40 Year Outdoor Weathering Study

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Introduction:

In 1983 a variety of sealant types were installed and placed on outdoor exposure racks at a weathering facility near Miami Florida, USA (see Figure 1). The original 1983 study was designed to serve two purposes; first, to provide shorter-term (i.e., 1-2 years) information on streaking / rundown effects of different sealants on glass and painted aluminum; secondly, to provide weathered and aged samples for longer-term durability evaluation. The sealants were applied to glass and painted aluminum panels at the test site and have remained in position since January 1983. The sealants have been periodically monitored over the past four decades for various performance criteria such as appearance, flexibility, hardness and adhesion. In January 2005, October 2013, and April 2024, after 22, 30, and 41 years of weathering respectively, the samples were inspected and photographed. In addition, samples of cured sealant product were cut from each individual test assembly and retained for further lab evaluation. For interested readers, a 20 year and a 30 year weathering study were published in an ASTM Symposia Paper in 2010 and 2014, respectively [1,2].

Test Site Location:

Exposures were conducted in Miami, Florida, USA at exposure fields operated by the Atlas Weathering Services Group – South Florida Test Service (SFTS). The sites are located in a rural environment with a general prevailing climate that provides high levels of ultraviolet radiation, humidity and temperature in a subtropical environment.

Figure 1 – Test Site, Aerial View (courtesy of Atlas Material Testing Technology LLC)

Test Panel Configuration & Assembly:

A series of test panels were assembled using 30.5 x 30.5 cm (12″ x 12″) square pieces of glass and painted aluminum set in aluminum channels fastened to create a supporting frame (test assembly) which was mounted to outdoor exposure racks at the test site location (see Figure 2). The assemblies were positioned on the racks at a 45° angle to the horizon and facing south. Each test assembly consisted of three glass (or painted aluminum) panels with two horizontal in-plane joints created between the panels (see Figure 3). Both joints, of each test assembly, were filled with the same sealant product. All joints in all test assemblies were 1.3 cm (1/2″) wide and created using small plastic shims placed at the left and right edges of the panels to maintain separation. Glass thickness was 0.64 cm (1/4″). Painted aluminum panels used a 90° return at the edges to provide sufficient surface length [1.91 cm (3/4″)] for bonding. All glass and painted aluminum panels were cleaned prior to installation of the sealant using soap and water. After cleaning the panels were thoroughly rinsed with water and dried. No primers were used in this study.

Figure 2 – Original appearance of the test panels. Picture taken September 2, 1983.

Test Panel Configuration & Assembly Cont.:

Polyethylene backer rod (held in place with masking tape) was used to hold the sealant in place. Once the sealants were fully cured, the backer rod was removed thus allowing the cured sealants to be exposed to the environment from both the top and bottom surfaces.

All sealants were installed using the procedures outlined by the manufacturer on the product datasheets.

In order to enhance the effects of streaking / rundown (one of the two original objectives of the study) the installed sealants were not tooled into the usual smooth concave profile. The lack of tooling during installation of these sealant beads in 1983 was thought to be of minimal importance for the durability aspect (from a material perspective) of this study.

Figure 3 – Test assembly at test site location. Picture taken April 15, 2024.

Description of Sealants:

All sealants in this study were commercially available products sold in 1983 and marketed for use in construction applications. The sealant products used were from six different manufacturers. Nine of the original thirteen (see Figure 4) products used in this study are still commercially available when this paper was prepared. Table 1 provides a brief description of the products in the study.

Figure 4 – SilPruf™ Silicone Sealant commercially available in 1973.

Table 1 – Description of Sealant Products

ID #	Polymer type, descriptors	Manuf	Filler type	Color
1	Silicone, 1PT, +/-25%, Ac	A	100% Fumed Silica	White
2	Silicone, 1PT, +/-50%, Al	A	Calcium Carbonate / Fumed Silica	Grey
3	Silicone, 1PT, +/-50%, Al	A	Fumed Silica	Trans/Clear
4	Silicone, 1PT, +/-50%, Al	A	Calcium Carbonate / Fumed Silica	Grey
5	Silicone, 1PT, +/-50%, Al	B	Calcium Carbonate / Fumed Silica	Grey
6	Silicone, 1PT, +100/-50%, Am	B	Calcium Carbonate / Fumed Silica	Limestone
7	Silicone, 1PT, +/-25%, Ac	B	100% Fumed Silica	Black
8	Silicone, 1PT, +/-25%, Ac	C	100% Fumed Silica	Black
9	Silicone, 1PT, +/-25%, Ac	D	100% Fumed Silica	Black
10	Polyurethane, 2PT, +/-50%	D	Fumed Silica	Black
11	Acrylic Terpolymer, 1PT, XX	D	Calcium Carbonate	Black
12	Polyurethane, 1PT, +/-25%	E	Calcium Carbonate / Fumed Silica	Limestone
13	Polyurethane, 1PT, +/-25%	F	Calcium Carbonate	Grey

