

What are the effects of hail on residential roofing products?

This article examines the sometimes-devastating effects that hail can have on asphalt shingles, wood shingles and shakes, and concrete tile shingles

by Jim D. Koontz

Editor's note: *The following article was adapted from a paper that was presented at the Third International Symposium on Roofing Technology, which was held in April 1991, in Montreal, Canada.*

Roofing products are subject to a number of severe weather exposures. These exposures include ultraviolet radiation, heat, wind, rain, pollutants and hail.

Hail damage to roofing products results in millions of dollars of losses on an annual basis. The result of this damage is an obvious boon for roofing contractors and, over the years, has certainly been very costly for the insurance industry. The ultimate cost, however, is borne by consumers.

Hail damage can affect virtually all types of roofing systems, including both commercial and residential. For the purposes of this paper, however, the primary area to be examined will be the hail resistance of common residential roofing products: asphalt shingles, wood shingles and shakes, and concrete tile shingles.

Whenever a city in North America is subjected to a severe hail storm, and the dollar losses exceed \$5 million, the area is listed as a catastrophic loss area by the American Insurance Association. This is a methodology in which the insurance industry can then keep statistics on the amount of loss for each particular geographical location. These numbers are later used in actuarial tables to develop insurance rates for any given location.

In the United States, the geographical frequency of hail has been studied by groups such as the National Board of Catastrophe (from 1949 to 1964) and the United States Weather Bureau (from 1950 to 1960). The data from both groups indicate that a large

number of severe hailstorms tends to occur in the central section of the United States. This covers an area from South Texas to Minnesota and from Colorado to Illinois. It should be pointed out, however, that no area in North America is totally excluded from the possibility of a hail storm occurrence.

The hail phenomena

Research on the phenomena of hail has been performed throughout the world, with the bulk being performed in Europe, South Africa, Australia and North America. Hail varies by size, shape, density and terminal velocity. Three of these factors—size, density and terminal velocity—affect the overall impact energy of hail.

1. *Size:* The size of hail has been reported from as small as sleet ($\frac{1}{4}$ inch or 6.35 mm) to sizes reportedly larger than softballs, with diameters exceeding 5 inches (127 mm). The frequency of hail and the number of impacts for any given area also varies. The overriding factor, however, of whether a hailstorm can inflict damage to a roofing system is the ultimate impact energy, or kinetic energy, imparted by the hailstone to the roofing system, and the impact resistance of the roofing system.

2. *Shape:* The shape of hail can be spherical or somewhat elliptical. For purposes of this particular study, spherical hailstones were used.

3. *Density:* Studies have shown that hailstones vary in density. In cold-weather storms, relatively soft hail with small diameters is generated. In the warmer, spring-type weather, however, large hail (several inches in diameter) is generated with a relatively high density.

Hail is initially formed as an embryonic droplet that goes through a series of updraft cycles. Each cycle

of rising and falling adds a layer of ice to the hailstone. The stronger the updraft force, the higher the hail is carried to colder and colder regions of the atmosphere. At these colder regions, the density of hail will increase, and approach that of ice (about 0.9 grams per cubic centimeter). Measurements of soft hail will show densities ranging from 0.5 to 0.7 grams per cubic centimeter.

It is normally assumed that hail has a density that approximates that of ice. However, a number of researchers have pointed out that hail is somewhat layered, and often consists of rings of ice. For purposes of this study, an overall density of 0.9 grams per cubic centimeter was used.

4. Terminal velocity: The terminal velocity of hailstones was originally determined by J.A.P. Lauri. These terminal velocities (see Figure 1) have been used throughout the industry in other research, particularly that performed by the National Institute of Standards and Technology (formerly the National Bureau of Standards).

