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Performance of Structural Silicone and Acrylic Tape Subjected to High Speed Shear and Extreme Temperatures

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Abstract: Since the 1960's silicone rubber has been utilized as an adhesive to bond glass/glass and glass/metal constructions for facades; an assembly method known as *Structural Silicone Glazing* (SSG). More recently, an adhesive acrylic foam tape material has been promoted for the same use. SSG-type glazing systems transfer wind and other applied glazing loads, including those from seismic events, through the adhesive. Seismic events in particular, impose loads into glazing systems which far exceed strain rates used in standardized laboratory testing protocols and the behavior of these two materials under increased strain rates is interesting to consider for adhesively-bonded glazing designs in seismically-active regions.

This paper presents data generated utilizing shear specimens in which the geometry of the adhesive material in both specimen types was identical with the exception of thickness (the specimens were assembled in thickness by product type). The specimens were of 'Lap Shear' configuration and of length and thickness that mimic actual SSG designs. Specimens were tested to destruction at a standardized strain rate [ASTM; 50.8 mm/min (2 in/min)] and at two higher strain rate(s) in the range of those measured during high intensity seismic events with ground-based recording devices: 1100 mm/s (43 in/s) and 5000 mm/s (197 in/s). Comparisons are presented for a two-part structural silicone and one acrylic foam tape. Data is presented under freezing, elevated and ambient temperature conditions.

Keywords: SSG, structural silicone, seismic, acrylic tape, high strain rate, elastic, viscoelastic

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Introduction

The term *Structural Silicone* (SS) was coined in the mid 1960's when silicone rubber sealants were selected for use in glass mullion systems that emerged in the industry soon after the commercial implementation of the float glass process in 1959 [1]. Silicone sealants were chosen for this application due to performance characteristics which were not otherwise available with other sealant technologies at that time. Those properties were: demonstrated durable adhesive bonding to glass and finished metals, and superior long-term elastic behavior due to inherent resistance to degradation from ultraviolet exposure and the effects of natural weathering [2]. Some silicone sealant formulations of the era also possessed physical properties deemed sufficient to stiffen, make watertight and transfer loads between bonded glass and metal components of these systems. Soon thereafter, around 1970, the glass-to-metal bonding technique known today as *Structural Silicone Glazing* (SSG) emerged and took root. Over the past 40+ years SSG systems have demonstrated successful performance and have become a common method of construction from single-story office buildings to modern day mega towers exceeding 100 stories. SS sealants are supplied as a paste-like material (a viscous liquid) which are injected or introduced into a cavity of variable dimension where they subsequently transform, by curing, into solid rubber. In their cured form, SS products are considered to be an elastic material in their working range.

In more recent years [3], an acrylic foam tape (AFT) has been promoted as an alternate adhesive bonding material for SSG curtainwall construction. This material is comprised of a closed cell acrylic foam core with an acrylic adhesive applied to both sides. The tape is slit to various widths and has a nominal thickness 2.3 mm (0.09 in.) with a ±10% variance yielding a thickness range of 2.07 to 2.53 mm (0.081 to 0.1 in.). The AFT is considered to be viscoelastic and is supplied as a 'tape' in roll form with a plastic release liner for transport and storage. The AFT is applied to substrates by removing the plastic liner and applying pressure, at least 100 kPa (15 psi) in roll down or platen pressure, as the product is unrolled. One notable difference between SS and AFT is the elastic vs. viscoelastic characterization of these materials. Elastic materials strain when stressed and will return rapidly to their original shape and dimensions when the stress is removed. Viscoelastic materials exhibit a combination of both viscous and elastic behavior and return to shape much slower than elastic materials. In addition, viscoelastic materials show more time (strain rate) and temperature dependency [4], [5] and exhibit greater change under these conditions than the elastomers.

It is this fundamental difference - elastic vs. viscoelastic - that could be relevant for SSG systems that are subject to imposed loads that impart higher velocity strains, such as seismic events and in *Protective Glazing* applications [6], [7] and whilst considering the various climatic variations (hot climate, cold climate) of installed systems. In a previous study, Bull and Cholaky [8] discuss the response and favorable performance history of SS under a seismic event and provide stress-strain data of SS under deformation rates of higher velocity. Other studies have tested full-scale curtainwall mockups for seismic response, however these were only performed under ambient conditions [20], [21]. The intent of this paper was to investigate and compare the behavior of both materials over a realistic temperature range for SSG design considerations.

Temperature Considerations

Logic dictates that a material's property profile across the range of conditions that it can be expected to see in service should be taken into consideration during the design process.

Exposure to extended higher temperatures for example, in an installed application in Dubai, UAE in the summer season (June through September, with an average high around 40°C (104°F)), both materials will experience a softening of modulus with some strength reduction. On the other hand, in an installed application in Ulaanbaatar, Mongolia in its cold season (December through February, with a typical average low temperature of -26°C (-15°F)), both materials will experience a hardening of modulus with some strength increase. Keep in mind that these examples represent seasonal averages and do not account for higher or lower daily temperatures or extended spikes. They also do not account for surface temperatures which, in hot climates, can increase the actual bulk temperature of the SS where it may reach up to temperatures of 60-80°C (140-176°F), depending on system configuration as well as type of glazing (monolithic vs. insulating) and glass type (solar control low emissivity, or tinted glass).

For SSG applications, global standards development organizations have chosen upper and lower possible temperature extremes, considering both ambient as well as surface temperatures, that these materials should be tested to and able to withstand under normal conditions of use. ASTM International is a consensus-based standards development organization and Committee C24 on Building Seals and Sealants has deemed this range should be as low as -29°C (-20°F) and as high as 88°C (190°F). China's national standard GB16776 *Structural Silicone Sealants for Building* [9] mirrors the same temperature range as ASTM. The European standard ETAG 002 *Guideline For European Technical Approval For Structural Sealant Glazing Kits* [10] has established a slightly narrower range of -20°C (-4°F) to 80°C (176°F) but also suggests that local climatic conditions should be considered with the example given for -40°C (-40°F) for Nordic countries. The ASTM C1472 *Standard Guide for Calculating Movement and Other Effects When Establishing Sealant Joint Width* [11], ASTM C1401 *Standard Guide for Structural Sealant Glazing* [12], and ETAG 002 offer commentary on the rationale for these ranges.

It is expected that both the viscoelastic (acrylic) and elastomeric (silicone) materials will be more ductile at elevated temperatures and more brittle at low temperatures. Since the strain of the acrylic foam is dependent on viscoelasticity, it will see a greater change with temperature. Since both SS and AFT materials possess physical properties that will vary depending upon temperature it is interesting to compare the two technologies over these ranges. The test matrix decided upon for this paper considers the wider ASTM range discussed above since it encompasses the ETAG standard range (excepting the lower Nordic suggestion). In addition to the extremes, testing was performed at laboratory *Standard Conditions* [6] which the ASTM C24 committee currently defines as: relative humidity of 50 ± 10% at an air temperature of 23 ± 2°C (73.4 ± 3.6°F).

