUMMARY OF 1988 ICE STONE IMPACT TESTS ON BUILT-UP ROOF SAMPLES

Number of Impacts	Ice Stone Size (in.)	Sample Type	Sample Base	Target Velocity	Range of Velocities	Test Results
12	1.00	Ballasted	Gypsum	73 ft/sec	55-76 ft/sec	No damage
12	1.25	Ballasted	Gypsum	82 ft/sec	44-83 ft/sec	No damage
12	1.50	Ballasted	Gypsum	90 ft/sec	72-118 ft/sec	No damage
12	1.75	Ballasted	Gypsum	97 ft/sec	98-113 ft/sec	No damage
13	2.00	Ballasted	Gypsum	105 ft/sec	85-116 ft/sec	No damage
3	1.625	Ballasted	Gypsum	105 ft/sec	103-110 ft/sec	No damage
3	1.625	Ballasted	Conc. Block	105 ft/sec	104-110 ft/sec	No damage
3	1.625	Ballasted	Bead Board	105 ft/sec	106-111 ft/sec	No damage
3	2.00	Ballasted	Conc. Block	105 ft/sec	102-109 ft/ sec	No damage
3	2.00	Ballasted	Gypsum	105 ft/sec	96-109 ft/sec	No damage
3	1.625	Spudded	Gypsum	105 ft/sec	107-112 ft/sec	No damage
3	1.625	Spudded	Conc. Block	105 ft/sec	63-115 ft/sec	No damage
3	1.625	Spudded	Bead Board	105 ft/sec	108-116 ft/sec	1 damaged
3	2.00	Spudded	Gypsum	105 ft/sec	96-109 ft/sec	No damage
3	2.00	Spudded	Conc. Block	105 ft/sec	99-114 ft/sec	1 damaged
3	2.00	Spudded	Bead Board	105 ft/sec	100-113 ft/sec	3 damaged