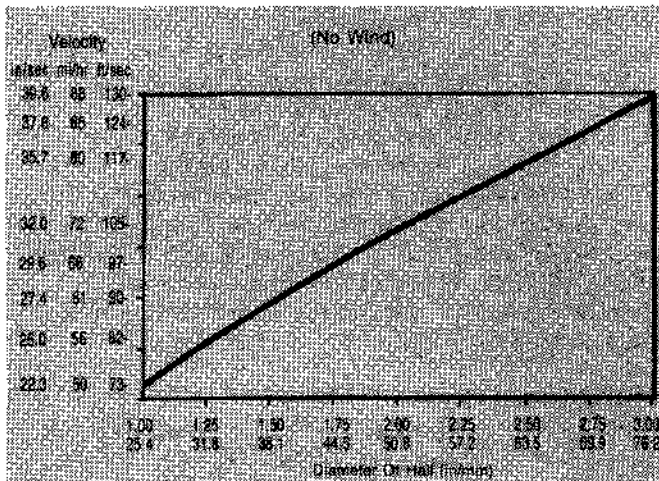


Figure 1: Terminal velocities of hail.

Terminal velocity assumes that a hailstone free-falls straight down, or in a vertical direction. However, it has generally been observed in severe hailstorms that hail does not fall vertically, but impacts surfaces at an angle. Obviously, the terminal velocity of the hailstone is determined by its free-fall velocity and its component horizontal wind velocity.

An example would be a 2-inch (51-mm) hailstone that would have a free-falling terminal velocity of 105 feet per second (32 meters per second) or 72 mph. If this stone was associated with a 59-feet per second (54 meters per second) or 40-mph horizontal wind, the resultant terminal velocity would increase to 120 feet per second (36 meters per second) or 82 mph.

The overall increase in kinetic energy would be from 23.29 pound force (31.58 joules) to 30.24 pound

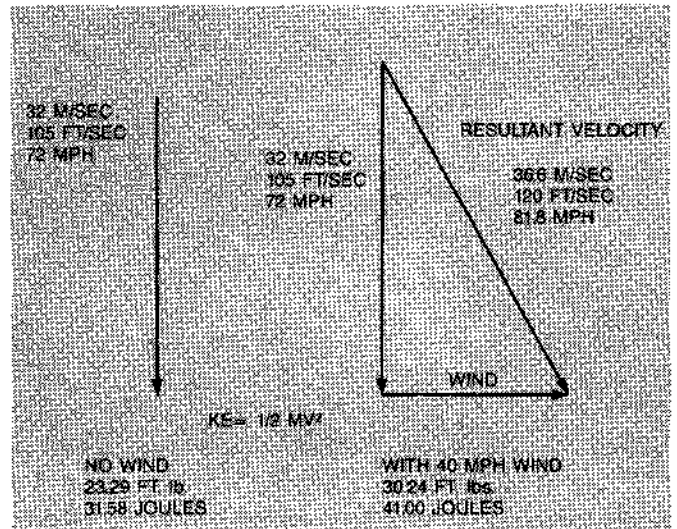


Figure 2: Effect of 40-mph wind on 2-inch-diameter hail.

force (41.0 joules), or an increase of 30 percent in impact energy. By varying the horizontal wind factor, the ultimate impact energy can be varied dramatically (see Figure 2).

In reviewing this initial data, it is also interesting to note the overall difference in impact energy between hailstones with diameters of 1 inch (25.4 mm) and 2 inches (51 mm). Increasing the diameter of the hail from 1 inch to 2 inches increases the ultimate impact energy from less than 1 foot per pound (1.4 joules) to approximately 22 foot per pound (29.83 joules—see Figure 3).

The approximate impact energy obviously increases on an exponential scale, which is determined by the mass and the increase in terminal velocity. These two factors, mass and velocity (which are both increasing exponentially), cause a dramatic increase in the impact energy with small, incremental fluctuations of hail diameters.

Testing equipment that was used

To test various residential roofing products for resistance to hail damage, a hail gun was constructed.

