THE EFFECTS OF HAIL ON RESIDENTIAL ROOFING PRODUCTS

JIM D. KOONTZ
Hobbs, New Mexico

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, 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 hailstorm, 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 indicates that a large number of severe hailstorms tend 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 can be totally excluded from the chance of hail.

KEYWORDS

Asphalt shingles, concrete tile shingles, hail damage, hail resistance, wood shingles.

HAIL

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 a number of parameters. These include size, shape, density and terminal velocity. Three of these factors— size, density and terminal velocity—obviously affect the overall impact energy.

Size: The size of hail has been reported from as small as sleet (¼ in./6.35mm) to size reportedly larger than softballs, with diameters exceeding 5in./127mm. The frequency of hail, the number of impacts for any one given area, can also vary. The overriding factor, however, of whether a hailstone can inflict damage to a roofing system will be the ultimate impact energy, or kinetic energy, imparted by the hailstone to the roofing system, and the impact resistance of the roof system.

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

Density: Studies have shown that hailstones can vary in density.[1] In cold weather storms, relatively soft hail with small diameters is generated. In the warmer, spring-type weather, however, large hail (several centimeters/inches in diameter) is generated with a relatively high density.

Hail is initially formed as an embryonic droplet which 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 approaches that of ice (approximately .9 grams-per-cubic-centimeter). Measurements of soft hail show densities ranging from .5 to .7 grams-per-cubic-centimeter.

It has normally been assumed that hail has a density which approximates that of ice. It has been pointed out by a number of researchers, however, that hail is somewhat layered, and often consists of rings of ice. For purposes of this study, an overall density of .9 grams-per-cubic-centimeter was utilized.

Terminal Velocity: The terminal velocity of hailstones was originally determined by LAURI.[2] These terminal velocities (Figure 1) have been used throughout the industry in other research, particularly that performed by the National Institute of Standards and Technology (formerly National Bureau of Standards).[3]

Terminal velocity assumes a hailstone free-falling straight down, or in a vertical direction. It has generally been observed in very severe hailstorms, however, 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 2in./51mm hailstone which would have a free-falling terminal velocity of 105 ft./sec., 32 meters/sec., or 72 mph. If this stone was associated with a 59 ft./sec., or 54 meters/sec., or 40 mph horizontal wind, the resultant terminal velocity would increase to 120 ft./sec., 36 meters/sec., or 82 mph. The overall increase in kinetic energy would be from 23.29 pound force/31.58 joules to 30.24 pound 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 (Figure 2).

In generally reviewing this initial data, it is also interesting to note the overall difference in impact energy between hailstones with diameters of 1in./25.4mm and 2in./51mm. Increasing the diameter of the hail from 1in./25.4mm to 2in./51mm increases the ultimate impact energy from less than one foot/pound, or 1.4 joules to approximately 22 foot/pounds, or 29.83 joules (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 impact energy with small, incremental fluctuations of hail diameter.

TEST EQUIPMENT

In order to test various residential roofing products for resistance to hail damage, a hail gun was constructed. This gun consisted of a pressurized air tank fitted with a quick-release, electrically-actuated valve (Photo 1). The barrels of the hail gun were interchangeable to accommodate the size of the hail, which was formed in molds (Photo 2).

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

TARGETS

Nineteen different roofing assemblies were tested for resistance to hail damage (Photo 3). The substrate for 18 of the samples was ½ in./12.7mm CDX plywood. One sample was tested with ½ in./12.7mm OSB decking. Prior studies have shown that variations in the substrate can affect the puncture resistance of roofing assemblies.[4] All targets were constructed on two foot by two foot by ½ in./.61mm X .61mm X 12.7mm sheets (Photo 4). And were constructed with one layer of ASTM D226-Type I organic underlayment beneath the shingles.

Eleven of the targets were asphalt shingles utilizing either fiberglass or organic mats, in a three-tab, T-lock, grain pattern and layered, and simulated wood configuration. Three wood shingle targets were used utilizing 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 overlayed 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.

TEST PROCEDURES

Each sample was impacted by hail 15 times. This included five different sizes of hail (¾ in./19mm, 1¼ in./32mm, 1¾ in./44mm, 2 in./51mm and 2½ in./64mm) impacting at three different angles of impact (15°, 45° and 90°) (Figure 4). A variation in the angle of impact from 15°, 45° to 90° produces a resultant force ranging from 25.88 percent, 70.7 percent to 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 impacting of each specimen, results were recorded. Tests were performed at a room temperature of approximately 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 in order to simulate the effects of high horizontal winds.

A fiberglass three-tab assembly over a plywood deck was subjected to three different surface temperatures (60°F/15.6°C, 80°F/27°C and 120°F/49°C) for hail damage evaluation with a 2in./51mm 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 some potential loss of performance in years to come. As each one of the targets was impacted with hail, the visible damage was recorded in a table (Figure 5). Various ratings for damage were utilized: "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 in order to observe the damage. In the case of a wood shingle, close examination may be required to observe the split or fracture.

