Hail: Sizing It Up!

By Vickie Crenshaw and Jim D. Koontz

Determining the size of hail impacting a roof following a storm event can be a challenging task. Correlating the size of hailstones to "splash marks" or indentations on metal surfaces, or both, is the subject of this article. To study this phenomenon, various common roofing metals were impacted with ice spheres cast in the laboratory.

Introduction

Hail sizes are often compared to everyday known objects, *Table 1.*

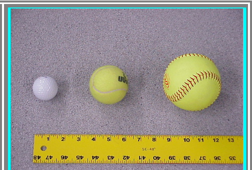
Hail Size	Description	Hail Size	 Description
0.25 inch	Pea Size	1.75 inch	Golf Ball Size
0.50 inch	Mothball Size	2.00 inch	Hen Egg Size
0.75 inch (Severe Criteria)	Dime/Penny Size	2.50 inch	Tennis Ball Size
0.88 inch	Nickel Size	2.75 inch	Baseball Size
1.00 inch	Quarter Size	3.00 inch	Teacup Size
1.25 inch	Half Dollar Size	4.00 inch	Grapefruit Size
1.50 inch	Walnut or Ping Pong Ball Size	4.50 inch	Softball Size

***Table 1**. – Hail Size Chart, NWS Tampa Bay, Florida*[1]

When examining roofs after hail events, debates often occur about hail stone sizes. Nationally recognized standards for determining the size of hail after a weather event are non-existent. Without a video camera on the roof or an official meteorological station near the roof, obtaining accurate hail information can be difficult.

Information about hail events is obtained from web sites such as HailTrax[1], Compu-Weather[2] and the National Climatic Data Center[3] (NCDC). They report hail events compiled from meteorological data, spotters in the field, law enforcement personnel, and other sources. The report often lists the longitude and latitude of the location and the size of the hailstones observed.

Other documenting sources include newspaper articles that report the hail event and damage. Police reports provide similar information. This subjective information is useful but not always accurate.

Splash Marks and Dents

Hail damage in the form of dents is often found on mechanical units, aluminum coils (*Photo 1*), exhauster covers (*Photo 2*), aluminum roof vents, edge metal, and coping. From these metal surfaces, information indicating hail size and the direction from which it came can be obtained. Examining a mechanical unit's aluminum coils also assists in determining the same information.

***Photo 1,** Aluminum Coil*

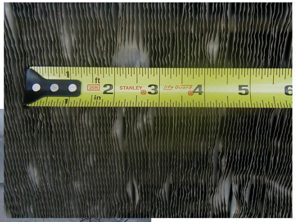


***Photo 2**, Hail Damage, Roof Exhauster*

Hail hitting the top and sides of metal surfaces leave evidence of impact in the form of marks as surface oxides and airborne deposited debris are disturbed. Hail striking these surfaces dislodges the oxides and particulates, leaving visible outlines or fingerprints *(Photo 3)* known as "splash marks." These "splash marks" supply additional information about hail size and direction.

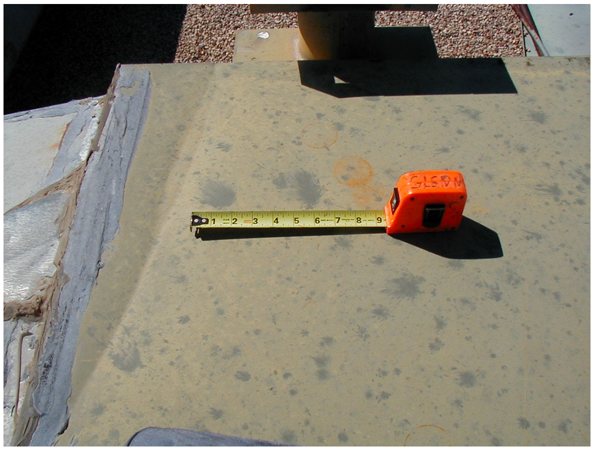


***Photo 3**, Splash Marks*

Hail Velocities and Impact Energy

Various organizations or testing agencies each have test standards or methods for determining impact or hail resistance of materials. Some include the American Society of Testing and Materials (ASTM), Factory Mutual Research Corporation (FMRC), Underwriters Laboratories (UL) and the National Institute of Standards and Technology (NIST), formerly National Bureau of Standards (NBS).