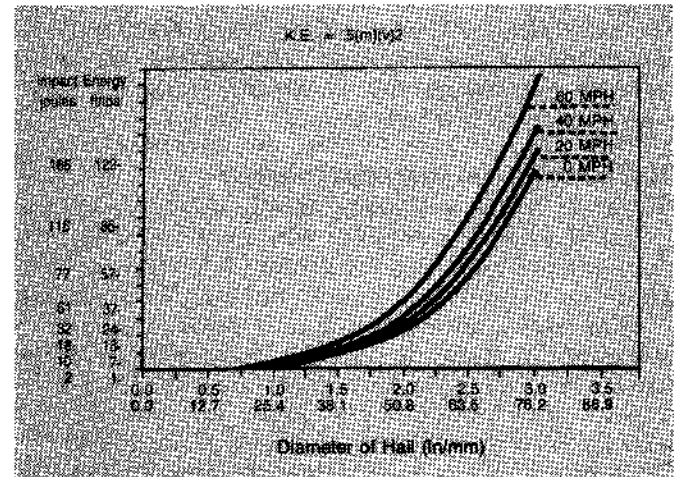


Figure 3: Impact energy of hail.

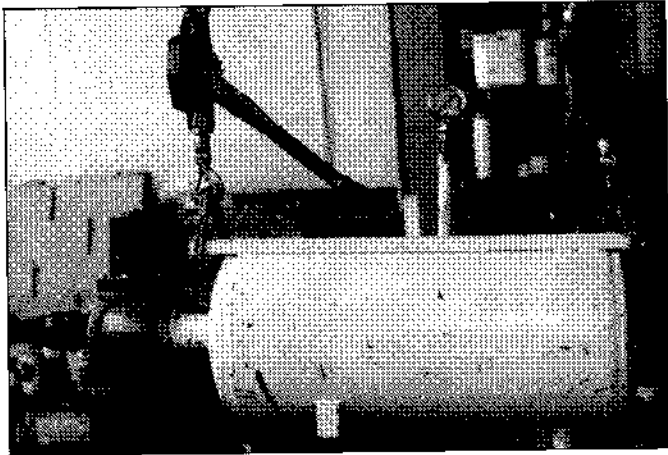


Photo 1: Hail gun with quick-release valve.

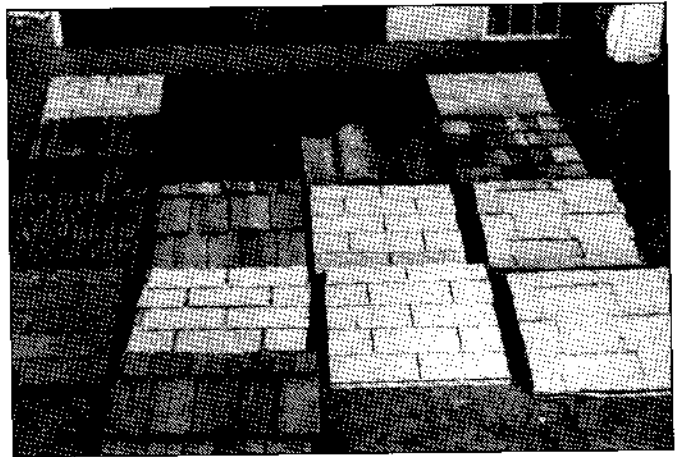


Photo 3: The hail targets.

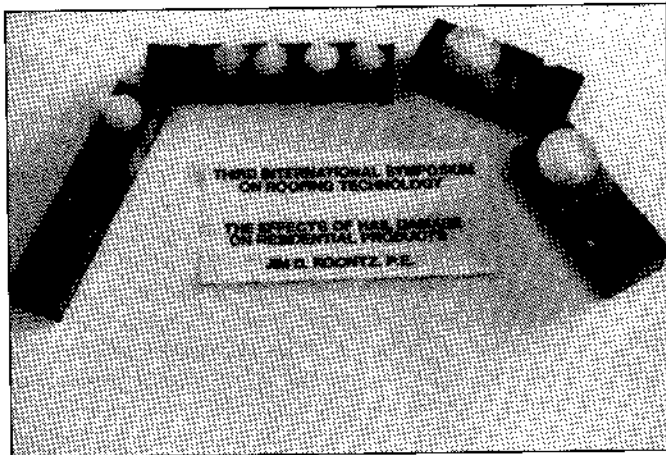


Photo 2: Hail molds.

