P47

Observations of Hailstone Characteristics Utilizing a New Instrumentation Platform

Tanya M. Brown*, Ian M. Giammanco, D. Scott Robinett

Insurance Institute for Business & Home Safety

Introduction

The Insurance Institute for Business & Home Safety (IBHS) is undertaking a multi-faceted research effort to study hailstorms with the goal of reducing property losses. As part of this effort, IBHS researchers are evaluating current impact testing standards for roofing products, and developing improvements to the test standards if warranted. A foundational element of this research effort is the characterization of damaging hail which is assumed to be a function of size, density, and hardness. IBHS conducted a pilot field project in the late spring of 2012 in an effort to quantify the hardness property of hailstones through in-situ measurements. There is much information regarding size, shape, and density of hailstones, yet little information exists regarding the hardness property of individual hailstones. Within historical literature, hailstones are often referred to as “soft”, “hard”, “spongy” or “slushy”, providing only a qualitative description of the hailstones (Bilhelm and Relf, 1937; Carte 1966; Knight and Knight 1973).

Instrumentation

A unique, custom-designed instrument was developed by IBHS engineers, scientists, and technical staff to measure the compressive stress of a hailstone. The application of load cell technology made it possible to obtain a quantitative assessment of the hardness property of individual hailstones, by measuring the force required to fracture the hailstone. The device was originally developed for laboratory use, but was modified to make it more rugged and portable for use in the field. A photograph of the field instrument is provided in Figure 1. In addition to the compressive force measurements, the physical dimensions of each stone must be recorded, to allow for the calculation of compressive stress at fracture. The mass of each stone is also determined to provide an additional basis for comparing results.

The device consisted of a clamping handle in which the compressive force was incrementally increased until the point of fracture and a 227 kg (500 lb) capacity single axis load cell attached to the bottom plate to measure the force applied to the stone. In order to collect and store the information, a unique piece of software was developed using National Instrument’s (NI) LabVIEW. The electrical current information from the load cell was routed through a signal conditioning circuit board to produce a voltage output, acquired through a NI universal serial bus (USB) module. In order to convert the voltage output into a compressive force value, the device was calibrated using known weights to develop a calibration function. The data acquisition graphical user-interface (gui) also allowed the user to enter each stone’s dimensions, mass, and other deployment information such as storm type and a deployment identification number. The program also interfaced with a GPS unit to record the latitude and longitude of each data collection location. Figure 2 provides a diagram of the measurement system.