Industry test methods developed for impacting roof targets with ice spheres include the NBS Building Science Series 23, "*Hail Resistance of Roofing Products"*[4] and FMRC Class Number 4473, *"Specification Test Protocol for Impact Resistance Testing of Rigid Roofing Materials by Impacting with Freezer Ice Balls."*[5] Previous researchers using ice spheres to evaluate hail damage include Rigby, 1952[6], Laurie, 1960[7], Greenfeld, 1969, Hairston, 1972[8], Koontz, 1988[9], 1991[10], Morrison, 1999[11] and Crenshaw/Koontz, 2001[12].

Currently the NBS Series No. 23, FMRC 4473, FMRC 4470[13], ASTM D3746[14] and UL2218[15] use kinetic energy in the calculations. The NBS Series 23, FM 4470 and FM 4473 address hail resistance of roofing materials. The UL 2218 and ASTM methods address impact resistance. The NBS Series No. 23 and FMRC 4473 employ laboratory cast ice spheres to substitute for hailstones while the other impact test methods use steel darts or balls.

Recent industry debate about employing momentum versus kinetic energy in calculations is noted but not addressed in this research. Mathey[16] concluded kinetic energy at impact is a suitable criterion since work required to stop a moving object is equal to its kinetic energy.

An earlier hail researcher, J.A.P. Laurie, derived hail sizes and correlating kinetic (impact) energies of hail in the 1960's. Laurie graphed the relationship between terminal velocity, hail diameter, and the approximate kinetic (impact) energy, *Table 2*. Laurie developed this information from data collected by Bilham and Relf[17] in prior research.

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 2. *Terminal velocities and energies of hailstones*

Ice Sphere Testing Method

The NBS Series 23 test method was selected since laboratory cast ice spheres closely correlate with hail. Prior studies have shown that approximately over 75 percent of large size hail is spherical or nearly spherical in shape[18]. Reported hail densities range between 0.7 and 0.91 gm/cm^3, the latter value being the density of pure ice. The densities of the ice spheres used in this research were approximately 0.91 gm/cm^3.

The diameters of ice spheres tested were: 1.0", 1.5", 2.0", 2.5" and 3.0". The ice spheres were propelled from a hail gun at velocities listed by the NBS Series No. 23 and impacted selected targets. A gauge measured the pressure of the compressed air from the hail gun, which was regulated to a preset value, and a ballistics timer measured the spheres' velocities.

Constructing the simulated hail in silicone molds in two stages permits the expansion of the ice without cracking. Weighing the mass of water into each mold provided consistency of the spheres' masses and diameters. Ice spheres were formed at 10?F. The known mass and velocity of the sphere allowed for an accurate determination of the kinetic energy. The spheres were propelled at a variety of supported and unsupported metal surfaces.

Test Targets

Test targets impacted included four distinct metal groups of various thickness including common metal products found on roofs:

- Parapet Caps of Galvanized Steel, Copper, & Aluminum
- Steel tops and sides from mechanical units
- Mechanical unit aluminum cooling fins
- Aluminum heater flue caps

Table 3 lists the thickness and type of each material tested.

Targets
Galvanized Steel 24, 26 gauge
Copper 16 oz
Aluminum .040
Mechanical Unit Cabinets 20 gauge, 22 gauge
Aluminum Cooling Fins from Mechanical Unit
Aluminum Heater Flue Caps .018

Table 3. *Target Materials*

Forming the sheet metal goods into coping metals profiles installed over 2"x12" wood nailers simulated actual field construction, (*Photo 4*). Unsupported metal coping profiles was also included for comparison purposes.

