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of
Acrylic Foam Structural
Glazing Tape Systems**

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Relating Artificial Weathering Testing to Service Life Estimation of Acrylic Foam Structural Glazing Tape Systems¹

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ABSTRACT: Structural adhesive bonding of exterior glass panels (structural glazing) is increasingly used in building construction because it affords designers greater architectural freedom than conventional mechanical fastening systems. There are now adhesive systems that have demonstrated their ability to effectively and reliably perform in long-term exterior applications. Conventional structural glazing methods of bonding glass panels to a metal frame have utilized either one-part or two-part structural silicone sealants. More recently beginning in 1990, select acrylic foam tapes have been successfully used in thousands of buildings globally as the bonding adhesive for this application. The design criteria for glass panel bonding applications require adhesive systems that maintain their functionality for greater than 20 years in actual field installations. Effective test methods are needed to evaluate the durability and develop service life estimations of these glass bonding adhesive materials. In principle, it is necessary to test to failure in order to do service life modeling. For systems designed for long-term durability, testing to failure can impose practical difficulties. This paper provides a basic overview of acrylic foam structural glazing tapes and the current laboratory weathering test procedures used to specify structural glazing bonding systems and will compare the stresses provided by these test protocols to those expected in example field applications.

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Introduction

Structural adhesive bonding systems are essential and commonplace in modern architectural designs of commercial building facades. They enable construction engineers to take the architect's vision and transform it from patterns on paper to a practical engineered reality.

Structural glazing is one prominent area where structural adhesives are playing a significant role in design of the commercial building facade. Structural glazing systems are increasingly used for attachment of exterior glass panels because they provide greater architectural design freedom than conventional mechanical fastening systems. With this comes the expectation that these curtain wall facades will stand the test of time. The design requirement for a glass curtainwall building facade is that the structurally bonded glass panels should have an effective service-life of at least 20 years. It was initially these long service life requirements that were cited for continuing to specify mechanical fastener systems. Those initial concerns about the strength and durability of structural adhesives for bonding exterior glass panels have largely been mitigated through more than 20 years of field experience around the world.

The first generation of structurally glazed commercial systems utilized liquid applied 1-part structural silicone sealants as the bonding agent. These adhesive sealants were relatively slow to reach full cure and build strength but they did demonstrate the expanded design possibilities. Following this, multi-component liquid applied silicone systems were developed to reduce cure time, raise ultimate bond strength and also increase production efficiency. The next adhesive bonding solution development for this application was acrylic foam structural glazing tapes. These are double-sided very high bond strength pressure sensitive adhesive tapes supplied in roll goods form. Structural glazing tapes apply easily and rapidly achieve ultimate structural strength

as the adhesive fully wets out the bonding surfaces. There is no cure time associated with the use these tapes which allows the fabricator immediate handling strength and considerable process benefits. These structural glazing bonding systems have demonstrated their ability to effectively and reliably perform in long-term exterior building applications for many years now. Success using adhesive systems in architectural structural glazing applications encourages designers and construction engineers to push for new capabilities in terms of increased productivity, reducing construction and maintenance costs and longer service-life performance.

The use, composition and performance of an acrylic foam structural glazing tape is significantly different than that of a conventional structural glazing tape also known as a spacer tape.

Conventional structural glazing tapes are employed in a structural glazing system to create a space between the glass and a typical metal glazing profile. The thickness of the structural silicone sealant is determined by the thickness of the conventional structural glazing tape. This tape keeps the space or face clearance constant during the curing of the liquid applied structural silicone sealant. It does not provide a structural bond of the glass to the glazing profile. The structural bond is provided by the structural silicone sealant once it is fully cured. Conventional structural glazing tapes are characterized by a foam core with a thin adhesive skin on two opposing sides. The only adhesive portion is the thin skin which contacts the glass and glazing profile. The internal foam strength of a conventional structural glazing tape is generally low as high strength is not required from this tape in this application.

Conversely, an acrylic foam structural glazing tape used in this application must assume the same bonding role of a structural silicone sealant as it replaces both the sealant and the

conventional structural glazing tape. That role is to adhesively bond the glass lite and transfer incidental windloads to the building facade structure. Acrylic foam structural glazing tapes are adhesive throughout their entire construction including the foam core. It is this unique construction that give acrylic foam structural glazing tape the strength and performance properties suitable to be used as the primary structural bond in a structural glazing system.

Figures 1 and 2 depict a typical glazing profile employing acrylic foam structural glazing tape.