Test Program

A test program was devised to test both SS and AFT via laboratory test specimens in a shear configuration under the three temperature conditions aforementioned and at three strain rates; standardized (slow), and two faster rates. The standardized default test speed of 50.8 mm/min. (2 in./min.) is a common rate used in ASTM test methods under the jurisdiction of the C24 committee. The test matrix is summarized in Table 1**.**

The products tested were:

- **Structural Silicone** – GE SSG4600 two component, both black and grey color (SS)
- **Acrylic Foam Tape** – "Structural Glazing Tape", grey color (AFT)

Table 1 – Test Matrix

	Test Rate				
	0.00085 m/s (0.33 in./s)	1.1 m/s (44 in./s)	5 m/s (197 in./s)	# of specimens	
Structural Silicone, shear, ambient	5	5	5	15	Total SS = 45 specimens
Structural Silicone, shear, cold	5	5	5	15	
Structural Silicone, shear, hot	5	5	5	15	
Acrylic Foam Tape, shear, ambient	5	5	5	15	Total AFT = 45 specimens
Acrylic Foam Tape, shear, cold	5	5	5	15	
Acrylic Foam Tape, shear, hot	5	5	5	15	
Total number of specimens	30	30	30	90	

Test Specimens

The shear specimens were of 'Lap Shear' type and based on the configuration in ASTM C 961 *Standard Test Method for Lap Shear Strength of Sealants* [15]. The specimens were assembled to be of the same bonding area geometry of 25.4 mm long x 25.4 mm wide (comprising 1 inch square), with only the thickness of the two types differing (SS vs. AFT). The SS specimens were created with a thickness of 6.4 mm (0.25 in.) based on real-world common use as well as product manufacturer recommendation. The AFT specimens were 2.3 mm (0.09 in.) thick based on actual tape thickness. Aluminium plates with dimensions of 76.2 x 25.4 x 2.3 mm (3 x 1 x 0.09 inches) were used as the substrates. Half inch diameter holes were drilled through the plates for fixation into the testing apparatus. Aluminium finish was anodized for all specimens. All specimen surfaces to receive adhesive were prepared using an isopropyl alcohol solvent wipe. The AFT specimens were assembled utilizing primer as recommended by the AFT manufacturer's literature. Primer was not utilized for the SS sealant specimens. See Figure 1 for shear specimen configuration.

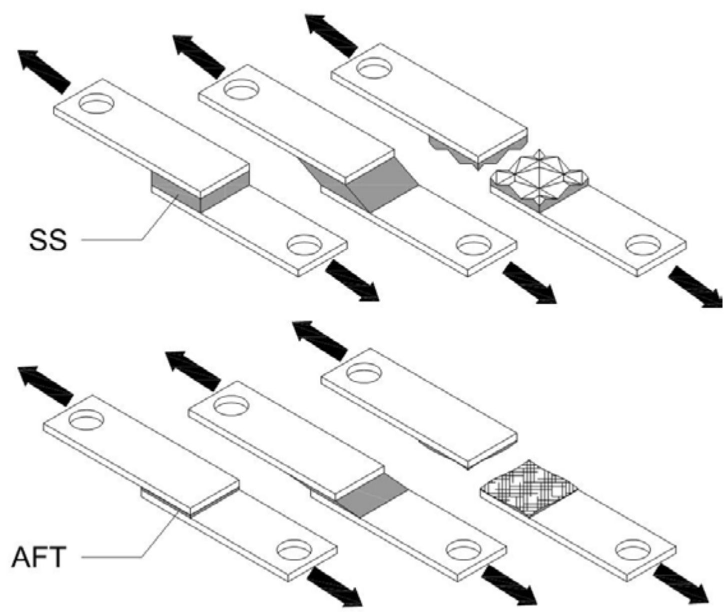

Figure 1: Shear Specimen Configuration

Results of Test Program and Discussion

Predictably, and as can be seen from the load-displacement curves (see appendix), the two materials repeat known patterns of behavior as can be found in various scientific textbooks [16] and previous published papers of similar nature [8], [17], [19]. Those patterns are:

- For elastomers - increasing load resistance and displacement (generally) with increase in rate.
- For viscoelastic materials – increasing load resistance but with decreasing displacement with increase in rate (exhibit ductility under slow rates tending to brittle under faster rates).

The differences in the strain behaviors of the acrylic foam and the silicone rubber at high rates can be explained by the molecular structure of the two polymer types. Acrylic is a thermoplastic, meaning that it is comprised of long intertwined polymer chains. When the acrylic is stressed at a low strain rate, the polymer chains have time to slip and reorient before tearing apart (Figure 2). This sliding behavior under stress is called viscoelasticity, which is both time and temperature dependent. At high strain rates, the polymer chains do not have time to reorient. Instead, they lock-up and break at lower displacements (Figure 3).

