HAIL IMPACT TESTING OF EPDM ROOFS ASSEMBLIES

by

Jim D. Koontz, PE, RRC
Thomas W. Hutchinson, AIA, CSI, FRCI, RRC

RCI 24th International Convention & Trade Show
March 12 - 17, 2009
Dallas, Texas

INTRODUCTION

Hail damage to roof assemblies within the United States and worldwide results in millions of dollars of economic loss each year. At least one state insurance agency allows insurance companies to provide a reduction in insurance rates if a hail resistant type roofing material is installed. Owners of properties that are largely self-insured are beginning to realize the importance of installing hail resistant roofing systems.

The EPDM Roofing Association (ERA) members knew from empirical experience that EPDM roof systems fared very well in hailstorm events, but desired scientific validation. In the spring of 2008 ERA decided to embark on a hail testing program. The technical committee decided that in addition to new material, the real question in the design, insurance and contractor communities is, "how do aged in situ roof covers perform"? Thus it was determined that in addition to new material, new material that was heat aged and existing EPDM roof materials removed from the field with 5 to 20 years of actual exposure would be procured and sent for testing. Carlisle SynTec and Firestone Building Products each provided 4'-0" x 4'-0" new 60-mil EPDM material samples, had new 60-mil EPDM material heat aged, and procured 60-mil samples from roof covers that have been exposed between 5 and 20 years.

Prior to sending the EPDM samples for testing, the EPDM material was fully adhered to various 4'-0" x 4'-0" substrates: mechanically fastened polysio insulation, mechanically fastened wood fiber board, and ½" plywood. Between 20 and 35 samples of each roof cover category were sent for testing.

Field experience from the examination of thousands of roofs has clearly shown that hail damage to a roofing system can be the result of several factors:

- Diameter of the hail
- Type of roofing system
- Age of the roof cover
- Substrate beneath the primary roof system
- Surface temperature at the point of impact

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

NATIONAL BUREAU OF STANDARDS 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. Sydney H. Greenfield of the NBS performed this initial research and generated technical article NBS 23, Hail Resistance of Roofing Products[1]. Mr. Greenfield, referring to research by Laurie, initially determined the free-fall or terminal velocity of hail (refer to **Table A).**

Terminal velocities and energies of hailstone

Diameter		**Terminal Velocity**			**Approximate Impact Energy**	
Inches	*cm*	*ft/s*	*mi/hr*	*m/sec*	*ft lbs*	*Joules*
1	(2.5)	73	50	(22.3)	<1	(<1.36)
1¼	(3.2)	82	56	(25.0)	4	(5.42)
1½	(3.8)	90	61	(27.4)	6	(10.85)
1¾	(4.5)	97	66	(29.6)	14	(18.96)
2	(5.1)	105	72	(32.0)	22	(29.80)
2¼	(6.4)	117	80	(35.7)	53	(71.9)
2¾	(7.0)	124	85	(37.8)	81	(109.8)
3	(7.6)	130	88	(39.6)	120	(162.7)

Table A

The technical data indicates that the free fall velocity of the hail increases with hail stones of larger diameters. A key factor is the amount of "Impact Energy" that is imparted to a target or roof surface.
Simply stated

$$\textbf{Impact Energy = Kinetic Energy = ½ Mass * Velocity}^2$$

The mass of a hail stone obviously is dependent upon the volume of the ice sphere and density of the ice. The density of hailstones is typically valued at .91.

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

$$\textbf{Mass} = \frac{\text{Volume*Density}}{32.2}$$

A substantial difference in impact energy occurs with only slight changes in diameter. Note the impact energy between 1”, 1½” and 2” hail. Increasing hail size from 1” to 2” hail only represents a 100% change in diameter. The impact energy, however, increases by percentage 1,580% (refer to **Table B**).

Diameter Inches	**Volume Inches^3**	**Mass Lbs.**	**Free Fall Velocity Ft/Sec**	**Impact Energy Ft. Lbs.**
1.0	.52	.0005	73	1.41
1.5	1.77	.0018	90	7.29
2.0	4.18	.0043	105	23.7

Table B

INDUSTRY IMPACT RESEARCH

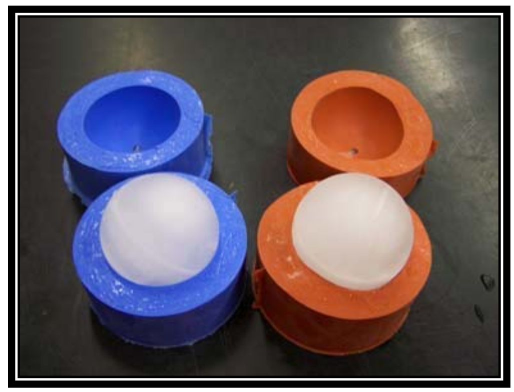
Historically, the hail resistance of roofing products has been tested by dropping steel balls or darts onto the roofing product. The procedures used to impact roofing products have varied between the United States, Canada and European organizations. Two primary United States entities that perform impact testing for code approval have been Underwriters Laboratory (UL)[2] and Factory Mutual Global (FMG)[3]. The Canadian groups utilize impact procedure CGSB 37-GP-52M[4].