ASPHALT SHINGLES

Fourteen different assemblies of asphalt shingles were targeted. Damage varied from no damage to puncture (Figure 5). All of the new, single layer, fiberglass three-tab shingle assemblies had a resistance to fracture in the ¾ in./19mm to 1¾ in./64mm category with angle of impact ranging from 15° to 90°. 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 superficial, with just minor granule loss. It was observed in some shingles, such as Target #1, that indentations would occur (hail size 2 in./51mm, angle 90°) as illustrated in Photo 5. 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 (Photo 6). This increased hail resistance appears to be a result of the smoother, flatter installation of the three-tab shingles. Although color does not affect the resulting damage or indentations, damage tends to be less visible with darker colored shingles.

The heavier-weight, laminated shingles (Target #7) offered a slightly higher hail resistance to that of other fiberglass shingles in that a fracture did not occur until 2in. hail at 90° angle was impacted upon 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 (Photo 7). As shingles age, asphalt within the shingle obviously hardens and becomes somewhat more brittle. This creates a situation in which two 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 overlayed, 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 #13, a fracture occurred with hail as small as 1¼ in./32mm fired at a 90° angle.

All asphalt shingles had a fairly low threshold of damage when the impact occurred at the butt edge, or shingle cutout in a three-tab assembly. This produces, typically, a somewhat semicircular break at the leading butt edge. Although this may not affect the performance of the shingle, it may cause some slight problems from an aesthetic standpoint.

Temperature

Temperature of the roof assembly surface is a definite factor in hail damage (Target #14). Lower-temperatured surfaces (60°F/15.6°C) are much more prone to fracture than higher-temperatured surfaces (Photos 8 and 9). The situation may occur in which a rain just prior to a hailstorm lowers the shingle surface temperature. This produces a lower threshold for damage. 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, at 120°F/49°C, the surface is somewhat softer and, although easily indented, does not readily fracture.

WOOD SHINGLES

Three different groups of wood shingles were utilized; new Number 1 Red Cedar Shingles, new Number 1 Red Cedar Handsplit Mediums, and 20-year old Number 1 Red Cedar Handsplit Heavies.

The three wood shingles impacted all exhibited various degrees of indentation, which occurred at very low thresholds of kinetic energy. When the wood shingles were impacted with hailstones from ¾ in./19mm to 1¾ in./44mm in diameter, fairly uniform indentations occurred (Photo 10). The indentations, depending upon angle of impact, were either circular or somewhat elliptical. Damage in this particular area, for the most part, was superficial and would not affect the overall performance of the roofing system.

When the wood shingles (Targets #15 and #16) were impacted with hailstones 1¾ in./44mm or larger, the shape of the indentation was not uniform (Photo 11). This was due to two factors. One, the hail tends to crush and rotate somewhat as it impacts the shingle. Two, since 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 nonuniform surfaces and subsurfaces. An example would be in the ½ in./13mm Number 1 Red Cedar Handsplit Medium shingle at the 90° angle of impact where splits developed in the shingles with hailstones of 1¼ in./32mm and 1¾ in./44mm. Indentations occurred, however, with 2 in./51mm hail, followed by fractures with 2½ in./64mm hail.

The thicker wood shingles did not necessarily result in higher hailstone resistance. The thinner red cedar shingles (⅜ in./9.5mm) 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 joints of the shingles. The bulk of this damage is somewhat superficial, and began at a fairly low threshold of kinetic energy (Photos 12 and 13).

CONCRETE TILE SHINGLES

The three concrete tile targets all exhibited fairly high degrees of hail resistance. Fracture/breakage did not occur with the 2½ in./64mm hail/90° angle. Fracture/breakage did occur, however, when the velocity was increased to 131 ft./sec., 40 meters/sec., or 89 mph, resulting in kinetic energy of 71.49 ft./sec./96.9 joules (Photo 14). The flatter concrete tile shingle was the most hail resistant concrete tile product tested. Multiple impacts with a 2½ in./64mm hailstone were required before fracture/breakage occurred.

CONCLUSIONS

Damage to residential roofing products is an obvious result of the size of hail, angle of impact, age of 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. The opposite side of the residence may have minimal to no damage since a glancing-type impact may have occurred.

Fiberglass and organic three-tab materials, in single layer applications over either plywood or OSB decking, 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 in order 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, the resistance to hail damage appears to improve.

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

REFERENCES

1. Browning, K.A., F.H. Ludlam, and W.C. Macklin, "The density and structure of hailstones," Quart. J.R. Meteorol. Soc. 89, 75-84 (1963) Roy. meteorol.
2. Laurie, J.A.P., "Hail and Its Effect on Buildings," C.S.I.R. Research Report No. 176, Bull. 21, 1-Type I2, National Building Research Institute, Pretoria, South Africa (1960).
3. Greenfeld, Sidney H., "Hail Resistance of Roofing Products," U.S. Department of Commerce, National Bureau of Standards, Building Science Series 23, 1-9, Washington, D.C., (1969).
4. Koontz, Jim D., P.E., "A Comparative Study of Dynamic and Static Loading of One-Ply Assemblies," ASTM STP 959 Publication, 1986.