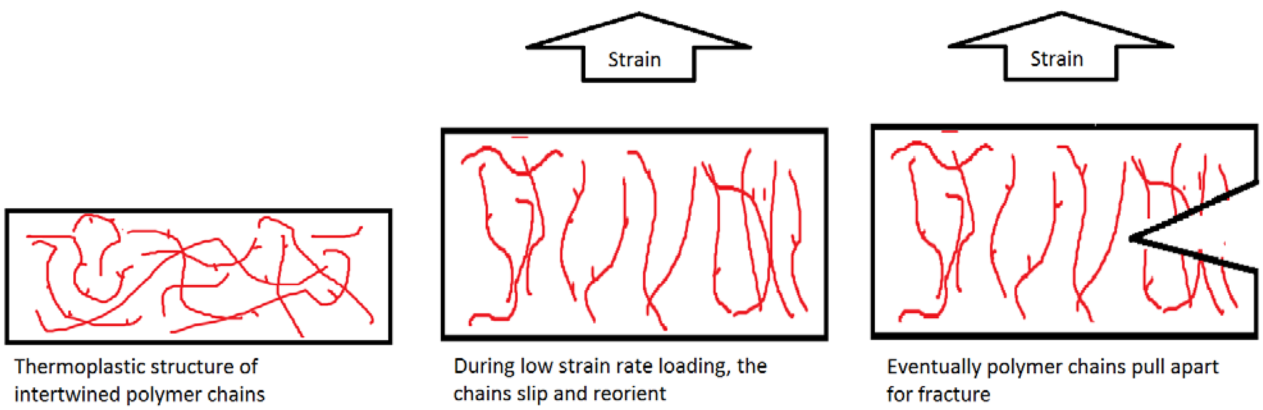

Figure 2: Diagram of a thermoplastic loaded at low strain rate tensile testing

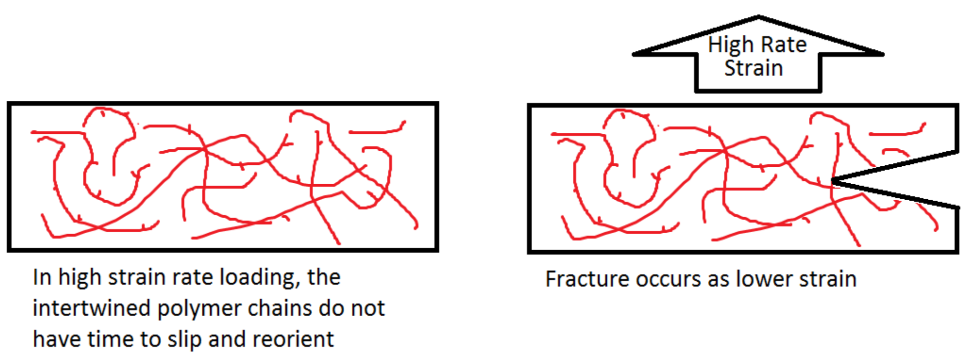

Figure 3: Diagram of a thermoplastic loaded at high strain rate tensile testing

In elastomers, such as silicone rubber, there is a degree of cross linking between the polymer chains. This cross linked structure allows the silicone to deform elastically a tremendous amount without the viscoelastic sliding of the polymer chains (Figure 4). The strain of elastomers is, therefore, less sensitive to strain rate.

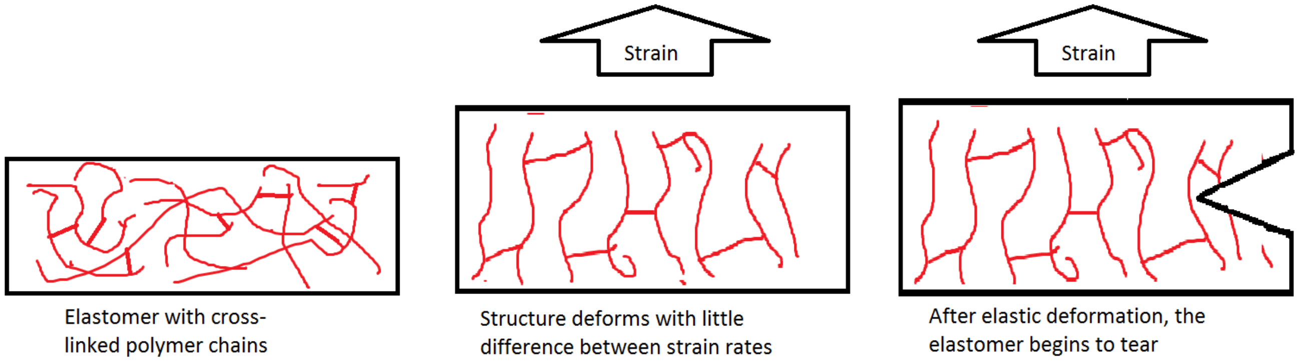

Figure 4: Diagram of an elastomer during tension testing

Results of Test Program – Test Data

Table 2, Table 3, and Table 4 tabulate the overall summary of the measured mechanical properties in shear when tested under ambient, hot and cold conditions respectively. Each data point represents the average of a minimum of five specimens. Data collected include the maximum load and the displacement at the maximum load at the target test rates. The measured test rates listed represent the average stroke rate across the test event. Failure modes for the tests are as noted in the summary tables as: AF = Adhesive failure, CF = Cohesive Failure, or some percentage thereof.

Table 2 – Measured Mechanical Properties Summary – Shear (AMBIENT)

Shear Tests – Ambient					
	Test Rate m/s		**Peak Load N (lb_f)**	**Displacement at Peak Load mm (in)**	**Failure Mode**
GE SSG4600 structural silicone	0.00085	Average	578 (130)	21.9 (0.861)	CF
		Std. Dev.	47 (11)	1.5 (0.057)	
		Coeff. Of Var [%]	8.2	6.7	
	1.1	Average	1160 (260)	26.1 (1.03)	CF
		Std. Dev.	50 (11)	1.3 (0.05)	
		Coeff. Of Var [%]	4.4	5.0	
	5	Average	1530 (343)	33.3 (1.31)	CF
		Std. Dev.	150 (34)	2.0 (0.08)	
		Coeff. Of Var [%]	9.8	6.1	
Acrylic foam tape	0.00085	Average	543 (122)	12.0 (0.471)	~50% AF
		Std. Dev.	28 (6)	0.4 (0.015)	
		Coeff. Of Var [%]	5.2	3.2	
	1.1	Average	3140 (707)	5.13 (0.202)	CF
		Std. Dev.	50 (12)	0.34 (0.013)	
		Coeff. Of Var [%]	1.7	6.6	
	5	Average	4320 (971)	6.91 (0.272)	CF
		Std. Dev.	130 (30)	0.77 (0.030)	
		Coeff. Of Var [%]	3.1	11.2	

Table 3 – Measured Mechanical Properties Summary – Shear (HOT)

Shear Tests – Hot					
	Test Rate m/s		**Peak Load N (lbf)**	**Displacement at Peak Load mm (in)**	**Failure Mode**
GE SSG4600 structural silicone	0.00085	Average	362 (81.5)	16.0 (0.630)	CF
		Std. Dev.	91 (20.4)	4.5 (0.178)	
		Coeff. Of Var [%]	25.0	28.3	
	1.1	Average	698 (157)	22.9 (0.902)	CF
		Std. Dev.	201 (45)	3.7 (0.145)	
		Coeff. Of Var [%]	28.7	16.1	
	5	Average	882 (198)	21.5 (0.846)	CF
		Std. Dev.	140 (32)	6.4 (0.250)	
		Coeff. Of Var [%]	15.9	29.6	
Acrylic foam tape	0.00085	Average	84.3 (19.0)	14.4 (0.565)	AF*
		Std. Dev.	16.8 (3.8)	1.8 (0.073)	
		Coeff. Of Var [%]	20.0	12.8	
	1.1	Average	537 (121)	10.3 (0.406)	~50% AF*
		Std. Dev.	86 (19)	0.3 (0.013)	
		Coeff. Of Var [%]	16.1	3.2	
	5	Average	861 (194)	5.63 (0.222)	~30% AF*, ~60% AF*, ~70% AF*, ~55% AF*
		Std. Dev.	119 (27)	1.89 (0.074)	
		Coeff. Of Var [%]	13.8	33.5	

Table 4 – Measured Mechanical Properties Summary – Shear (COLD)