The Canadians, UL and FMG use steel darts to impact targets, typically at room temperature. Other organizations such as ASTM have developed impact tests that use steel darts, ASTM D 3746[5]. Within the last few years, greater consideration has been given to impacting targets with ice spheres. Prior research by Jim Koontz and Associates, Inc. (JKA)[6] has also reviewed the issue of ice spheres versus steel darts. The use of ice spheres, obviously, comes closer to replicating what occurs during a real hailstorm event.

HAIL GUN

A key factor in performing the test is to have reproducible impact energies with each shot of "hail." The hail gun propels ice spheres by utilizing the quick release of compressed air from a tank to a barrel. In order to achieve reproducibility, several factors have to be taken into consideration. Consistent "air pressure" is required for each shot. This necessitates controlling the air pressure to 0.01 psi.

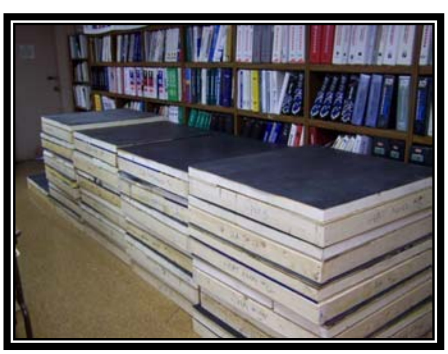
Molds for ice spheres are fabricated using precise diameter steel spheres. Each ice sphere of a given diameter is then weighed to .01 grams prior to each shot. Laboratory grade barrels or tubes with precise internal diameters are also necessary to develop consistent impact energies. Basically, the charge, i.e., air pressure, the quick release valve and the bullets (ice spheres) require precise fabrication in order to achieve reproducible impact energies.



The ice spheres are initially weighed to 0.01 gram and then placed in the barrel, similar to a lead shot for a muzzle loader. As the ice sphere is pneumatically launched towards the target, the velocity is measured with a ballistics timer. The kinetic energy, or "impact energy", is then calculated for each hail shot. The minimum kinetic energies listed by the NBS are maintained within a tolerance of plus zero plus ten percent.

EPDM TARGETS

Carlisle and Firestone provided a total of eighty-one test targets constructed with 60-mil non-reinforced EPDM for impact testing. The new, heat aged and field aged targets listed in **Table C** included:



Material Age	Test Targets
New	25
Heat Aged	20
Field Aged	36

Table C

The field aged and exposed EPDM samples were collected from six states across the country and ranged in age from five to twenty years. The field aged samples are listed in **Table D**.

Field Aged & EPDM Membrane		
Deck #	**Location**	**Age**
1	Des Moines, IA	5 - 10 years
2	Des Moines, IA	5 - 10 years
3	Des Moines, IA	5 - 10 years
4	Lawrence, KS	10 - 15 years
5	Wichita, KS	10 - 15 years
6	Denver, CO	15 - 20 years
7	Lakewood, CO	15 - 20 years
8	Kansas City, KS	10 -15 years
9	Lawrence, KS	10 -15 years
10	Holcomb, KS	10 -15 years
11	Omaha, NE	10-15 years
12	Omaha, NE	10-15 years
13	Littleton, CO	10-15 years
14	Wheatridge, CO	10-15 years
15	Farmington, UT	5-10 years
16	Farmington, UT	5-10 years
17	Indianapolis, IN	15-20 years
18	Indianapolis, IN	15-20 years

Table D

The artificially heat aged samples were prepared at Cascade Technical Services of Hillsboro, Oregon. The samples were heat aged for 1,440 hours at a temperature of 240 degrees Fahrenheit.

The 4’-0” by 4’-0” EPDM “targets” were installed over a variety of substrates that included polysio and wood fiber insulation, plywood and OSB board. Fully adhered EPDM was utilized in the target construction (refer to **Table E**). Table E indicates the material age, substrate and number of samples of each prepared.