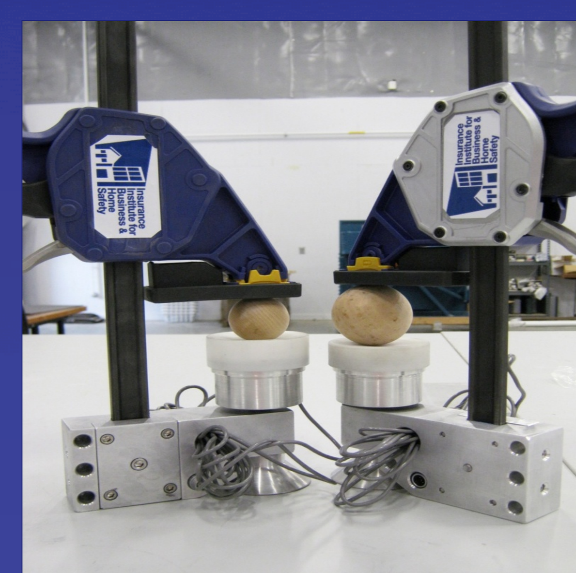

Figure 1. Photograph of the two compressive force devices

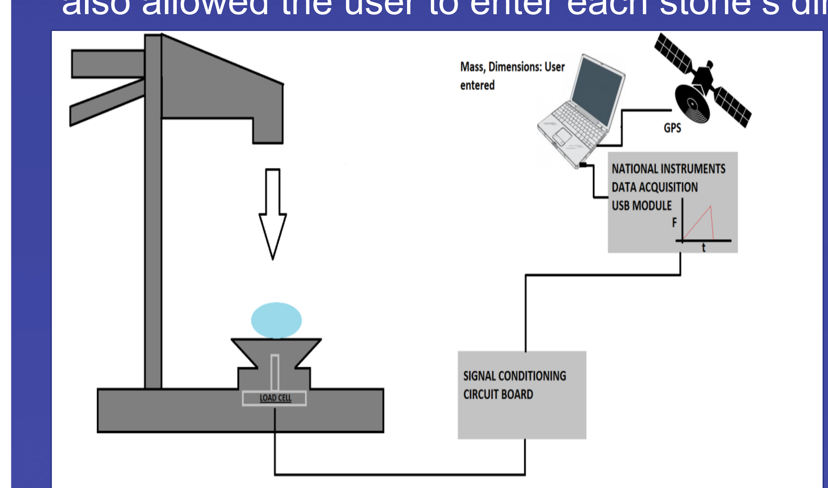

Figure 2. Diagram of the field measurement system.

Each stone was photographically cataloged, weighed, and measured before the compressive force test was conducted. Hailstones were assumed to be spheroidal In shape and the dimensions x_1, y shown in Figure 3 were measured using a caliper. All team members were responsible for collecting a relatively representative sample of the range of stones found at each deployment location. However, it is unlikely that the sample size was representative of the mean storm-scale hail fall distribution and may not necessarily represent the true distribution at the given deployment site. Data collection periods typically ranged from 15-45 minutes and were dependent upon approaching convection and the density of hail fall at a given deployment site.

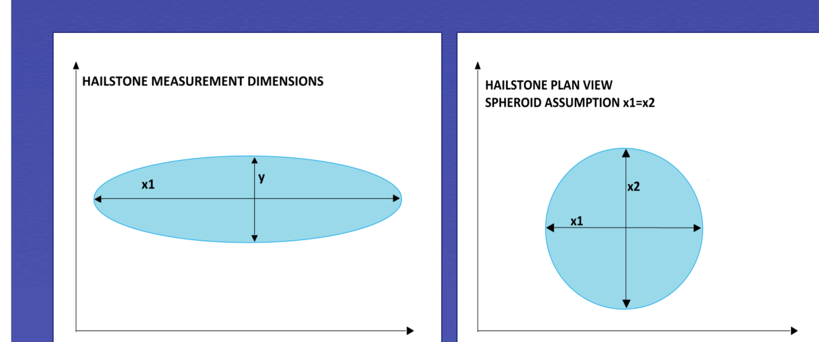

Figure 3. Diagram of the measured dimensions of hailstones. Each stone was assumed to be a spheroid in shape with dimensions x_1 and x_2 equal. Only dimensions x_1 and y were measured in the field.

*Corresponding Author Address: Tanya M. Brown, PhD.
Insurance Institute for Business & Home Safety Research Center
Richburg, SC 29729
tbrown@ibhs.org

2012 Pilot Field Study

Experimental plans and procedures were developed and applied during field operations. The project domain was the general Great Plains region of the United States as this region generally experiences more severe hail events than other parts of the U.S (Changnon et al. 2009)..Idealized deployment and data collection strategies were developed for various storm types (e.g. supercell, linear convection, multi-cell), road networks, and number of teams. Teams were safely positioned in close proximity to the target storm but removed from the region of hail fall. As the target storm passed, teams would proceed to the region of hail fall to collect measurements. An example of the typical data collection strategy is shown in Figure 4.

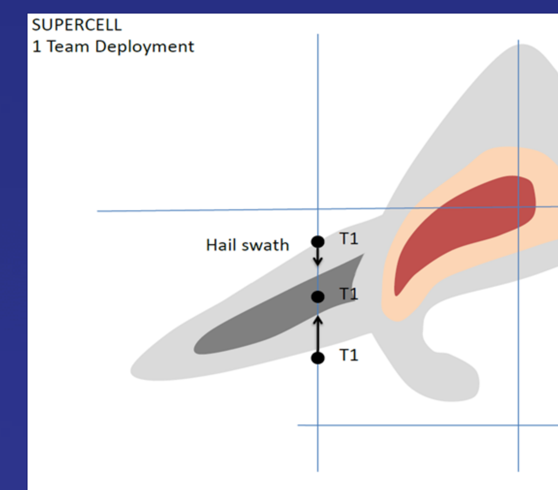

Figure 4. Typical deployment and data collection strategy.