Shear Tests – Cold					
	Test Rate m/s		**Peak Load N (lbf)**	**Displacement at Peak Load mm (in)**	**Failure Mode**
GE SSG4600 structural silicone	0.00085	Average	1190 (267)	26.9 (1.06)	CF
		Std. Dev.	100 (23)	1.6 (0.06)	
		Coeff. Of Var [%]	8.7	6.0	
	1.1	Average	1680 (378)	16.4 (0.648)	CF
		Std. Dev.	320 (72)	6.0 (0.236)	
		Coeff. Of Var [%]	19.0	36.4	
	5	Average	2210 (497)	19.1 (0.750)	CF
		Std. Dev.	330 (74)	4.3 (0.168)	
		Coeff. Of Var [%]	15.0	22.4	
Acrylic foam tape	0.00085	Average	2440 (548)	0.571 (0.0225)	~95% AF*, AF*, ~95% AF*, ~95% AF*, ~70% AF*
		Std. Dev.	450 (100)	0.397 (0.0156)	
		Coeff. Of Var [%]	18.3	69.5	
	1.1	Average	2000 (450)	1.25 (0.0494)	AF*, AF*, ~95% AF*, ~95% AF*, AF*
		Std. Dev.	240 (54)	0.11 (0.0043)	
		Coeff. Of Var [%]	12.0	8.7	
	5	Average	2460 (553)	1.39 (0.0548)	AF*, ~95% AF*, AF*, ~97% AF*, ~98% AF*
		Std. Dev.	350 (79)	0.45 (0.0176)	
		Coeff. Of Var [%]	14.3	32.1	

Results of Test Program – Test Rate versus Max Load

Figure 5 and Figure 6 show the response of SS and AFT (respectively) to the change in test rate and temperature as to maximum load. From the data and summary plots pertaining to load:

- Under ambient conditions, both products exhibited significant increases in maximum load with each increase in rate. The overall increase in load for the SS and the AFT was ~170 and 700% respectively.
- Under hot conditions, the SS exhibited increases in maximum load with each increase in rate. The overall increase in load was 145%.
- Under hot conditions, the AFT exhibited significant increases in maximum load with each increase in rate. The overall increase in load was 715%.
- Under cold conditions, the SS exhibited increases in maximum load with each increase in rate. The overall increase in load was 86%.
- Under cold conditions, the AFT behavior is more complicated showing no significant change with increase in rate (likely due to compete adhesion loss of AFT to substrates)

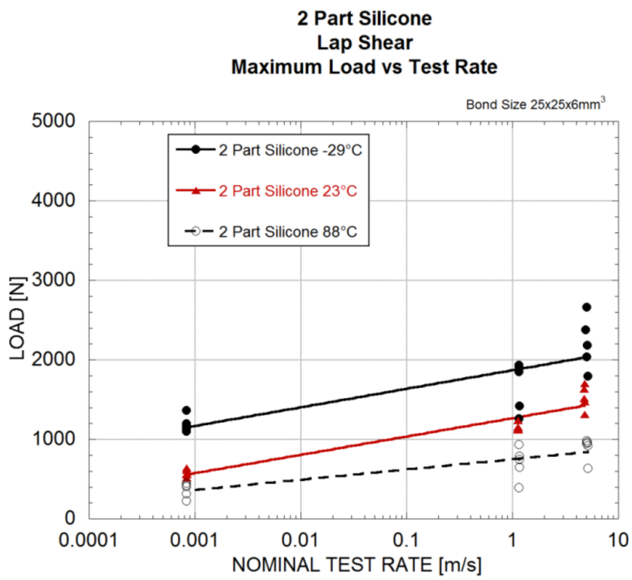

Figure 5: Maximum Load versus Test Rate - SS

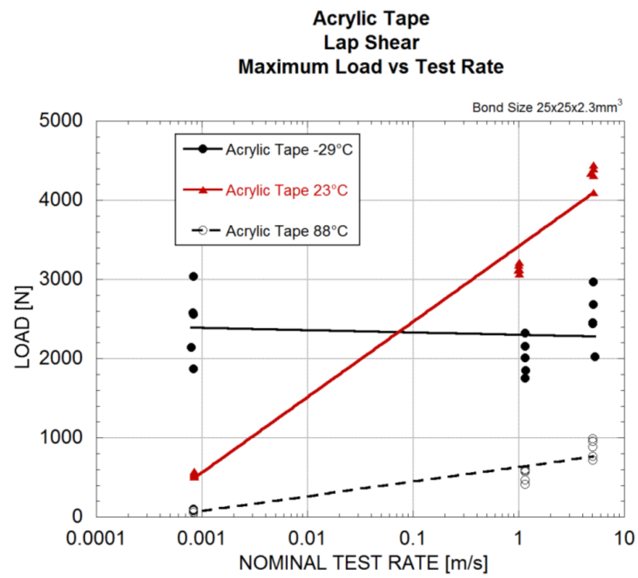

Figure 6: Maximum Load versus Test Rate - AFT

Results of Test Program – Test Rate versus Displacement at Peak Load

Figure 7 and Figure 8 show the response of SS and AFT (respectively) to the change in test rate and temperature as to displacement at peak load. From the data and summary plots pertaining to displacement:

- Under <u>ambient</u> conditions, the SS saw a significant increase in the displacement across rates, 52% overall.
- Under <u>ambient</u> conditions, the AFT had an overall decrease in displacement rates of -53%.
- Under <u>hot</u> conditions, the SS saw an increase in the displacement across rates, 41% overall.
- Under <u>hot</u> conditions, the AFT exhibited a significant decrease across rates, -63% overall.
- Under <u>cold</u> conditions, the SS shows slight decrease between the slow and faster rates, -29% overall.
- Under <u>cold</u> conditions, the AFT shows little change between rates (complete adhesion loss of AFT to substrates).