Note:
1PT = single component product
2PT = multi-component product
±25%, ±50%, +100/50% = the manufacturer's published movement capability
Ac = acetoxy chemistry; sealant releases acetic acid during cure
Al = alcohol chemistry; sealant releases an alcohol during cure
Am = acetoamide chemistry; sealant releases N-ethylacetamide during cure
XX = unknown/not published

Evaluation Methods:

Surface Appearance & Condition - The aged sealants were visually examined for general appearance and surface degradation (i.e., cracking, crazing, bubbling or other surface irregularity, etc.., and discoloration or dirt-pickup) and observations of each condition were recorded at that time. A cursory cleaning (using a commercial household cleaning detergent and sponge to scrub the sealant beads including the surrounding glass and/or metal panels in the vicinity of the sealant beads) of the panels was performed to assist in visual assessment of sealant surface conditions (see Figure 5). Test assemblies were cleaned and photographed prior to and after sealant cleaning and removal to allow for best visual examination of the sealant surface(s).

Table 2 provides a qualitative assessment of the physical appearance and condition of the sealants. The following ratings were assigned and are tabulated in Table 2:

- For overall surface appearance and condition: Samples were visually and qualitatively assessed as Excellent, Good or Poor.
- For dirt-pickup: Samples were visually and qualitatively assessed as: Light, Moderate or Significant.
- For surface irregularity: Samples were visually and qualitatively assessed as: None, Moderate or Significant (See Figure 6).
- For discoloration or color change: Samples were visually and qualitatively assessed as: None, Moderate or Significant.

Table 2 – Surface Appearance & Conditions

ID #	Polymer type, descriptors	Overall	Dirt-Pickup	Surface Irregularity	Discoloration
1	Silicone, 1PT, +/-25%, Ac	Excellent	Significant	None	None
2	Silicone, 1PT, +/-50%, Al	Good	Significant	Moderate	None
3	Silicone, 1PT, +/-50%, Al	Excellent	Significant	None	Significant
4	Silicone, 1PT, +/-50%, Al	Excellent	Significant	None	None
5	Silicone, 1PT, +/-50%, Al	Excellent	Significant	None	None
6	Silicone, 1PT, +100/-50%, Am	Good	Significant	Moderate	Significant
7	Silicone, 1PT, +/-25%, Ac	Good	Significant	Moderate	Significant
8	Silicone, 1PT, +/-25%, Ac	Excellent	Significant	None	None
9	Silicone, 1PT, +/-25%, Ac	Excellent	Significant	None	Moderate
10	Polyurethane, 2PT, +/-50%	Poor	Light	Significant	N/A
11	Acrylic Terpolymer, 1PT, XX	Poor	Light	Significant	None
12	Polyurethane, 1PT, +/-25%	Poor	Light	Significant	Significant
13	Polyurethane, 1PT, +/-25%	Poor	Significant	Moderate	None

Figure 5 – Sealant #1 surface condition after cursory clean. Picture taken April 15, 2024.

Figure 6 – Significant surface irregularities on sealant #12. Picture taken April 16, 2024.

Evaluation Methods Cont.:

General Overall Condition - This study tested the sealants for flexibility, resiliency and toughness. Cut samples were assessed by stretching, bending, twisting, gouging, etc. Samples were assigned a score of Excellent, Good or Poor and are shown in Table 3. The following definitions were used as guidance when scoring:

- Flexible - capable of being easily bent, without breaking or cracking (see Figure 7).
- Resilience - the ability to return to the original form, position, etc., after being bent or stretched.
- Toughness – not easily gouged or defaced (see Figure 8).

