Dents in Metal Roof Appurtenances Caused by Ice Ball Impacts

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KEY WORDS

Dents, hail, hail-caused damage, hail damage, hailstones, ice balls

ABSTRACT

During inspections of roof systems to evaluate hail-caused damage, useful information regarding sizes and hardnesses of hailstones can be estimated based on sizes of dents in metal roof appurtenances. This paper quantifies dent sizes in common metal appurtenances struck by freezer ice balls in simulation of hailstones.

PURPOSE

The purpose of this paper is to report sizes of dents caused by impacts of freezer ice balls against common metal roof appurtenances. The sizes of dents are useful when estimating the sizes of hailstones that caused those dents during inspections of roof systems and assessing expectations of damage to various roofing materials.

AUTHOR BIOGRAPHY

Scott J. Morrison, P.E. graduated from Iowa State University with a B.A. in Architecture and a B.S. in Civil Engineering. He also has earned an M.S. in Civil Engineering from the University of Oklahoma. The author has inspected thousands of residential and commercial roofs to assess hail- and wind-caused damage and other roof system problems. He has participated in the writing of *Wood Roofs: Damage and Repair, Composition Shingle Roofing Pictorial,* and *Wood Shingle and Shake Roofing Pictorial*. In addition to teaching courses regarding assessment of roof systems, the author coordinates research and testing at Haag Engineering Co.

ROOF APPURTENANCES

Common lead, steel and aluminum roof appurtenances were selected for impact testing. The following are descriptions of appurtenances tested.

Lead Soil Stack Flashing

The tested lead soil stack flashing had a nominal 3-inch (7.6-cm) diameter and a base roughly 12 inches (30.5 cm) square. The material was approximately 0.045 inch (1.14 mm) thick. The flashing was slipped over a 3-inch (7.6-cm) (nominal) diameter polyvinyl chloride (PVC) plastic pipe projecting through and affixed to a test panel to mimic typical soil stack installations. The base was fastened to the test panel with four roofing nails, and the top end of the lead sleeve folded into the PVC pipe. See Figure 1.

Figure 1. Lead soil stack flashing.

Galvanized Steel Turbine Ventilator

The turbine ventilator (turbine) had a 12-inch (30.5-cm) (nominal) size and, as supplied, was braced internally. Its overall height was 17 1/2 inches (44.5 cm), and its base was 18 inches (45.7 cm) square. Thickness of the ribbed metal blades measured approximately 0.032 inch (0.81 mm). Eight screws fastened the base to the test panel. See Figure 2.

Figure 2. Galvanized steel turbine ventilator.

Aluminum Cover for a Water Heater Combustion Products Flue

The aluminum cover was 6 inches (15.2 cm) tall with an ellipsoidal cap and 8 inches (20.3 cm) in diameter with a 1 1/4-inch (3.2-cm) crown. The metal thickness was approximately 0.020 inch (0.51 mm). The cover was clamped to a pipe secured with screws to the test panel. See Figure 3.

Figure 3. Aluminum cover for a water heater combustion products flue.

Aluminum Static Vent

This vent comprised an open box-like form (cover) mounted over a base flashing with 9- by 9-inch (22.9- by 22.9-cm) projections. The cover measured 12 inches (30.5 cm) square and 3 inches (7.6 cm) deep; aluminum thickness was approximately 0.024 inch (0.61 mm). Two screws secured the base flashing to the test panel. See Figure 4.

Figure 4. Aluminum static vent.

Aluminum Air-Conditioning Unit Fins

Aluminum fins of an air-conditioning unit condenser coil measured approximately 1 inch (2.5 cm) wide by 28 inches (71.1. cm) long by 0.007 inch (0.18 mm) thick. These fins were pierced and soldered at 1/16 inch (1.6 mm) intervals to copper condenser tubing 3/8 inch (9.5 mm) in diameter. Fins were mounted integrally within an air-conditioning condenser cabinet. See Figure 5.

Figure 5. Aluminum air-conditioning unit fins.

TEST PROCEDURES

Appurtenances were inspected for damage and, except for the aluminum fins of the air-conditioning unit, mounted with fasteners driven through the base flashings to 3- by 3-foot (91.4- by 91.4-cm) test panels. The panel frames (perimeter elements plus third-span braces), built of 2 x 4 (nominal) lumber, were covered with 1/2-inch-thick (12.7-mm) plywood. Freezer ice balls, propelled to develop free-fall energies of same size hailstones, were launched against the appurtenances. These ice balls measured approximately 1/2 inch (12.7 mm), 3/4 inch (19.1 mm), 1 inch (25.4 mm), 1 1/4 inches (31.8 mm), 1 1/2 inches (38.1 mm), 1 3/4 inches (44.5 mm), 2 inches (50.8 mm) and 2 1/4 inches (57.2 mm) in diameter. The ice balls were frozen to desired sizes in molds and maintained at 0° F (-17.8° C) plus or minus 7° F (3.9° C). Ice balls were removed from the freezer, inspected by unaided eye for fractures, weighed and launched within 60 seconds at 90-degree or 45-degree angles of incidence against the appurtenances. The targets were conditioned for 24 hours at 72° F (22.2° C) plus or minus 3° F (1.7° C) before testing began. See Figure 6.