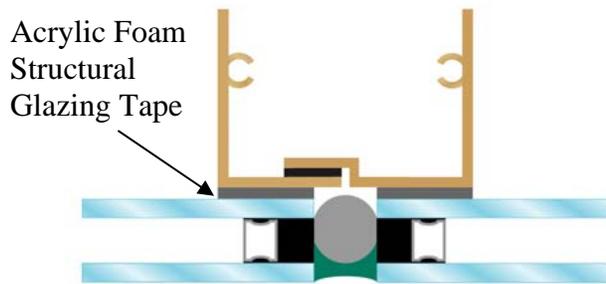


Figure 1: Vertical Split Mullion

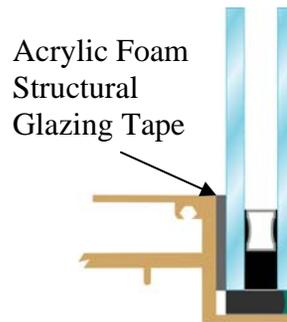


Figure 2: Horizontal Mullion

The construction materials industry continues to advance the state-of-the-technology by developing new and improved systems to meet the demands of designers and architectural engineers. As new materials are developed, effective test methods are necessary to evaluate their potential for long term durability in outdoor environments. The decisive quantitative measure of durability for any structural bond is “real time” time-to-failure in the actual end-use application and environment. For systems designed for very long-term durability, testing to failure does impose practical difficulties. However, there are also significant risks associated with not testing long enough to adequately estimate time-to-failure. The purpose of this paper is to provide an overview on the role of using artificial accelerated exposure testing to evaluate the durability potential of acrylic foam tape structural glazing systems compared to a structural silicone sealant. This paper will provide an overview of the existing artificial accelerated weathering test methods

and standard requirements for the durability of structural glazing bonding systems. The weathering stresses provided by those test protocols will be compared to those expected in model field applications. A comparative example will be used to highlight the requirements for artificial accelerated weathering testing of high durability materials.

Artificial Accelerated Weathering of Structural Glazing

The most commonly cited reference specification for structural glazing systems is ASTM C1184-05: Standard Specification for Structural Silicone Sealants [1]. It is currently the only technical specification published in the United States for this application. Therefore, although the scope of the specification states it is for “chemically curing elastomeric structural silicone sealants”, its requirements are regularly construed by users as applying to all types of structural adhesive glazing – for example, acrylic foam structural glazing tape which has been used in building construction since the early 1990’s. ASTM C1184-05 allows the use of two substantially different exposure conditions for establishing conformance to the weathering requirements. Exposure testing in either a fluorescent UV device or a xenon arc device with daylight filters is allowed. The specifics of the two sets of conditions are described in ASTM C1442-06: Standard Practice for Conducting Tests on Sealants Using Artificial Weathering Apparatus (Table 1) [2]. While ASTM Specification C1184-05 does note “test results may differ between the two types of tests”, it does not provide guidance regarding the potential magnitude of any differences nor how to choose the appropriate set of conditions. Since both sets of conditions are given equal weight in the specification, the user could reasonably expect the two sets of exposure conditions to be fundamentally equivalent.

Table 1: Summary of the Two Alternate Exposure Conditions prescribed in ASTM Specification C1184-05 for Artificial Weathering Exposure Testing of Structural Sealants

Apparatus	Exposure Parameters	
	Fluorescent UV/Condensation	Xenon Arc
Light source	UVA-340 lamp	Xenon Arc with daylight type filters
Irradiance at 340 nm (W/(m ² ·nm))	0.89	0.35 or 0.51
Uninsulated Black Panel Temperature (BPT)	60 °C	70 °C
Exposure cycle:		
Light	8 hrs	102 min light only/ 18 min light with wetting
No Light	4 hrs	--
Wetting	wetting by condensation during "No Light"; BPT 50 °C	wetting by front face water spray (or immersion)
Exposure Duration:		
Minimum Time	5000 hr*	--
Minimum Radiant Exposure @ 340 nm	--	9180 kJ/(m ² ·nm)