This gun consisted of a pressurized air tank fitted with a quick-release, electronically actuated valve (see Photo 1). The barrels of the hail gun were interchangeable to accommodate the size of the hail, which was formed in molds (see Photo 2).

By pressurizing the tank and by opening the electronically actuated, quick-release valve, the sudden surge of air pressure propels the hailstone towards the target. To accurately measure the terminal velocity of the hailstone, a ballistic timer was used. Once this equipment was assembled, the hail gun was calibrated between air pressures and terminal free-fall velocities for different sizes of hailstones.

Hailstone targets that were used

Nineteen roofing assemblies were tested for resistance to hail damage (see Photo 3). The substrate of 18 of the samples was $\frac{1}{2}$ -inch (12.7-mm) CDX plywood. One sample was tested with $\frac{1}{2}$ -inch (12.7-mm) OSB decking.

Prior studies have shown that variations in the substrate can affect the puncture resistance of roofing assemblies. All targets were constructed on 2-foot x 2-foot x $\frac{1}{2}$ -inch (.61-mm x .61-mm x 12.7-mm) sheets. And all were constructed with one layer of ASTM D226-Type-I organic underlayment beneath the shingles.

Eleven of the targets were asphalt shingles with

either fiberglass or organic mats, in a three-tab, T-lock, grain pattern and layered, and simulated wood configuration. Three wood shingle targets had medium shake shingles, cedar shingles and 20-year-old, heavy red cedar shake shingles. Three concrete tiles were used in three configurations: "S," barrel and shake.

Two of the previously impacted asphalt shingle targets (constructed of 15-year-old, three-tab organic and T-lock organic) were then overlaid with new shingles (three-tab fiberglass and T-lock fiberglass, respectively). These roofing assemblies were included in the study because, in many cases, hail-damaged residential roofs are simply overlaid with a second layer of shingles. The older shingles, by default, serve as an underlayment on many residential roofing projects.

Most building codes, however, do not allow a third layer due to potential structural limitations. It has also been experienced that the fastener length for a third layer of shingles becomes too long and results in some movement of the roofing materials due to a slight flexing, or rotation, of the fastener itself.

Testing procedures

Each sample was impacted by hail 15 times. This included five different sizes of hail— $\frac{3}{8}$ inch (19 mm), $1\frac{1}{4}$ inch (32 mm), $1\frac{1}{2}$ inch (44 mm), 2 inch (51 mm) and $2\frac{1}{2}$ inch (64 mm)—impacting at three different angles of impact (15, 45 and 90 degrees—see Figure 4). A variation in the angle of impact from 15, 45 to 90 degrees produces a resultant force ranging from 25.88 percent, 70.7 percent and 100 percent, respectively.

Simulated hailstones were frozen in molds at approximately 10 F (12 C). The hailstones were quickly removed, placed in the gun barrel and fired within 30 seconds of loading. Following the impact of each specimen, results were recorded. Tests were performed at a room temperature of about 80 F (27 C).

All hail was fired at its terminal free-fall velocity (Figure 1). Concrete tile targets were then impacted in a secondary test with hail at speeds higher than normal terminal velocity to simulate the effects of high horizontal winds.

A fiberglass three-tab assembly over a plywood deck was subjected to three surface temperatures—60 F

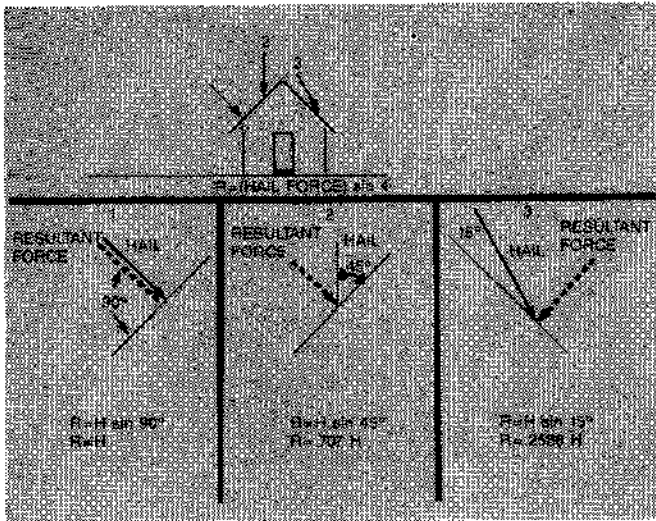


Figure 4: Angle of impact of hail.