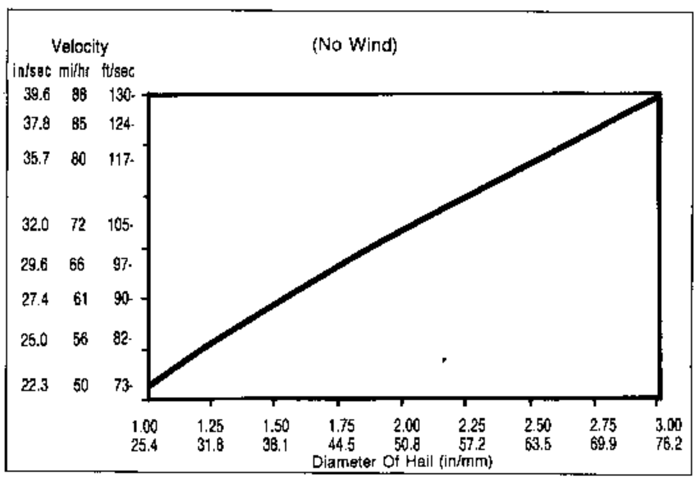

Figure 1 Terminal velocities of hail.

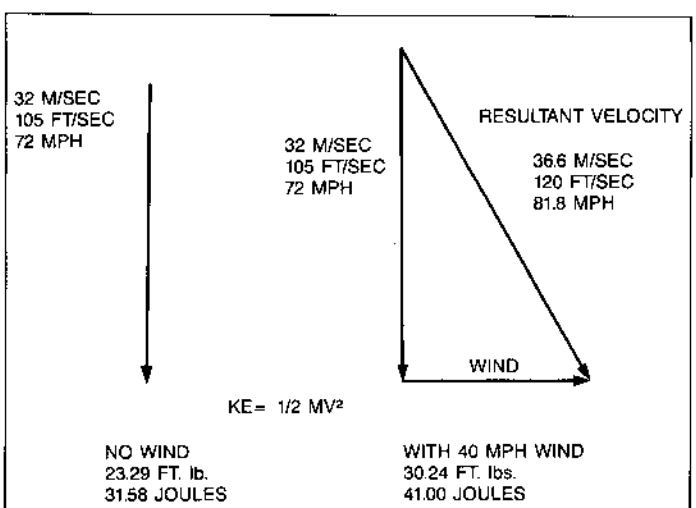

Figure 2 Effect ofu 40 MPH wind on 2" diameter hail.

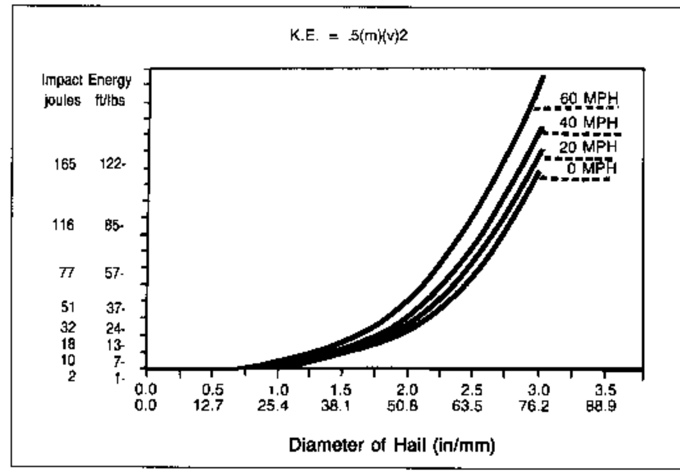

Figure 3 Impact energy.

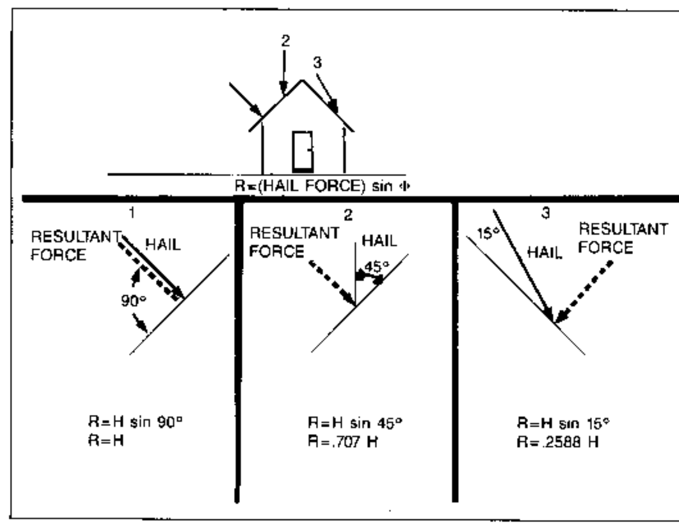

Figure 4 Angle of impact.

