NATIONAL BUREAU OF STANDARDS REPORT

9871

Not for publication or for reference.

HAIL RESISTANCE OF ROOFING PRODUCTS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards[1] was established by an act of Congress March 3, 1901. Today, in addition to serving as the Nation's central measurement laboratory, the Bureau is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To this end the Bureau conducts research and provides central national services in three broad program areas and provides central national services in a fourth. These are: (1) basic measurements and standards, (2) materials measurements and standards, (3) technological measurements and standards, and (4) transfer of technology.

The Bureau comprises the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, and the Center for Radiation Research.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement, coordinates that system with the measurement systems of other nations, and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of an Office of Standard Reference Data and a group of divisions organized by the following areas of science and engineering:

Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic Physics—Cryogenics[2]—Radio Physics[2]—Radio Engineering[2]—Astrophysics[2]—Time and Frequency.[2]

THE INSTITUTE FOR MATERIALS RESEARCH conducts materials research leading to methods, standards of measurement, and data needed by industry, commerce, educational institutions, and government. The Institute also provides advisory and research services to other government agencies. The Institute consists of an Office of Standard Reference Materials and a group of divisions organized by the following areas of materials research:

Analytical Chemistry—Polymers—Metallurgy — Inorganic Materials — Physical Chemistry.

THE INSTITUTE FOR APPLIED TECHNOLOGY provides for the creation of appropriate opportunities for the use and application of technology within the Federal Government and within the civilian sector of American industry. The primary functions of the Institute may be broadly classified as programs relating to technological measurements and standards and techniques for the transfer of technology. The Institute consists of a Clearinghouse for Scientific and Technical Information,[3] a Center for Computer Sciences and Technology, and a group of technical divisions and offices organized by the following fields of technology:

Building Research—Electronic Instrumentation — Technical Analysis — Product Evaluation—Invention and Innovation— Weights and Measures — Engineering Standards—Vehicle Systems Research.

THE CENTER FOR RADIATION RESEARCH engages in research, measurement, and application of radiation to the solution of Bureau mission problems and the problems of other agencies and institutions. The Center for Radiation Research consists of the following divisions:

Reactor Radiation—Linac Radiation—Applied Radiation—Nuclear Radiation.

---

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C. 20234.
[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
421.04-20-4212247	July 2, 1968	9871

HAIL RESISTANCE OF ROOFING PRODUCTS

by

Sidney H. Greenfeld

Sponsored by
Asphalt Roofing Manufacturers Association
National Bureau of Standards

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

Hail Resistance of Roofing Products

by

Sidney H. Greenfeld
Research Associate
Asphalt Roofing Manufacturers Association [1/]

Sponsored by
Asphalt Roofing Manufacturers Association

[1/] Formerly Asphalt Roofing Industry Bureau

ABSTRACT

A test was developed for evaluating the hail resistance of roofings, in which synthetic hailstones (ice spheres) of various sizes were shot at roof assemblies at their free-fall terminal velocities. Indentations, granule loss and roofing fracture were observed. The following conclusions could be made from these results:

(a) All roofing materials have some resistance to hail damage, but as the size of the hail increases, a level of impact energy is reached at which damage occurs. This level lies in the area of 1 1/2 to 2 inch stones for most prepared roofings.

(b) Because of the ways in which prepared roofings are applied, most products have areas of different vulnerability.

(c) The solidly supported areas of roofing tend to be the most resistant to hail damage.

(d) Heavy duty shingles tend to be more hail-resistant than Type 235 shingles.

(e) Weathering tends to lower the hail resistance of asphalt shingles.

(f) Built-up roofs on dense substrates tend to resist hail better than those on soft substrates.

(g) Built-up roofs made with inorganic felts tend to be more hail resistant than those made with organic felts.

(h) Coarse aggragate surfacing tends to increase the hail resistance of roofing.

Contents

Hail Resistance of Roofing Products

Sidney H. Greenfeld

1. Introduction

Hail, as a destructive force of nature, has plagued man, his crops and his property since the very beginnings of civilization. By far the vast majority of hailstorms contain hailstones that are relatively small. These small stones can damage crops, but not property. However, every year there are a number of storms in which hailstones in the range of one-and-a-half to three or more inches in diameter occur.

In the United States, except on rare occasions, these storms containing large hailstones are encountered in the States between the Appalachian and Rocky Mountains. While there is no evidence that the number of such storms has been increasing in recent years, the population has grown in this part of the country, more buildings have been constructed and, consequently, the incidence of building damage has increased.