A total of 12 datasets were collected from nine storms, all which exhibited supercell characteristics at some point in their lifecycle. The project featured seven operation days from May 25 through June 7, 2012. Figure 5 provides a map of all deployment locations and the data summary of each deployment is provided in Table 1. The sizes of hailstones measured ranged from as small as 0.41 cm to as large as 7.75 cm. The majority of stones measured were generally disk-shaped or roughly spherical Although some measured stones were smaller than the severe criteria, the majority (65%) of stones had at least one dimension over the 2.54 cm (1 in) threshold for severe hailstones while 75% of the dataset exhibited diameters less than 4 cm.

Table 1. Data summary for each deployment. First number represents operations day, letter represents parent thunderstorm On a given operations day. Last number represents deployment number on the given parent thunderstorm.

Deployment	Date	Location	No. stones measured	Max. stone dimension (cm)	Mean stone dimension (cm)	Max. compressive stress (kPa)	Mean compressive stress (kPa)	Min. compressive stress (kPa)
1A1	05/27/2012	Ravenna, NE	5	1.93	1.35	1327	877	712
2A1	05/28/2012	Lindsay, OK	32	4.75	2.77	2208	892	184
3A1	05/29/2012	Kingfisher, OK	20	7.75	2.31	3714	1244	132
3B1	05/29/2012	Greenfield, OK	17	3.05	1.93	4317	1310	271
4A1	06/01/2012	Channing, TX	45	3.12	1.80	4197	853	160
5A1	06/02/2012	Eads, CO	17	3.33	1.63	759	389	186
6A1	06/06/2012	Remmington Ranch, WY	16	3.07	2.03	477	199	108
6A2	06/06/2012	Remmington Ranch, WY	20	3.23	2.57	542	231	59
7A1	06/07/2012	Cheyenne, WY	8	3.76	3.12	639	381	200
7B1	06/07/2012	Cheyenne, WY	14	3.66	2.44	2766	680	127
7B2	06/07/2012	Cheyenne, WY	35	5.41	3.25	752	497	262
7B3	06/07/2012	Cheyenne, WY	10	4.45	3.38	783	527	187

The mean mass of the measured hailstones was 9.8 g with 90% of the dataset falling below 20 g. The most massive stone measured was 124 g which was associated with the largest diameter measured. This stone had a diameter of over 7 cm and was found near Kingfisher, OK on 29 May 2012. The relationship between the measured diameter and mass was found to be in relative agreement with historical literature (Dennis et al. 1971) and exhibited an exponential increase in mass with diameter (Figure 6). As shown in Figure 7, compressive force measurements exhibited a relationship with diameter such that larger stones typically required a larger compressive force in order to fracture the stone.

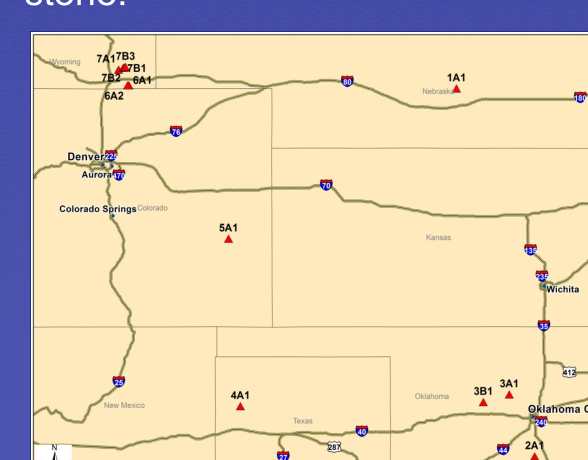

Figure 5. Map of deployment locations for the 2012 field study

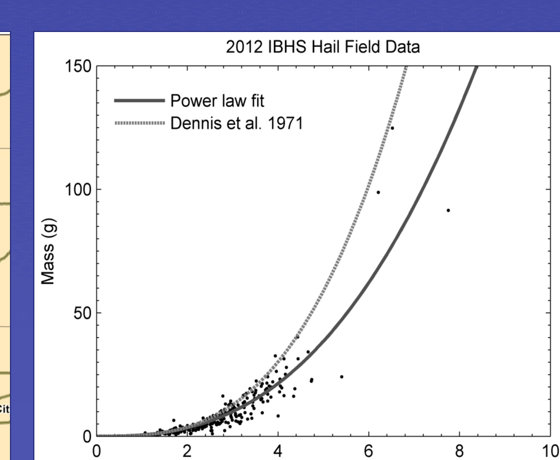

Figure 6. Mass of each hailstone is shown as a function of diameter. A power-law least-squares fit is shown (solid) and the exponential model of Dennis et al. (1971) is also provided (dashed).

