Severe hail events are responsible for nearly $1 trillion in annual insured property losses in the United States (Changnon et al. 2009). Despite a general negative trend in population growth across the Great Plains of the United States, an increasing trend in hail-related losses has been observed over the past decade (Mutch et al. 2013). The increase in property losses, has generated a renewed interest in understanding how the characteristics of hail may influence damage to existing building stock and new construction.

In 2011, the Insurance Institute for Business & Home Safety (IBHS) began a comprehensive research program focused on understanding the damage potential of hail, improving laboratory test methodologies, developing damage functions for a variety of new and aged building components, and evaluating construction practices which may help mitigate losses. A key component to this program has been a field phase in which in-situ measurements of the characteristics of hailstones are made.

MEASUREMENTS

Each hailstone was photographed cataloged in the field based on its collection location and its associated measured hailstone characteristics. The measurements taken included: (x1, y, z) assuming that two dimensions of the stone (x1, x2) were relatively similar and larger than the third axis (y) as shown in Figure 1. Measuring these dimensions also allowed for a building components, and evaluating construction practices which may help mitigate losses.

The test-device measures the applied compressive force at the point of impact where a peak compressive stress value (1.6 mPa). The rate of force applied to a hailstone until it fractures or deforms enough to produce a fast deformation is referred to as: “hard”, “soft” or “slushy” hailstone. Each stone was also weighed in the field using a digital scale.

HAIL OBSERVATIONS

The 2012-2013 dataset contains 521 hailstones measured on 14 operation days. The measurements locations for the study are shown in Figure 5. Table 1 provides a summary of each sampled event and the associated summary statistics.

<table>
<thead>
<tr>
<th>Case</th>
<th>Event Date</th>
<th>Location</th>
<th>Sampled #</th>
<th>Measured Diameter</th>
<th>Measured Mass</th>
<th>Measured Oblateness</th>
<th>Measured Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>5A-2012</td>
<td>6-2-12</td>
<td>Eads, CO</td>
<td>17</td>
<td>3.33</td>
<td>1.63</td>
<td>0.76</td>
<td>0.39</td>
</tr>
<tr>
<td>7A-2012</td>
<td>6-7-12</td>
<td>LaGrange, WY</td>
<td>8</td>
<td>3.76</td>
<td>3.12</td>
<td>0.64</td>
<td>0.38</td>
</tr>
<tr>
<td>3D-2013</td>
<td>5-19-13</td>
<td>Cedar Vale, OK</td>
<td>59</td>
<td>5.41</td>
<td>3.02</td>
<td>2.77</td>
<td>0.57</td>
</tr>
<tr>
<td>2A-2013</td>
<td>5-18-13</td>
<td>Paradise, KS</td>
<td>6</td>
<td>1.82</td>
<td>0.96</td>
<td>0.41</td>
<td>0.40</td>
</tr>
</tbody>
</table>

The relationship between diameter and mass was examined with respect to the four shape classifications. A power-law fit was effective in describing the relationship as shown in Figure 7.

**CONVEXTIVE MODE**

• Connective modes associated with each event were examined to identify any correlation between hailstone characteristics and storm mode. The radar-based classification scheme presented by Smith et al. (2012) was used to classify each event. The classification tree is shown in Figure 11.

**HARDNESS PROPERTY OF HAIL**

• Compressive stress values ranged from 0.9 x 10^7 mPa to a maximum of 7.5 x 10^7 mPa. The mean value of the compressive stress distribution was 0.68 mPa. The probability distribution is shown in Figure 9.

• The largest compressive stress values were typically not associated with the largest diameter hailstones. Approximately 9% of the cataloged stones were too strong or exhibited a ductile failure such that a peak compressive stress could not be effectively determined.

• Laboratory ice spheres failed very close to the mean of that observed in the field (Figure 10). Field data were binned by equivalent diameter size for the complete dataset.

**SUMMARY**

The data collected during the 2012-2013 IBHS field phases has provided a much needed baseline to evaluate the representativeness of existing laboratory testing methodologies. The overall sample size from the two years of field measurement is minuscule compared to the number of hailstones a single thunderstorm can produce.

• Spherical hailstones were the dominant type of hailstone encountered with a quarter of the dataset being disk-shaped. Two predominant shapes were observed in all parent thunderstorms. The typical size of stone measured during the two year field phase was approximately 2 cm with 60% of the dataset falling below the National Weather Service’s severe threshold (2.54 cm / 1 in).

• Mean compressive stress values were generally similar to that found in laboratory testing of clear ice.

• Both hard and soft stones were encountered in most events. However discrete storm modes did exhibit some clustering of compressive stress values.

• The relationship between mass and diameter suggests a laboratory ice sphere of a given diameter will have a larger mass than a natural hailstone of equivalent diameter.

• The contribution of the hardness property of hailstones and how it relates to the impacted force and duration of impact is not well understood. Future work will continue to focus on understanding this contribution and how common building materials perform in their new and aged states.