It has been extremely difficult to determine precisely the damage attributable to hail for a number of reasons. The same storm fronts that spawn large hailstones contain high winds, not too infrequently of tornadic velocities. The short hail period is usually followed by torrential rains. Consequently, in the "post-mortem" analysis of building damage caused by a storm, the allocation of the causes cannot always be made. Therefore, the Weather Bureau Reports (1)[1/] usually lump these three causes of damage together, but where possible, have separated them.

The hailstones in a storm are rarely of uniform size and, consequently, some damage remains hidden and does not appear until months or years later, in another storm, which might not be damaging on its own, or in cold weather, when ice penetration increases the destruction sufficiently to be observable. However, even when only the damage unequivocally attributable to hail is considered, hail produces a greater annual building loss than the more-spectacular tornado.

It is beyond the scope of this paper to go into the theories of hail formation and growth or storm development. For those who might be interested, the following articles are very informative: Recent Hail Research (2), The Language of Hailstorms and Hailstones (3), Hailstorm Characterization and the Crystal Structure of Hail (4), Texas Hailstorms (5) and The Theory of Hailstone Formation (6).

Briefly, there are two types of damaging hailstorms encountered in the United States (5). The most prevalent type is known as the frontal storm. It involves the encounter of a cold, high air mass with a low, moist, warm air mass. The cold air tends to fall and the warm, moist air tends to rise, carrying its moisture with it. The moisture cools through

[1/] The numbers in parenthesis refer to the references in the Literature Cited section of this paper.

heat exchange with the cold air and evaporation as the air expands upward. Eventually it becomes cooled significantly below the freezing point and remains sub-cooled until it encounters a nuclei upon which to freeze. As more water hits any particular ice particle, the particle grows. Because everything in these upper regions is much below the freezing point of water, the ice that forms does so rapidly, and air is entrapped. When an ice particle gets too heavy to be raised farther by the up-draft, it starts to fall. As it falls, it gathers more condensation and, once it is in regions above the freezing point, the condensation on it is liquid water. The air can escape.

The particle sooner or later encounters another strong up-draft, starts up again and freezes, sub-cools and goes through its tumbling cycle over and over again. Thus, the hailstone is found to consist of alternate layers of milky (low density) ice and clear (high density) ice. At some point, the hailstone encounters no up-draft sufficient to lift it and it falls to earth, usually at a velocity approximating the free-fall terminal velocity.

The second type of storm occurs on the eastern slopes of the Rocky Mountains; thus, it is called an orographic storm. A front of warm, moist air hits the base of the mountains, expands upward until the nucleation, freezing and tumbling processes occur and then the hailstones drop out as in the frontal storm. This type of storm tends to drop its hailstones at about 6000 feet.

Figure 1 is a map of central United States showing the distribution of storms in which at least $5000 worth of building damage was done by hail during the years 1960-1966. The orographic storms form an imperfect line at the left of the figure; the frontal storms account for the rest of the points. Only infrequently do building-damaging storms occur outside of this area.

Hailstorms occur all over the world in open regions where rapidly moving air masses can develop. However, only meteoralogical reports on storms and studies on the physics of hail formation can be found in the literature. Occasionally reports appear in the trade literature (7)(8) on hail damage to buildings, but only one paper has appeared in which a serious effort has been made to evaluate the effects objectively. In this paper (9), J. A. P. Laurie reported that he used 2-1/2 inch artificial hailstones, made by cutting cylindrical cores from blocks of ice, cutting them to heights equal to their diameter and molding them to roughly spherical shape. They fired these missiles at various velocities at building materials with a grenade launcher and determined the threshold energy of damage. The velocities were controlled by the size of the charge in the blank cartridges used in the launcher.

Because of the difficulties in controlling the hail velocities, an air operated piston was developed and used as the launcher in the latter part of Laurie's study.

Laurie's paper, being the only one in its field, was the base from which this work was developed. It was conceded that ordinary impact tests were not satisfactory, the use of ice spheres was extremely desirable, if not absolutely necessary, that hail usually struck at its approximate free-fall terminal velocity (corroborated by others) and a criterion for failure was damage that would permit the penetration of liquid water to an appreciable extent. However, it was decided to use a less complicated launcher, use "Hailstones" of various sizes, cast the "hailstones" to approximate spheres more closely and explore areas of different vulnerability on various roofing systems. The work was primarily directed at bituminous roofing materials, but a representative sample of other roofings was made.

2. Apparatus

2.1 Test Apparatus

The apparatus consisted of a compressed air gun, for launching the hailstones, a timer, for determining their velocity, and a target area, for positioning the specimen to be tested. The physical layout of the apparatus is shown in Figure 2.