* Equivalent to 10,680 kJ/(m²·nm) @ 340 nm

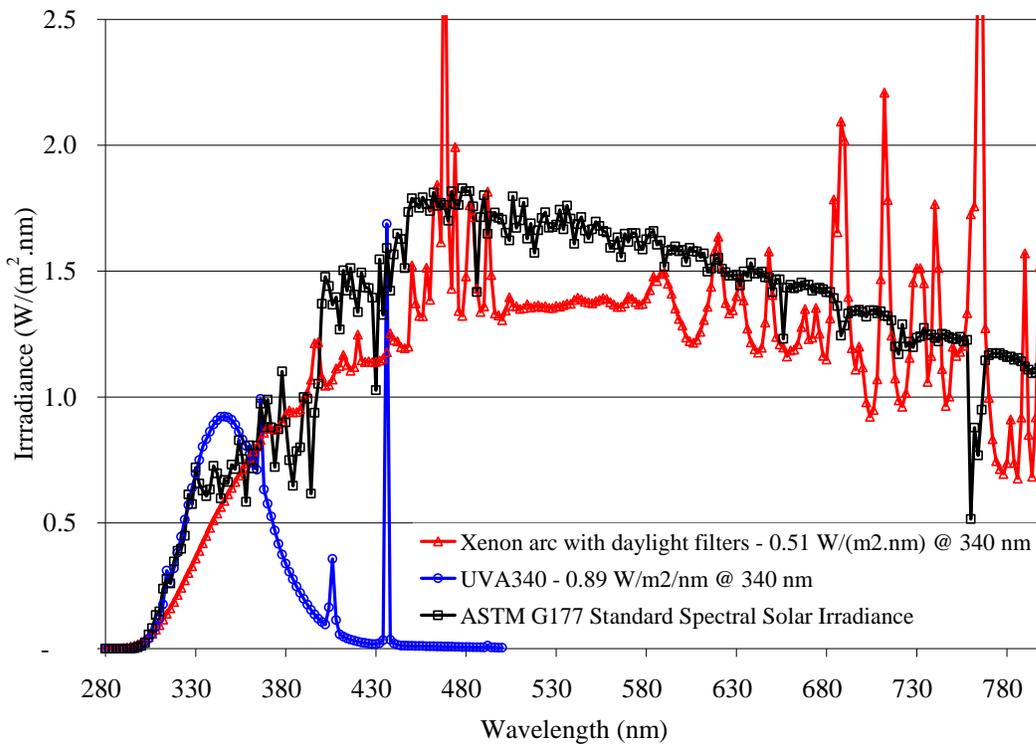


Figure 3: Comparison of Artificial Weathering Light Sources and Standard Spectral Solar Irradiance

Figure 3 illustrates major differences in irradiance between these two sets of conditions. The figure shows typical spectral irradiance of the light sources in the two types of weathering devices. The spectra are based on radiometric measurements of the light sources in the respective devices controlled at the required 340-nm irradiance set points. The filtered xenon arc spectrum shown is for an irradiance level of $0.51 \text{ W}/(\text{m}^2 \cdot \text{nm})$ at 340 nm, which is described in ASTM C1442 as representative of the solar irradiance sealants are exposed to in common outdoor benchmark exposure sites. A reference standard solar spectral distribution for natural sunlight is provided for comparison. This reference spectrum is based on ASTM G177 [3]

extended out to 800 nm using the SMARTS model [4]. The xenon arc with daylight filters provides a relatively good match to daylight across the spectrum from the solar cut-on at about 290 nm through the entire visible and near infrared regions. The fluorescent UVA-340 lamp, on the other hand, is primarily a narrow band ultraviolet source peaking at nominally 343 nm with essentially no radiation greater than 450 nm. Photodegradation of a polymeric material occurs when it absorbs sufficient energy to initiate degradation reactions. As a general rule, radiation with wavelengths in the ultraviolet (400 nm and below) provides sufficient energy to break covalent bonds holding the polymer together and initiate chemical reactions, such as oxidation and chain scission [5]. Figure 4 focuses on the irradiance distribution of the two light sources in the ultraviolet region. The plot shows the UVA-340 lamp is a very good simulation of solar ultraviolet from 300-330 nm while the xenon arc with daylight filters is a better match for wavelengths 340 nm and longer.