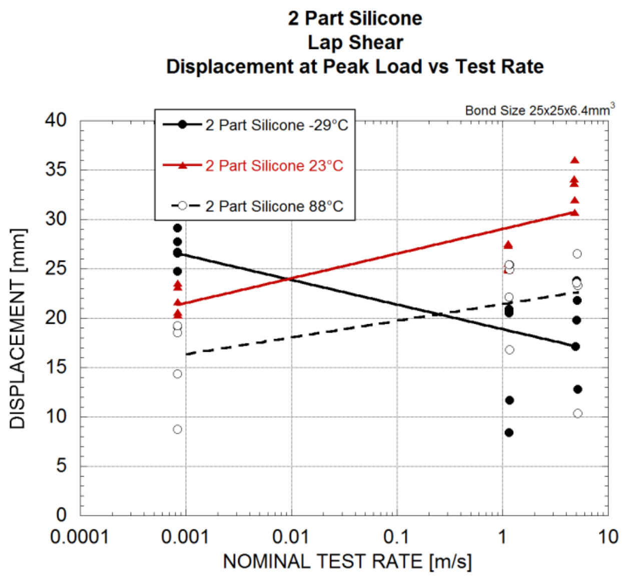

Figure 7: Test Rate versus Displacement at Peak Load - SS

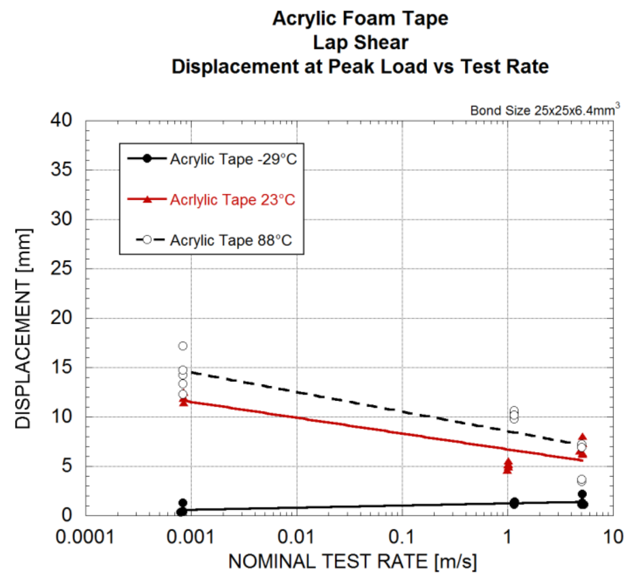

Figure 8: Test Rate versus Displacement at Peak Load - AFT

Results of Test Program – Energy Dissipation

Figure 9 compares the two materials in joules vs. rate change under the three tested conditions. The data shows that for the same size adhesive bond, the structural silicone demonstrates the highest overall capacity to dissipate or absorb imparted energy, across all conditions and rates when compared to the AFT. The AFT is especially sensitive to temperature as compared to the silicone under the ranges tested.

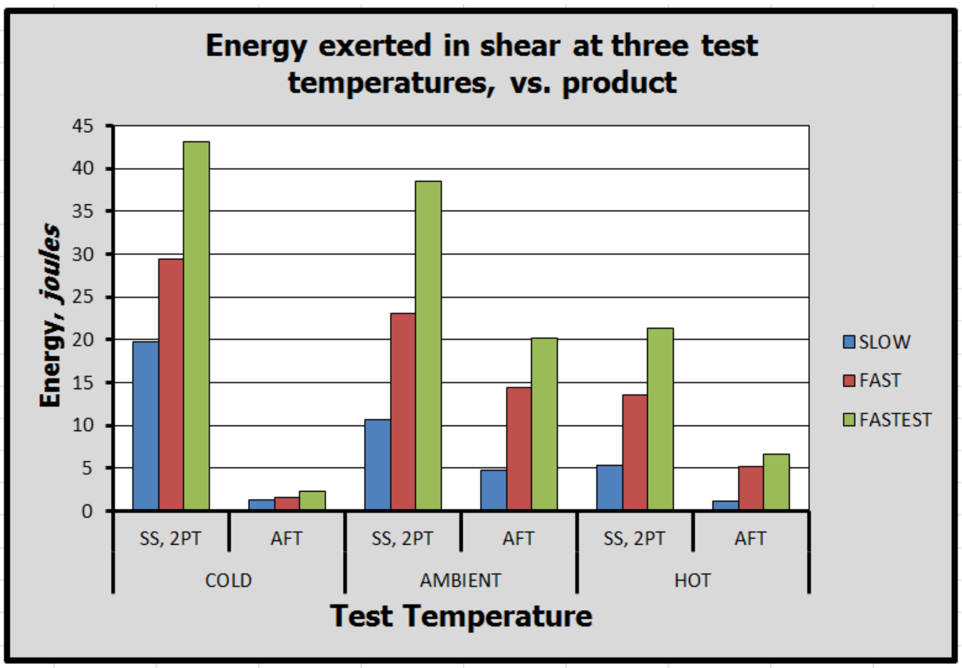

Figure 9: Energy Exerted vs. Rate Change vs. Temperature

In *Protective Glazing* applications [7], the adhesive utilized in the system engages to dissipate energy from imparted loads where a material's strength and elasticity contribute (in addition to its resistance to tearing). Another way then to compare the test data is to calculate the area under the load-displacement curves in terms of energy, summarized below in Figure 10 and Figure 11 in joules vs. displacement rate all for the same size adhesive bond. Here we see steeper increases in energy from lowest (AFT) to highest (SS) depending on rate. The silicone tested show favorable values under this comparison when compared to the AFT product.

Energy, or work performed, may be the most useful way to compare these materials because comparing the maximum load alone or the displacement alone does not complete the picture. As an example, while the AFT showed the highest overall increase in maximum load (700%), it also showed the greatest decrease in displacement (-77%). So it got increasingly strong as rate increased, but fractured sooner; thus combined, AFT shows lower overall capacity than the SS to dissipate or absorb imparted energy under the tested rates. This can be easily visualized when comparing load-displacement curves; see appendix.

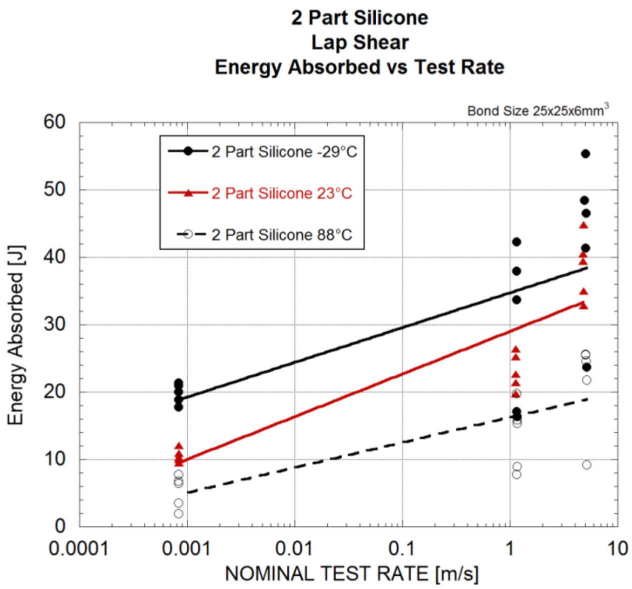

Figure 10: Energy Exerted vs. Rate Change, SS

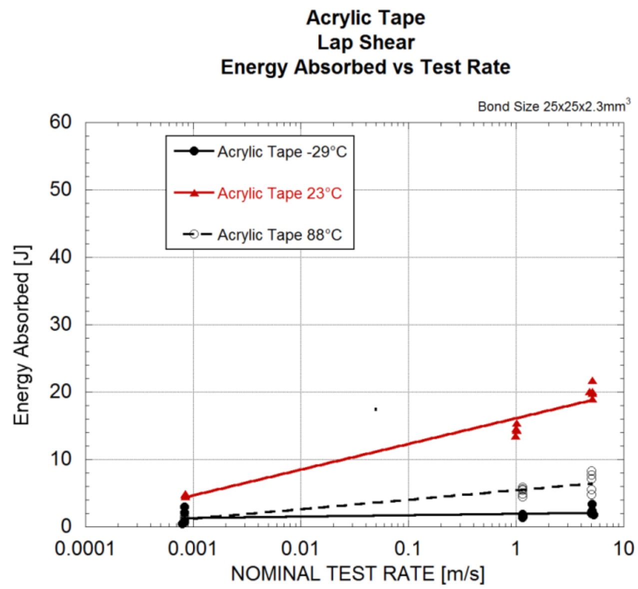

Figure 11: Energy Exerted vs. Rate Change, AFT

Results of Test Program – Adhesion Performance

As it related to adhesion, the two materials did show notable differences under the three tested rates and temperature conditions. From the data pertaining to adhesion:

- Under <u>all three</u> conditions (hot, cold & ambient) for the SS, adhesion was not affected across the rates with all specimens failing cohesively. Note: substrates were not primed.
- Under <u>ambient</u> conditions, the AFT adhesion was affected on the slowest rate with all specimens failing 50/50; roughly half adhesive failure and half cohesive failure. See Figure 12. At the two higher rates adhesion was not affected with all specimens failing cohesively. Substrates were primed according to manufacturer's literature recommendation.