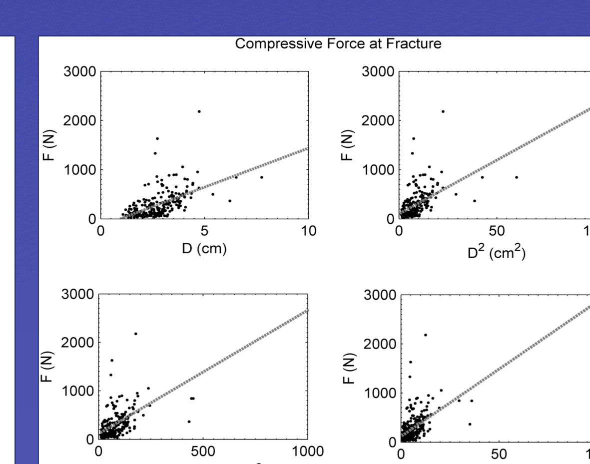

Figure 7. Peak compressive force for measured hailstones shown as a function of diameter (top-right), square of the diameter (top-left), surface area (bottom-left), and estimated cross-sectional area (bottom-right).

Analyses

The measured dimensions of each hailstone were examined in order to investigate the appropriate scaling variable for analyses of the compressive force data. The diameter, diameter squared, cross-sectional area, and surface area assuming an oblate-spheroid shape were investigated for use in scaling the peak compressive force in order to arrive at a peak compressive stress. The cross-sectional area of the two measured dimensions was considered appropriate to represent a compressive stress. Qualitative evidence from the field suggested that although the plane of fracture was not exactly along the cross-section through which the force was applied, it was considered roughly aligned and both dimensions which make up that area were physically measured. The peak stress (σ_c) is a function of the peak compressive force (F_c), the dimensions (x_1, y), and a coefficient of error (c) which accounts for cross-sectional error, which is unknown.

The distribution of the peak compressive stress values during the 2012 pilot field study fit a Weibull distribution well (Figure 8). The mean compressive stress at fracture was 728 kPa with 75% of the measured stones having a compressive stress less than 790 kPa. A maximum compressive stress of 4317 kPa was observed during deployment 3B1 near Greenfield, OK (see Table 1) associated with a 1.6 cm diameter hailstone.

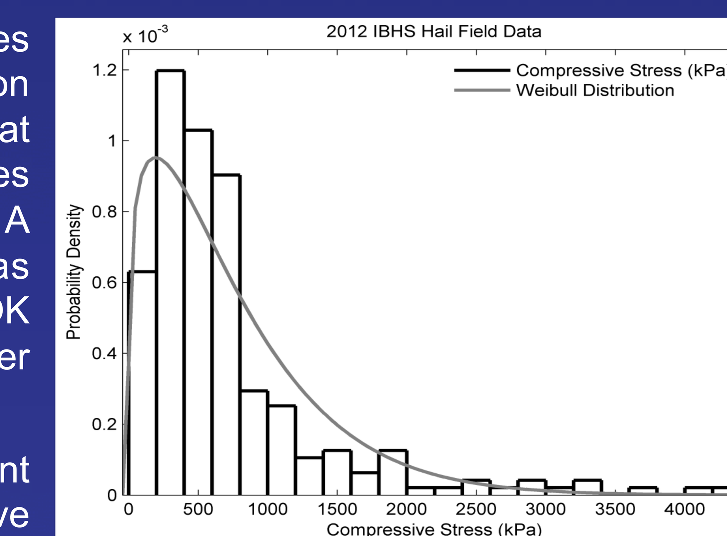

Figure 8. Probability distribution for measured compressive stress at fracture. A fitted Weibull distribution is provided (gray)..

Observations were stratified by individual deployment and parent thunderstorm. When peak compressive stress values were examined as a function of mass, a storm dependency was observed for several events (Figure 9). Values were often clustered by deployment day with hailstones having similar values of peak stress. Despite very complex microphysical hail growth processes, the result is somewhat expected given the general environmental influences on hail production (Fawbush and Miller 1952; Miller 1972; Kitzmiller and Briedenbach 1993; Doswell and Rasmussen 1994; Billet et al. 1997; Edwards and Thompson 1999; Jewell and Brimelow 2009).

