Hail Study on a 15 Year Old Sprayed Polyurethane Foam Roofing System

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The Dallas Independent School District (DISD) has utilized Alpha sprayed polyurethane (SPF) roof systems since the 1980s. Alpha SPF roof systems are high performing roof systems if installed properly and are very resistant to hail damage (hail damage is significant in the Dallas area). However, DISD, due to their low bid award procurement system, have had some poor performing roof systems installed by contractors who did not utilize performing materials and processes. The Alpha SPF roof system is now being questioned by designers who are not aware of their high performance and wanted to tear-off one of the oldest SPF roofing systems after a hail storm. This case study is on one of DISD roofs which were studied to determine the actual and potential service period based on actual performance. It was concluded that the roof is capable of lasting another 15 more years with a simple recoat (resulting in 38 years of performance at a fraction of the cost of a traditional modified roof).

Keywords: Roofing, high performance, SPF, performance measurement, Neogard.

Introduction

Sprayed Polyurethane Foam (SPF) roofing systems have been installed since the 1960s, and have several advantages over other systems. These advantages include:

- The SPF system is considerably lighter (PCI) than any other roofing systems. The SPF is a 3 – 4 PCF material, with a coating weight that is negligible.
- The SPF system can be applied over existing roofing systems, eliminating the tear-off of the existing system.
- The SPF roofing system can also be sprayed to non-uniform surfaces (corrugated metal decks, roof penetrations, and parapet walls).
- The SPF insulates the roof.
- The entire system creates a monolithic (seamless) roof that eliminates seams.
- The system can be easily renewed by recoating the existing system.

On April 26, 2015 heavy rain and power outages were observed in the various parts of Dallas and Ft. Worth region. Along with major power outages, a hail report estimated the hail size of about 1" damaging the skylights and car windshield. Again on May 10, 2015 the Dallas region experienced a severe thunderstorm where the hail size was estimated to be about 1.75". Over the past five years, there have been approximately 51 hailstorms in the Dallas Fort Worth area with hail ranging up to 3" in diameter (www.stomersite.com). One of the major components of a building that is exposed directly to the environment is the roofing system of a building. A severe hail storm (1.75 inch diameter hail) can cause major damages to the roofing system.

The Dallas Independent School District (DISD) has been installing the Alpha Sprayed Polyurethane Foam (SPF) Roofing System for the last 15 years. SPF roofing has an R-value of R6 per inch and is used by the owners of the building as a recovery system over existing roofs including built-up roof, modified bitumen, concrete, wood, asphalt shingles, clay tile, and metal (Knowles, 2005). The Alpha Sprayed Polyurethane Foam (SPF) roofing system has documented performance of 20 years with the ability to last 32 years with a simple recoat (Wattle & Daub Performance Line, 2015). The advantage of the Alpha SPF roof system is that it does not require the removal of the existing modified or BUR system saving owners as much as $6/SF (50% less than the traditional BUR system) in removal costs and costs of a new modified or BUR system. However, installation workmanship is one of the major reasons for SPF roofing defects which can severely minimize the service period (Alumbaugh et. Al., 1984; Kashiwagi & Tisthammer, 2002)

For this reason, DISD has used a high performance "Alpha" urethane coated SPF roof system installed by expert Alpha contractors in a quality control roofing program known as the Alpha Program (Gajjar, 2012). A properly installed Alpha roof system has been documented to resist up to 4 inch diameter simulated hail stones (four inch diameter steel ball dropped from more than 17-3/4 feet height). The Dallas Independent School District is self-insured against hail damage and is interested in using roofing systems that have the capability to withstand hail damage to minimize their cost. The Alpha Program is a group of high-performing contractors that have to meet strict performance requirements as follows:

- Roof inspections of risky roofs (leaks or have defects) once every two years
- Annually perform customer satisfaction checks on newly installed SPF roofs over 5,000 SF
- 98% of the roofs checked not currently leaking
- 98% customer satisfaction of all roofs
- Respond to leaks within 7 days of notification and fix within a couple of weeks