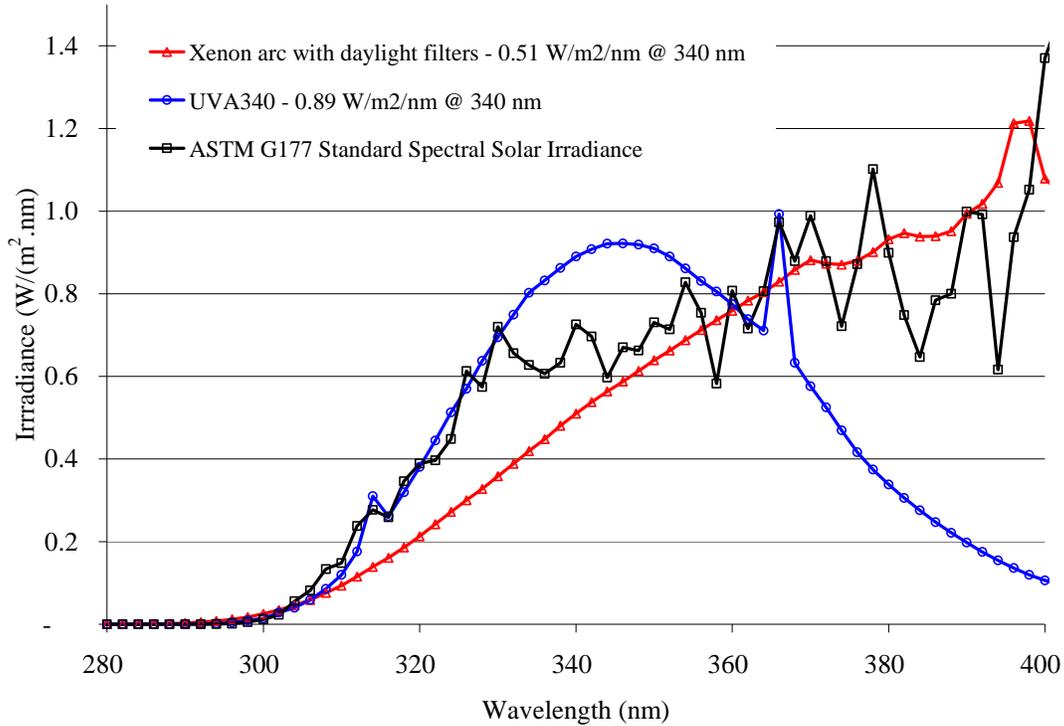


Figure 4: Comparison of Artificial Weathering Light Sources to Standard Spectral Solar Irradiance in the Ultraviolet

One can not directly compare the two alternate exposure conditions based strictly on 340-nm irradiance since the light the fluorescent UV apparatus is on for only 16 hrs out of any 24 hour period (67%). A comparison can be made in terms of radiant exposure (dosage). The fluorescent UV conditions outlined in ASTM C1184-05 requires a minimum exposure duration of 5000 hrs corresponding to a radiant dose of 10,680 kJ/(m²·nm) at 340 nm. The exposure requirement for the filtered xenon arc is a minimum radiant exposure of 9180 kJ/(m²·nm) at 340 nm and the user is allowed choices as to the irradiance level. Compared in this manner the fluorescent UV conditions provide a radiant exposure at 340 nm that is 16% higher than the xenon arc. However, in terms of total ultraviolet radiant exposure from 280-400 nm the xenon arc exposure provides nearly twice the dosage of the fluorescent UV - 1076 MJ versus 605 MJ,

respectively. In order for any ‘equivalency’ of the two exposures conditions allowed for in ASTM Specification C1184-05 to be generally valid, every structural glazing material would need to have the same relative spectral sensitivity to both radiation sources. While this requirement may be met by a material whose photodegradation is initiated by absorption in the 310-360 nm region, it is unlikely to be generally satisfied since many materials are also degraded by energy in spectral regions where the two sources have different emission characteristics.

The primary intent for running artificial exposures is to accelerate the degradation processes, so testing is almost always done at elevated temperatures to increase the reaction rate of those processes. In addition to spectral irradiance differences, there are differences in the temperature control points of the two exposure conditions. The fluorescent UV apparatus is run at a black panel temperature (BPT) of 60°C during the light phase and allowed to cool down to 50°C during the “No Light” condensation phase. These control temperatures are 10°C and 20°C cooler than the xenon arc device’s 70°C BPT set point, respectively. Also, there are differences in the amount and type of moisture in the two types of exposures. Moisture is provided by water spray or immersion in the xenon arc and by condensation in the fluorescent UV apparatus. Spectral irradiance, temperature and moisture all influence the results obtained in a given artificial exposure. In order to intelligently assess the impact of these stresses on the durability of any specific structural glazing system it is necessary to characterize the responses of that system.