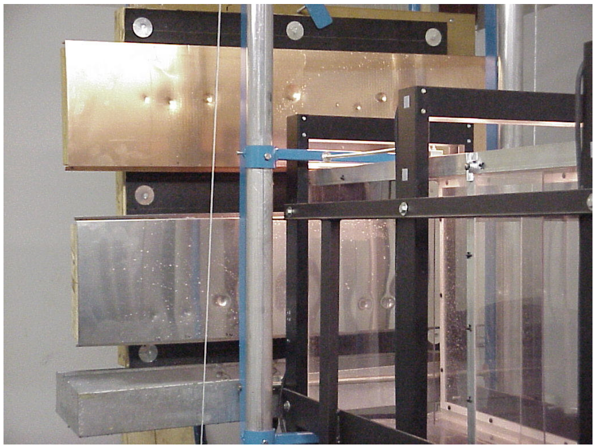


Photo 4*, Parapet Targets at 90 Degree Angle*

Research

Test targets were impacted at 45 and 90-degree angles to the plane of the test target. At a 45-degree angle the kinetic energy of hail increases significantly, *Table 4*. This scenario represents an extreme wind driven hail event. Rotating the target at a 45-degree angle to the plane and increasing the velocity of the hail sphere accomplished this.

Diameter nom.	Weight		Terminal Free-Fall Velocity	Resultant Velocity 45^o Angle	Kinetic Energy ft-lb *	
In	**Gm**	**Lb**	**Ft/sec**	**Ft/sec**	**Ft-lb Free-Fall**	**Ft-lb 45^o Angle**
1	7.85	0.0174	73	103	1.43	2.57
1.5	26.50	0.0588	90	127	7.35	14.72
2	62.81	0.1394	105	148	23.71	47.49
2.5	122.67	0.2723	117	165	57.48	115.17
3	211.98	0.4705	130	183	122.55	245.70

Table 4, *Resultant Velocity*

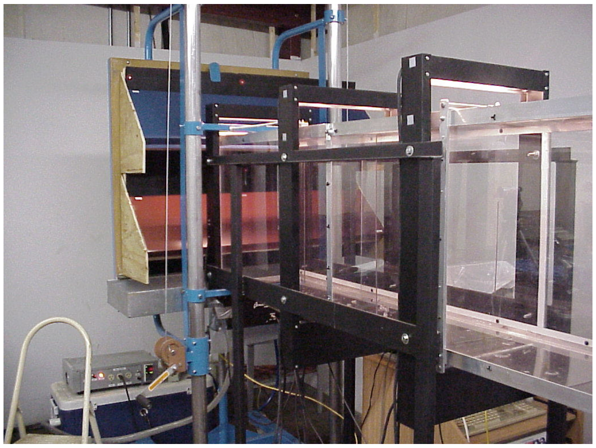


Photo 5, *Parapet Caps Impacted at 45-Degree Angle*

Targets were tested at room temperature and at 40?F. A circulating sprinkler system distributed chilled water over target surfaces.

The impacts of the ice spheres produced dents or splash marks. The diameter and depth of the impacts were measured with calipers. Mathey[19] reported impacts have an overall diameter and an indentation diameter, (*Figure 1*) as was observed with this research.

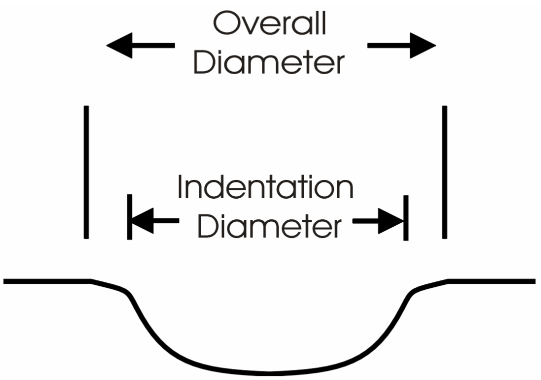


Figure 1, *Cross Section View of Metal Indentation*

Impact Observations

Recorded data included sphere size, impact angle, velocity, target temperature, indentation diameter, indentation depth and the size of splash marks.

Parapet Caps

Chart 1 contains impact data from sheet metal parapet caps constructed with 24 and 26 gauge galvanized steel, copper and aluminum. Variations in indentations occurred due to slight differences in substrate conditions.

