the construction specifier

The Proven Durability of EPDM Roof Assemblies

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Photo courtesy Carlisle Construction Materials

HAIL AND OTHER FORMS OF PHYSICAL DAMAGE (INCLUDING FROM FOOT TRAFFIC OR WORKMANSHIP) TO ROOFS RESULT IN MILLIONS OF DOLLARS OF ECONOMIC LOSS EACH YEAR. AT LEAST ONE STATE, TEXAS, ALLOWS INSURANCE COMPANIES TO PROVIDE A REDUCTION IN RATES WHEN A HAIL-RESISTANT TYPE OF ROOFING MATERIAL IS INSTALLED. OWNERS OF PROPERTIES THAT ARE LARGELY SELF-INSURED ARE BEGINNING TO REALIZE THE IMPORTANCE OF CALLING FOR SUCH ASSEMBLIES.

Empirical experience has long suggested ethylene propylene diene monomer (EPDM) roof systems fare well in hailstorm events. To validate this, the EPDM Roofing Association (ERA) decided to embark on a testing program for the synthetic rubber material.

The technical committee decided an important question in the design, insurance, and contractor communities concerns performance of aged, in-situ EPDM roof covers. Therefore, it was determined the test sample pool would include both new membrane material and samples from the field. The major EPDM manufacturers each provided new 1.2 x 1.2-m (4 x 4-ft) 1524-µm (60-mil) material samples, had new 60-mil material heat-aged, and procured 60-mil samples from roof covers that have been exposed between five and 20 years.

Just as roofs are required to perform in various meteorological events—such as wind, snow, and rain—they should be able to withstand some degree of hail impact over their expected service lives.

Prior to sending the samples for testing, the EPDM material was fully adhered to various 1.2 x 1.2-m substrates: mechanically fastened polyisocyanurate (polyiso) insulation, mechanically fastened wood fiber board, and 12-mm (½-in.) plywood. Between 20 and 35 samples of each roof cover category were sent for testing.

Field experience from the examination of thousands of roofs and from Roofing Industry Committee on Weather Issues (RICOWI) reports have clearly shown hail damage can be the result of several factors:

- diameter of the hail stone;
- type of roofing system;
- roof cover's age;
- substrate beneath the primary roof system;
- surface temperature at the point of impact.

To evaluate an assembly's resistance to hail damage, these reference points have to be considered as part of a research project.

NBS impact research

In the early 1960s, the National Bureau of Standards (NBS) in Washington, D.C., conducted research by impacting roof systems with ice spheres. The group's Sydney H. Greenfield performed this initial research and, in 1969, generated technical article NBS 23, *Hail Resistance of Roofing Products*. Referring to earlier research,[1] he initially determined hail's freefall velocity (Figure 1).

The technical data indicates the freefall velocity of the hail increases with hail stones of larger diameters. A key factor is the amount of 'impact energy' imparted to a target or roof surface. Simply stated:

$$\text{Impact energy} = \text{kinetic energy} = \tfrac{1}{2}\,\text{mass} * \text{velocity}^2$$

The mass of a hailstone obviously depends on the volume of the ice sphere and density of the ice. The density of hailstones is typically valued at .91.

$$\text{Volume of a sphere} = 1.33 * \Pi * \text{Radius}^3$$

Ballasted ethylene propylene diene monomer (EPDM) systems can be energy-efficient in almost any climate because the ballast provides thermal mass, which helps minimize heat loss in the winter and solar heat gain in the summer.

Photos courtesy Hutchinson Design Group, Ltd.

Figure 1

DIAMETER	TERMINAL VELOCITY	APPROXIMATE IMPACT ENERGY
25 mm (1 in.)	22.3 m/sec (73 ft/sec)	<1.36 J (<1 ft lb)
32 mm (1 ¼ in.)	25 m/sec (82 ft/sec)	5.42 J (4 ft lb)
38 mm (1 ½ in.)	27.4 m/sec (90 ft/sec)	10.85 J (6 ft lb)
45 mm (1 ¾ in.)	29.6 m/sec (97 ft/sec)	18.96 J (14 ft lb)
51 mm (2 in.)	32 m/sec (105 ft/sec)	29.8 J (22 ft lb)
64 mm (2 ¼ in.)	35.7 m/sec (117 ft/sec)	71.9 J (53 ft lb)
70 mm (2 ¾ in.)	37.8 m/sec (124 ft/sec)	109.8 J (81 ft lb)
76 mm (3 in.)	39.6 m/sec (130 ft/sec)	162.7 J (120 ft lb)

Terminal velocities and energies of hailstones.