- Under hot conditions, the failure mode of AFT under the slow strain rate was adhesive. See Figure 13. Under the faster rates the mode was mixed ~50/50 adhesive/cohesive. See Figure 14. At all rates, a certain percentage of a transparent tacky layer remained on the aluminium substrate; it is believed that the pressure sensitive adhesive (PSA) released from the foam core material.
- Under cold conditions, the failure mode of AFT under the all rates was adhesive. See Figure 15. At all rates, a certain percentage of a transparent tacky layer remained on the aluminium substrate; it is believed that the pressure sensitive adhesive (PSA) released from the foam core material.

Figure 12: Failure Mode of AFT in shear at slowest rate (AMBIENT)

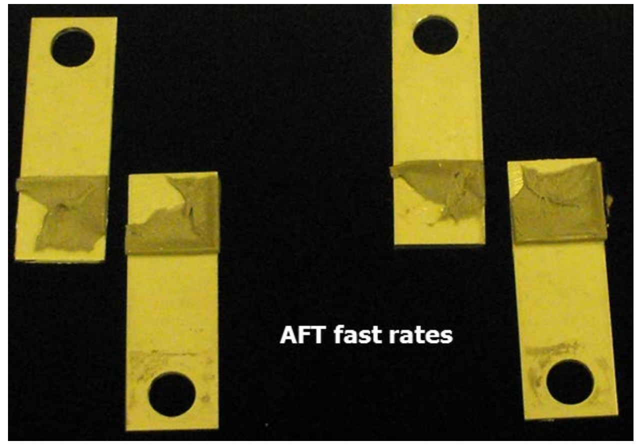

Figure 14: Failure Mode of AFT in shear at fast rates (HOT)

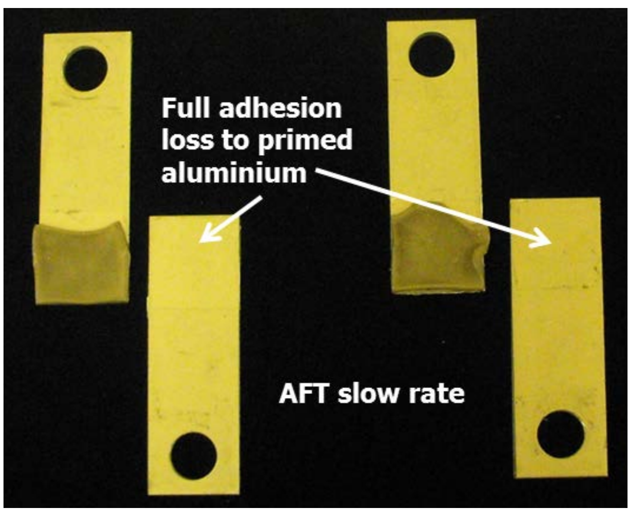

Figure 13: Failure Mode of AFT in shear at slowest rate (HOT)

Figure 15: Failure Mode of AFT in shear (COLD)

Summary and Conclusions

1. **Regarding elastic vs. viscoelastic behavior;** it was expected that the viscoelastic acrylic foam tape would have a greater sensitivity to test rate and temperature whereas the elastomeric structural silicone was expected to be sensitive to rate and temperature, but to a lesser degree. This test program verified these concepts.
    a. With regard to **rate sensitivity**, testing revealed that the AFT was indeed sensitive to strain rate. It demonstrated decreasing maximum strain and increasing strength with increasing test rate for the ambient tensile and shear tests and the hot shear tests. The AFT did not follow the expected trend for the cold shear tests and had a flat response with respect to change in rate. The SS had the trend of increasing strength with test rate for all temperatures. It had increasing maximum strain with increasing test rate for the ambient and hot tests, but decreasing strain with increasing test rate in the cold condition. The AFT showed greater sensitivity to strain rate, for example having an increase in strength of 700% from lowest to highest test speed for the lap shear tests at ambient conditions. In comparison, the SS was less sensitive, having a 170% increase in strength from the lowest to highest test speed for the lap shear tests at ambient conditions.
2. **Regarding thermal stability;** in this test program the mechanical properties of the structural silicones tested showed less sensitivity to temperature as compared to the acrylic foam tape. The SS followed the expected trend of increasing strength and energy absorbed with decreasing temperature. In comparison, the acrylic foam tape showed notable sensitivity to the temperature extremes. At the lowest test speed, the AFT showed an increase in strength with decreasing temperature; however at higher test speeds the strength was lower at both hot and cold conditions (likely due to the adhesion failure of the AFT under these conditions). The AFT had significant declines in energy absorbed at hot and cold conditions.
3. **Regarding the ability to absorb (dissipate) imparted energy under shear;** in this test program the structural silicone tested demonstrated the capability to absorb more energy than the acrylic foam tape at each condition of temperature and rate tested.
4. **Regarding adhesion;** in this test program the structural silicone tested demonstrated superior ability to remain adhered vs. the acrylic foam tape over all three test temperatures and rates. Notably, the acrylic foam tape lost adhesion on numerous specimens tested at the temperature extremes, in some cases completely.
5. **Regarding integrity;** on numerous tested AFT specimens it was observed that a certain percentage of a transparent tacky layer remained on the aluminium substrate. This is believed to be the pressure sensitive adhesive (PSA) which had released from the foam core material suggesting that there are limits to the integrity of the composite (closed cell acrylic foam core with an acrylic adhesive applied to both sides) when subjected to the conditions in this test program.