Figure 6. Test setup.

Locations of impacts were separated sufficiently that the dent caused by one did not influence a dent caused by another. Speeds of the launched ice balls were measured with a ballistics chronograph positioned within 1 foot (30.5 cm) of the target. Accuracy of the launch speeds was plus or minus 1 foot per second (0.30 mps). Ice ball weights and calculated kinetic energies were between 100 percent and 110 percent of free-fall kinetic energies or the datum was discarded. Table 1 lists target locations on appurtenances, and Table 2 lists particulars of the ice balls.

Table 1. Target locations on appurtenances.

APPURTENANCE	TARGET LOCATION
Lead soil stack flashing	Center line of the lead sleeve
Galvanized steel turbine ventilator	Center line of a blade
Aluminum cover for water heater combustion products flue	Crown of the ellipsoidal cap (at least two ice ball diameters away from the perimeter)
Aluminum static vent	Cover (at least two ice ball diameters away from the perimeter)
Aluminum air-conditioning unit fins	Not necessarily at the condenser tubing

Table 2. Free-fall speeds and kinetic energies for ice balls.

DIAMETER (IN)	DIAMETER (mm)	WEIGHT (LB_m)	WEIGHT (g)	SPEED (MPH)	SPEED (kph)	KINETIC ENERGY ($FT\text{-}LB_f$)	KINETIC ENERGY (J)
1/2	12.7	0.0022	0.998	38.3	61.6	0.11	0.15
3/4	19.1	0.0073	3.311	45.1	72.6	0.50	0.68
1	25.4	0.0173	7.847	51.4	82.7	1.53	2.07
1 1/4	31.8	0.0338	15.331	57.3	92.2	3.72	5.04
1 1/2	38.1	0.0584	26.490	63.1	101.5	7.77	10.53
1 3/4	44.5	0.0928	42.093	69.4	111.7	14.94	20.25
2	50.8	0.1385	62.822	76.1	122.5	26.80	36.32
2 1/4	57.2	0.1972	89.448	81.4	131.0	43.68	59.20

Deformations in the metal were examined by unaided eye, and their widths and depths were measured carefully. The dents were highlighted by rubbing a length of chalk across the impacted zone. Deformations were identified as *dents* when they were distinct and approximately the sizes of the impacting ice balls. A second category included *buckling of the metal*, deformations substantially larger than the projectiles. See Figures 7 through 11.

Figure 7. Dents in lead soil stack flashing from impacts at 45 degrees by 1 1/4-inch- (31.8-mm) diameter ice balls.

Figure 8. Buckle in the blade of a galvanized steel turbine ventilator from impact at 90 degrees by 1 1/2-inch- (38.1-mm) diameter ice ball.

Figure 9. Dent in the aluminum cover for a water heater combustion products flue from impact at 90 degrees by 1/2-inch- (12.7-mm) diameter ice ball.

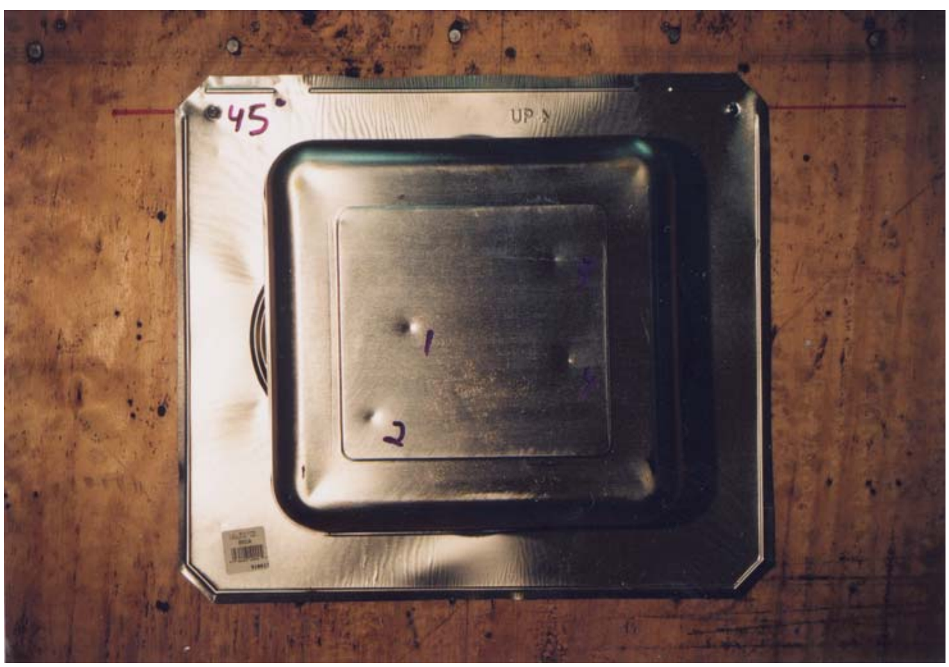

Figure 10. Dents in an aluminum static vent from impacts at 45 degrees by 1 1/2-inch- (38.1-mm) diameter ice balls.