Reading from left to right, the apparatus consisted of a specimen (target) area (1), a timing range (2), the gas gun (3), the gas cylinder (4), the timer (5), hailstone carrier (6), the hailstone molds (7) and the triggering mechanism (8). The roofing specimen to be tested is mounted on a roof deck, just as in service, and clamped in place against the backstop in position (1). The timing range consists of a metal frame of 3/4-inch angle iron on which are mounted two microswitches 2.0 feet apart. The actuating levers on the microswitches contain metal hooks, which are used to hold one end of one-inch computer tapes, the other ends of which are fastened to the top members of the frames with masking tape, also 2.0 feet apart. The tapes are kept under tension such that any impact on them will close the microswitches and actuate the triggering mechanism to start and stop the counter (5).

The compressed air gun (4) is a commercially available device manufactured by Diamond King, Inc. (El Segundo, California). It is their Mark 14 model, with a 3-1/4 inch inside diameter barrel and a maximum muzzle velocity of 300 ft/sec. The counter is a Hewlett-Packard Model No. 523B microsecond counter, with both starting and stopping gates and a direct readout.

Figure 1 - Hail Storm Distribution Map.
Each pin represents a storm in which at least $5000 worth of building damage was done by hail.

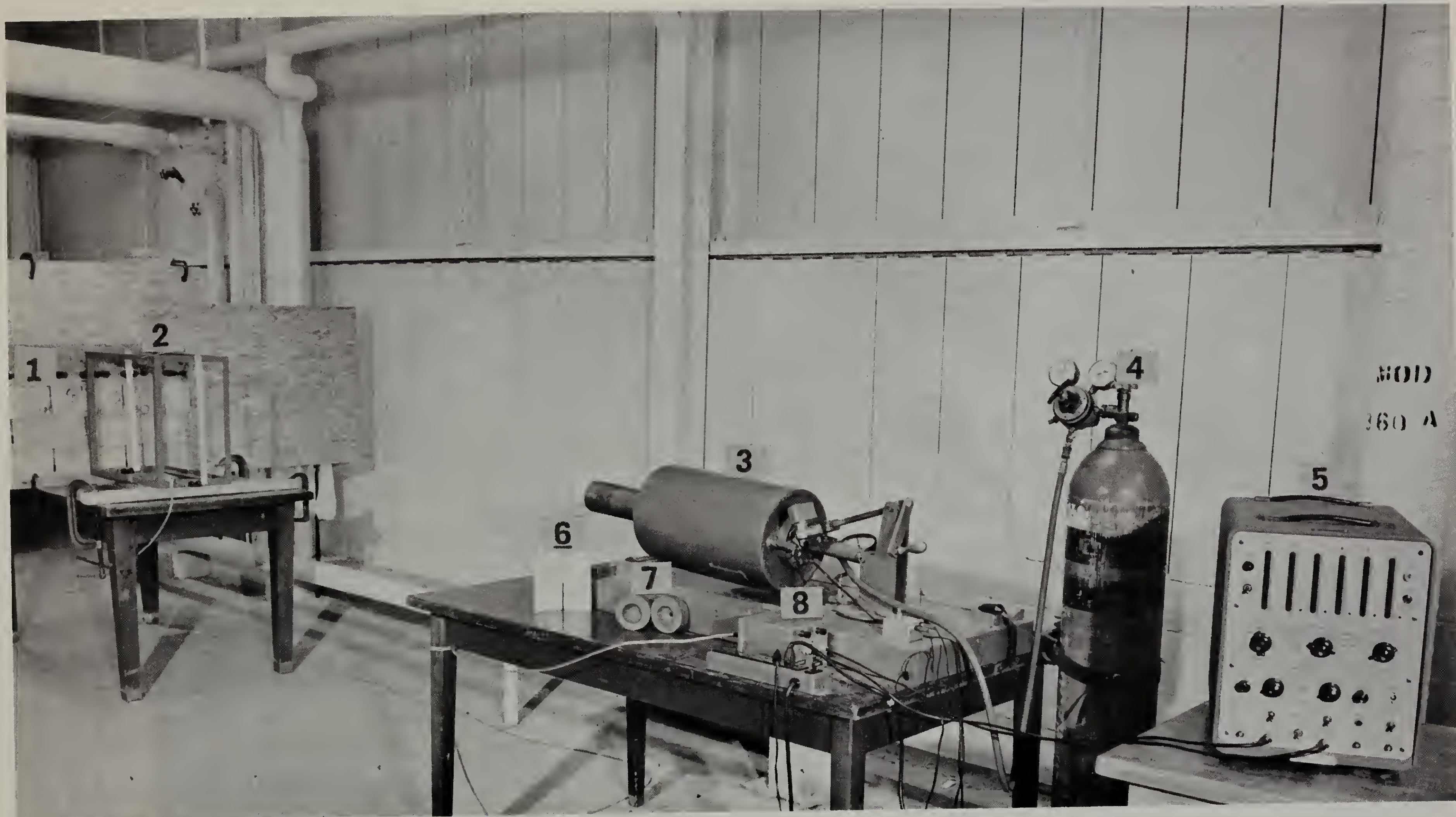

Figure 2 - Hail-Resistance Apparatus
The hail resistance of building materials was determined by shooting progressively large hailstones at different parts of these materials until failure occurred.