An Alpha roof system is installed by an Alpha contractor (meets the above quality control requirements) with 45mils of Alpha urethane roof coating and SPF that has 50 PSI compressive strength. If it is installed correctly (meeting the requirements of the Alpha specification), the Alpha roof system has a potential of 30 year service period at half the cost of installing another new BUR or modified bitumen system. There are several problems that have occurred at the DISD with limitation of funding being one of the major ones. This has led to the following practices:

1. A 10 year traditional SPF roof system instead of the 15 year Alpha SPF roof.
2. The Alpha contractors hired in "low bid" environment by general contractors, making it a low bid roof with low bid materials.
3. The SPF roof system is installed in less than ideal conditions (over moisture laden BUR/insulation systems).
4. SPF roofs being installed over existing SPF or BUR systems with moisture.
5. The SPF roof system is stepped on before it adequately cures causing blistering.

These issues have confused DISD project managers into thinking that the Alpha System may not perform as expected. Doubts such as the Alpha system being a performing roof system and the Alpha system being resistant to hail damage have emerged amongst the DISD project managers.

Problem

Some of the low bid installed SPF roof systems are having problems. One of those roofs (Foster Elementary) at DISD, which was installed in 2002 (one of the first Alpha SPF roofs installed before the other low bid SPF roofs), experienced a severe hail storm in 2014 and was inspected by the insurance company representative (DISD are self-insured). The inspector proposed that the entire roof (both the existing BUR underneath and the over layed Alpha SPF roof system) to be replaced after 13 years of installation in the summer of 2015. This paper will study the economic and waterproofing performance of the Alpha roof system installed at Fosters Elementary by testing it against hail damage and inspecting the SPF and coating characteristics.

Methodology

The Foster Elementary Alpha SPF system will be studied in the following ways:

1. The inspection report of the past four years of the roof will be reviewed.
2. The roof will be tested according to the ASTM Hail Test using a 2 inch steel ball being dropped from 17 feet, 9 inches height (the standard test is using a 1-3/4 inch diameter steel ball). This test used a larger ball as a more conservative approach. The Alpha roof system warrants against hail damage if a 1-3/4 inch steel ball rips through the Alpha urethane coating.
3. The roof will be tested using a 4 inch diameter steel ball dropped from 17 feet 9 inch height. This is an oversized hail test (Kashiwagi, 2004).
4. Test the SPF under the Alpha coating to ensure that it is a 50 PSI SPF.
5. Make a conservative estimate of the performance of the SPF roof system if it had been recoated instead of tear-off.
6. Conclude whether an Alpha SPF roof system is a performing system for DISD.
7. Conclude on the ramifications of this case study on the expectations of the Alpha roof system at DISD.

Inspection of the Fosters ES Roof

The Fosters ES roof has the following history:

1. Original roof was BUR that was installed in the 1970s (conservative estimate).
2. A SPF roof system was installed over the existing BUR system previous to 1988.
3. A second SPF roof system, that is an Alpha roof system, is installed over the existing BUR and SPF roof in 2002.

4. Hail storm occurred in 2015, and a hail inspector recommends that the roof is damaged and should be replaced.
5. The hail test and analysis of the SPF was then conducted in the summer of 2015.
6. The Foster Alpha SPF roof was removed due to "perceived hail damage" in the summer of 2015, and replaced with a $16/SF roof system.

The roof was physically inspected every year from 2011 to 2014 to measure the percentage of blisters on Fosters ES as shown in Table 4. The contractor fixed the blisters in 2012 with no cost to the client and the manufacturer. Only 3 SF (0.006%) of blisters currently exist on the roof. This roof was in no danger of failing. The roof defects and repairs for the last four years are shown in Table 1.

Table 1

Inspection Results (2011 – 2014)

2011		2012		2013		2014	
SF Blisters	% Blisters	SF Blisters	% Blisters	SF Blisters	% Blisters	SF Blisters	% Blisters
74	0.150%	260	0.510%	3	0.006%	3	0.006%