Table 3 – General Overall Condition

ID #	Polymer type, descriptors	Flexibility	Resilience	Toughness
1	Silicone, 1PT, +/-25%, Ac	Excellent	Excellent	Excellent
2	Silicone, 1PT, +/-50%, Al	Poor	Poor	Poor
3	Silicone, 1PT, +/-50%, Al	Excellent	Excellent	Good
4	Silicone, 1PT, +/-50%, Al	Poor	Poor	Excellent
5	Silicone, 1PT, +/-50%, Al	Good	Good	Poor
6	Silicone, 1PT, +100/-50%, Am	Excellent	Excellent	Poor
7	Silicone, 1PT, +/-25%, Ac	Excellent	Excellent	Excellent
8	Silicone, 1PT, +/-25%, Ac	Excellent	Excellent	Excellent
9	Silicone, 1PT, +/-25%, Ac	Excellent	Excellent	Excellent
10	Polyurethane, 2PT, +/-50%	Good	Poor	Poor
11	Acrylic Terpolymer, 1PT, XX	Poor	Poor	Excellent
12	Polyurethane, 1PT, +/-25%	Poor	Poor	Excellent
13	Polyurethane, 1PT, +/-25%	Poor	Poor	Excellent

Figure 7 – Sealant #8 was bendable, tretchable, and twistable in the joint. Picture taken April 16, 2024.

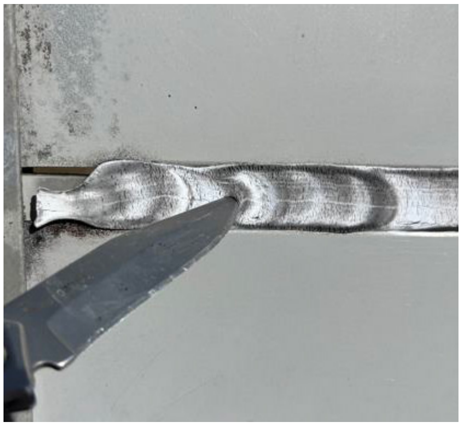

Figure 8 – Sealant #7 resistant to gouging from a pocketknife. Picture taken April 16, 2024.

Adhesion – Sections of each sealant were physically cut out from each glass and aluminum panel test assembly and at that time the adhesion was qualitatively evaluated by hand pull and visual inspection of the joint bondline for mode of failure (cohesive or adhesive, see Figure 9). Adhesion results are shown in Table 4.

Evaluation Methods Cont.:

Flexibility – Sections of each sealant were physically cut out from each glass and aluminum panel test assembly. In an effort to qualitatively assess the flexibility and/or elasticity of each sealant, the cut samples were manually bent 180° and photographed and flexibility (or not) was noted. Results of this 180° bend are shown in Table 4 as Excellent, Good or Poor; and defined as follows:

- Excellent – sealant able to withstand 180° bend without breaking or cracking (see Figure 10).
- Good - sealant able to withstand 180° bend but with some cracking.
- Poor – sealant unable to withstand 180° bend without breaking.

Elastic Recovery – Immediately after each sealant was manually flexed/bent 180°, the sealant was released and the elastic recovery was noted and photographed (see Figure 11). Elastic recovery is defined as the percent recovery to original shape within 5 minutes of release from the 180° bend position. Elastic recovery results are shown in Table 4. Sealants that broke after the 180° bend test could not be tested for elastic recovery, noted as N/A in Table 4.

Table 4 – Adhesion, Flexibility, & Elastic Recovery

ID #	Polymer type, descriptors	Adhesion Check		Flexibility	Elastic Recovery
		Glass	Aluminum		
1	Silicone, 1PT, +/-25%, Ac	Adhesive	Cohesive	Excellent	Yes, 100%
2	Silicone, 1PT, +/-50%, Al	Cohesive	Cohesive	Poor	N/A
3	Silicone, 1PT, +/-50%, Al	N/A	Cohesive	Excellent	Yes, 100%
4	Silicone, 1PT, +/-50%, Al	Cohesive	N/A	Poor	N/A
5	Silicone, 1PT, +/-50%, Al	50% Cohesive	Cohesive	Poor	N/A
6	Silicone, 1PT, +100/-50%, Am	Cohesive	Cohesive	Excellent	Yes, 90%
7	Silicone, 1PT, +/-25%, Ac	N/A	Cohesive	Excellent	Yes, 100%
8	Silicone, 1PT, +/-25%, Ac	N/A	Cohesive	Excellent	Yes, 100%
9	Silicone, 1PT, +/-25%, Ac	Adhesive	Cohesive	Excellent	Yes, 100%
10	Polyurethane, 2PT, +/-50%	N/A	N/A	N/A	N/A
11	Acrylic Terpolymer, 1PT, XX	Adhesive	Cohesive	Poor	N/A
12	Polyurethane, 1PT, +/-25%	N/A	Adhesive	Good	N/A
13	Polyurethane, 1PT, +/-25%	N/A	Adhesive	Poor	N/A

Figure 9 – Cohesive failure of sealant #2 in aluminum joint. Picture taken April 15, 2024.