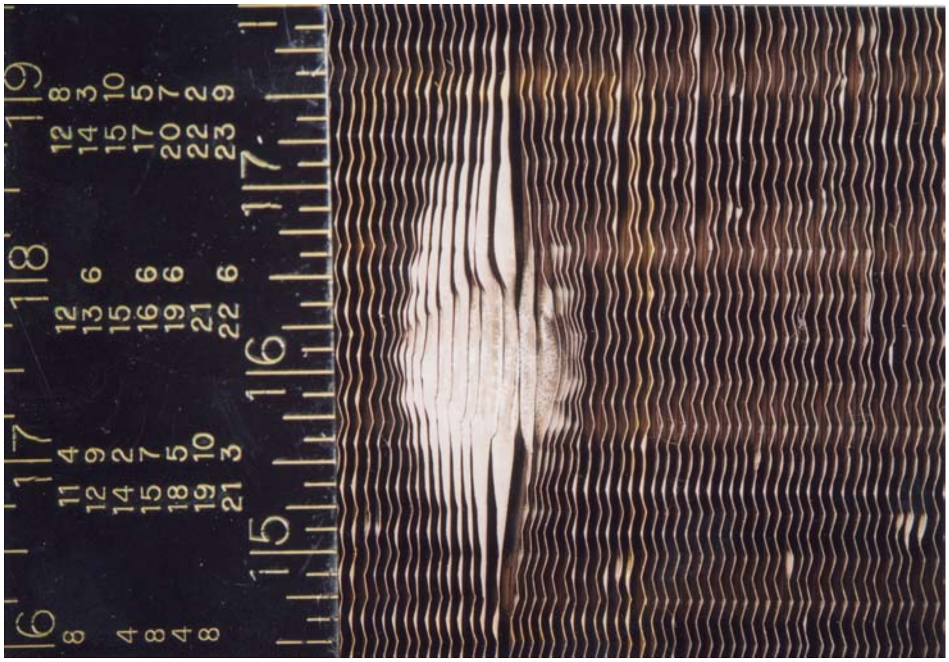

Figure 11. Dent in aluminum air-conditioning unit fins from impact at 90 degrees by a 1 1/4-inch- (31.8-mm) diameter ice ball.

DENT MEASUREMENT

Shapes of dents in roof appurtenances varied from approximately circular to oval. Deformations within the dents included two regions: one bounded by well-defined steep slopes about the center of the impact termed an *inner* dent, the other with shallow slopes surrounding the inner dent and termed the *outer* dent. See Figure 12.

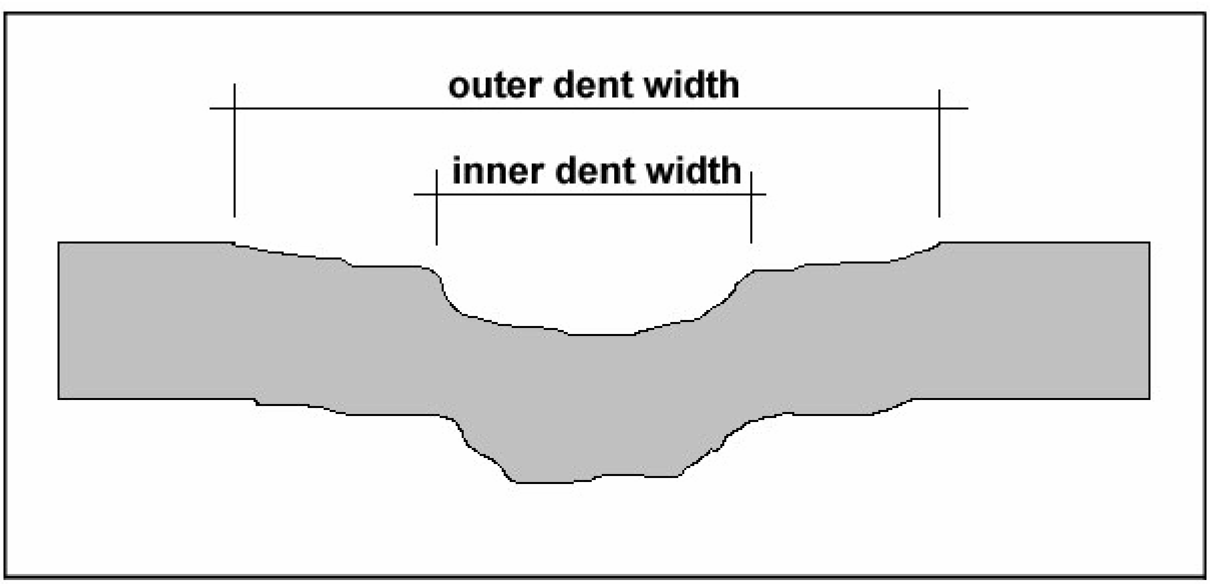

Figure 12. Cross section at inner and outer dents in thin-gauge metal.

Measurements of outer dents and depths of inner dents were scattered enormously about mean values, and their correlations with ice ball diameters ultimately were abandoned. These outer dents had little repeatability in correlation with ice ball size.