However, an independent insurance adjuster identified that the Foster elementary school Alpha roof was damaged by hail. An inspection by the PBSRG research staff identified minimal hail damage on the roof. PBSRG then decided to run the FM hail test and the severe hail test (FM-SH Hail Test #4470 (SH)) on the roof. Evaluating roof coverings using physical inspection have been used for asphalt composition shingles, wood shingles and shakes, and slate and clay tile roofs (Sharara et. al., 2009). Hail test studies have been performed on numerous building materials to test their ability to withstand hail (Nelson, 2012; Askari et. al., 2011). ASTM D-1621 test was also performed by the Naval Laboratory at Port Hueneme, CA by Robert Alumbaugh. In 1996, PBSRG at Arizona State University did a similar comprehensive hail study, and in 1998 followed it up with a hail test using a 4 inch diameter steel ball. It was called a severe hail (SH) test. PBSRG reached the following conclusions in those two studies:

1. The Factory Mutual (FM) publication on their hail test results was inconsistent with the PBSRG test results. FM identified the silicone coating as the most resistant, and the urethane coating as the least resistant. PBSRG could not duplicate the FM results. Conversations with FM resulted in no action. Since that time FM has proposed new hail standards. However, there has been no new information since their publication in the 1990s.
2. The FM weathering test using the Weatherometer (Xeno 1200 Xenon light source) was not valid. The test results from the Weatherometer did not match the results of aged samples from the field.)
3. The silicone coating could not pass the hail test. The acrylic coating could also not pass the hail test.
4. A high strength acrylic coating put on at a 40 mil thickness was tested, and the 1-3/4 inch steel ball smashed right through the coating and the SPF. This result was not published at that time due to an agreement with the contractor who provided the sample. It is being published now due to the time that has elapsed.
5. Aged Neogard urethane coated SPF roofs passed the hail test with 20 mil coating after 20 years of age.

6. Aged Neogard coating systems passed the FM SH (4 inch diameter steel ball dropped from 17-3/4 feet height) at 15 years of service period at 50 mils of urethane coating.

Due to the poor performance of the majority of the SPF roofing systems to hail damage, roof traffic, and improper application, SPF systems are traditionally thought of as a cheaper roofing system, with marginal performance. This has contributed to its lack of popularity (less than 3% of the roofing market). PBSRG has published the following publications that relate to the performance of Sprayed Polyurethane Foam Roofing Systems:

1. Hail Resistance of SPF Roof Systems – 1996
2. Oversize Hail Resistance Test of SPF Roof Systems – 1997
3. Hail Resistance of the Alpha SPF Roof System – 2003
4. Hail Resistance of SPF Roof Systems – 2008

The previous hail tests revealed that the customers were extremely satisfied (9.8 out of 10) with the SPF roofing system. SPF roofing systems are high performing roofs when installed by an expert and capable contractor and can resist severe hail damage (drop of 4 inch diameter steel ball from 17-3/4 feet height). In 2015, PBSRG performed several tests on the aged Foster Elementary SPF roofing systems to confirm the opinion of the independent insurance adjuster. The roof information is as follows:

Roof Name: Stephen Fosters ES
Location: 3700 Clover Ln, Dallas, TX 75220
Job Area: 50,754 SF
Year Installed: October 2002

The test performed in Dallas was done in early July, with an average roof temperate of 78 degrees.

On-Field Testing of the Coating Using the FM-SH Test

The Factory Mutual Severe Hail (FM-SH) test #4470 was utilized. This test simulates the damage caused by freefalling severe hail (up to 1.75" in diameter). This test requires dropping a 1.75"steel ball from a height of approximately 18 ft onto an SPF sample (figure 1). PBSRG researchers used a more conservative larger 2 inch and 4 inch diameter steel balls. The result of the impact cannot show any signs of failure (cracking or tearing) in the coating system. The FM-SH test has been used on previous publications that the PBSRG has published, and was used once again for this research test.

Figure 1: Hail Testing Apparatus.

After setting up and dropping each steel ball, the impact was examined to determine if there were any failures (cracks or tears) in the system. A total of 20 hail drops were performed (10 drops with 2" steel ball and 10 drops with 4" steel ball). Nineteen (19 out of the 20 hail drops passed the test.

Foam Testing using the ASTM Test

The American Society for Testing and Materials (ASTM) Test D-1621 is used to measure the compressive strength and the density of the SPF. A sample from the roof was collected and analyzed. Five tests were performed for each SPF sample for a total of 15 tests for three layers of SPF. The three layers of SPF are as follows with 4" total thickness (figure 2).

- Bottom layer: Old, yellow foam materials (2" thick).
- Middle Layer: New SPF material (1" thick).
- Top Layer: New SPF material (1" thick).