Relationship between Weathering Stress in Artificial Exposures and Field Installations

As an initial starting point to relate artificial weathering results to the durability of a system in a real world location one can use the relative exposure stress to generate a rough first approximation. There are three primary environmental stresses relevant to weathering durability – radiation (light), heat and water. Table 2 shows average annual environmental statistics for a number of global locations. The data was extracted from Meteonorm version 6.0, a global meteorological reference database designed for solar energy applications, building design and environmental research [6]. The statistics for each location are based on climatological models derived from 30 years of temperature and humidity data and a 20-year measurement period for radiation. Meteonorm provides average total solar irradiance summed over the range from 250 to 3000 nm. To allow comparison with the exposure requirements of ASTM Specification C1184-05 in Table 1, we calculated average annual energy at 340 nm from the hourly Meteonorm irradiance values and sun height using the SMARTS Solar Spectrum Model [7]. The data in Table 2 represent the environmental stresses for a vertical surface facing the equator, which can serve as a model for the exterior surface of a glass curtain wall building. The table gives data for average annual solar energy dosage in $\text{kJ}/(\text{m}^2 \cdot \text{nm})$ at 340 nm, ambient temperatures and relative humidity for each location.

Table 2: Average Annual Radiant Energy Dose, Ambient Temperatures and Average Relative Humidity for model equatorial facing vertical exterior building surfaces as a function of location

City	Country	Average Annual Radiant Dose at 340 nm	Ambient Temperature (°C)				Relative Humidity	Time to a Radiant Dose of 9180 kJ/(m ² ·nm) at 340 nm
			T _{min}	T _{avg}	T _{max}	ΔT (max-min)		
		kJ/(m ² ·nm)						
Singapore		1532	15	28	41	26	86	6.0
Paris	France	1796	-6	12	37	43	79	5.1
Oslo	Norway	1956	-19	8	34	53	74	4.7
Tokyo	Japan	2053	-4	17	41	45	66	4.5
Guatemala	Guatemala	2334	6	20	36	30	75	3.9
Beijing	China	2360	-15	14	43	58	58	3.9
Miami, FL	USA	2380	13	26	42	29	74	3.9
New York, NY	USA	2381	-13	14	41	55	63	3.9
Barcelona	Spain	2382	1	17	40	40	68	3.9
Baghdad	Iraq	2634	-3	23	50	54	48	3.5
Minneapolis, MN	USA	2647	-30	8	41	71	70	3.5
Madrid	Spain	2694	-4	15	40	44	65	3.4
Los Angeles, CA	USA	2761	5	20	41	36	70	3.3
Phoenix, AZ	USA	3129	-3	25	49	52	38	2.9
Sao Paulo	Brazil	1991	9	20	37	28	78	4.6
Brasilia	Brazil	2383	10	23	39	29	69	3.9
Melbourne	Australia	2549	-1	16	37	38	69	3.6
Buenos Aires	Argentina	2618	1	19	38	37	73	3.5
Townsville	Australia	2673	11	26	42	31	66	3.4

Increasing temperature serves to accelerate polymer degradation. However, it is the solar actinic energy absorbed by the material that sets the degradation processes into motion. Using the data from Table 2 we can calculate a rough relationship between the radiant exposure required for conformance to ASTM C1184-05 and the average annual energy hitting the exterior glass surface of a model building at our example locations. While use of radiant dose alone is an oversimplification, it does give a rough idea of the magnitude of the accelerated test conditions relative to the real world. Dividing the average annual radiant dose at each location into the radiant exposure required in ASTM Specification C1184-05 yields the number of years approximated by the artificial weathering. In these examples we used the radiant dosage needed for exposure in a xenon arc device. For our limited set of model locations the outdoor exposure time represented by the 9180 kJ/m^2 artificial exposure is approximately equivalent to 3-6 years. This is only a fraction of the 20 year minimum service life expected of structural glazing. While degradation rates may vary depending on the composition of the structural glazing system, these results suggest testing to higher radiant exposures may be required.

Considerations for Artificial Weathering of High Durability Materials

Artificial weathering has not reached the state where accurate service life prediction of outdoor survival is possible. However, it can be used to provide a reliable estimate of the relative stability of one material to another of known performance (a control) when the two materials are exposed at the same time [10]. In order to quantify the durability of a material sufficiently well to make a judgment on its expected service-life, one needs to expose the material until failure has

occurred under a reasonably defined set of environmental stress conditions. The most common industry practice today is testing for a fixed time under fixed irradiance conditions. Durable materials by definition are those that can survive longer times or higher stress conditions before they fail. So, to push them to failure requires long test times, high test stresses or possibly both. This can be an issue for materials, like structural glazing systems, designed to provide sustained performance over the course of decades.