The strongest correlation between dent size and ice ball diameter was determined to be the smallest width of the inner dent. The accuracy and repeatability in measurements of the inner dents lay in the identification of the transition between the inner and outer dents. Several techniques were evaluated with the simplest proving the most repeatable. The most effective method involved examining the deformation, visually determining the demarcation between slopes of inner and outer dents, and measuring the least dimension of the inner dent.

BUCKLE MEASUREMENT

Shapes of buckles in roof appurtenances as well as measurements of buckle widths and depths varied radically. Correlations of buckle particulars with ice ball sizes were abandoned.

FINDINGS

Impacts with freezer ice balls at 90 degrees and 45 degrees against appurtenances produced a variety of results from no visible marks to dents to buckles in metal surfaces. Except for larger ice balls, five impacts were made with ice balls of each diameter at two angles of incidence in all test appurtenances. Impacts by the largest ice balls grossly buckled the metals. Average widths of inner dents and sample standard deviations (as percentages of ice ball diameters) are presented in Figures 13 through 22 as shown as solid and broken lines, respectively. **ND** indicates no dent, **B** indicates buckled and **SSD** indicates sample standard deviation.

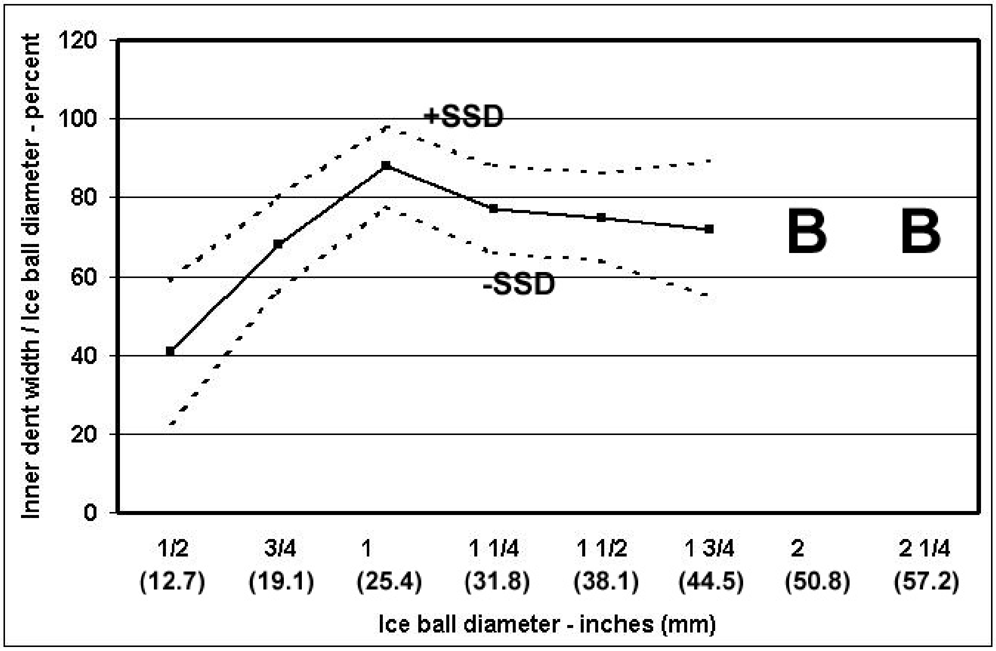

Figure 13. Inner dent width versus ice ball diameter for 90-degree impacts against lead soil stack flashing.

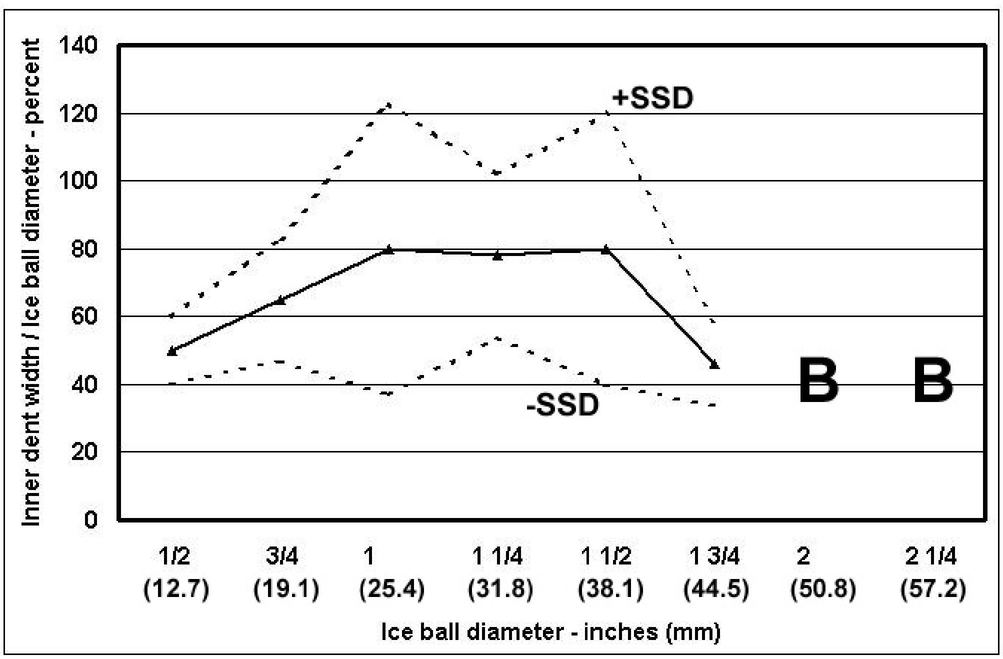

Figure 14. Inner dent width versus ice ball diameter for 45-degree impacts against lead soil stack flashing.