(15.6 C), 80 F (27 C) and 120 F (49 C)—for hail damage evaluation with a 2-inch (51-mm) hailstone. The effects of higher and lower surface temperatures were then evaluated.

Damage assessment

Evaluating marginal damage to roofing products has not been clearly understood by either the roofing or insurance industries. Catastrophic failure damage is very clear and easy to observe. This would be a complete fracture/puncture through the installed residential roofing product.

Other types of damage, however, are not so obvious. Indentations may not fracture, but may result in some aesthetic loss, or in some potential loss of performance in years to come. As each of the targets was impacted with hail, the visible damage was recorded in a table (see Figure 5 for a representative number of testing samples). Various ratings for damage were used: ND (No Damage); I (Indentation); IG (Indentation with Granule Loss); ED (Edge Damage); IF (Indentation with Fracture); and P (Puncture).

In some cases, an indentation can occur, and the fracture in either the reinforcement mat (fiberglass or organic) or in some cases, even a fracture in the wood shingle is not readily observable. In the case of an organic or fiberglass mat shingle, desaturation of the shingle may be required to observe the damage. In the case of a wood shingle, close examination may be required to observe the split or fracture.

Asphalt shingle performance

Fourteen assemblies of asphalt shingles were targeted. Damage varied from no damage to puncture. All of the new, single-layer, fiberglass three-tab shingle assemblies had a resistance to fracture in the 3/8-inch (19-mm) to 1 3/8-inch (64-mm) category, with an angle of impact ranging from 15 to 90 degrees. Fiberglass asphaltic shingles installed over OSB decking had the same degree of fracture resistance as similar shingles installed over plywood decking.

Indentations in the bulk of these areas were super-

ficial, with just minor granule loss. It was observed in some shingles, such as Target No. 1, that indentations would occur (hail size of 2 inches or 51 mm, 90-degree angle). At this point, the shingles were desaturated with hot solvent, and fractures were observed in the shingle mat. These fractures were not readily detected by visual observation.

There did not appear to be a visible difference in hail resistance between organic and fiberglass three-tab products. The three-tab, assembly-type shingles, however, did have a higher hailstone resistance than T-lock shingles (see Photo 4). This increase in hail resistance appears to be a result of the smoother, flatter installation of the three-tab shingles.

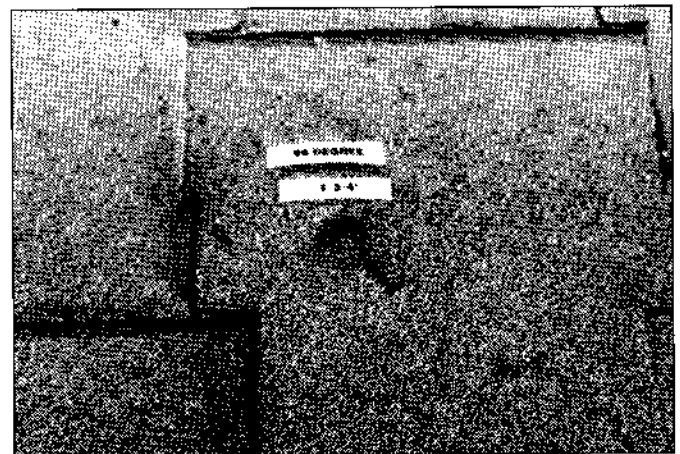


Photo 4: A 1 3/4-inch hailstone impacted this T-lock shingle at a 90-degree angle.

The heavier-weight, laminated shingles (Target No. 7) offered a slightly higher hail resistance to that of other fiberglass shingles in that a fracture did not occur until 2-inch hail (51-mm) at a 90-degree angle impacted the target. It should be pointed out, however, that the damage was not readily visible, and could not be observed until the shingle was desaturated.