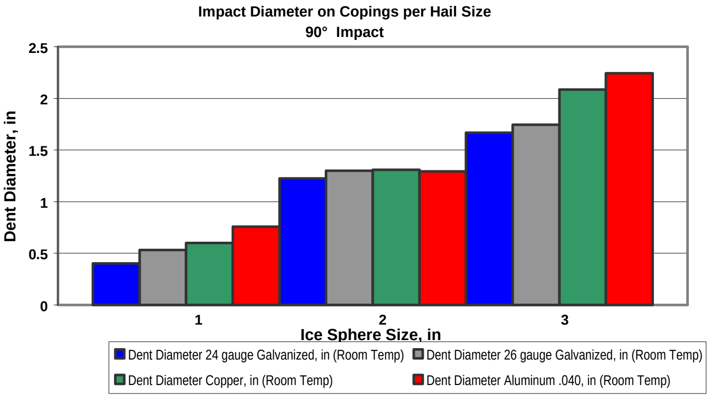


Chart 1

The dent diameter in metal increased as the thickness of the metal decreased. Copper and aluminum exhibited dent diameters higher than galvanized steel, *Chart 1*. A correlation exists between ice sphere diameter and depths of indentations, *Chart 2*.

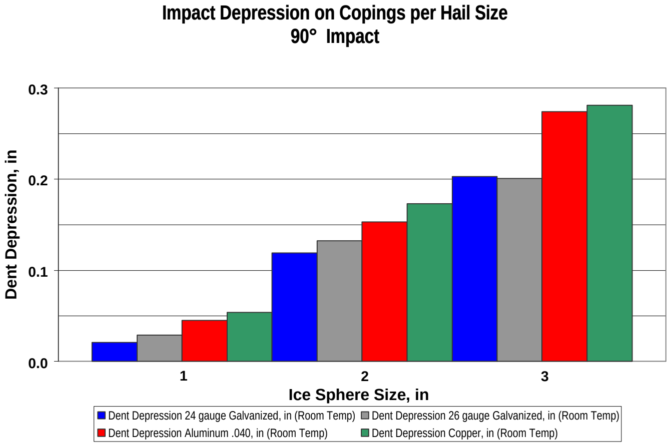


Chart 2

Metal Cabinets

Chart 3 depicts the dent depressions, dent diameters, splash mark diameters, and splash mark lengths at room temperature and 40?F.

At a 45-degree impact angle to the plane, 1”, 1.5”, 2”, 2.5” and 3” ice spheres impacted 20 gauge mechanical panels. In each instance, the diameter of the dent and splash mark is smaller than the ice sphere diameter. The length of the splash mark remains fairly close to the diameter of the ice sphere until larger spheres are introduced. The splash mark length increases significantly when the ice sphere diameter exceeds 2”.

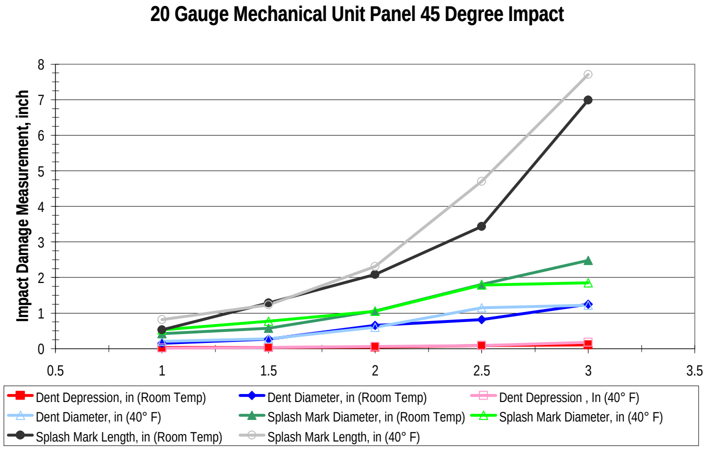


Chart 3

Mechanical unit cabinets impacted at 90 degrees produced dent and splash marks, (*Photo 6*).

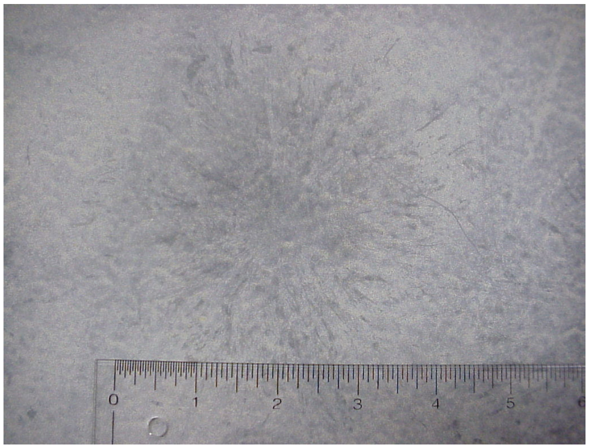


***Photo 6**, 3” Ice Sphere, 20 ga. Metal, 90 degree impact*

Chart 4 shows the correlation between splash mark diameter and length at 40 and 90-degree impact angles. Impacting metal cabinets at 45-degree angles produced splash marks with "tails" leading away from the initial point of contact, (Photo 7).