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

LEGEND:

ND: NO DAMAGE
I: INDENTATION
IG: INDENTATION W/ GRANULE LOSS
IED: INDENTATION W/ EDGE DAMAGE
IF: INDENTATION W/ FRACTURE
P: PUNCTURE
NV: FRACTURE NOT VISIBLE WITHOUT SOLVENT DESATURATION

HAILSTONE SIZE	3/4" (19/MM)	1-1/4" (32/MM)	1-3/4" (44/MM)	2" (51/MM)	2-1/2" (64/MM)	TARGET DESCRIPTION
TARGET NUMBER : ANGLE OF IMPACT						
NUMBER 1:						FIBERGLASS, WHITE, 3-TAB, ASTM D3018-1, CLASS A, 210 LBS./SQ., PLYWOOD DECK
90°	ND	ND	I	IF/NV	IF	
45°	ND	ND	I	IG	IF	
15°	ND	ND	ND	EED	IFP	
NUMBER 2:						FIBERGLASS, WHITE, 3-TAB, ASTM D3018-1, CLASS A, 210 LBS./SQ., WAFERBOARD DECK
90°	ND	ND	I	IF	IF	
45°	ND	ND	IG	IF/NV	IF	
15°	ND	IED	ND	IED	IFP	
NUMBER 3:						FIBERGLASS, LT. BROWN, 3-TAB, ASTM D3018-1, CLASS A, 210 LBS./SQ., PLYWOOD DECK
90°	ND	ND	I	IF/NV	IF	
45°	ND	ND	IG	IG	IF	
15°	ND	ND	ND	IFP	IED	
NUMBER 4:						FIBERGLASS, DK. BROWN, 3-TAB, ASTM D3018-1, CLASS A, 210 LBS./SQ., PLYWOOD DECK
90°	ND	ND	I	IF/NV	IF	
45°	ND	ND	IG	IF/NV	IF	
15°	ND	ND	ND	IFP	IFP	
NUMBER 5:						ORGANIC, WHITE, 3-TAB, ASTM D225-1, 235 LBS./SQ., PLYWOOD DECK
90°	I	I	IF	IF	F/P	
45°	ND	IG	IG	IF	IF	
15°	ND	ND	ND	IG	IG	
NUMBER 6:						FIBERGLASS, BROWN, GRAINED PATTERN, CLASS A, 260 LBS./SQ., PLYWOOD
90°	ND	IG	IG	IF	IF	
45°	ND	IG	IG	IG	IF	
15°	ND	ND	IED	IFP	IED	

Figure 5

TARGET RESULTS						
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 8:						
90°	IFP	P	P	P	P	15 YEAR OLD ORGANIC, WHITE, 3-TAB, ASTM D225-1, PLYWOOD DECK
45°	ND	P	P	P	P	
15°	ND	I	I/ED	I/FD	P/F	
NUMBER 9:						
90°	IG	P	P	P	P	15 YEAR OLD ORGANIC, WHITE, T-LOCK, ASTM D225-1, PLYWOOD DECK
45°	ND	IG	P	P	P	
15°	ND	ND	IG	IFP	IED	
NUMBER 10:						
90°	ND	I	IF	IF	IF	ORGANIC, WHITE, T-LOCK, ASTM D225-1, CLASS C, 240 LBS./SQ.
45°	ND	I	IG	IF	IF	
15°	ND	ND	ND	IG	ED	
NUMBER 11:						
90°	IG,	IG	IF	IF	IF	FIBERGLASS, WHITE, T-LOCK, ASTM D3018-82, CLASS A, PLYWOOD DECK
45°	ND	I	IG	IF	IF	
15°	ND	ND	ED	ED	ED	
NUMBER 12:						
90°	ND	I	IF	IF	IF	FIBERGLASS, WHITE, 3-TAB, ASTM D3018-1, CLASS A, 210 LBS./SQ., PLYWOOD DECK
45°	ND	IG	IF	IF	IF	
15°	ND	ND	ED	ED	ED	*** OVERLAY OLD 3-TABS ***
NUMBER 13:						
90°	ND	IF	IF	P/F	P/F	FIBERGLASS, WHITE, T-LOCK, ASTM D3018-1, CLASS A, 210 LBS./SQ., PLYWOOD DECK
45°	ND	IG	IG	P/F	P/F	
15°	ND	ND	EP	IG	IGED	*** OVERLAY OLD T-LOCKS ***
NUMBER 14:						
60°F./90°	ND	IF	IF	P	P	FIBERGLASS, WHITE, 3-TAB, ASTM D3018-1, 210 LBS./SQ., PLYWOOD DECK
80°F./90°	ND	ND	I	IF/NV	IF	
120°F./90°	ND	I	I	I	IF	** TEMPERATURE VARIATION **
NUMBER 15:						
90°	I	IF	I	IF	IF	WOOD, SAW CUT, BOTH SIDES
45°	I	I	I	IF	IF	18" LONG
15°	I	I	I	I	I	6" EXPOSURE 3/8" THICK

Figure 5 continued.