Figure 10 – Sealant #1 bent 180° without any cracking. Picture taken July 26, 2024.

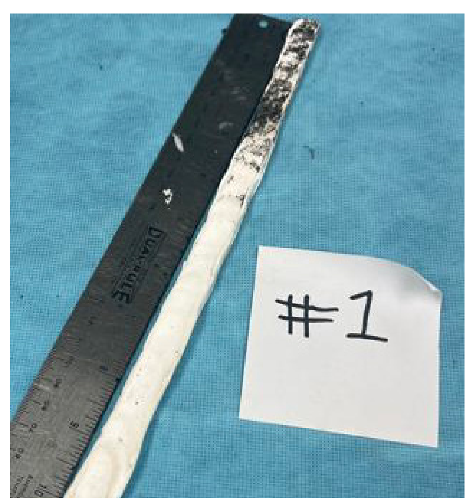

Figure 11 – Sealant #1 recovered to its original length after being bent 180°. Picture taken July 26, 2024.

Evaluation Methods Cont.:

Hardness – Sections of each sealant were physically cut out from each glass and aluminum panel test assembly. Samples were taken to lab and measured for Type A hardness using a sealant hardness tester manufactured by Fowler, Canton, MA (see Figure 12). For each specimen, a minimum of three readings (instantaneous values) were taken and recorded (see Figure 13). Table 5 lists the average hardness readings.

Table 5 – Hardness

ID #	Polymer type, descriptors	Initial Published Hardness	40 Year Hardness Readings	% Change
1	Silicone, 1PT, +/-25%, Ac	35	38	9%
2	Silicone, 1PT, +/-50%, Al	22	75	242%
3	Silicone, 1PT, +/-50%, Al	22	33	50%
4	Silicone, 1PT, +/-50%, Al	22	67	205%
5	Silicone, 1PT, +/-50%, Al	30	66	120%
6	Silicone, 1PT, +100/-50%, Am	15	12	-20%
7	Silicone, 1PT, +/-25%, Ac	25	31	25%
8	Silicone, 1PT, +/-25%, Ac	30	31	3%
9	Silicone, 1PT, +/-25%, Ac	24	30	25%
10	Polyurethane, 2PT, +/-50%	20-40	11	-62%
11	Acrylic Terpolymer, 1PT, XX	40-50	94	110%
12	Polyurethane, 1PT, +/-25%	35-45	87	118%
13	Polyurethane, 1PT, +/-25%	38	79	108%

Figure 12 – Fowler Type A Durometer. Picture taken July 26, 2024.

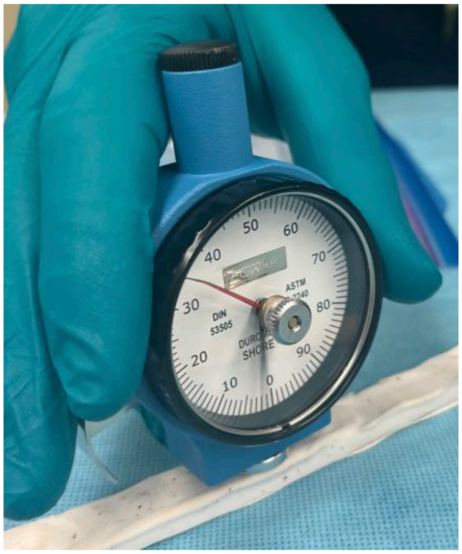

Figure 13 – Durometer reading of sealant #1. Picture taken July 26, 2024.

Overall Durability Ranking:

In an effort to provide a way to quantify the overall durability of these sealants, the following ranking procedure was used in this study. Only performance characteristics, deemed to have influence on weathering durability, are used (i.e., visual appearance or superficial surface conditions are not included). The following properties are thought to be fundamental requirements necessary for a product to be capable of withstanding long-term outdoor weathering for use in building construction applications: flexibility, resilience (elastic recovery), toughness, resistance to hardness change, and ability to maintain long-term adhesive bonding (as demonstrated on painted aluminum used in this study). Table 6 shows the overall durability ranking of the sealants reviewed in this study.