To illustrate the difficulty associated with taking structural glazing materials to failure we initiated a long term artificial weathering exposure study. The testing was conducted for research purposes. The test samples were chosen to represent different types of structural glazing systems. One was a commercial 2-part neutral-cure structural glazing silicone sealant designed for use in curtainwall production. Once cured, the adhesive bond can be warranted for 20 years. The other was a high performance double-coated pressure sensitive acrylic foam structural glazing tape also designed to attach glass to metal frames in glass curtain wall systems. Only one commercially available brand of 2-part structural silicone sealant glazing system was tested and only one commercially available brand of acrylic foam structural glazing tape (2.3 mm thickness) was tested. Manufacturer recommendations were followed for the application of each product and bonding of test substrates. The 2-part structural silicone sealant was black in color while the acrylic foam structural glazing tape was gray. Multiple replicate sets of test specimens were made up in the laboratory using each structural glazing product. The test specimens consisted of clear float glass (6.4 mm thick) bonded to black anodized aluminum with a 25.4 mm by 25.4 mm bonded area and 102 lineal mm of edge exposure. The 2-part structural glazing test specimens were fabricated in accordance with the requirements of ASTM C1184-05,

ASTM C1135-00 [11] and standard industry practices to achieve a 9.5 mm thick adhesive bond. The only variance was the bonded area was 25.4 mm by 25.4 mm rather than 50.8 mm by 12.7 mm. The substrates were first cleaned with isopropanol and water, and then allowed to dry before bonding. Afterwards the 2-part structural silicone sealant glazing test specimens were allowed to cure and condition for a minimum of 7 days at 21°C/50% RH prior to initial testing and exposure. The metal substrate used with the acrylic foam structural glazing tape test specimens was also cleaned with isopropyl alcohol and water and allowed to dry before bonding. The glass substrate was primed with a silane surface treatment (3-glycidoxypopyl trimethoxysilane) prior to bonding. The bonded acrylic foam structural glazing tape test specimens were conditioned for a 3 days at 21°C/50% RH prior to initial testing and exposure.

Both sets of test specimens were exposed in a rotating rack xenon arc weathering device under conditions similar to those described in Table 1. The only difference was that the device was operated at approximately 3 times the irradiance in Table 1 and greater than 1 W/(m²·nm) at 340 nm, which was possible through the use of a new type of daylight filter [12]. All the test specimens were exposed at the same time in the same device. Sets of replicate specimens were removed at regular intervals for measurement of the tensile adhesion properties of each structural glazing material according to ASTM Test Method C1135-00 using a rate of pull of 12.7 mm/min as required in ASTM Specification C1184-05. Figure 5 is a summary of the tensile results to date. The results are presented in terms of radiant exposure at 340 nm to allow comparisons with the requirements of ASTM C1184-05, which are also plotted for reference. Error bars represent ± 1 standard deviation around the mean of the specimens tested at each exposure interval.