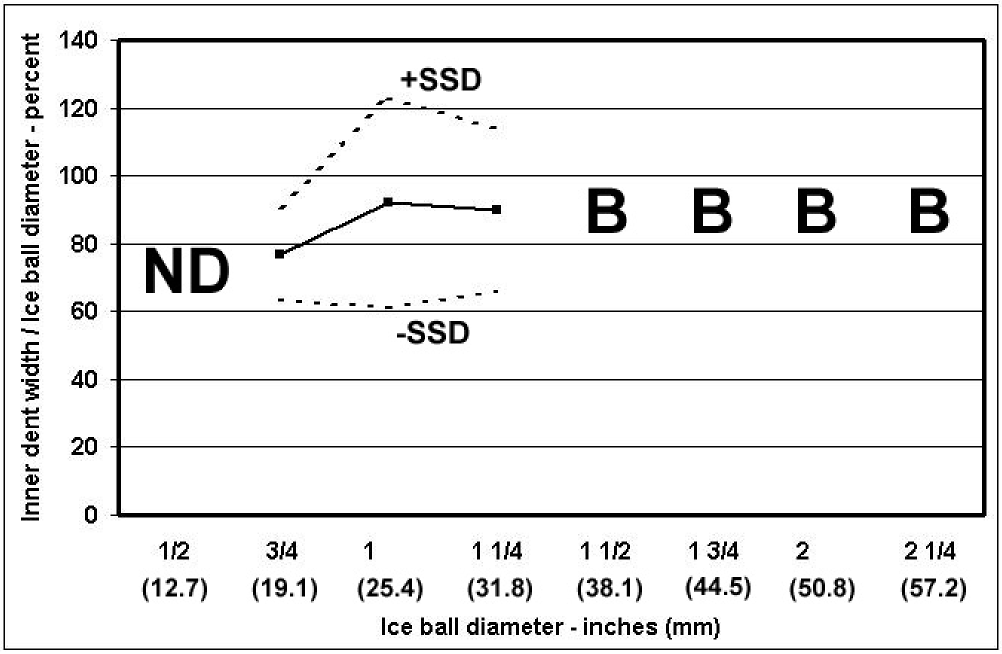

Figure 15. Inner dent width versus ice ball diameter for 90-degree impacts against blades of galvanized steel turbine ventilator.

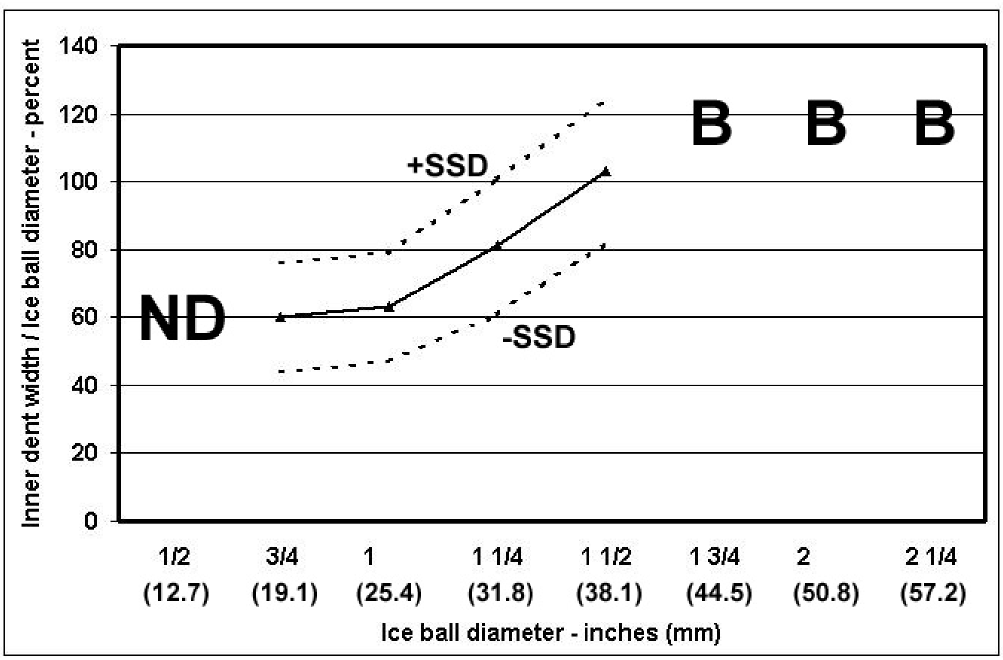

Figure 16. Inner dent width versus ice ball diameter for 45-degree impacts against blades of galvanized steel turbine ventilator.