For ranking, the following rating system is used for Table 7:

- For Flexibility (ref Table 4) → Excellent = 3, Good = 2, Poor = 1
- For Resilience (ref Table 3) → Excellent = 3, Good = 2, Poor = 1
- For Toughness (ref Table 3) → Excellent = 3, Good = 2, Poor = 1
- For % Change in Hardness (ref Table 5) → 0-33 = 3, 34-66 = 2, > 66 = 1
- Ability to Bond for 40 years (based on results of painted aluminum test assemblies) (ref Table 4) → Adhesive Failure = 1, Partial Adhesion = 2, Cohesive failure = 3

Table 6 – Overall Durability Ranking

ID #	Polymer type, descriptors	Flexibility	Resilience	Toughness	Change in Hardness	Adhesive Bond Durability	Rating Totals
1	Silicone, 1PT, +/-25%, Ac	3	3	3	3	3	∑ = 15
2	Silicone, 1PT, +/-50%, Al	1	1	1	1	3	∑ = 7
3	Silicone, 1PT, +/-50%, Al	3	3	2	2	3	∑ = 13
4	Silicone, 1PT, +/-50%, Al	1	1	3	1	3	∑ = 9
5	Silicone, 1PT, +/-50%, Al	1	2	1	1	3	∑ = 8
6	Silicone, 1PT, +100/-50%, Am	3	3	1	2	3	∑ = 12
7	Silicone, 1PT, +/-25%, Ac	3	3	3	3	3	∑ = 15
8	Silicone, 1PT, +/-25%, Ac	3	3	3	3	3	∑ = 15
9	Silicone, 1PT, +/-25%, Ac	3	3	3	3	3	∑ = 15
10	Polyurethane, 2PT, +/-50%	2	1	1	1	1	∑ = 6
11	Acrylic Terpolymer, 1PT, XX	1	1	3	1	3	∑ = 9
12	Polyurethane, 1PT, +/-25%	2	1	3	1	1	∑ = 8
13	Polyurethane, 1PT, +/-25%	1	1	3	1	1	∑ = 7

Conclusions:

Durability & Adhesion:

1.) In all cases but one, silicone sealants ranked higher than polyurethane and acrylic terpolymer sealants in overall durability to weathering at this test site location.

2.) In all cases, acetoxy silicone sealants ranked higher than all other sealants in overall durability at this test site location.

3.) In general, the silicone sealants performed the best of all sealant types in elastic recovery with instantaneous or near-instantaneous 100% rebound.

4.) In regards to the silicones, the 100% fumed silica filled products performed best in toughness. The polyurethane and acrylic products rated high in toughness also, but this was due to their high degree of hardness increase that occurred during this 40 year weathering study.

Conclusions Cont.:

Surface Appearance & Cleanability:

5.) With the exception of two single component polyurethane products, all sealant products evaluated in this study demonstrated the ability to maintain an adhesive bond to the painted aluminum substrate used in this study.

6.) Two polyurethane sealants and the acrylic sealant evidenced very little dirt pickup.

7.) The silicone products exhibited the most dirt pickup.

8.) The general overall surface condition of the silicone products was better than the non-silicone products.

9.) The low-modulus neutral cure silicone product showed a discolored surface that was not able to be restored back to the original sealant color by washing or cleaning.

10.) The low-modulus neutral cure silicone product exhibited numerous small surface pot-hole like cavities spread sporadically across the bead surfaces on both the glass and aluminum test panel assemblies. It is worthy of note that the glass and aluminum test panel assemblies were not located side-by-side but were separated by greater than 25 feet. No other sealants showed this phenomenon.

11.) Two of the 100% fumed silica filled silicones (one was originally black, the other clear/translucent) showed a similar white-ish surface discoloration that was not able to be restored back to the original sealant color by washing or cleaning.

References:

[1] **Bull, Errol D., Lucas, Gary M..** ***Long-Term Outdoor Weathering Study of Construction Sealants***. Published in ASTM STP48962S, ASTM International, West Conshohocken, PA, 2010. DOI: 10.1520/STP48962S.

[2] **Bull, Errol D., Lucas, Gary M..** ***30 Year Outdoor Weathering Study of Construction Sealants***. Published in ASTM STP158320140060, ASTM International, West Conshohocken, PA, 2014. DOI 10.1520/STP158320140060:.

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