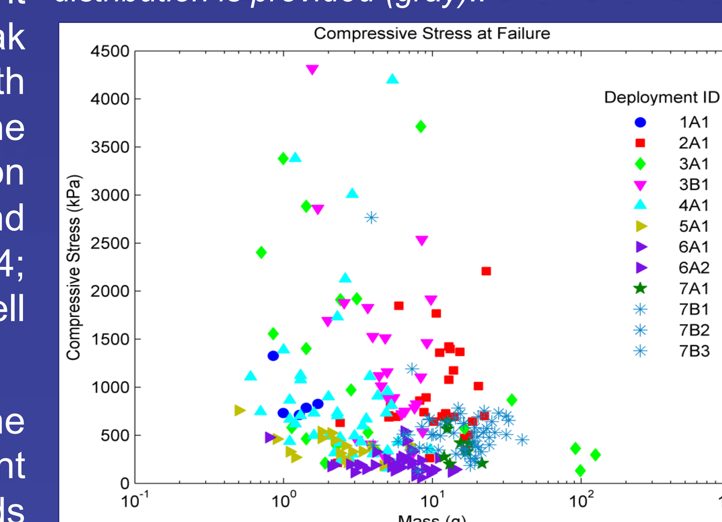

Figure 9. Compressive stress at fracture shown as a function of mass. Data are stratified by deployment identification number which is provided in the legend (see Table 1).

A proximity sounding approach was used to examine the convective environment for each sampled event according to the methodology described in Edwards and Thompson 1998. The most unstable parcel path in the lowest 300 mb was used in accordance with Doswell and Rasmussen (1994). The energy shear index (ESI) was calculated for each proximity sounding. The index is the product of the surface-based CAPE and 1.5 – 6 km wind shear (Brimelow et al. 2002a). As shown in Figure 10, the peak compressive stress exhibited a general increase with ESI. All cases, except one, exhibited ESI values over 3. Although the sample size is quite small, the result is encouraging.

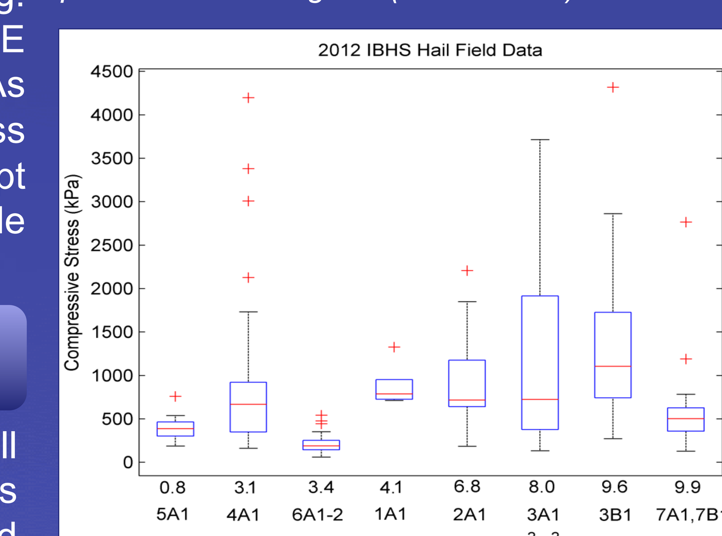

Figure 10. Boxplot distribution of compressive stress at fracture shown as a function of energy shear index. The deployment ID included in each distribution is also provided.

Summary

The dataset acquired during the project is a very small sample but illustrates that in-situ compressive stress measurements can be made. It also highlights the need for continued and improved measurements of hailstone characteristics. It is vital to establish an accurate approach to estimating the compressive stress in order to derive a reliable proxy for the hardness of individual stones so that laboratory stones with similar ranges of hardness can be produced. Ultimately the hardness will affect the complex impact dynamics, including fracturing of the hailstone, the stone with a roof cover, siding or some other object and the resulting damage.

For references please see the associated manuscript

Acknowledgements

The authors would like to thank the IBHS staff who participated in collecting the data presented in this study as well as the IBHS Research Center Technicians for assistance in developing the compressive force testing device. The authors would also like to acknowledge Dr. Dave Bachiochi and Dave Hamilton from WeatherPredict Consulting Inc. for assistance in radar, sounding, and numerical model archival and support.