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References

[1] Pilkington, L., "Review Lecture. The Float Glass Process", *Proceedings of the Royal Society A*, Published 16 December 1969, doi:10.1098/rspa.1969.0212, Proc. R. Soc. Lond. A, 16 December 1969, vol. 314 no. 1516 1-25. http://rspa.royalsocietypublishing.org/

[2] Bull, E., Lucas, G., "Long-Term Outdoor Weathering Study of Construction Sealants", *Journal of ASTM International*, Vol. 6, No. 4, Paper ID: JAI101946, www.astm.org

[3] "Acrylic Foam Structural Glazing Tape: A New Bonding Alternative", *Advertorial course provided by 3M*, May 2007, http://continuingeducation.construction.com/article.php?L=21&C=222&P=1

[4] Townsend, B.W., Ohanehi, D.C., Dillard, DA, Austin, S.R., Salmon, F., Gagnon, D.R., "Characterizing acrylic foam pressure sensitive adhesive tapes for structural glazing applications—part I: DMA and ramp-to-fail results". *International Journal of Adhesion & Adhesives*, doi:10.1016/j.ijadhadh.2011.06.017

[5] Townsend, B.W., Ohanehi, D.C., Dillard, DA, Austin, S.R., Salmon, F., Gagnon, D.R., "Characterizing acrylic foam pressure sensitive adhesive tapes for structural glazing applications—part II: Creep rupture results". *International Journal of Adhesion & Adhesives*, doi:10.1016/j.ijadhadh.2011.06.018

[6] ASTM C717-14 *Standard Terminology of Building Seals and Sealants*, www.astm.org

[7] ASTM C1564-04(2009) *Standard Guide for Use of Silicone Sealants for Protective Glazing Systems*, www.astm.org

[8] Bull, E., Cholaky, J., "A Review of the Behavior of Structural Silicone Glazing Systems Subjected to a Mega-Earthquake", *Journal of ASTM International*, Vol. 9, No. 5, Paper ID: JAI104151, www.astm.org

[9] China's National Standard – GB16776 *Structural Silicone Sealants for Building*.

[10] *Guideline For European Technical Approval For Structural Sealant Glazing Kits (ETAG 002), Part 1: Supported And Unsupported Systems*, 3rd amendment, May 2012, Section 4.4 Safety in Use and 4.4.4.1 Effect of Temperature. http://www.ue.itb.pl/files/ue/etag/etag_002.pdf

[11] ASTM C1472-10 *Standard Guide for Calculating Movement and Other Effects When Establishing Sealant Joint Width*, www.astm.org

[12] ASTM C1401-09a *Standard Guide for Structural Sealant Glazing*, www.astm.org

[13] ASTM C1135-00(2011) *Standard Test Method for Determining the Tensile Adhesion Properties of Structural Sealants*, www.astm.org

[14] ASTM C1184-13 *Standard Specification for Structural Silicone Sealants,* www.astm.org

[15] ASTM C961-06(2011) *Standard Test Method for Lap Shear Strength of Sealants,* www.astm.org

[16] Askeland, D., "*The Science and Engineering of Materials*", 3rd ed. PWS Publishing Company, Boston, ©. 1994 pp. 467-515

[17] Karpati, K.K., "Mechanical Properties of Sealants: II. Behavior of a Silicone Sealant as a Function of Rate of Movement", *Journal of Paint Technology*, Vol. 44, No. 569, June 1972, p. 58-66

[18] Salisbury, C., Garmendia, I.U., Worswick, M., "High Rate Deformation of VHB Tapes", University of Waterloo; Department of Mechanical Engineering, Nov. 2007; http://solutions.3m.com/wps/portal/3M/en_US/Adhesives/Tapes/Industries/Architechure/VHB/

[19] Memari, A., Hartman, K., and Kremer, P. (2011) Racking Test Evaluation of Unitized Curtain Wall Systems Using Glazing Tapes. AEI 2011: pp. 148-155. http://dx.doi.org/10.1061/41168(399)18

[20] Traduction of Dictuc Report N^{o} 869240: "Crystal Curtain Walls Modules Adhered to Aluminium Profiles by Means of 3M Adhesive Tape Cyclic Shear Test and Monotonic Emptying Test, January 13, 2010". 28/12/2010. Rev. 0 http://solutions.3m.com/wps/portal/3M/en_US/Adhesives/Tapes/Industries/Architechure/VHB/

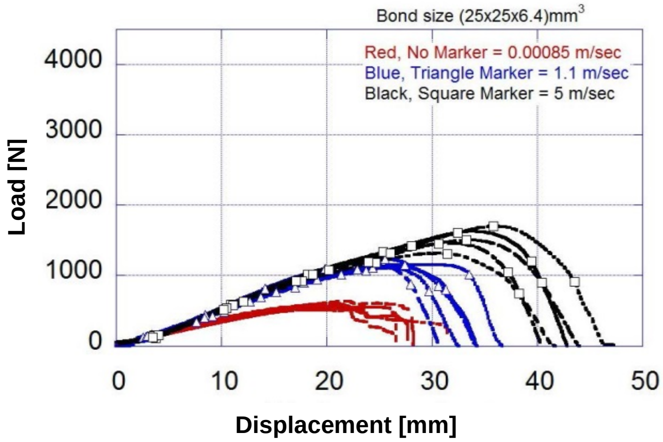
Appendix

Load-Displacement curves

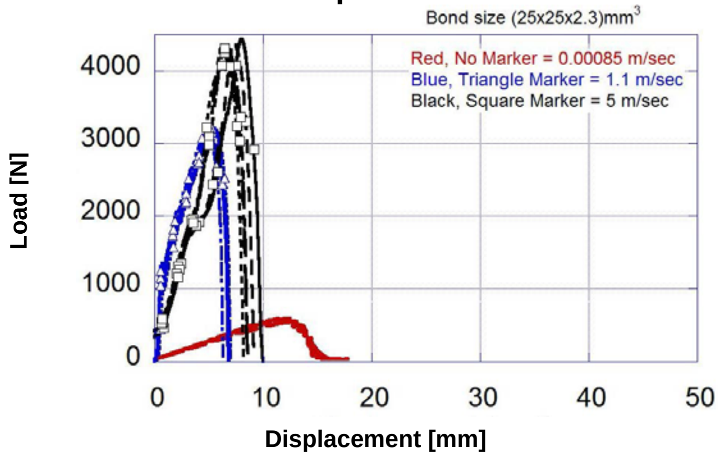
Structural Silicone and Acrylic Foam Tape

Ambient – Hot - Cold

GE SSG4600
Lap Shear



Acrylic Foam Tape
Lap Shear



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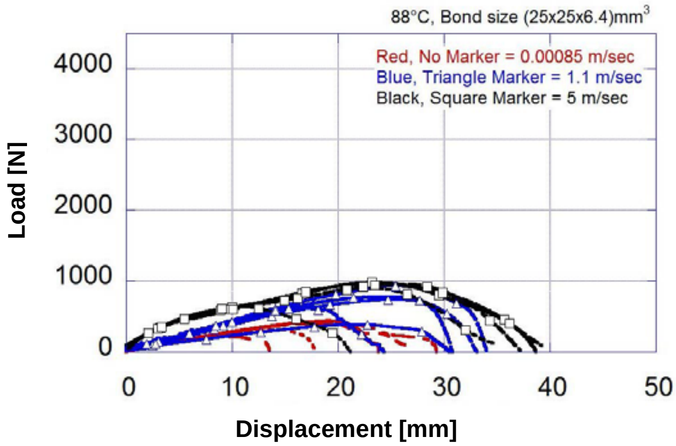
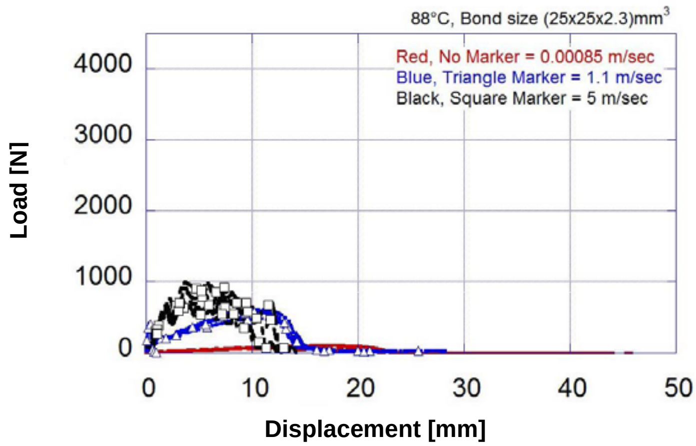
Lap Shear