TARGET RESULTS						
NUMBER 16:						
90°	I	IF	IF	IF	IF	WOOD, SAW CUT, ONE SIDE
45°	I	I	I	IF	IF	24" LONG 10" EXPOSURE 1/2" THICK
15°	I	I	I	I	I	
NUMBER 17:						
90°	I	I	IF	IF	IF	OLD WOOD, SAW CUT, ONE SIDE
45°	I	I	I	IF	IF	24" LONG 10" EXPOSURE 3/4" THICK
15°	I	I	I	I	I	
NUMBER 18:						
90°	ND	ND	ND	ND	F *	CONCRETE TILE, RED, "S" CONFIGURATION, 900 LBS./SQ., 16-1/2" X 13"
45°	ND	ND	ND	ND	ND	
15°	ND	ND	ND	ND	ND	
NUMBER 19:						
90°	ND	ND	ND	ND	F *	CONCRETE TILE, RED, BARREL PROFILE CONFIGURATION, 950 LBS./SQ., 16-1/2" X 13"
45°	ND	ND	ND	ND	ND	
15°	ND	ND	ND	ND	ND	
NUMBER 20:						
90°	ND	ND	ND	ND	F *	CONCRETE TILE, GREY, SHAKE CONFIGURATION, 950 LBS./SQ., 16-1/2" X 13"
45°	ND	ND	ND	ND	ND	
15°	ND	ND	ND	ND	ND	

* VELOCITY INCREASED TO 131 FT/SEC, 40 METERS/SEC, OR 89 MPH
KINETIC ENERGY 71.49 FT/SEC, OR 96.92 JOULES

Figure 5 continued.