1. Test Specimen
2. Timing Section
3. Compressed Gas gun
4. Gas Cylinder
5. Timer
6. Hailstone Carriers - One in gun and one open to show cavity
7. Hailstone Mold
8. Triggering Mechanism.

2.2 Hailstone Carriers

The hail carriers were made from 3-inch diameter foamed polyethylene cylinders (Ethafoam - Dow Chemical Co., Midland, Michigan). This material was obtained as cylinders nine feet long, sliced into short cylinders six inches long and split in half longitudinally. Each hemi-cylinder was truncated at one end at 45° to its long axis from the central cut to its outer wall and milled with one of a series of sizes of hemispheres centered 2-1/4 inches from its other end. Thus, when the two hemi-cylinders were reassembled, they formed carriers for the several sizes of hailstones and permitted one size barrel to be used for all of the hailstones. Carriers with cuts for 1-1/2, 2, 2-1/2 and 2-3/4 inches were made. The 1-1/4 inch stones were carried in the 1-1/2 inch carrier and the 1-3/4 inch stones, in the two-inch carrier.

2.3 Hailstone Molds

The hailstones were cast in molds made from a silicone casting resin (RTV-60 - General Electric Co.). The models for the hailstones were plastic fishing floats, which are produced in increments of one-quarter-inch diameters from one inch to three inches. Each float was suspended on the end of a rod, which fit the indentation in the float, in the center of a polyethylene container of suitable size. The casting resin was de-aerated, poured into the mold and cured, as directed. The following day the casting was removed from the polyethylene container and sliced through with a razor blade at the equator of the float. The float and rod were removed and the cut interface covered with a thin layer of silicone grease.

The hailstones were cast in these molds in two stages, in order to permit expansion of water during freezing to occur without shattering the hailstones. Water was poured into the mold through the opening (called the gate) left by the removal of the suspending rod until the cavity (left by the float) was about one-half full and frozen in the freezing compartment of a conventional refrigerator. Four hours later water was added to fill the mold just to the bottom of the gate and the mold was returned to the freezer. Only by this two-stage process was it possible to freeze ice spheres without shattering.

The ice spheres were stored in a chest-type freezer at about 10°F (-12°C) until ready for use.

2.4 Specimen Construction

The shingle specimens were applied with four staples (per strip) to 1'6" x 3'0" decks, representative of those used in construction (3/8" and 1/2" plywood, 1" x 6" T & G boards). The decks were supported on 2 - 2" x 4" "rafters", to which they were fastened six inches from each of the long sides by 8d common nails. Thus, each deck represented a 1'6" x 3'0" section out of a conventional roof.

The built-up roofing specimens were solidly mopped to 1/2" plywood or 1" asbestos cement board (to simulate a concrete deck) or to various types of insulation mopped solidly to these decks. Where metal decking was used, the insulation was mopped solidly to the decking, too.

Wood, slate, asbestos cement, tile and sheet metal roofing were applied as directed by their suppliers to decks supported on 2" x 4" rafters, two feet on centers.

3. Procedures

3.1 Shooting Hailstones at Roofing

The specimen on its deck was held against the backstop in Figure 2 with large C clamps. The 1-inch computer tapes were hooked to the microswitches and fastened under tension, just insufficient to close the switches, with masking tape to the top of the timing frame. A hailstone of the desired size was taken from the freezer, cleaned of any burrs or projecting pieces of ice (from the gate in the mold), weighed, and placed in its carrier, which was slid into the barrel of the gun as far as possible. Air, or nitrogen, was permitted to enter the gun until the desired pressure was reached. The valves between the gun and the tank were closed (to protect the pressure regulator), the pressure gage was removed from the gun, and the gun was fired by opening the solenoid valve.

The carrier was propelled out of the gun, where the air resistance opened the two halves and permitted the hailstone to travel alone toward the target. As the hailstone hit the first tape it started the counter, and as it hit the second tape, it stopped the counter. Then it hit the specimen. Approximately two out of three hailstones bounced off the target specimen without shattering; the third shattered.