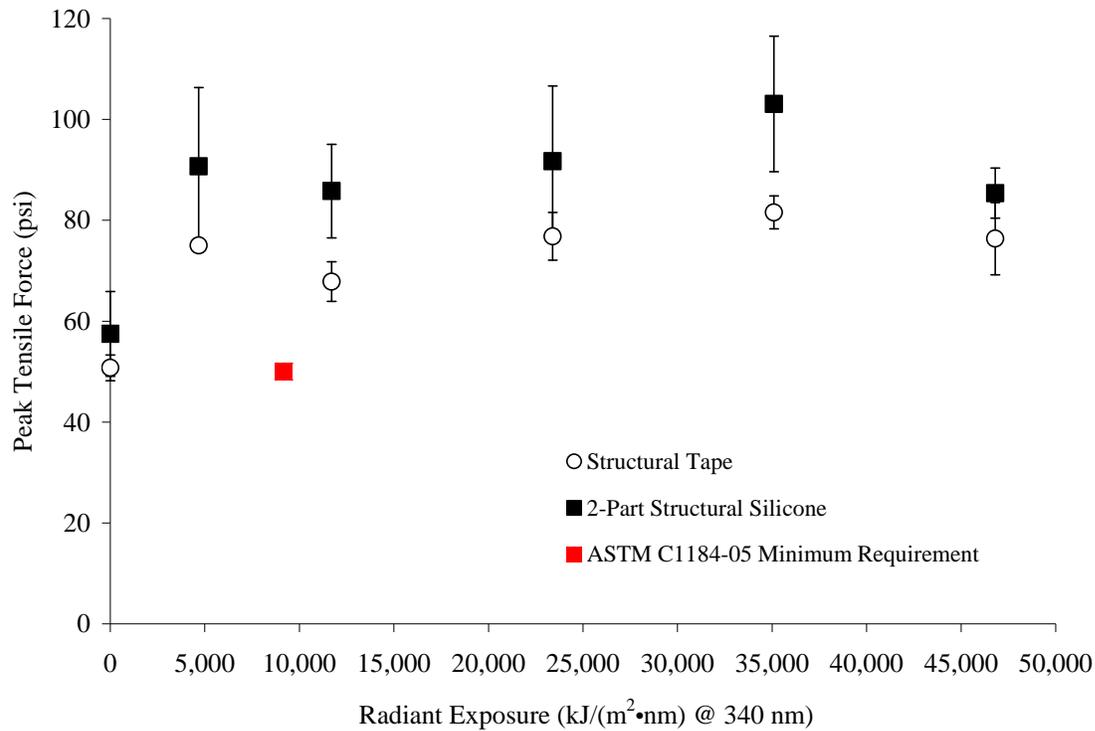


Figure 5: Tensile Strength (12.7 mm/min) after Artificial Weathering for Two Commercial Structural Glazing Systems as a function of Radiant Exposure

Test specimens have been exposed to a radiant dose of 46,800 kJ/(m²·nm) at 340 nm. This represents a total exposure 5 times greater than called for in ASTM Specification C1184-05. Using our example locations in Table 2 for reference this dosage is approximately equivalent to outdoor exposures of 15 years in Phoenix, 20 years in Guatemala City and 26 years in Paris. Other than an initial rise in the peak tensile values of both materials, the properties of neither system have changed substantially with exposure. The intent at the beginning of this experiment was to test the materials to failure. As time has gone on and the number of test specimens still under exposure has dwindled it is becoming doubtful we will be able to differentiate the durability of the two systems – acrylic foam structural glazing tape and 2-part structural silicone

sealant – at least based on tensile strength. While it has taken several years to amass these exposure durations, the fact that the samples do not appear to have degraded significantly gives confidence that the tensile strength service life for these structural glazing systems is on the order of 20 years or more.