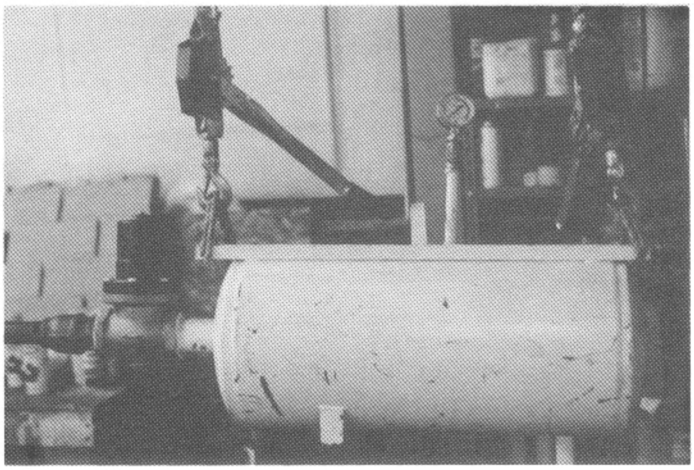

Photo 1 *Hail Gun with quick-release valve.*

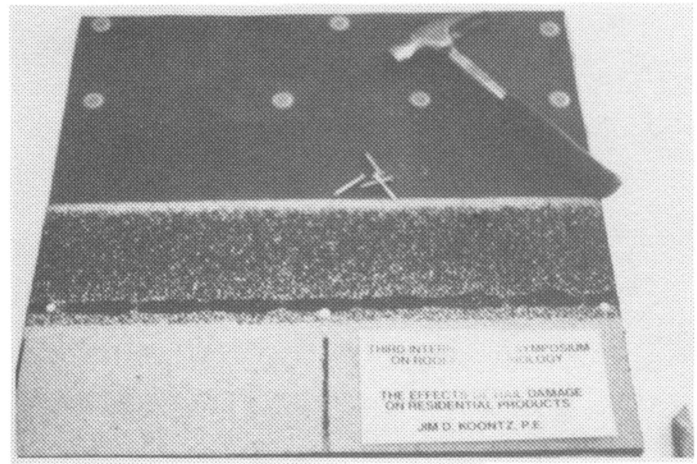

Photo 4 *Construction of targets.*

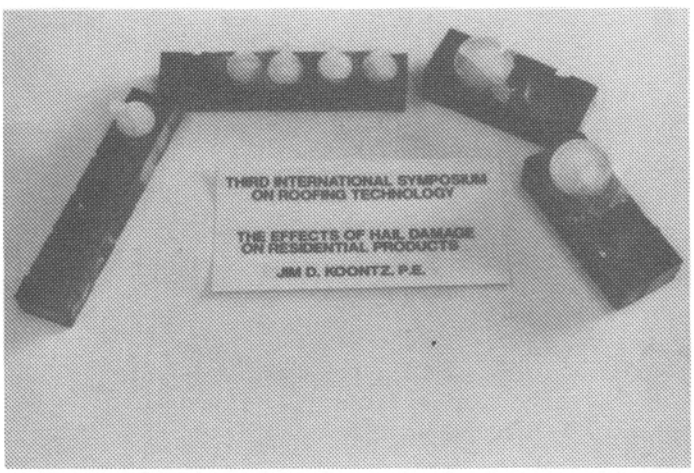

Photo 2 *Hail molds.*

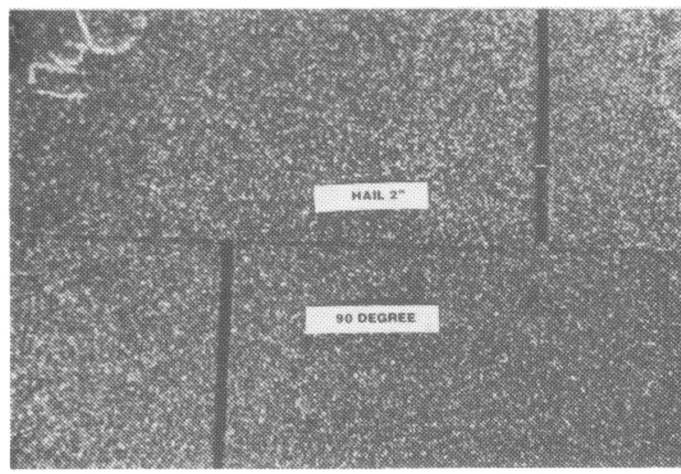

Photo 5 *Target 1—impact area of 2 in. hail at 90° angle.*

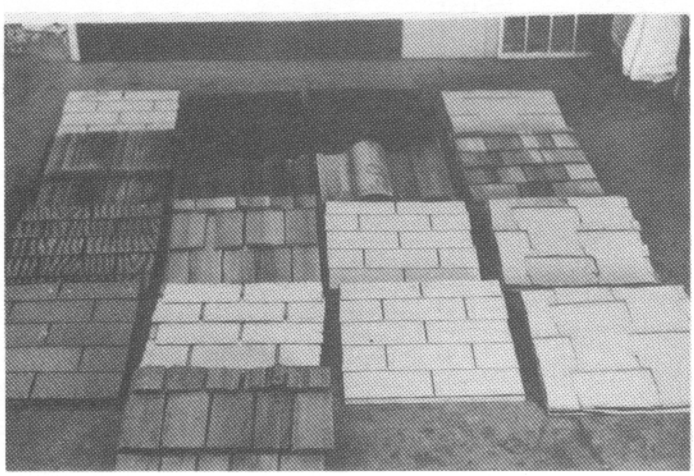

Photo 3 *Hail targets.*

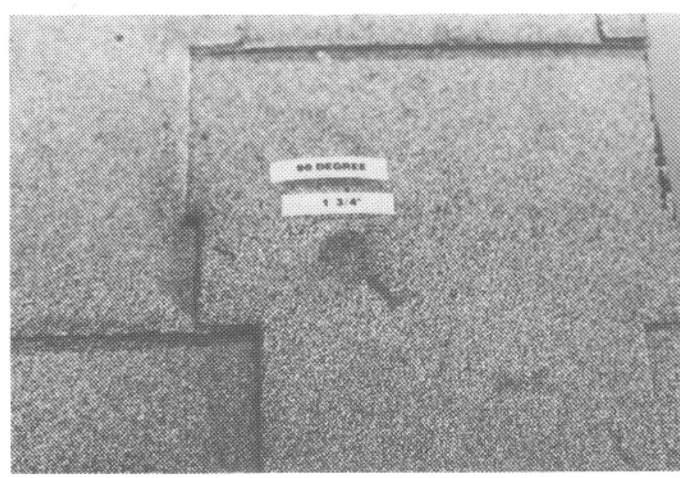

Photo 6 *1¾ in. hailstone impact/90° angle/T-lock shingle.*

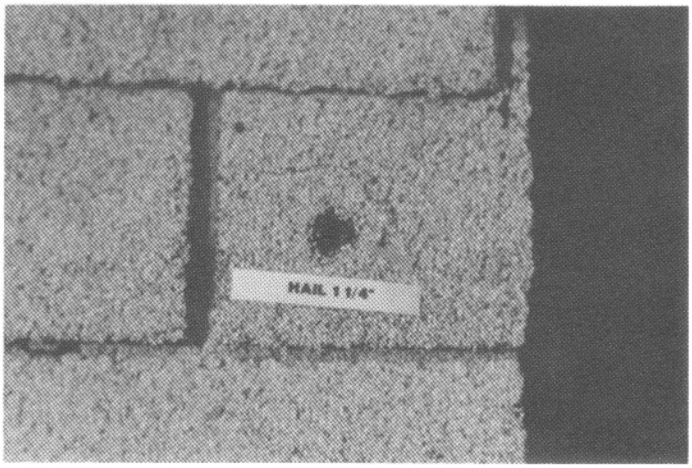

Photo 7 1¼ in. hailstone impact/older, three-tab shingle.