The indentation on the specimen was measured and the condition of the specimen noted. Granule losses, coating and felt fractures and deck damage were recorded. The velocities and energies of the hailstones averaged over the two feet immediately in front of the test specimen also were calculated and recorded.

3.2 Evaluating Failure

Damage done by hail to roofing falls into two general categories: (1) Severe damage, which leads to penetration of the structure by the elements and (2) Superficial damage, which affects appearance adversely but does not materially interfere with the performance of the roofing. While the latter is distracting and leads to insurance claims, the former is the type of damage that should be of most concern, because the possible loss can exceed the replacement cost of the roofing many fold. Thus, while the dents will be reported,only the fractures of the coating, felt or other shingle material will be called failure in this report. For each material and roofing system, the thresholds of failure, or the smallest hail size producing these failures, will be reported.

4. Results

Although hailstones vary in size, shape, density, and velocity, those that do damage to buildings tend to fall within the narrow limits of ice spheres falling at about their free-fall terminal velocity (9).

The density of large hailstones has been shown to approximate that of solid ice (10) and seems to range between 0.89 and 0.91 g/cm^3. Hailstones, while rarely smooth spheres, aerodynamically can be treated as smooth spheres and conclusions reached that are close to observed results (11). The terminal velocities and energies of ice spheres have been calculated and reported graphically by Laurie (9); they are tabulated below as taken from these graphs for the hailstone sizes used:

Table 1

Terminal Velocities and Energies of Hailstones 1/

Diameter, inches	Terminal Velocity ft/sec	Terminal Velocity Mi/Hr	Approximate Impact Energy Ft Pdls	Approximate Impact Energy Ft lbs
1	73	50	<30	<1
1 1/4	82	56	130	4
1 1/2	90	61	250	8
1 3/4	97	66	450	14
2	105	72	700	22
2 1/2	117	80	1700	53
2 3/4	124	85	2600	81
3	130	88	3800	120

1/ Read from graphs in reference (9).

All of the results reported are based on hailstones of any given size travelling within ± 10 percent of the velocities reported in Table 1 for hailstones of that size. The results will be reported under the types of roofing studied.

4.1 Asphalt Shingles

When applied according to the recommendations of their manufacturers, Type 235 square-tab shingles have three regions of different vulnerability: (1) The tab edges, (2) The surface over the unsupported areas between the top of one strip and the "line" where the strip above it contacts the deck or underlayment and (3) The triple coverage area solidly supported from the deck up.

The resistances of these areas to hail damage are different; therefore, results will be reported for each area. The results for the Type 235 square-tab shingles are shown in Table II.

Table II

Hail Resistance of Type 235 Square Tab Shingles Exposed Five Inches

Deck	Hail Size Cracking Felt					
	No Underlayment			15# Felt Underlayment		
	Edges	Unsupported Portion	Triple Coverage	Edges	Unsupported Portion	Triple Coverage
3/8-in.plywood	1 3/4	1 3/4	1 3/4	1 1/2	1 1/2	1 3/4
1/2-in.plywood	1 3/4	1 3/4	1 3/4	1 1/2	1 1/2	1 1/2
1 x 6-in. T&G	2	1 3/4	2 1/2	1 1/2	1 1/2	2

These specimens were also exposed to 1 1/4-in. hailstones. Only small, superficial indentations were made in the shingles by the 1-1/4 inch hailstones. The larger size hailstones produced progressively larger dents. In general, the smaller stones produced circular indentations approximating one half their diameter and the larger stones, those above the felt-damage threshold, produced dents greater in diameter than one-half the hailstone diameter. Hailstones 2 3/4 inches in diameter and larger produced damage to the decks on which the shingles were mounted.

Shingles on 3/8 inch and 1/2-inch plywood performed equally well; those on 1 x 6-inch T&G roof boards were more resistant to hail damage than those on plywood. The yellow pine from which these boards were made seemed to be a better base than the fir plywood.

The shingles without an underlayment consistently had a higher threshold of hail damage than did those with the conventional 15# saturated felt underlayment on all three decks. Apparently, the soft layer of felt makes the shingle slightly more vulnerable. The improved performance usually involved only one-quarter inch larger hailstones, but this represented resistance to 200 or 300 more foot poundals of kinetic energy. From these results, it would seem that the more uniformly dense systems performed better than those with some plane of low density. This observation is consistent with the fact that these materials are stronger in compression than in tension and the best performance can be expected when the impact forces can be kept as pure compression forces. Any soft layer within the system permits the back of the layer above it to be in tension and fail more easily.