Conclusions and Recommendations

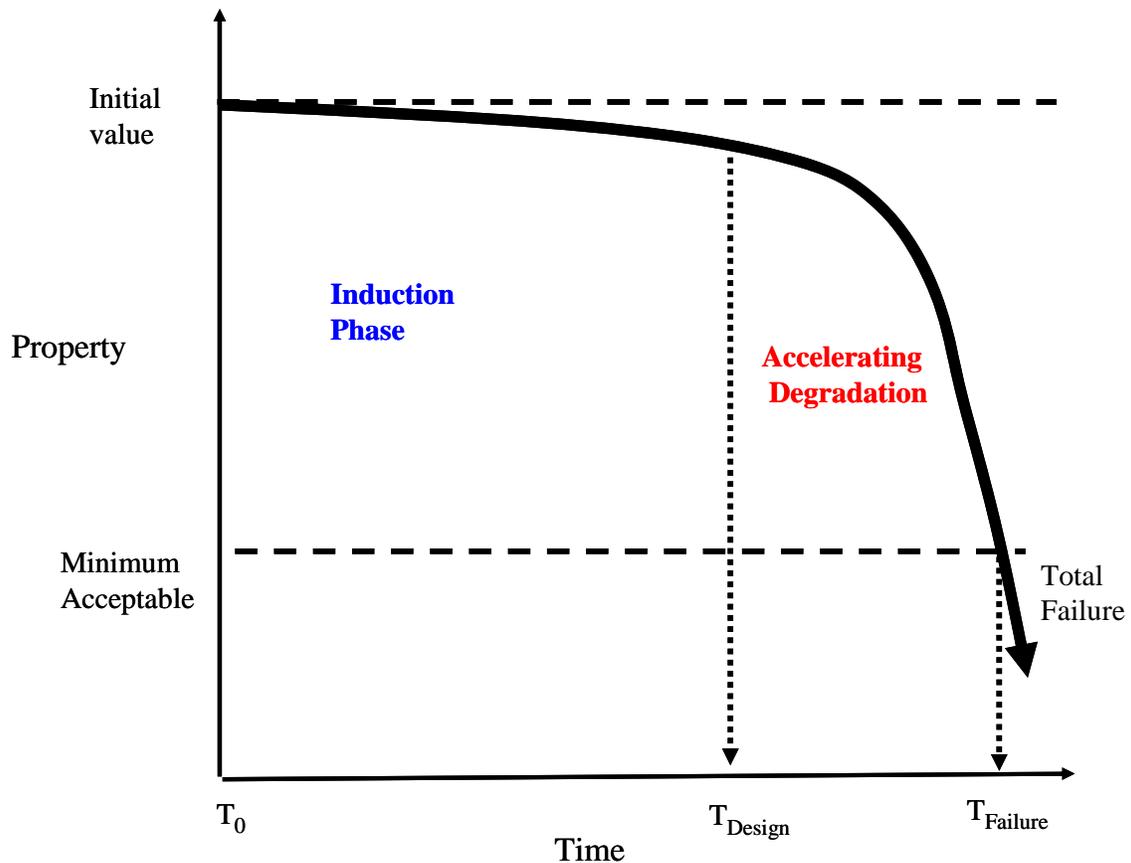


Figure 6: Schematic of the Classic S-shaped Degradation Curve

Structural adhesive glazing systems do provide building designers greater architectural freedom.

The systems available today – principally structural silicone sealants and high bond strength,

pressure sensitive acrylic foam structural glazing tape – have established track records for long term sustained performance. However, for the industry to develop new and improved systems – in terms of service life performance as well as reducing construction and repair costs – more relevant test methods are needed for evaluating their durability. The fundamental definition of durability is based on the total time at fixed stress, or total stress at fixed time, required for the critical properties of a material to degrade from an initial value to a defined minimum functional value. It is our experience that structural adhesives generally follow the classic S-shaped degradation curve (Figure 6). There is an initial induction period during which time the functional properties of the material change very little. This is followed by a period of accelerating degradation resulting eventually in total system failure, indicated as “ T_{Failure} ” in Figure 6. The time to T_{Failure} is the maximum functional life of the material, but typically not the design life used by construction engineers. For a structural bonding application, like structural glazing, the design life is normally based on when the properties of the system just begin to change appreciably indicated by T_{design} in the figure. This provides a margin of safety.

Our model calculations found the minimum total radiant exposure required by ASTM C1184-05 roughly equates to about 3 to 6 years of vertical exposure. These exposures are far less severe in terms of total radiant dosage than would be experienced over the course of the minimum 20-year design service life desired by construction engineers. There is a very high probability that the 9180 kJ/(m²·nm) at 340 nm exposure takes a relatively durable structural glazing material only into the “induction” phase. This may be sufficient to weed out very poor durability materials, but it would provide little information for estimating the long term service life of new systems, which at the end of the day is the parameter of interest to engineers. In order to realistically

estimate service life, one should expose specimens to stresses simulating long term exposure and test to failure. For structural glazing systems, testing to failure imposes practical difficulties. Much longer exposure durations will be required to reach exposures roughly comparable to the minimum 20-year effective service life target. One approach to reducing the total time required is by using higher irradiance exposures. This is the approach we took in our study of a structural silicone sealant and structural tape. To date, we have tested these two systems to a radiant exposure 5 times that required in ASTM C1184-05 and have not observed significant degradation in the tensile properties of either system. Longer duration and/or higher irradiance exposures may still not induce failure. However, they considerably increase the confidence a material will maintain its functional properties long term. Requiring more demanding exposure testing may be inconvenient, but it is necessary to minimize the potential risk of failure in use.

As stated up front, there is one technical specification available for structural glazing - ASTM C1184-05 – and it is limited in scope to structural silicone sealants. There are other viable and proven technologies for structural glazing. Lack of appropriate industry specifications has the potential for discouraging the use of alternate technologies and hindering development of new and improved structural bonding systems for this application. Serious consideration needs to be given to the development of a technology and material independent “performance-based” specification for structural glazing systems. This would encourage innovation within the industry. This new specification would focus on end-use requirements. There are several issues highlighted in this paper that should be considered in the development of this new “performance” specification. First, the specification should settle on a single set of exposure conditions for conducting the artificial accelerated weathering. This should include requiring a “daylight

spectrum” light source. A concept central to artificial weathering for purposes of assessing outdoor durability is that the artificial light source should provide a good approximation of daylight. Polymers often contain colored additives or produce colored degradation products that absorb into the visible and serve to catalyze further degradation.

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