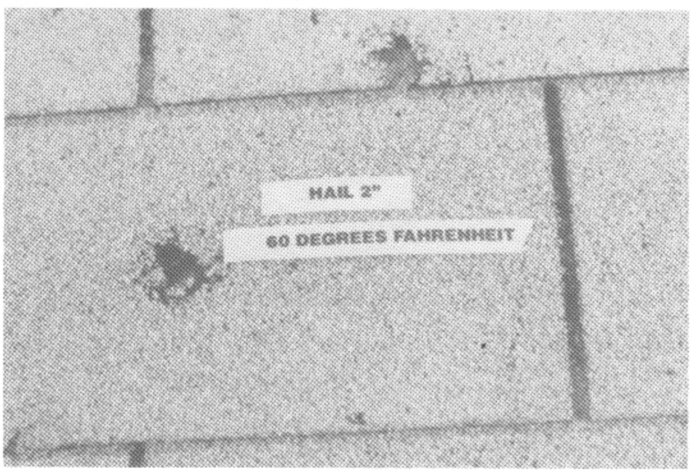

Photo 8 2 in. hailstone impact/surface temperature of shingle 60°F.

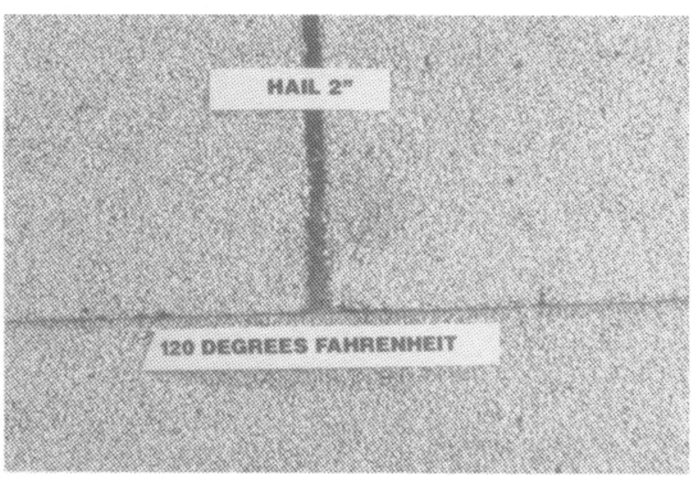

Photo 9 2 in. hailstone impact/surface temperature of shingle 120°F.

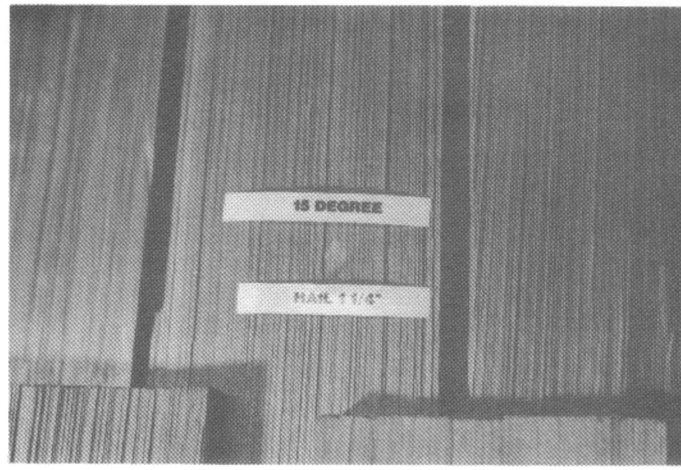

Photo 10 Impact of wood shingle/1¼ in. hailstone/90° angle.