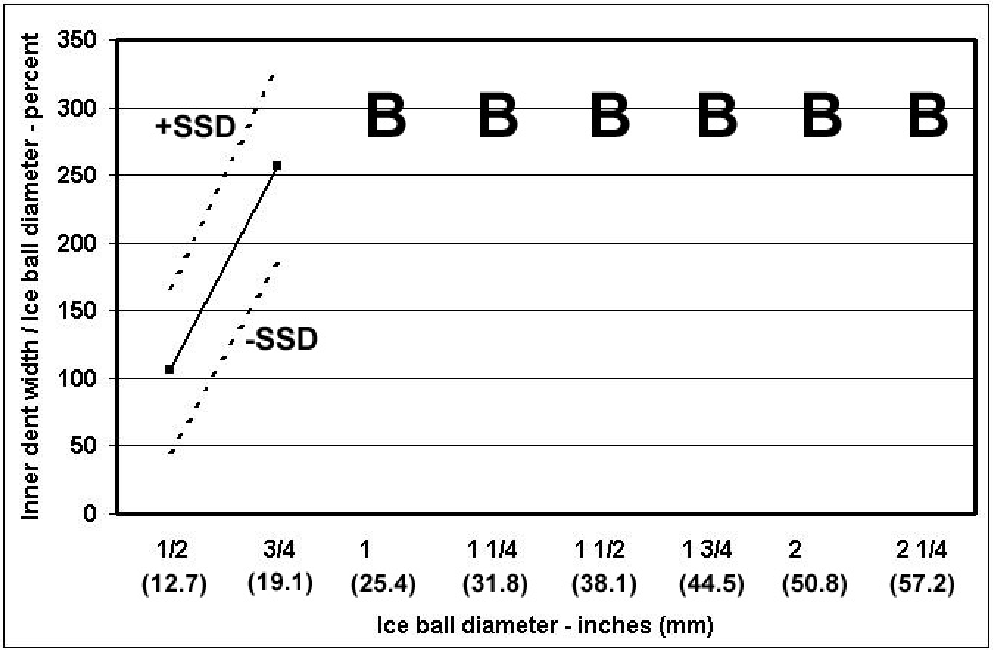

Figure 17. Inner dent width versus ice ball diameter for 90-degree impacts against aluminum cover for a water heater combustion products flue.

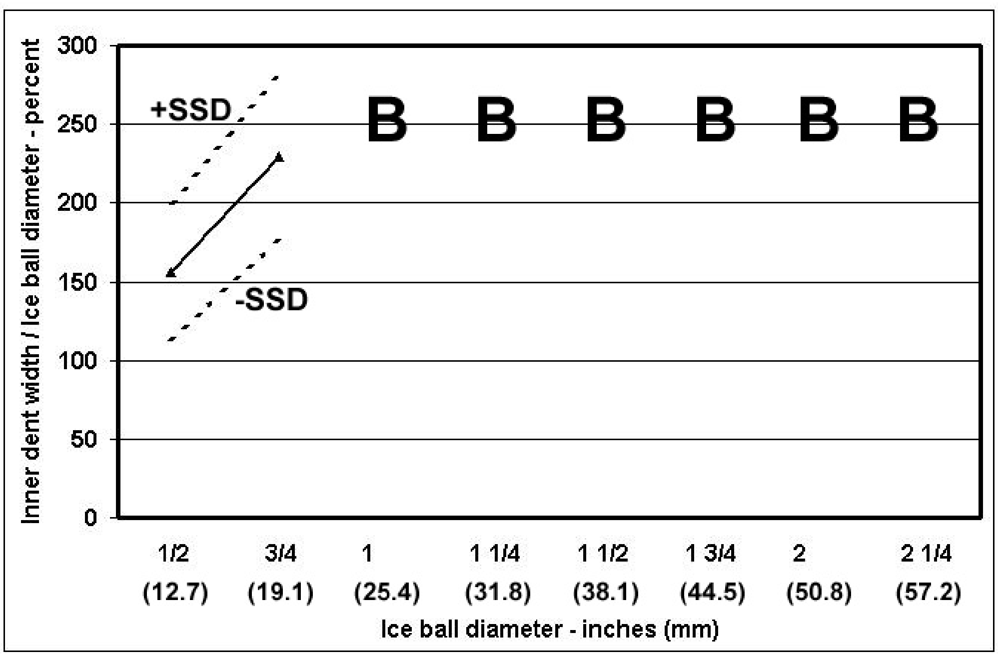

Figure 18. Inner dent width versus ice ball diameter for 45-degree impacts against aluminum cover for a water heater combustion products flue.