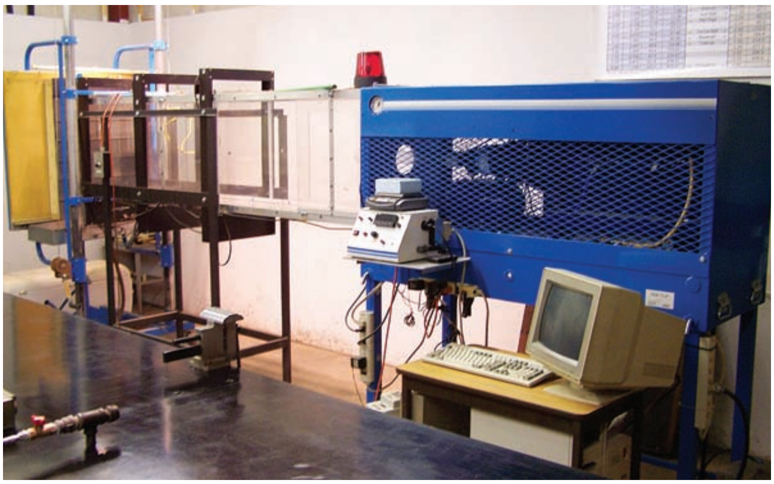
Figure 2

DIAMETER	VOLUME	MASS	FREEFALL VELOCITY	IMPACT ENERGY
25 mm (1 in.)	8.5 cm^3 (0.52 $in.^3$)	7.7 g (0.017 lb)	22.3 m/sec (73 ft/sec)	1.9 J (1.41 ft lb)
38 mm (1 ½ in.)	29 cm^3 (1.77 $in.^3$)	26.3 g (0.058 lb)	27.4 m/sec (90 ft/sec)	9.9 J (7.29 ft lb)
51 mm (2 in.)	68.5 cm^3 (4.18 $in.^3$)	62.6 g (0.138 lb)	32 m/sec (105 ft/sec)	32.1 J (23.7 ft lb)

The relationship between a hailstone's size and its impact energy.

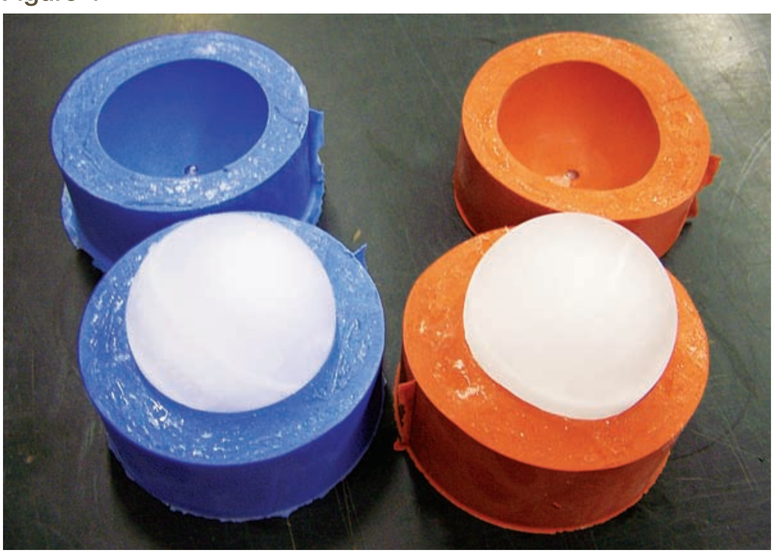
Ballasted EPDM roofing systems perform especially well in hailstorms, as the material atop the roofing membrane serves to break ice balls on impact, protecting the substrate from damage.

Figure 3



For the study, a hail launcher propelled ice spheres by employing the quick release of compressed air from a tank to a barrel.

Figure 4



The 'hail' molds were fabricated using precise-diameter steel spheres.

A substantial difference in impact energy occurs with only slight changes in diameter. It is important to note the impact energy between 25, 38, and 51-mm (1, 1½, and 2-in.) hailstones. This increase in size represents a 100 percent change in diameter, but a 1590 percent increase in impact energy (Figure 2).

Hail launcher

Historically, a roofing product's hail resistance has been tested by dropping steel balls or darts onto it. The specific procedures vary between U.S., Canadian, and European organizations. In this country, two primary entities perform testing for code approval—Underwriters Laboratory (UL) and Factory Mutual Global (FMG). The respective standards are UL 2218, *Impact Resistance of Prepared Roofcovering Materials*, and FM Class I 4470, *Approval Standard for Single-ply, Polymer-modified Bitumen Sheet, Built-up Roof (BUR), and Liquid-applied Roof Assemblies for Use in Class I and Noncombustible Roof Deck Construction*.