As shingles age during exposure they tend to undergo a number of physical changes, which may affect their resistance to hail. A number of shingles that had been exposed to the weather in Washington, D. C. for for 9 1/2 years became available and were tested. These shingles had been exposed at a four-inch pitch facing due south. Three different Type 210 shingles showed failures (felt cracking) on all three areas of different vulnerability with 1 1/4-inch hailstones. One Type 255 and one Type 290 shingle experienced spalling of the coating with 1 1/4-inch hailstones, but felt damage did not occur until 1 1/2 inch hailstones were used. Two Type 250 shingles showed felt damage in all areas of vulnerability with 1 1/4-inch stones; however, one Type 250 and one Type 275 shingle showed no damage below 1 3/4 inch hailstones on the tab centers, but both developed felt damage in the other two areas with 1 1/4-inch stones. No direct comparison can be made between these aged shingles and unexposed ones because of changes in design and production. However, the aged shingles tended to be less resistant to hail damage than the new ones.

A number of heavy weight and premium shingles were also investigated. Some of these resisted hail no better than the regular Type 235 square-tab shingles. However, a few performed significantly better.

A Class B shingle based on a glass fiber mat, instead of the conventional organic felt, did not show failure on the back of its tabs below 2-inch hailstones on the tab edges and unsupported areas. It failed with 2 1/2-inch hailstones on the solidly supported areas. Similarly, three other shingles, all Class A, based on glass mat felts showed no felt damage on their obverse sides with hailstones below two inches in diameter; one of these had a damage threshold at the two-and-a-half inch hailstone on all three portions of its surface. Some of the conventionally made heavy shingles, usually with Number 9 granules or with high concentrations of mineral additives, performed equally well. One Type 290 Class C shingle actually had a damage threshold at the two-and-three-quarter-inch hailstone. While it is outside the province of this report to identify these heavy Class C and Class A shingles more completely, the manufacturers have been informed of how their individual products have performed and the basic principles required to make more hail-resistant products.

Because the vast majority of hailstorms occur in warm weather, the roofs are above ambient temperatures when the hailstorm starts. Hailstorms with large hail are always of short duration and are preceded by a cloud cover, which drops the roof temperatures below their daily highs. Therefore, the hail resistance evaluation was conducted at 75-80°F (24-27°C). However, one Type 235 and one Type 315 Class C shingle, and one Type 240 Class A shingle were tested at 120°F (49°C) on a 1/2-inch plywood deck with a 15# saturated felt underlayment. The hail resistance of the Type 235 shingle was increased to the 2 1/2-inch hailstones from the 1 1/2-inch hailstones on all three surfaces. That of the Type 315 shingle was improved only on the unsupported areas and that of the Type 240 was not changed. Thus, the results on these three shingles indicate that shingles tend to be more resistant to hail damage at higher temperatures. It is fortunate that the hail storms occur in warm weather.

4.2 Built-Up Roofs

Occasionally in residential construction and much more frequently in commercial and industrial construction relatively flat roofs are used. These roofs are not "factory manufactured", but "built up" on the site from alternate layers of bitumen and reinforcing membranes. Some of these roofs are surfaced with a smooth layer of bitumen and others are surfaced with a layer of pebbles, crushed stone or light weight aggragate particles. There are many variations of this type of roof system; only a few representative ones were tested. The construction of these roofs and the results of the hail-resistance tests are summarized in Table III.

Table III

Hail Resistance of Built-Up Roofs
Visual Inspection

Hailstone Size, in.	Hail Damage - Indentation Size [1] 1 1/2 in.	1 3/4 in.	2 in.	2 1/2 in.
Roof Construction				
(1) Base Sheet + 3 plies of 15# Organic Felt plus a 60# Asphalt Flood Coat (20-25# Interply Asphalt) on				
(1a) 1/2 in. plywood	5/8	5/8	5/8C	1 1/4C
(1b) 1-in.Fiberboard on 1/2-in. plywood	5/8	1C	1 1/4C	1 5/8C
(1c) 1-in.Foamboard A on 1/2-in. plywood	5/8	-	5/8	2 1/4P
(1d) 1-in.Foamboard B on 1/2-in. plywood	3/4	-	1 1/4D	-
(1e) 1-in.Asbestos Cement	7/8	-	1C	1 1/4C
(1f) 1-in.Fiberboard on 22 Ga. Steel Decking	3/4	7/8C	1 1/4C	1 3/4C
(1g) 1-in. Glass Fiber Insulation on 22 Ga. Steel Decking	N	1C	1 1/4C	2 1/4F
(2) Base Sheet + 3 Asbestos Felts + 60# Asphalt Food Coat (20-25# Interply Asphalt) on				
(2a) 1/2-in. Plywood	N	-	N	N
(2b) 1-in. Asbestos Cement	N	N	1	N
(2c) 1-in.Fiberboard on 1/2-in. Plywood	N	N	1 1/8C	-