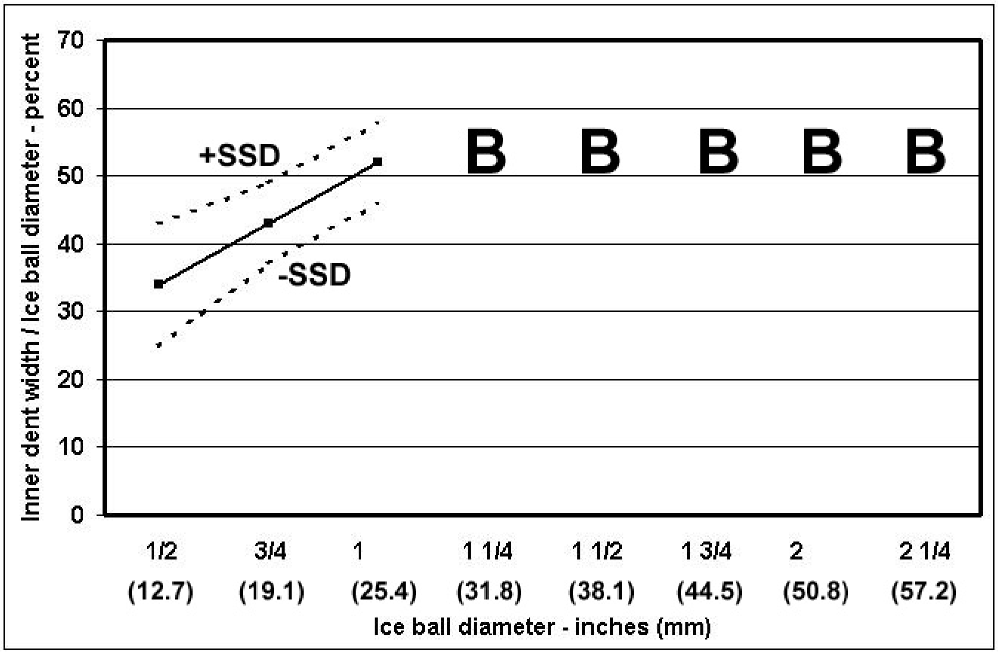

Figure 19. Inner dent width versus ice ball diameter for 90-degree impacts against aluminum static vent.

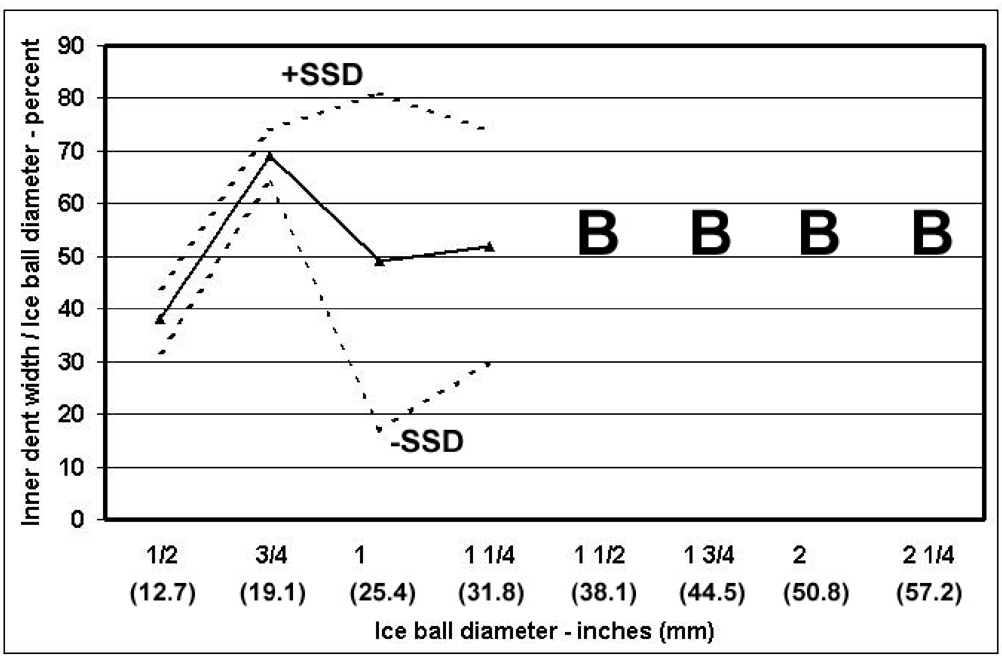

Figure 20. Inner dent width versus ice ball diameter for 45-degree impacts against aluminum static vent.