Acrylic Foam Tape
Lap Shear



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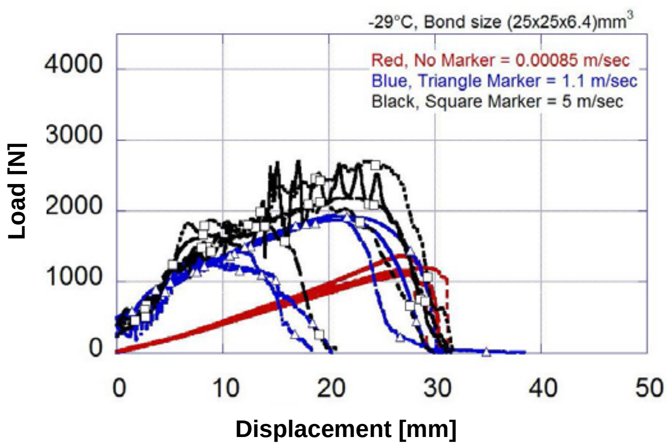
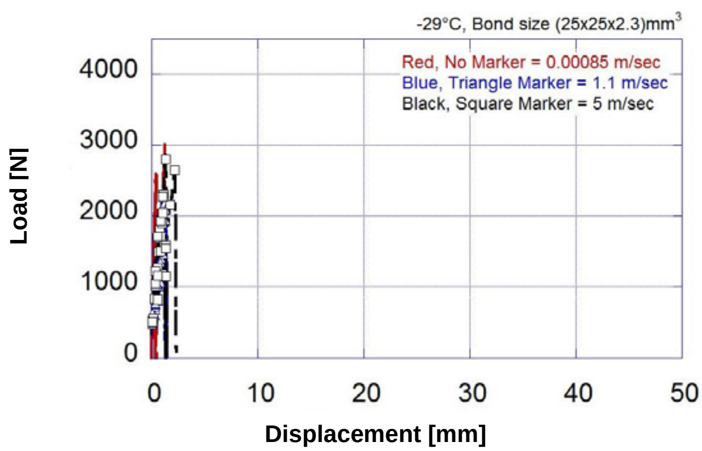
Lap Shear



Acrylic Foam Tape
Lap Shear



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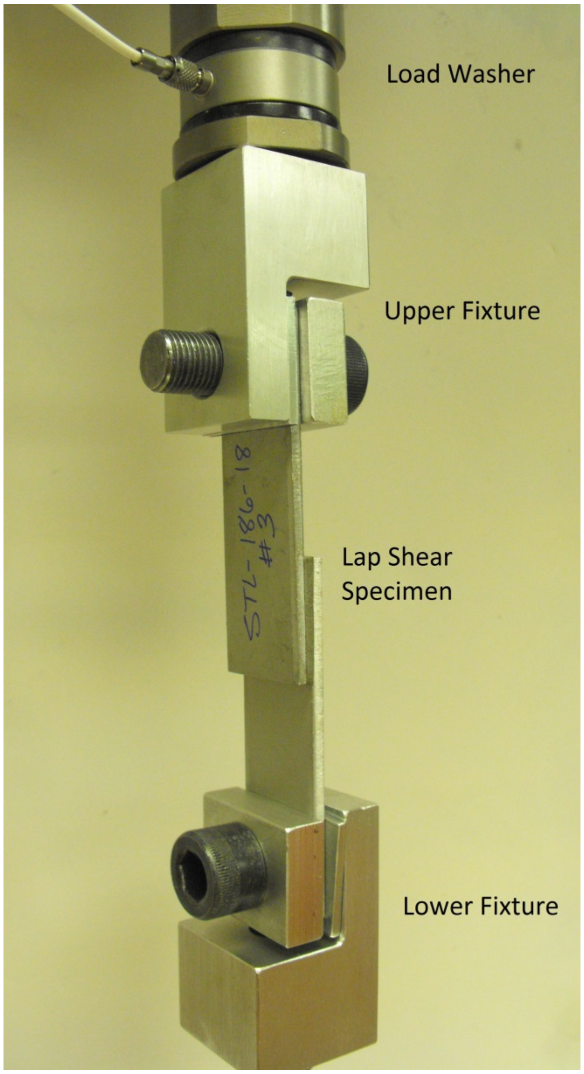

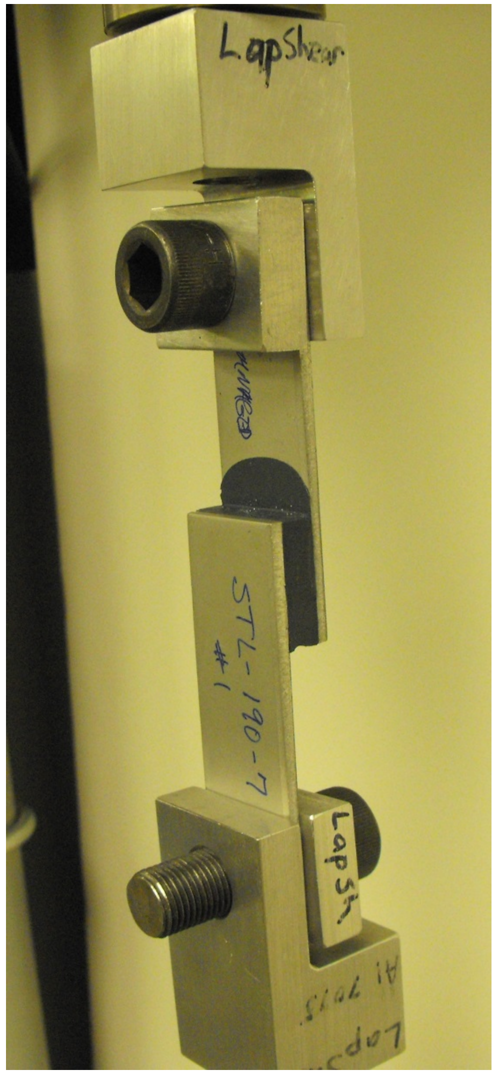

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