Figure 2: Three Layers of SPF (4" thickness).

Research Results

Measurements were taken after the tests were performed to determine the impact depth and impact diameter of the 2" steel ball and 4" steel ball (figure 3).

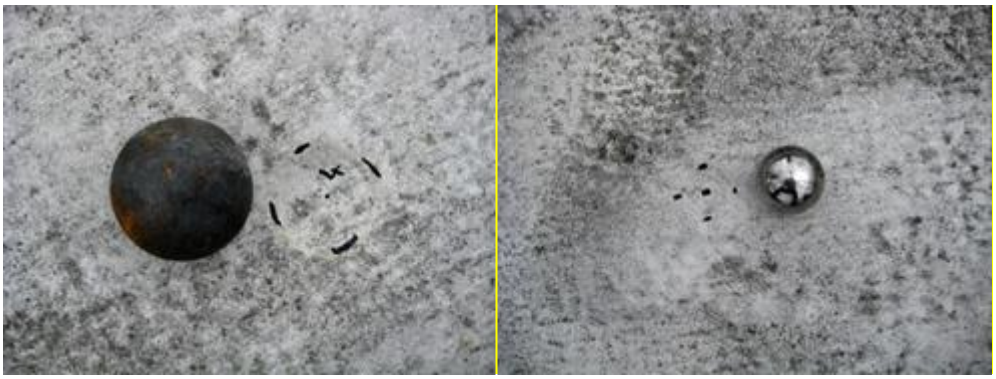

Figure 3: Indentations - 4" and 2" steel ball.

Table 2 provides a detailed analysis of the impact depth and impact diameter of the hail drops. The average impact width for 2" steel ball and 4" steel ball were 1.5" and 3.5" respectively whereas the average impact depth for 2" steel ball and 4" steel ball was 0.193" and 0.388" respectively.

Table 2

Impact depth and impact diameter

2" Steel Ball				4" Steel Ball			
Drop No.	Pass / Fail	Average Impact Width (in.)	Average Impact Depth (in.)	Drop No.	Pass / Fail	Average Impact Width (in.)	Average Impact Depth (in.)
1	Pass	1.5	0.125	1	Pass	3.5	0.5
2	Pass	1.5	0.25	2	Pass	3.5	0.25
3	Pass	1.5	0.125	3	Pass	3.5	0.875
4	Pass	1.5	0.125	4	Pass	3.5	0.25
5	Pass	1.5	0.375	5	Pass	3.5	0.375
6	Pass	1.5	0.1875	6	Pass	3.5	0.25
7	Pass	1.5	0.125	7	Pass	3.5	0.375
8	Pass	1.5	0.375	8	Fail	3.5	0.375
9	Pass	1.5	0.125	9	Pass	3.5	0.25
10	Pass	1.5	0.125	10	Pass	3.5	0.375
Average		**1.5**	**0.193**	**Average**		**3.5**	**0.388**

Slit samples were taken on the roofs to determine the average coating thickness of the in-place systems (figure 4). Sixteen (16) total slit samples were taken from the dropped locations. Four (4) measurements per sample were taken to determine the average thickness of the sample (64 total measurements).

Figure 4: Slit Sample Mil Thickness.

The average coating thickness and the minimum coating thickness were measured on each slit sample. The results of the measurements are shown in Table 2a and Table 2b, and indicate that the average mil thickness was 46.25 mils and 44.11 mils for 2" and 4" steel ball drops respectively.

Table 2a

Analysis of Coating Thicknesses (2" Steel Ball)

Drop No	Pass / Fail	1st Coating Thickness (mils)	2nd Coating Thickness (mils)	3rd Coating Thickness (mils)	4th Coating Thickness (mils)	Average Coating Thickness (mils)
1	Pass	50	50	50	50	50
2	Pass	50	45	45	50	47.5
3	Pass	40	45	45	50	45
4	Pass	50	50	50	50	50
5	Pass	N/A	N/A	N/A	N/A	N/A
6	Pass	N/A	N/A	N/A	N/A	N/A
7	Pass	40	45	45	40	42.5
8	Pass	45	50	35	50	45
9	Pass	35	45	40	40	40
10	Pass	50	50	50	50	50
					Average	**46.25**