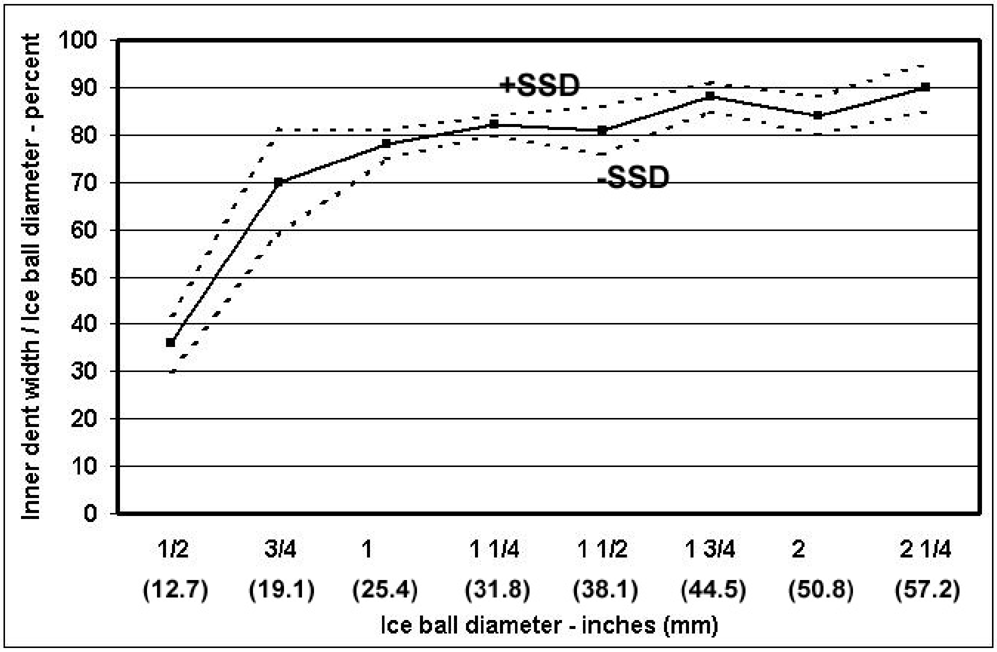

Figure 21. Inner dent width versus ice ball diameter for 90-degree impacts against aluminum air-conditioning unit fins.

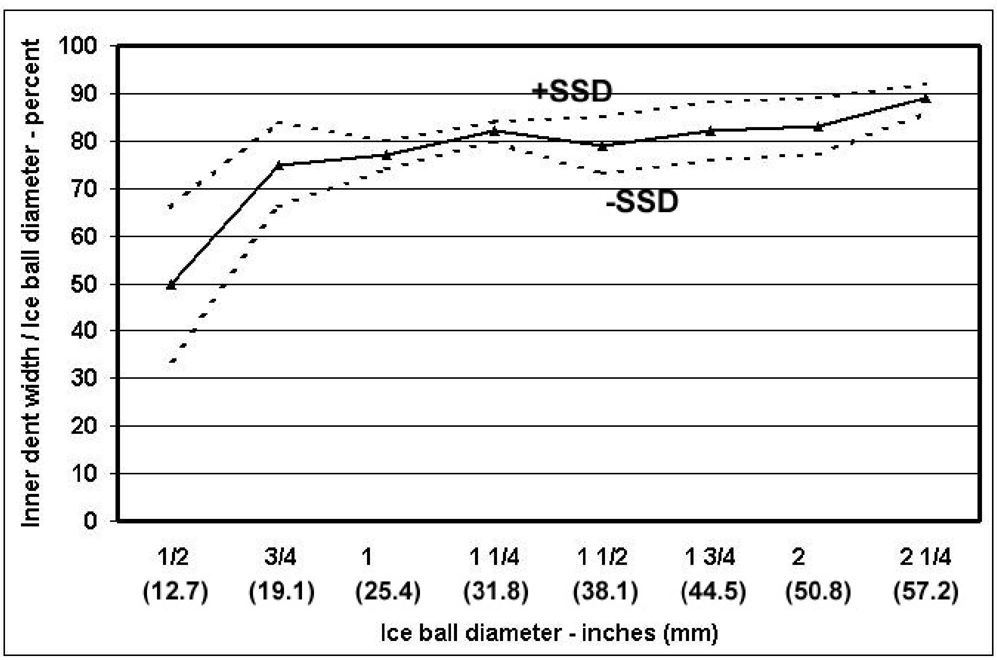

Figure 22. Inner dent width versus ice ball diameter for 45-degree impacts against aluminum air-conditioning unit fins.

DISCUSSION

General rules-of-thumb derived from graphs presented in Figures 13 through 22 are listed in Table 3.

Table 3. General rules-of-thumb for inner dent width / ice ball diameter as percentages in roof appurtenances.

ROOF APPURTENANCE	ICE BALL DIAMETER				INNER DENT WIDTH / ICE BALL DIAMETER (PERCENT)
	MINIMUM (IN)	MINIMUM (mm)	MAXIMUM (IN)	MAXIMUM (mm)	
Lead soil stack flashing	3/4	19.1	1 3/4	44.5	80
Galvanized steel turbine ventilator[1]	3/4	19.1	1 1/4	31.8	90
Aluminum cover for water heater combustion products flue	1/2	12.7	3/4	19.1	200
Aluminum static vent	1/2	12.7	1 1/4	31.8	50
Aluminum air-conditioner unit fins	3/4	19.1	2 1/4	57.2	80

NOTE:

1. No dents for ice balls 1/2-inch (12.7-mm) size.

CONCLUSIONS

The sizes of hailstones that fall at any location can be estimated by measuring widths of dents in metal roof appurtenances. In this study, freezer ice balls were launched against targets at no less than free-fall energies of same-size hailstones. The smallest widths of resulting inner dents were determined to correlate best with the sizes of the simulated hailstones. Rules-of-thumb (with limitations) for estimating sizes of hailstones that struck the appurtenances are listed in Table 3. These rules-of-thumb are specific to appurtenance types, mechanical properties of the metals, and thickness and profile of the metals impacted in this study.

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