UL and FM use steel darts to impact targets, typically at room temperature. Other organizations, such as ASTM, have developed impact tests that use steel darts (*i.e.* ASTM D3746, *Standard Test Method for Impact Resistance of Bituminous Roofing Systems*). Within the last few years, greater consideration has been given to impacting targets with ice spheres. Prior research by one of this article's co-authors has also reviewed the issue of ice spheres versus steel darts.[2] The use of the former, obviously, comes closer to replicating what occurs during a real hailstorm.

A key factor in performing the test is to have reproducible impact energies with each shot of 'hailstone.' The hail gun or launcher (Figure 3)

Figure 5

Manufacturers provided more than 80 targets constructed with 1524-μm (60-mil) non-reinforced ethylene propylene diene monomer (EPDM) for impact testing.

EPDM stays flexible throughout its lifecycle, providing good hail resistance even at the end of its estimated service life.

Photos courtesy Carlisle Construction Materials

propels ice spheres by employing the quick release of compressed air from a tank to a barrel. To achieve reproducibility, several factors have to be taken into consideration. Since consistent air pressure is required for each shot, it must be controlled to 70 Pa (0.01 psi).

Molds for ice spheres are fabricated using precise-diameter steel spheres (Figure 4). Each ice sphere of a given diameter is then weighed to 0.01 g before each shot. Laboratory-grade barrels or tubes with precise internal diameters are also necessary to develop consistent impact energies. Basically, the charge (*i.e.* air pressure), the quick release valve, and the bullets (*i.e.* ice spheres) require precise fabrication to achieve reproducible impact energies.

The ice spheres are initially weighed to 0.01 g and then placed in the barrel, similar to a lead shot for a muzzle loader. As the ice sphere is pneumatically

Figure 6

DECK #	LOCATION	AGE
1	Des Moines, Iowa	Five to 10 years
2	Des Moines, Iowa	Five to 10 years
3	Des Moines, Iowa	Five to 10 years
4	Lawrence, Kansas	10 to 15 years
5	Wichita, Kansas	10 to 15 years
6	Denver, Colorado	15 to 20 years
7	Lakewood, Colorado	15 to 20 years
8	Kansas City, Kansas	10 to15 years
9	Lawrence, Kansas	10 to15 years
10	Holcomb, Kansas	10 to15 years
11	Omaha, Nebraska	10 to 15 years
12	Omaha, Nebraska	10 to 15 years
13	Littleton, Colorado	10 to 15 years
14	Wheatridge, Colorado	10 to 15 years
15	Farmington, Utah	Five to 10 years
16	Farmington, Utah	Five to 10 years
17	Indianapolis, Indiana	15 to 20 years
18	Indianapolis, Indiana	15 to 20 years

Field-aged and EPDM membrane.

launched toward the target, the velocity is measured with a ballistics timer. The kinetic (or 'impact') energy is then calculated; minimum kinetic energies listed by NBS are maintained within a tolerance of minus zero, plus 10 percent.

Understanding the EPDM targets and impact procedures

Manufacturers provided a total of 81 test targets constructed with 1524-μm (60-mil) non-reinforced EPDM for impact testing (Figure 5). There were 25 'new' samples and 20 samples heat-aged for 1440 hours at a temperature of 116 C (240 F) at Cascade Technical Services (Hillsboro, Oregon). The 36 samples for the field-aged/exposed category were collected from six states across the country, and they ranged in age from five to 20 years (Figure 6).

The 1.2 x 12.-m (4 x 4-ft) EPDM 'targets' were installed over various substrates that included polyiso and wood fiber insulation, plywood, and oriented strandboard (OSB). Fully adhered EPDM was utilized in the target construction. Figure 7 indicates the material age, substrate, and number of samples of each prepared.

Each target and substrate was vertically mounted. Hailstones measuring 38, 51, 64, and 76 mm (1 ½, 2, 2 ½, and 3 in.) impacted the targets at a 90-degree

With the recent spate of major hailstorms that have affected the United States, the installation of an EPDM roofing membrane can increase safety and minimize potential damage to property.

Figure 7

MATERIAL	SUBSTRATE	SAMPLES PREPARED
New	45-mm (1 ¾-in.) polyisocyanurate (polyiso)	Three
New	51-mm (2-in.) polyiso	Four
New	12-mm (½-in.) oriented strandboard (OSB), 51-mm polyiso	Seven
New	51-mm polyiso, neoprene cover at fastener head	Five
New	12-mm wood fiber, 51-mm polyiso	Six
Heat-aged	12-mm wood fiber, 51-mm polyiso	Six
Heat-aged	12-mm plywood, 51-mm polyiso	Three
Heat-aged	12-mm OSB, 51-mm polyiso	Three
Heat-aged	51-mm polyiso	Eight
Field-aged	51-mm polyiso	18
Field-aged	12-mm OSB, 38-mm (1 ½-in.) polyiso	18

Roof targets.

Figure 8

MATERIAL	SUBSTRATE	SAMPLES PASSED
New	45-mm (1 ¾-in.) polyiso	Three
New	51-mm (2-in.) polyiso	Four
New	12-mm (½-in.) oriented strandboard (OSB), 51-mm polyiso	Six of seven
New	51-mm polyiso, neoprene cover at fastener head below the ethylene propylene diene monomer (EPDM) target	Five
New	12-mm wood fiber, 51-mm polyiso	Six
Heat-aged	12-mm wood fiber, 51-mm polyiso	Six
Heat-aged	12-mm plywood, 51-mm polyiso	Three
Heat-aged	12-mm OSB, 51-mm polyiso	Three
Heat-aged	51-mm polyiso	Eight
Field-aged	51-mm polyiso	14 of 18
Field-aged	12-mm OSB, 38-mm (1 ½-in.) polyiso	18

Roof samples' results.

angle at velocities listed by NBS. To replicate severe weather conditions, such as cold rain during a hailstorm, the test targets were sprayed with water at 4 C (40 F). Prior research and experience has shown roof assemblies exhibit different levels of impact resistance depending on surface temperature.

The various targets were impacted both in the 'field' area and also directly over fasteners and plates used to secure the substrate below the EPDM. Failure was defined as a visible split or cut in the surface.

Of the 25 'new' EPDM test targets tested, 24 were not damaged by 76-mm hail balls. None of the 20 'heat-aged' targets failed when impacted by this size of hail, however. The 'field-aged' EPDM target samples included:

- 18 over a 51-mm (2-in.) thick polyiso insulation substrate; and
- 18 over a 12-mm (½-in.) thick OSB substrate, supported by 38-mm thick polyiso roof insulation.

Fourteen of the EPDM targets that were adhered directly over the polyiso did not fail when impacted with 76-mm hail balls. (The mode of failure typically is a split or cut in the roof membrane.) One sample failed with a 76-mm hail ball, a second sample failed with a 64-mm one, and the two other samples failed with a 51-mm diameter hail ball. None of the 18 EPDM 'field-aged' targets over the OSB were damaged by the 76-mm diameter specimens (Figure 8).

Commentary

Some geographical areas of the United States are clearly more prone to severe hail. Roof assemblies should be capable of resisting impact from reasonably expected hail storms for a given location. Just as roofs are required to perform in various meteorological events, such as wind, snow, and rain—a roof should be able to withstand some degree of hail impact over its expected service life.

In the 2006 *International Building Code* (*IBC*), Paragraph 1504.7 of Chapter 15 ("Roof Assemblies and Rooftop Structures") states roof coverings shall resist impact damage based on tests conducted in accordance with:

- ASTM D3746;[3]
- ASTM D4272, *Standard Test Method for Total Energy Impact of Plastic Films By Dart Drop*; and
- Canadian General Standards Board (CGSB) 37-GP-52M, *Roofing and Waterproofing Membrane, Sheet-applied, Elastomeric.*

These procedures are conducted with steel darts versus ice spheres at room temperature. The testing is for new products and does not address the long-term effects of UV exposure. The results of testing following these protocols may provide false positive results.

Jim D. Koontz & Associates—the firm of one of this article's authors—has examined hundreds of EPDM roofs that have been impacted by hail. Two noteworthy investigations include a telephone building in Fort Worth, Texas, that was impacted by softball-size hail in 1995. The non-reinforced EPDM over polyiso did not fail. A second investigation was at the University of Nebraska in Kearney. All of the campus buildings covered with non-reinforced EPDM survived softball-sized (*i.e.* 96.5-mm [3.8-in.]) hail. The manufacturer of the roof was notified of the performance of the aged EPDM assembly. The gravel built-up roofing (BUR), metal, slate, clay tile, and modified-bitumen (mod-bit) roof covers on the 65 other university buildings all failed.

During the examination of hundreds of roofs, direct impacts over fasteners and plates used to secure underlayment have been extremely rare. Damage observed of this kind has not constituted a failure of the entire roof, and has been repairable. The increasing use of adhesives to fasten insulation and coverboards is eliminating the already unlikely chance of damage caused by hail impact with mechanical fastener plates.

Conclusion

The new, heat-aged, and aged non-reinforced EPDM tested within this study provided excellent resistance to large hail. Of the 81 targets installed over polyiso, wood fiber, plywood, and OSB, 76 did not fail when impacted with hail balls that were up to 76 mm (3 in.) in diameter.

The overall results clearly indicate non-reinforced EPDM roof assemblies offer a high degree of hail resistance over various substrates, and validate empirical experiences. The impact resistance of both the field-aged and heat-aged membrane also demonstrates EPDM retains the bulk of its impact resistance as it ages.

EPDM roofing membranes have a proven track record of resisting hail damage and keeping water out of buildings.

Owners of critical facilities—hospitals, schools, data centers, airports, and sensitive government buildings—demand durability and long-term service lives of their roofs. The use of non-reinforced EPDM can provide an additional level of long-term protection, especially in hail-prone areas.[4]

In heating-dominated northern climates, roof designers should consider using black EPDM in fully adhered assemblies where the top layer of cover board is set in urethane adhesive—beads or full-coverage sprayed polyurethane foam (SPF). From a design standpoint, this assembly has many built-in safeguards, like the durability of non-reinforced EPDM without any hard insulation fastening plates or fastener heads directly under the membrane.

For cooling-dominated southern climates, a white EPDM fully adhered assembly would be the logical choice. Additionally, a ballasted roof assembly utilizing black EPDM is a great choice for hail resistance in both northern and southern markets. Further, roof cover durability in hail events is linked to membrane thickness. Design professionals should consider specifying greater roof membrane thickness.

From empirical observation by the authors and witnessed in the testing, there are several key characteristics of roof systems that are designed for hail resistance:

- employ non-reinforced roof covers with greater thickness and protection (*e.g.* 2286 instead of 1524 µm [90 instead of 60 mils];
- provide high-density support for the roof cover (*i.e.* do not allow the membrane to be depressed

The durability of EPDM makes it an ideal membrane for institutions, such as Gibbons Hall on the campus of James Madison University in Harrisonburg, Virginia.

under hail ball impact);

- place any screw fasteners and stress plates below the cover board, not the roof covers;
- remember ballasted roof systems provide the greatest protection; and
- specify roof covers with a history of general in-situ performance (*i.e.* 20 years) to ensure performance as the membrane ages and is exposed to ultraviolet radiation and various climatic conditions. **CS**

Notes

[1] This research, conducted by J.A.P. Laurie, appeared as "Hail and Its Effects on Buildings" in CSIR Research Report No. 176, Bull. 21, 1-12, published in 1960 by South Africa's National Building Research Institute.

[2] See Koontz' "Simulated Hail Damage and Impact Resistance Test Procedures for Roof Coverings and Membranes," published in October 2000.

[3] Developed by Carl Cash at ASTM, co-author Koontz sees the test as the easiest and best. It replicates Underwriters Laboratories (UL) Class 4, 51-mm (2-in.) steel ball drop from about 6 m (20 ft).

[4] See Koontz' "A Comparative Study of Dynamic Impact and Static Loading of One-Ply Roofing Assemblies," reprinted from Special Technical Publication 959-1988: 24.

ADDITIONAL **INFORMATION**

Authors

Jim D. Koontz, PE, RRC, has been involved in the roofing industry since 1960 and began testing roofing materials in 1976. President of Jim D. Koontz & Associates, he has experience as a roofer, estimator, consultant, lecturer, researcher, and expert witness. Koontz has written numerous articles relating to roofing material/product research, including research on single-ply products and hail/wind impacts. He can be reached at jim@jdkoontz.com.

Tom Hutchinson, AIA, FRCI, RRC, is a principal in Hutchinson Design Group. A licensed architect and registered roof consultant, he specializes in roof design, contract document preparation, specifications, inspections, and the determination of moisture penetration and failure of existing roof system. Hutchinson is a former president of RCI Inc. He is also a Certified Energy Professional in Chicago and secretary of the Conseil International du Bâtiment/Réunion Internationale des Laboratoires d'Essais et de recherches sur les Matériaux et les constructions (CIB/RILEM) International Joint Committee on Roof Materials and Systems. Hutchinson can be contacted via e-mail at hutch@hutchinsondesigngroup.com.

Abstract

When selecting roofing systems, design professionals and owners should consider the long term weatherability and repairability of EPDM as major points of differentiation. Ballasted EPDM performs especially well in hail storms, as the rock serves to break the ice balls upon impact and protects the substrate from being damaged. Ballasted EPDM roofs are energy-efficient in both warm and cold climates and can be considered sustainable—this article explores why.

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