Table III - continued

Hailstone size, in.	Hail Damage - Indentation Size			
	1 1/2 in.	1 3/4 in.	2 in.	2 1/2 in.
(3) Base Sheet + 3 Tarred Felts + 75# Tar Flood Coat (25# Interply Tar) on				
(3a) 1/2-in. Plywood	C	1/2C	C	CS
(3b) 1-in. Asbestos Cement	C	-	N	C
(3c) 1-in. Fiberboard on 1/2-in. Plywood	C	-	C	2C
(4) 2 Glass Felts + 1 Glass Cap Sheet (20-25# Interply Asphalt) on				
(4a) 1/2-in. Plywood	N	-	1/2	1
(4b) 1-in. Asbestos Cement	N	-	N	N
(4c) 1-in. Fiberboard on 1/2-in. Plywood	3/4	-	1	1 1/2C
(4d) 1-in. Fiberboard on 1-in. Asbestos Cement	1/2	-	N	1 1/2C
(4e) 3/4-in. Glass Fiber Insulation on 1/2-in. Plywood	5/8	-	1 1/8	1 3/4C
(4f) 3/4-in. Glass Fiber Insulation on 1-in.Asbestos Cement	1/2	-	7/8	1 1/2C
(5) 2 Base Sheets + 60# Asphalt Flood Coat (20-25# Interply Asphalt) on				
(5a) 1/2-in. Plywood	1/2C	-	7/8C	1 1/4C
(5b) 1-in.Asbestos Cement	N	-	N	N
(5c) 1-in.Fiberboard on 1/2-in. Plywood	3/4C	3/4C	1 1/8C	-
(5d) 1-in.Fiberboard on 1-in. Asbestos Board	5/8C	7/8C	1C	-

Table III - continued

Hailstone size, in.	Hail Damage - Indentation Size 1 1/2 in.	1 3/4 in.	2 in.	2 1/2 in.
(6) 2 Base Sheets + 60# Asphalt Flood Coat + 300# Slag on				
(6a) 1/2-in. Plywood	N	-	N	N
(6b) 1-in. Asbestos Cement	N	-	N	N
(6c) 1-in. Fiberboard on 1/2-in. Plywood	N	-	N	N
(6d) 1-in. Fiberboard on 1-in. Asbestos Cement	N	-	N	N

1/ Mean diameter of indentation

C - Surface Cracked

D - Foamboard delaminated

F - Felts Cracked

N - No Visible Damage

P - Penetrated Roofing

The conventional smooth-surface built-up roof on a dense deck showed visible signs of damage; i.e., cracking of the surface, when 2-inch hailstones were used. Smaller stones usually indented the flood coat, but did not crack it. When fiberboard or glass fiber insulation was installed between the deck and the roof membrane the indentations were larger and coating cracks appeared with 1-3/4 inch stones. The roofing on one of the foamboard insulations performed better than on the dense decks when 2-inch hailstones were used, but the 2 1/2-inch stones penetrated through the roofing into the insulation. The roofing on glass fiber insulation on steel decking was also penetrated by the 2 1/2-inch stones. The second foamboard delaminated; i.e., the insulation broke away from its protective asphalt coated felts, when the 2 1/2-hailstones were used.

The flood coat of the built-up roof made with asbestos felts on a plywood deck did not crack or become indented by 2 1/2-inch stones; however, the flood coat was indented and cracked by 2-inch stones when fiberboard insulation was used between the membrane and the deck. The asbestos-felt roofs had a better hail resistance than the rag felt built-up roofs on comparable decks.

The built-up roofs made with coal tar pitch, referred to as tar in Table III, did not indent, but developed concentric cracks with all sizes of hailstones. The 2 1/2-inch stones caused some of the flood coat to spall from the top felts. Coal tar pitch generally tends to be more brittle than does asphalt and would be expected to respond to the hail impact as a brittle material.

The roofs built up with glass fiber felts on the dense decks (plywood and asbestos cement) did not experience flood coat cracking with hailstones 2 1/2-inches in diameter and smaller, but when insulation was present, cracks were produced with the 2 1/2-inch stones. The glass felt roofs fell in-between the organic felt built-up roofs and asbestos felt built-up roofs in hail resistance.

The roofs constructed of two base sheets performed much better on the asbestos cement deck than on plywood; their performances on plywood or insulation were about the same as conventional asphalt-organic-felt built-up roofs on the same substrates. Where these roofs were covered with 300 lb/square of slag, no damage was done to the roof membrane by any of the hailstones. The hailstone energy was dissipated in scattering the slag; "nests" of various sizes were left in the slag.