Roof Targets		
Material Age	**Substrate**	**No. of Samples Prepared**
New	1.75” Polysio	3
New	2” Polysio	4
New	½” OSB 2.0” Polysio	7
New	2.0” Polysio Neoprene cover at fastener head	5

New	½ “ Wood Fiber 2.0” Polysio	6
Heat Aged	½” Wood Fiber 2.0” Polysio	6
Heat Aged	½ “ Plywood 2.0” Polysio	3
Heat Aged	½” OSB 2.0” Polysio	3
Heat Aged	2.0” Polysio	8
Field Aged	2.0” Polysio	18
Field Aged	½ “ OSB 1.5” Polysio	18

Table E

IMPACT PROCEDURES

Each target with substrate was mounted vertically. Hailstones measuring 1.5”, 2.0”, 2.5”, and 3.0” impacted the targets at a 90-degree angle at velocities listed by the NBS. In order to replicate severe weather conditions, cold rain during a hailstorm, the test targets were sprayed with water at forty degrees Fahrenheit. Prior research and experience has shown that roof assemblies exhibit different levels of impact resistance depending upon surface temperature.

The various targets were impacted both in the “Field Area” and also directly over fasteners and plates utilized to secure the substrate below the EPDM. Failure was defined as a visible split or cut in the surface of the EPDM.

IMPACT RESULTS

Of the twenty-five “new” EPDM test targets tested, twenty-four targets were not damaged by 3.0” hail balls. None of the twenty “Heat Aged” targets failed when impacted with 3.0” hail balls.

The “Field Aged” EPDM target samples included eighteen over a 2” thick polysio insulation substrate and eighteen over a ½” thick OSB substrate, supported by 1½” thick polyiso roof insulation. Fourteen of the EPDM targets that were adhered directly over the polyiso did not fail when impacted with 3.0” hail balls. (One sample failed with a 3.0” hail ball, a second sample failed with a 2.5” hail ball and the two other samples failed with a 2.0” diameter hail ball.) None of the eighteen EPDM “Field Aged” targets over OSB were damaged by 3.0” diameter hail balls (refer to **Table F).**

Roof Samples' Results		
Material Age	**Substrate**	**Samples Passed**
New	1.75" Polyiso	3
New	2" Polyiso	4
New	½" OSB 2.0" Polyiso	6 of 7
New	2.0" Polysio Neoprene cover at fastener head below the EPDM target	5
New	½" Wood Fiber 2.0" Polysio	6
Heat Aged	½" Wood Fiber 2.0" Polysio	6
Heat Aged	½" Plywood 2.0" Polysio	3
Heat Aged	½" OSB 2.0" Polysio	3
Heat Aged	2.0" Polysio	8
Field Aged	2.0" Polysio	14 of 18
Field Aged	½" OSB 1.5" Polysio	18

Table F

COMMENTARY

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

The International Building Code 2006[7], paragraph 1504.7, states: roof coverings shall resist impact damage based on tests conducted in accordance with ASTM D 3746, ASTM D 4272, CGSB 37-GP-52M. 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, Inc. has examined hundreds of EPDM roofs that have been impacted by hail. Two noteworthy projects include a telephone building in Fort Worth, Texas that was impacted by softball size hail in 1995. The non-reinforced EPDM over polysio did not fail. A second project was at the University of Nebraska in Kearney campus building covered with non-reinforced EPDM survived softball sized hail. The manufacturer of the roof was notified of the performance of the aged EPDM assembly. The roofs on sixty-five other buildings 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 that 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-ball impact and mechanical fastener plates.

CONCLUSIONS

The new, heat aged and aged non-reinforced EPDM tested within this study provided excellent resistance to large hail. Of the eighty-one targets installed over polysio, wood fiber, plywood and OSB board, seventy-six did not fail when impacted with hail ice balls up to three inches in diameter.

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

Owners of critical facilities, such as hospitals, schools, computer centers, airports and sensitive government buildings have come to realize the importance of installing a hail resistant roof assembly over critical facilities. The use of non-reinforced EPDM can provide an additional level of long-term protection.

REFERENCES

[1] National Bureau of Standards NBS 23, Sidney H. Greenfield, August 1969
[2] Underwriters Laboratory UL 2218, May 31, 1996
[3] Factory Mutual Class I 4470, August 29, 1992
[4] Canadian General Standards Board CGSB 37-GP-52M
[5] ASTM D 3746
[6] Simulated Hail Damage and Impact Resistance Test Procedures for Roof Coverings and Membranes, Jim D. Koontz, PE, RICOWI, October 27, 2000
[7] International Building Code 2006, Chapter 15 Roof Assemblies and Rooftop Structures, Impact Resistance 1504.7