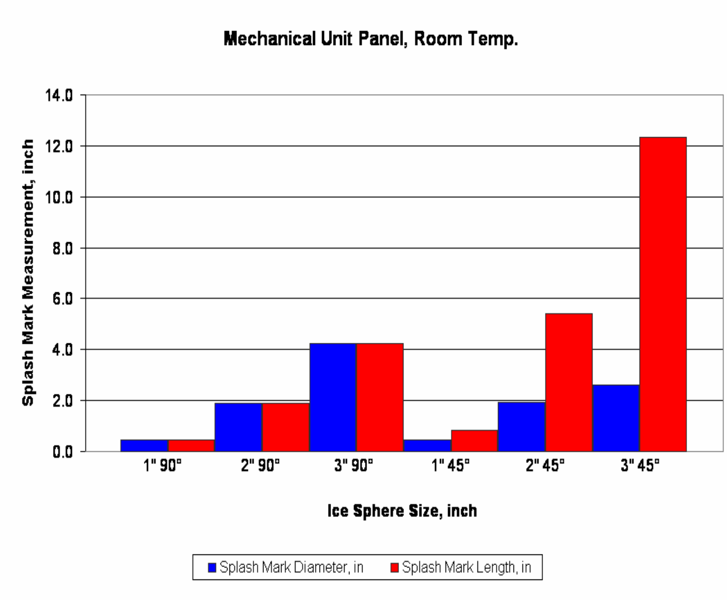


Chart 4

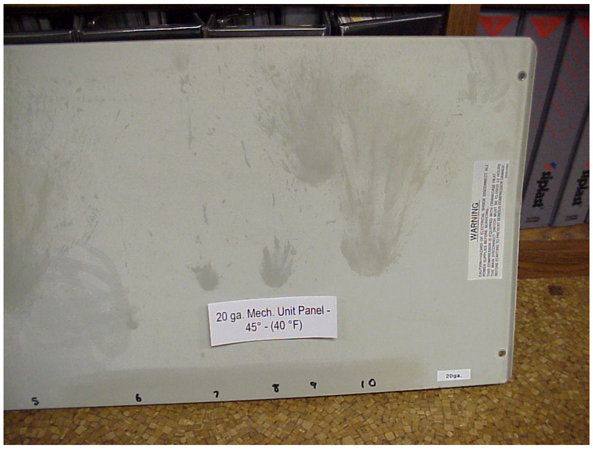


***Photo 7**, Splash Marks*

Aluminum Fins

Aluminum fins from mechanical cooling units were impacted with ice spheres at a 45-degree angle (Photo 8).

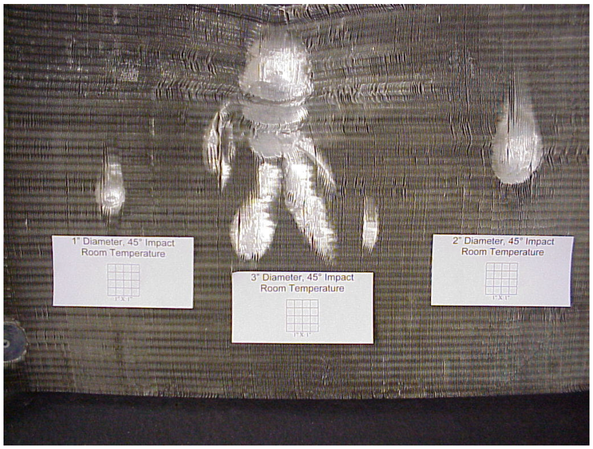


***Photo 8**, Aluminum Fins*

The minor diameter of the oval indentation is fairly close to the diameter of the ice sphere. The length and depth of the indentation increase dramatically with larger ice spheres. (*Chart 5,*) Aluminum Fins.

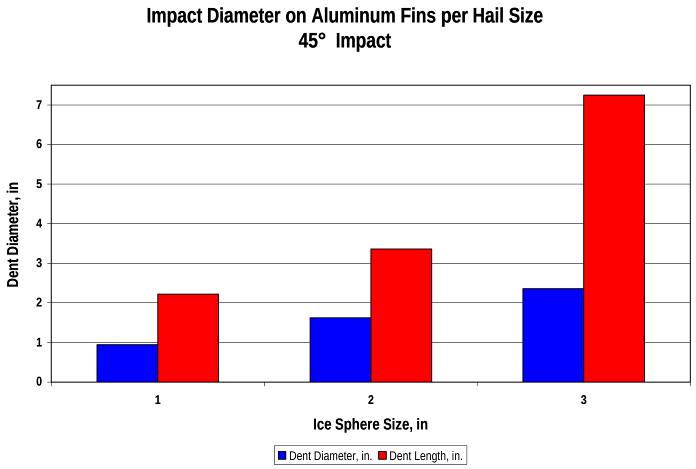


Chart 5

Aluminum Heater Flues

Small ice spheres, 1" in diameter easily dent relatively thin aluminum heater flue cap material, .018" thick. The dent diameters exceed the size of the ice sphere diameters by factors as high as three times. (*Chart 6*), (*Photo 9.*)

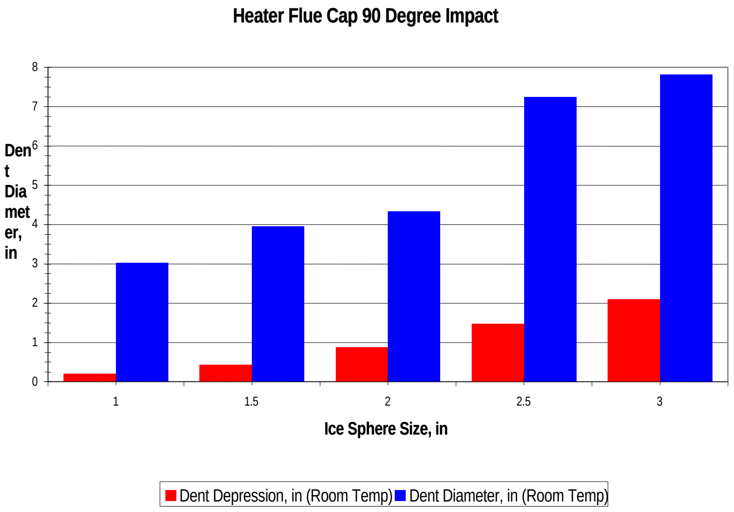


Chart 6

***Photo 9**, Heater Flue 1" Sphere, 90 Degree*

Conclusions

- Diameters of indentations in formed galvanized steel, copper, and aluminum sheet metal are smaller than the diameters of impacting ice spheres.
- Lower temperatures of the substrates did not result in a significant difference in indentation diameters or dent depressions.
- Indentation diameters in aluminum fins of mechanical cooling units are close to the diameters of impacting ice spheres.
- Splash marks on heavy gauge surfaces of mechanical units provide an indication of hail direction and size.
- Supported targets show increased resistance to damage.
- Same-size ice spheres produced larger dents on unsupported metals than on supported metals.

In many cases, a variety of metal types will be present on a roof. By examining several surfaces such as heater flues, parapet caps, and the tops and sides of mechanical units, a reasonable conclusion about the size of the hail in an event can be reached.

Different types and thickness of metals will exhibit different degrees of damage. Factors such as substrate, substrate support, and impact angle affect the depth and diameter of indentations.

Evaluating indentations and splash marks provides a roof examiner with useful information. In addition, an examiner should consider weather data, and other physical evidence of damage gleaned from the project site.

Being able to differentiate between multiple hail events at one location requires skill and knowledge to be able to isolate the physical damage that has resulted from separate storms.

Hail damage can be expensive, and difficult to understand and evaluate. Investigators involved in assessing resulting roof damage need reliable information and guidelines to determine the size of hail after the event. This research will provide assistance in this area. Because hail is such a complicated phenomenon, further research covering this topic is warranted.

References

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