The older, organic three-tab and T-lock shingles exhibited a very low threshold of hail resistance (see Photo 5). As shingles age, asphalt within the shingle obviously hardens and becomes somewhat more brittle. This creates a situation in which tow residences could be next door to one another, and one residence could sustain damage to a slightly older roof, while the other residence could have virtually no damage with a new roofing system.

When a roof system is overlaid, there is an increased void space between the new and old shingles. This is particularly evident in the case of new T-locks installed over old T-locks. In this situation, as demonstrated by Target No. 13, a fracture occurred with hail as small as 1 1/4 inches (32 mm) fired at a 90-degree angle.

All asphalt shingles had a fairly low threshold of

Velocity:						
Feet/Second	65	82	97	105	117	
Meters/Second	20	25	30	32	36	
Miles/Hour	44	56	66	72	80	
Kinetic Energy:						
Angle of Impact						
Ft. Lbs./Joules: 90°	43/59	4/5.4	14/19	22/30	53/72	
Ft. Lbs./Joules: 45°	31/42	2.8/3.8	9.9/13.4	15.6/21.2	37.4/50.9	
Ft. Lbs./Joules: 15°	11/15	1.0/1.4	3.6/4.9	5.7/7.8	13.7/18.6	
Hailstone Size	3/4 inch (19 mm)	1 1/4 inch (32 mm)	1 3/4 inch (44 mm)	2 inch (51 mm)	2 1/2 inch (64 mm)	Target Description
Target Number:						
Angle of Impact						
Number 1:						
90°	ND	ND	I	IF/NV	IF	Fiberglass, White, 3-Tab, ASTM D3018-1, Class A, 210 Lbs./Sq., Plywood Deck
45°	ND	ND	I	IG	IF	
15°	ND	ND	ND	EED	IFP	
Number 7:						
90°	ND	I	I	IF/NV	IF	Fiberglass, Brown, Laminated, Class A, 300 Lbs./Sq., Plywood
45°	ND	ND	IG	IG	IF	
15°	ND	ND	ND	I/ED	I/ED	
Number 13:						
90°	ND	IF	IF	P/F	P/F	Fiberglass, White, T-Lock, ASTM D3018-1, Class A, 210 Lbs./Sq., Plywood Deck ***Overlay Old T-Locks***
45°	ND	IG	IG	P/F	P/F	
15°	ND	ND	EP	IG	IGED	
Number 14:						
60°F/90°	ND	IF	IF	P	P	Fiberglass, White, 3-Tab, ASTM D3018-1, 210 Lbs./Sq., Plywood Deck **Temperature Variation**
80°F/90°	ND	ND	I	IF/NV	IF	
120°F/90°	ND	I	I	I	IF	
Number 15:						
90°	I	IF	I	IF	IF	Wood, Saw Cut, Both Sides 18 inches long 6-inch exposure 3/8 inches thick
45°	I	I	I	IF	IF	
15°	I	I	I	I	I	
Number 16:						
90°	I	IF	IF	IF	IF	Wood, Saw Cut, One Side 24 inches long 10-inch exposure 1/2 inches thick
45°	I	I	I	IF	IF	
15°	I	I	I	I	I	

Figure 5: Nineteen roofing assemblies were tested for resistance to hail damage—the results of six of these are shown above. The ratings for damage that were used are: ND (no damage); I (indentation); IG (indentation with granule loss); IED (indentation with edge damage); IF (indentation with fracture); P (puncture); and NV (fracture not visible without solvent desaturation).

damage when the impact occurred at the butt edge (or shingle cutout) in a three-tab assembly. This typically produces a somewhat semi-circular break at the leading butt edge. Although this may not effect the performance of the shingle, it may cause some slight problems from an aesthetic standpoint.

Variations in temperature

Temperature of the roof assembly surface is a definite factor in hail damage (see Target No. 14). Lower surface temperatures, such as 60 F (15.6 C), are much more prone to fracture than higher surface temperatures. This produces a lower threshold for damage.

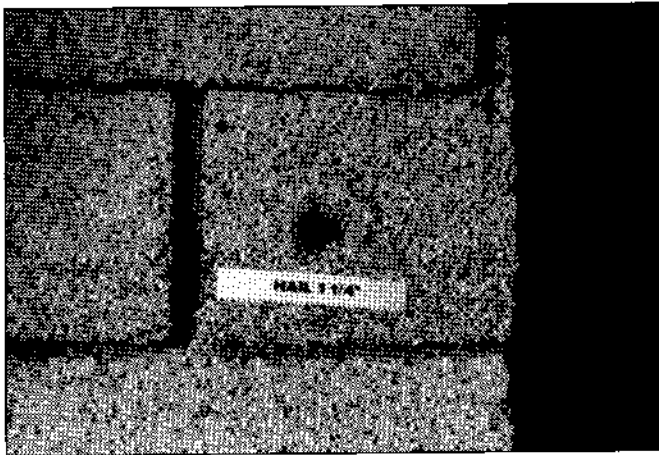


Photo 5: 1¼-inch hailstones impacted on an older, three-tab shingle.

The asphalt into which the granules are imbedded appears to shatter more readily at colder temperatures. When the surface temperature of the shingle is somewhat higher, such as 120 F (49 C), the surface is somewhat softer and, though easily indented, does not readily fracture.

Wood shingle performance

Three different groups of wood shingles were used; new No. 1 red cedar shingles, new No. 1 red cedar handsplit mediums and 20-year-old No. 1 red handsplit heavies.

The three wood shingles that were tested exhibited various degrees of indentation, which occurred at very low thresholds of kinetic energy. When the wood shingles were impacted with hailstones from ¾ inches (19 mm) in diameter to 1 ¼ inches (44 mm) in diameter, fairly uniform indentions occurred.

The indentations, depending upon the angle of impact, were either circular or somewhat elliptical. Damage in this particular area, for the most part, was superficial, and would not effect the overall performance of the roofing system.

When the wood shingles (Targets No. 15 and 16) were impacted with hailstones 1 ¼ inches (44 mm) or larger, the shape of the indentation was not uniform (see Photo 6). This was due to two factors: One, the



Photo 6: Irregular indentation of hailstone impacted on a wood shingle.

hail tends to crush and rotate somewhat as it impacts the shingle; two, because the surface of the wood shingle is irregular, the indentation becomes erratic.

The threshold for damage within the wood shingle was not clear-cut. This can obviously be due to the different thicknesses of the wood, points of impact, and non-uniform surfaces and sub-surfaces. An example is the ½-inch (13-mm) No. 1 red cedar handsplit medium shingle, where, at a 90-degree angle of impact, splits developed in the shingles with hailstones of 1 ¼ inches (32 mm) and 1 ¾ inches (44 mm). Indentations occurred, however, with 2-inch (51-mm) hail followed by fractures with 2 ½-inch (64-mm) hail.

The thicker wood shingles did not necessarily result in higher hailstone resistance. The thinner red cedar shingles (¾ inch or 9.5 mm) with smoother surfaces and a greater uniformity in the substrate produced hailstone resistance equal to the thicker shingles. Some indentation of the wood shingles did occur at the leading butt edge and at the joint of the shingles. The bulk of this damage is somewhat superficial, and began at a fairly low threshold of kinetic energy (see Photo 7).

Concrete tile shingle performance

The three concrete tile targets all exhibited fairly high degrees of hail resistance. Fracture/breakage did not occur with the 2 ½-inch (64-mm) hail at a 90-degree angle of impact. Fracture/breakage did occur, however, when the velocity was increased to 131 feet per second (40 meters per second) or 89 mph, resulting in kinetic energy of 71.49 feet per second (96.9 joules—see Photo 8).

The flatter concrete tile shingle was the most hail-resistant concrete tile product tested. Multiple impacts with 2 ½-inch (64-mm) hail was required before fracture/breakage occurred.

In conclusion

Damage to residential roofing products is an obvious result of the size of hail, angle of impact, age of

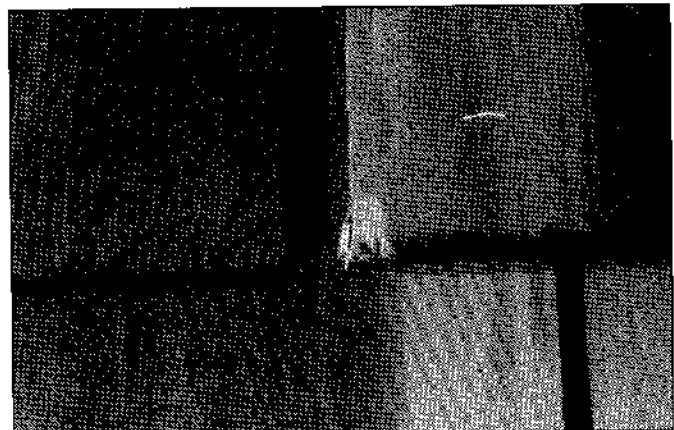


Photo 7: Wood shingle indentation at butt edge.

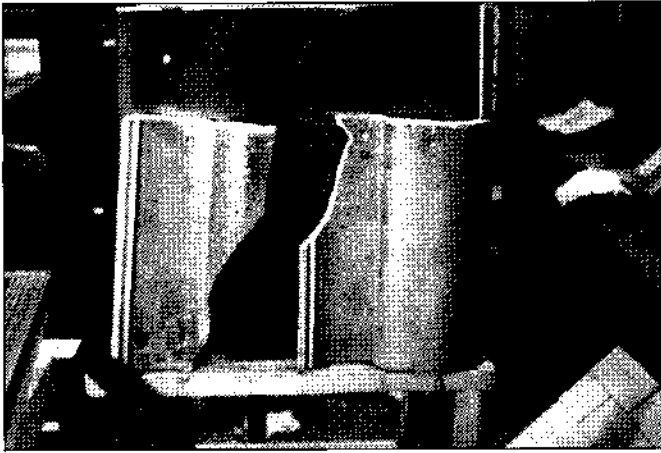


Photo 8: Fracture of a concrete tile.

materials, type of roofing system, temperature and substrate condition.

If the angle of impact is great enough, a situation could occur in which one side of a sloped residential roof is severely damaged due to an impact with a high normal resultant force, while the opposite side may have minimal to no damage because a glancing-type of impact may have occurred.

Fiberglass and organic three-tab materials, in single-layer applications over either plywood or OSB deck-

ing, appear to offer a high degree of hail resistance in asphaltic shingle construction.

It is obvious that in some questionable circumstances, desaturation of asphalt shingles is required to determine whether or not the reinforcing mat has suffered damage.

Threshold damage of wood shingle roofs are a result of the point of impact on the shingle assembly. Fracture of the wood shingles appears to be somewhat dependent upon whether the shingles are sawn on one or both sides.

When the shingles lay relatively flat, as in a double-sawn shingle, resistance to hail damage appears to improve.

Concrete tile systems appear to offer a very high degree of hail resistance. The lower-profile shingle—either flat or lower configurations—result in increased hail resistance. **PR**

Jim Koontz, PE, is president of Jim Koontz & Associates Inc., Hobbs, New Mexico. For a copy of references and the complete testing results (Figure 5), contact NRCA's Aimee Anderson at (708) 299-9070.

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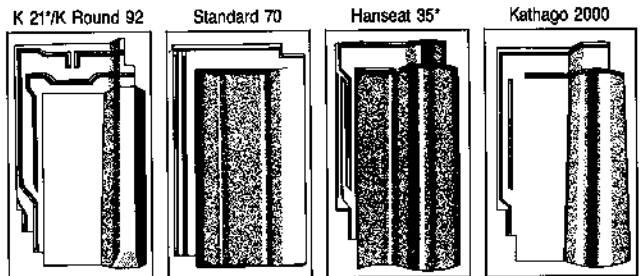


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