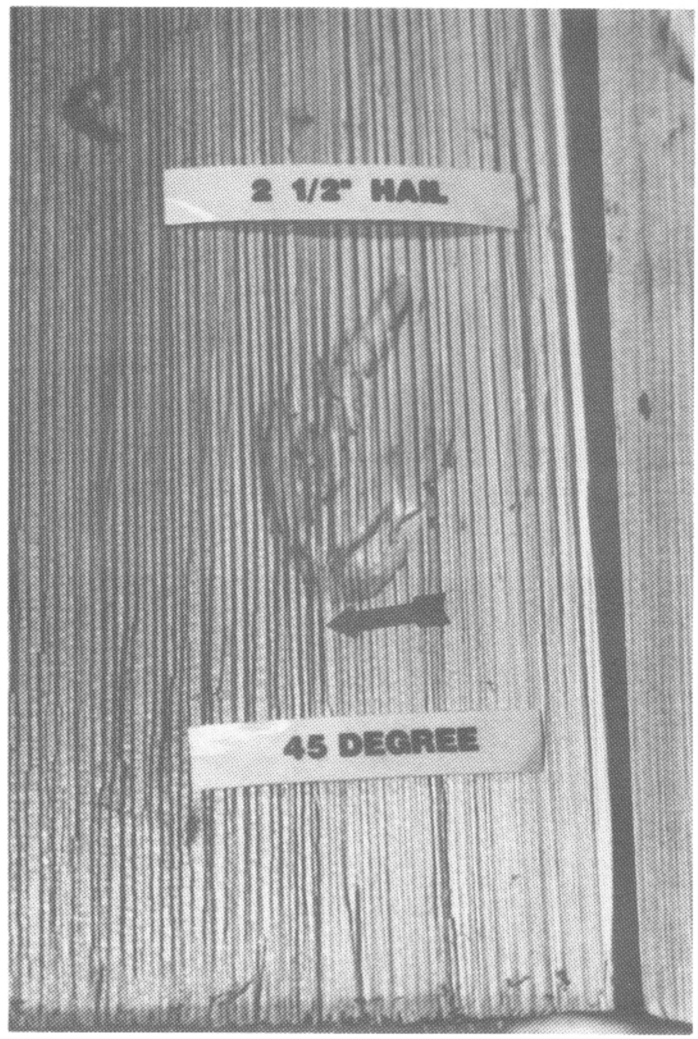

Photo 11 Irregular indentation of hailstone impact on wood shingle.

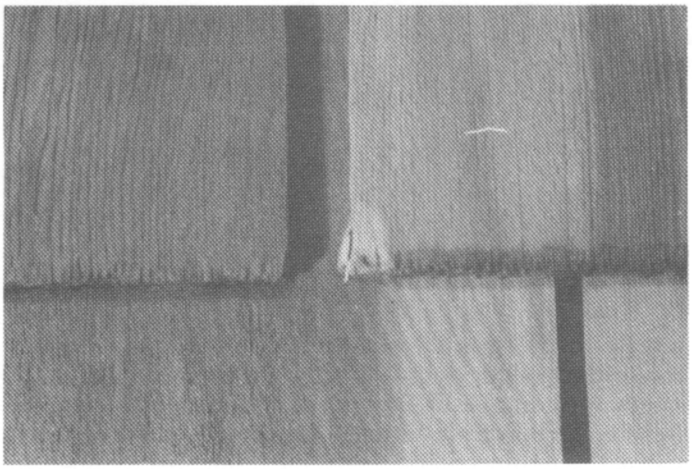

Photo 12 *Wood shingle indentation at butt edge.*

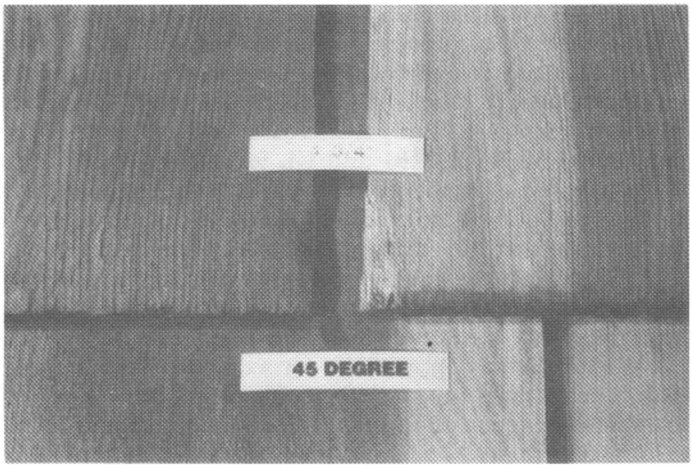

Photo 13 *Wood shingle indentation.*

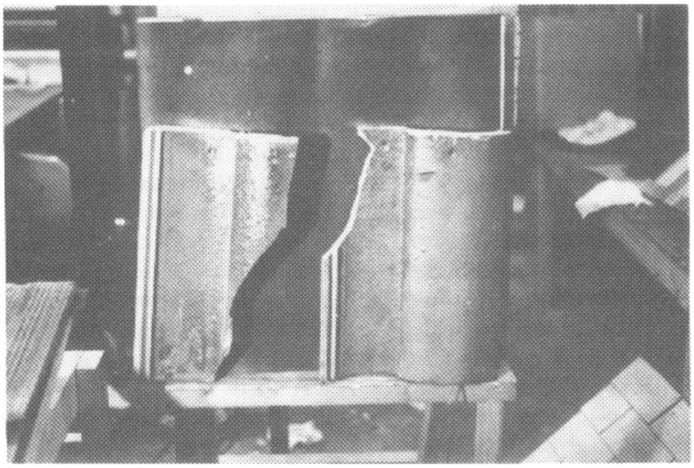

Photo 14 *Fracture of concrete tile.*