Table 2b

Analysis of Coating Thicknesses (4" Steel Ball)

Drop No	Pass / Fail	1st Coating Thickness (mils)	2nd Coating Thickness (mils)	3rd Coating Thickness (mils)	4th Coating Thickness (mils)	Average Coating Thickness (mils)
1	Pass	40	40	40	40	40
2	N/A	N/A	N/A	N/A	N/A	N/A
3	Pass	40	50	70	50	52.5
4	Pass	45	50	45	50	47.5
5	Pass	35	45	40	50	42.5
6	Pass	40	40	40	40	40
7	Pass	35	40	35	35	36.25
8	Fail	60	70	50	50	57.4
9	Pass	40	40	50	45	43.75
10	Pass	45	35	35	35	37.5
					Average	**44.11**

The compressive strength and the density of the SPF material were tested individually for three different layers as shown in Table 3. Similar tests have previously been performed on foam materials to verify the physical properties (Priddy & Newman, 2010).

Table 3

Compressive Strength and Density of SPF

Bottom Layer SPF (2")			Middle Layer SPF (1")			Top Layer SPF (1")		
No	Comp. Strength (psi)	Density (pcf)	No	Comp. Strength (psi)	Density (pcf)	No	Comp. Strength (psi)	Density (pcf)
1	56.5	3.12	1	49.9	3.17	1	34.8	2.73
2	57.9	3.14	2	53.2	2.91	2	42.9	2.85
3	58.3	3.11	3	52.3	2.80	3	43.9	2.89
4	61.7	3.10	4	51.6	2.77	4	40.5	2.69
5	53.6	3.15	5	53.2	3.22	5	50.8	2.72
Avg.	**57.6**	**3.12**	**Avg.**	**52.0**	**2.97**	**Avg.**	**42.58**	**2.78**

The Fosters roof is a high performance roofing system that has performed for 28 years with the potential of performing for another 15 years with a recoating. The Alpha SPF system ($5/SF - $8/SF cost) becomes an economic and value based alternative to the $16/SF traditional modified roofing system.

Conclusion

The Fosters SPF roof system that was analyzed in this case study was 15 years old. In 2002, additional SPF and the Alpha hail resistant coating were added to increase the performance to 28 years, and were in perfect condition to extend the service life to 38 years old. Instead of recoating the system, the roof was removed and a new modified bitumen roofing system was installed. The modified system is estimated at $16/SF, which is twice the cost of the Alpha recoating system.

The reason why the roof was removed was the concern that a recent hail storm had damaged the existing modified bitumen system and the existing Alpha roof system (split system roof). To ensure that the Alpha SPF roof system could perform in a 1-3/4 inch hail, the Factory Mutual (FM) hail test was performed with a 2" diameter steel ball resulting in no damage to the Alpha SPF roof system. To identify if the roof could withstand a 4" diameter steel ball dropped from 17 – ¾ feet height (very severe hail damage, only one of the ten drops resulted in a break of the Alpha roof coating).

A summary of the test results of the Alpha SPF roof system as an alternate value for the traditional $16/SF modified bitumen system include:

- The hail test on the Alpha coating showed no signs of damage.
- Only 1 out of 10 drops of the 4" steel ball (severe hail simulation) resulted in a ½" slit.
- The SPF sample had a total thickness of 4", average compressive strength of 50.7 psi and average density of 2.96 PCF (matching new Alpha roof SPF requirements).
- The roof only has 3 SF of blisters (.006% of roof area) and is free of leaks and deterioration.
- Roof is capable of lasting another 15 more years with a simple recoat (resulting in 38 years of performance at a fraction of the cost of a traditional modified roof).
- Roof is being replaced after the hail storms, but there is no visual damage on the roof (figure 5).

Figure 5: Actual Roof.

The authors conclude that the Alpha SPF roof system should not have been tear-off, but should have been recoated at a cost of $5.00SF. The roof would have lasted an additional 15 years, taking the full service period of the roof at 38 years. The roof would have cost DISD less than 50% of the procured BUR system, and would have been a financial windfall. The Fosters Elementary School also shows that the Alpha SPF roof system is a renewable, green roofing system that is an economic alternative to the modified BUR system.

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