In summary, each roofing membrane performed better on the denser substrates than on the lighter substrates, the roofings made with inorganic felts performed better than those made with organic felts and the slag surfaced roofing was not damaged by hailstones up to and including 2 1/2 inches in diameter.

4.3 Non-Bituminous Roofing

A number of non-bituminous roofings were tested for comparison purposes. These were applied in accordance with their supplier's recommendations. The levels of failure used in these evaluations were cracking for brittle roofings and objectionable indentations for metal roofing. Table IV is a summary of the results of these tests.

Table IV

Threshold of Hail Damage for Non-Bituminous Roofings

Description	Diameter of Smallest Hailstone Cuasing Damage		
	Edge in.	Center in.	Unsupported in.
1/8-in. Asbestos Cement Shingles	1 1/2	1 3/4	-
1/4-in. Asbestos Cement Shingles	2	2	1 3/4
12"x18"x1/4" Green Slate, 7-in.Exposure	1 3/4	>2	2
12"x18"x1/4" Grey Slate, 7-in.Exposure	-	2	1 1/2
1/2" Cedar shingles - Dry	-	1 1/2	1 3/4
1/2" Cedar shingles - Wet	-	1 1/2	1 1/2
3/4" Red Tile	-	2	1 3/4
Standing seam terne metal [1/]			

[1/] Dents proportional to hail size - visible for all hailstone sizes. The plywood deck cracked below the dents with stones larger than 2 1/2 inches.

All roofings tested were vulnerable to hail damage. As with the asphalt shingles, these other products contained areas of different vulnerability. The heavy asbestos cement shingles seemed to have the highest threshold of hail resistance.

5. Conclusions

(a) All roofing materials have some resistance to hail damage, but as the size of the hail increases,a level of impact energy is reached at which damage occurs. This level lies in the area of 1 1/2 to 2 inch stones for most prepared roofings.

(b) Because of the ways in which prepared roofings are applied, most products have areas of different vulnerability.

(c) The solidly supported areas of roofing tend to be the most resistant to hail damage.

(d) Heavy duty shingles tend to be more hail-resistant than Type 235 shingles.

(e) Weathering tends to lower the hail resistance of asphalt shingles.

(f) Built-up roofs on dense substrates tend to resist hail better than those on soft substrates.

(g) Built-up roofs made with inorganic felts tend to be more hail resistant than those made with organic felts.

(h) Coarse aggragate surfacing tends to increase the hail resistance of roofing.

6. Literature Cited

(1) "Storm Data", Environmental Science Services Administration, U. S. Department of Commerce, Asheville, N. C.

(2) Douglas, R. H. "Recent Hail Research: A Review", Meteorological Monographs, 5, 157-167, 1963.

(3) Werckmann, H., "The Language of Hailstorms and Hailstones", USASRDL Tech Rep. 2277, U. S. Army Research & Development Laboratory, Ft. Monmouth, N.J., 1962.

(4) Schleusener, R.A., "Hailstorm Characterization and the Crystal Structure of Hail", Meteorological Monographs 5, 173-176, 1963.

(5) Texas Hailstorms, Texas State Board of Insurance, Austin, Texas.

(6) Schumann, T.E., "The Theory of Hailstone Formation", Quart. J. R. Met. Soc. 64, 3-4, 1938.

(7) Flora, S. D., "The Serious Toll of Hail Storms", Rough Notes 82, 14, 1939.

(8) Fuchs, E. R., "Hailstorm", American Roofer, 10, Nov. 1955.

(9) Laurie, J.A.P., "Hail and Its Effects on Buildings", C.S.I.R. Research Report No. 176, Bull. 21, 1-12, National Building Research Institute, Pretoria, South Africa, 1960.

(10) Browning, K. A., F. H. Ludlam and W. C. Lacklin, "The Density & Structure of Hailstones", Quart. J. R. Met. Soc. 89, 75-84, 1963.

(11) Bilham, E. G. and E. F. Relf, "The Dynamics of Large Hailstones", Quart. J. Roy Met. Soc. 63, 149-162, 1937.

7. Acknowledgment

This work was sponsored by the Research Committee of the Asphalt Roofing Manufacturers Association, under the Research Associate Plan, at the National Bureau of Standards. The author wishes to thank Messrs. Royce Stine and Thomas Crowe for their help in constructing the apparatus and collecting the data upon which this article is based. He also thanks the Materials Durability and Analysis Section, and particularly its Chief, Mr. W. C. Cullen, for all of their help that went into making this work possible.

USCOMM–DC–NBS

DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS