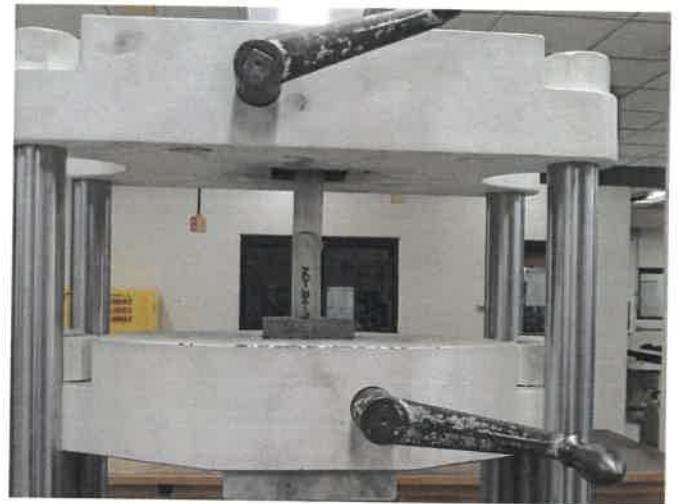


Adhesive Testing

Conducted for

FreMarq Innovations, Inc



March 27, 2019

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Project Background:

FreMarq Innovations is developing a line of commercial windows utilizing new materials and construction techniques. As part of this development process, testing of various components of the windows is necessary to ensure performance of the final product. FreMarq contacted the UW-Stout Manufacturing Outreach Center (MOC) with their needs for testing. This report outlines the test procedures used and summarizes the test results.

Test Procedure:

Test methods ASTM D897-08 (for tension loading) and ASTM D1002-10 (for shear loading) were used as references.

Testing was conducted on a Tinius Olsen, model 602 hydraulic universal testing machine, with a 60,000 pound load capacity. A cross-shaped test specimen design was used for testing the adhesives in tension, and an in-line lap test specimen design was used for testing in a shear mode. The bonded area for the cross-shaped specimens was 1" x 1", and the bonded area for the in-line lap-shear specimens was 1/2" x 1". Testing temperature was 68 degrees Fahrenheit.

Here we see:

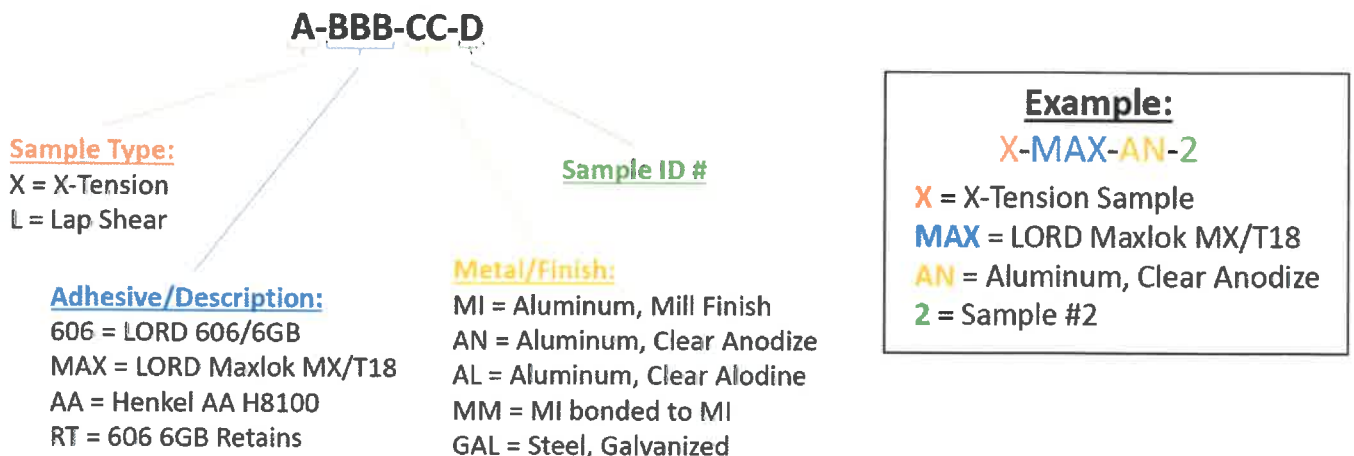
Cross-shaped specimens (left) and in-line lap-shear specimens (right) before and after testing.



List of Samples:

Adhesive/ Sample Description	Lap Shear		X-Tension	
	Sample Names	Qty.	Sample Names	Qty.
LORD 606/6GB	L-606-MI-#	6	X-606-MI-#	6
	L-606-AN-#	6	X-606-AN-#	6
	L-606-AL-#	6	X-606-AL-#	6
	L-606-MM-#	3	X-606-MM-#	3
LORD Maxlok MX/T18	L-MAX-MI-#	6	X-MAX-MI-#	6
	L-MAX-AN-#	6	X-MAX-AN-#	6
	L-MAX-AL-#	6	X-MAX-AL-#	6
	L-MAX-MM-#	3	X-MAX-MM-#	3
Henkel AA H8100	L-AA-MI-#	6	X-AA-MI-#	6
	L-AA-AN-#	6	X-AA-AN-#	6
	L-AA-AL-#	6	X-AA-AL-#	6
	L-AA-MM-#	3	X-AA-MM-#	3
Retains from Previous	L-RT-MI-#	6	X-RT-MI-#	6
	L-RT-GAL-#	6	X-RT-GAL-#	6
Samples for Setup	N/A	7	N/A	7
	Total	82	Total	82

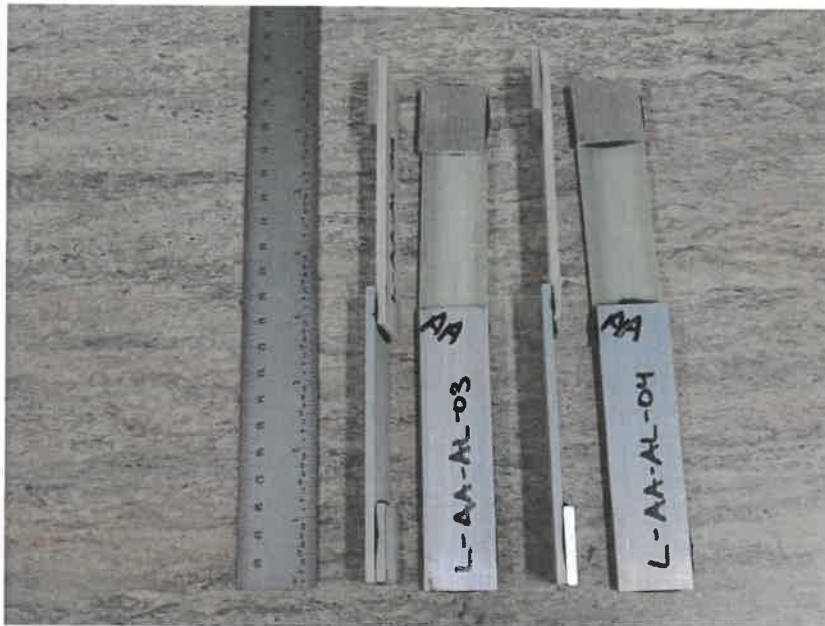
Naming Convention



Test Procedure continued:

For testing in shear, samples were loaded into standard wedge-action grips to keep the specimens in line with the force being applied by the test frame. Adhesive squeeze-out was not an issue, as it occurred away from the area where the specimens were gripped. Manual force on the pinion gears of the grips was necessary to get the grips to hold at the low initial loads for the test.

Lap shear samples showing the construction used to align the shear force with the bonded area.



Lap shear sample loaded into the wedge-action grips. Manual handles for the pinion gears of the grips are visible as well.



Test Procedure continued:

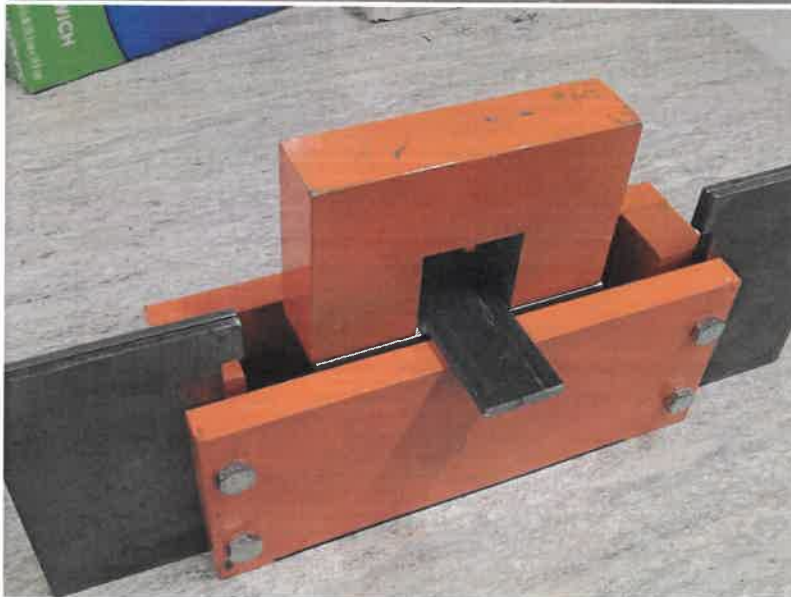
For testing in tension, cross-bar samples were loaded into a custom made fixture to keep the specimens normal to the force being applied by the test frame. The squeeze-out of adhesive required the use of some additional spacers to prevent the hardened adhesive from interfering with the test results. Spacing between the supports of the upper and lower test fixtures were 1.26" and 1.27" respectively for all tests.

Here, we see:

A cross-bar specimen loaded into the fixture, ready to test. (top photo).

Another cross-bar specimen in the fixture before testing. (bottom photo).

A typical cross-bar specimen with adhesive squeeze out showing on left side. (right photo)



All cross bar specimens tested
in tension on 3-15-2019



Test Procedure continued:

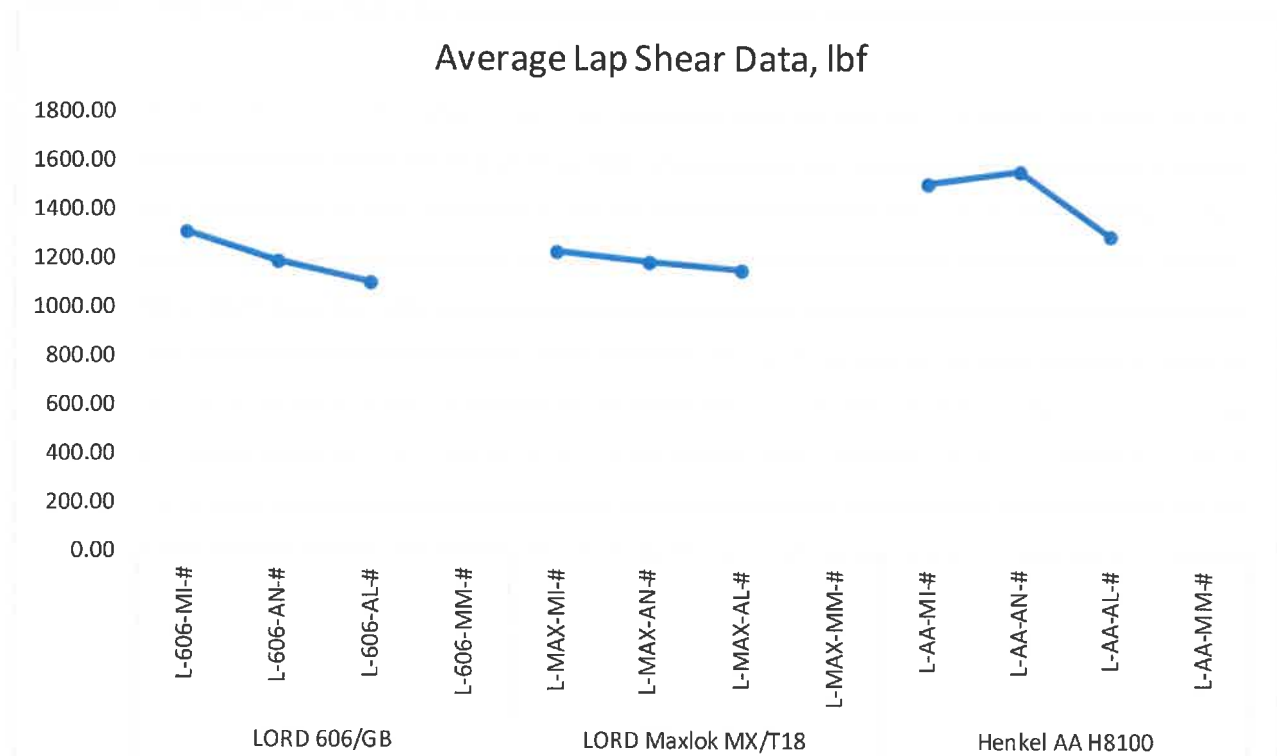
Once the samples were in the test fixtures, the universal test frame was used to apply force in either a tension (cross bar specimens) or a shear (in-line lap shear specimens) loading. The load was applied at a rate of 0.05" per minute for both types of tests. A plot of force vs position was generated, and peak force for each sample was recorded.

Please refer the summary reports provided for all force / position plots.

Test Results Continued:

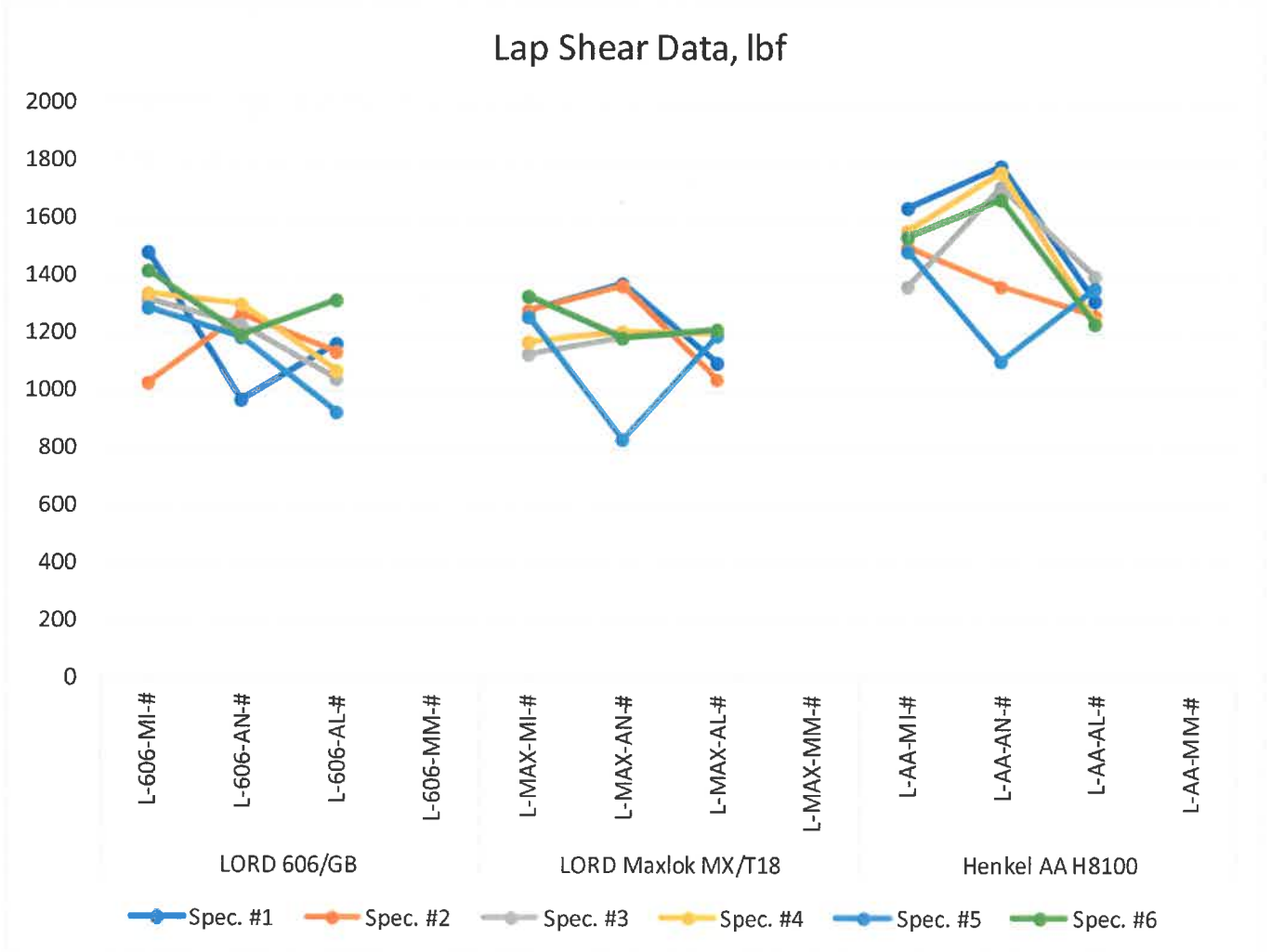
Test results are shown below for the in-line lap-shear specimens. All samples were tested on 3-22-2019.

Lap Shear Forces		Flyer low	Flyer high	Did not test		Samples Unavailable			
Adhesive / Sample Description	Lap Shear	Spec. #1	Spec. #2	Spec. #3	Spec. #4	Spec. #5	Spec. #6	Average	St. Dev.
LORD 606/GB	L-606-MI-#	1480.74	1027.89	1315.57	1338.56	1290.04	1421.25	1312.34	156.41
	L-606-AN-#	971.74	1269.32	1230.75	1302.1	1190.64	1191.04	1192.60	116.72
	L-606-AL-#	1165.39	1137.6	1042.35	1068.91	929	1315.11	1109.73	130.33
	L-606-MM-#								
LORD Maxlok MX/T18	L-MAX-MI-#	1283.3	1281.5	1127.22	1173.5	1262.89	1333.72	1243.69	77.41
	L-MAX-AN-#	1372.37	1370.89	1190.29	1210.09	831	1189.98	1194.10	197.57
	L-MAX-AL-#	1099.21	1040.12	1207.55	1198.72	1191.4	1216.44	1158.91	72.10
	L-MAX-MM-#								
Henkel AA H8100	L-AA-MI-#	1644.7	1507.85	1368.21	1565.34	1492.02	1539.32	1519.57	91.60
	L-AA-AN-#	1787.86	1371.16	1717.94	1761.46	1109.65	1672.12	1570.03	271.25
	L-AA-AL-#	1319.69	1267.41	1406.95	1245.99	1359.83	1235.43	1305.88	68.33
	L-AA-MM-#								
Retains from Previous	L-RT-MI-#								
	L-RT-GAL-#								
Samples for Setup	N/A								



Test Results Continued:

Test results are shown below for the in-line lap-shear specimens. All samples were tested on 3-22-2019.

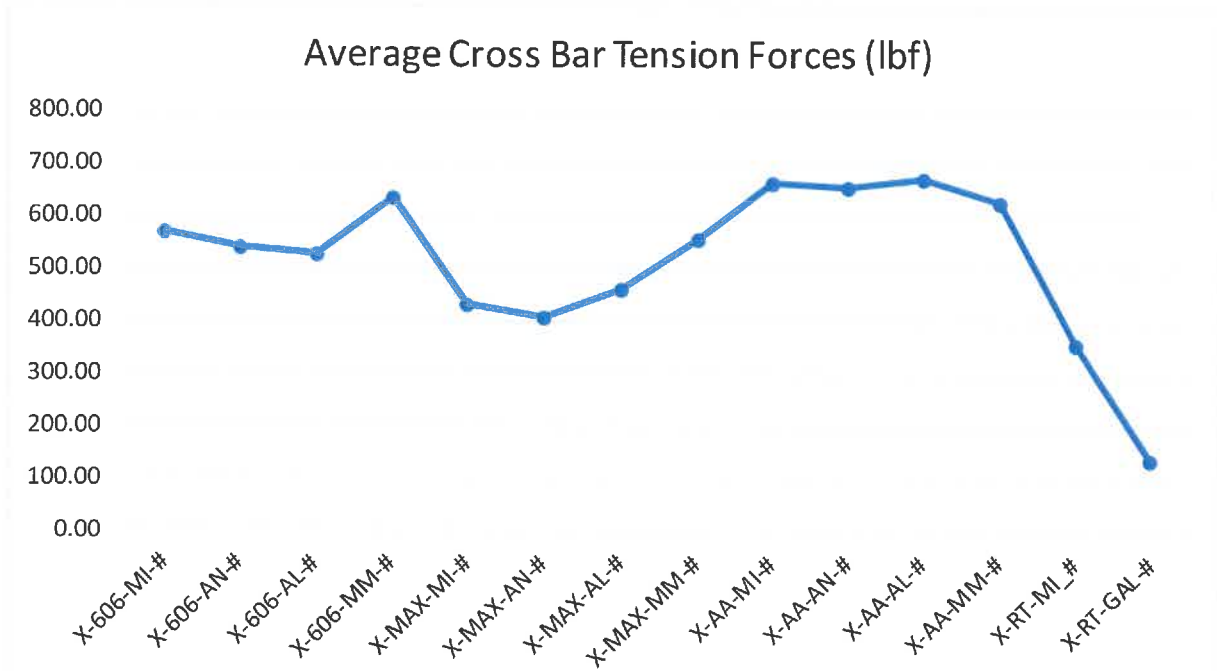


Test Results Continued:

Test results are shown below for the cross bar specimens tested in tension. All samples tested on 3-15-2019.

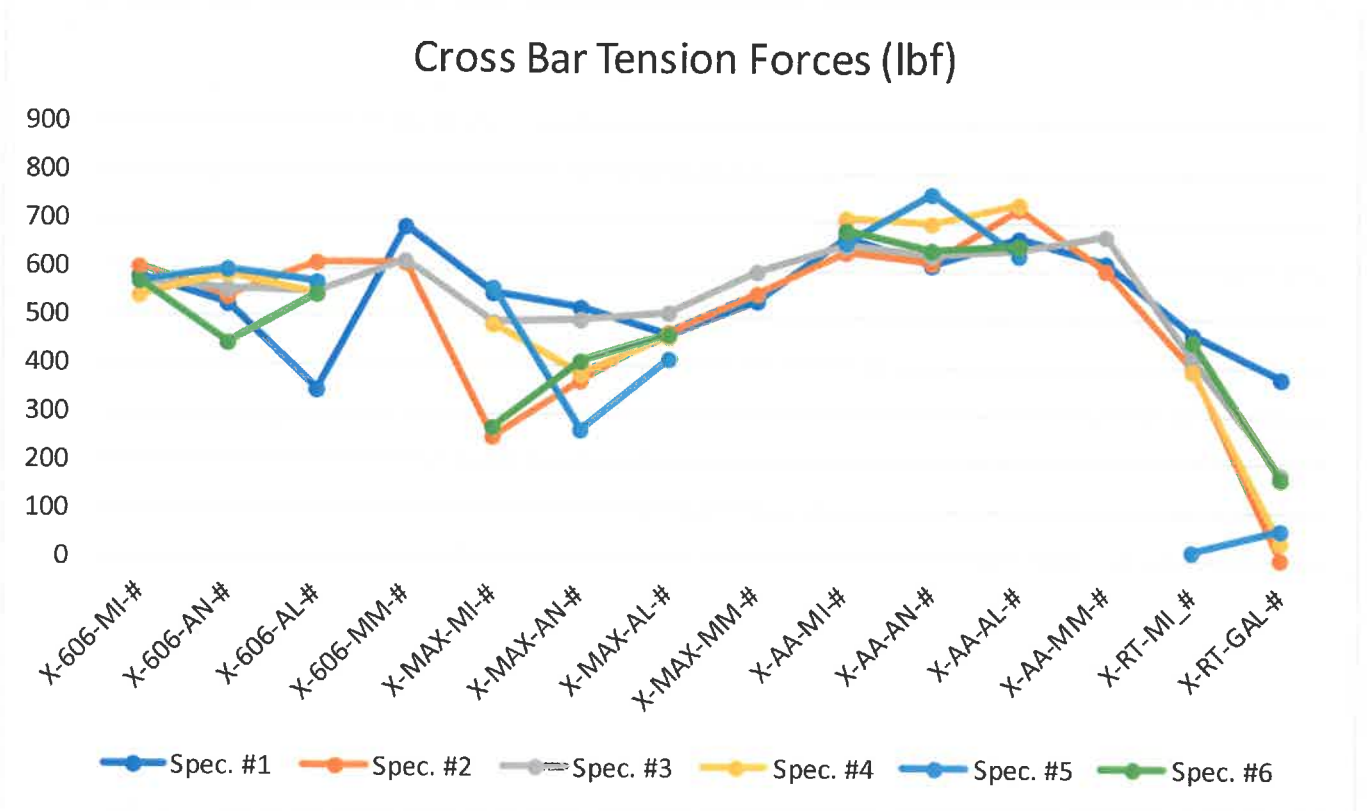
X-Bar Tension Forces

		Flyer--low		Flyer--high					
X-Tension		Ultimate Force (lbf)							
Adhesive / Sample Description	Sample Names	Spec. #1	Spec. #2	Spec. #3	Spec. #4	Spec. #5	Spec. #6	Average	St. Dev
LORD 606/GB	X-606-MI-#	584.5	601.51	571.52	542.04	573.25	573.58	574.40	19.46
	X-606-AN-#	526.71	542.85	558.33	586.36	596.82	445.04	542.69	54.54
	X-606-AL-#	348.39	614.85	552.38	545.31	573.19	548.42	530.42	92.87
	X-606-MM-#	687.11	614.93	617.24				639.76	41.02
LORD Maxlok MX/T18	X-MAX-MI-#	552.54	251.92	492.34	488.52	564.4	272.76	437.08	138.94
	X-MAX-AN-#	523.28	369.38	498.62	383.45	270.18	409.77	409.11	92.29
	X-MAX-AL-#	465.74	470.8	509.88	462.47	413.86	464.64	464.57	30.56
	X-MAX-MM-#	535.03	549.9	595.61				560.18	31.57
Henkel AA H8100	X-AA-MI-#	670.68	638.99	652.76	707.31	656.65	686.23	668.77	24.84
	X-AA-AN-#	611.42	617.62	635.53	701.77	762.22	643.43	662.00	58.65
	X-AA-AL-#	668.38	728.17	644.24	737.88	631.28	651.81	676.96	45.16
	X-AA-MM-#	620.72	602.4	675.18				632.77	37.86
Retains from Previous	X-RT-MI_#	470.69	401.35	418.58	397.52	21.93	456.78	361.14	168.79
	X-RT-GAL-#	378.27	3.98	182.06	41.01	64.81	169.25	139.90	136.64



Test Results Continued:

Test results are shown below for the cross bar specimens tested in tension. All samples tested on 3-15-2019.





Tester's Notes:

When analyzing these test results, keep in mind that the cross bar specimens had a bonded area of 1" x 1", while the lap-shear specimens had a bonded area of 1/2" x 1".

For the lap-shear specimens, once the peak load was reached, the yielding of the adhesive was very rapid, and the joint came completely apart.

For the cross bar specimens loaded in tension, many specimens exhibited a double peak on their graph, with an initial yield, often followed by a slightly higher final failure load. It is not certain if this was a property of the adhesive bond or if it was caused by the deflection of the aluminum and fiberglass pieces. Some aluminum pieces exhibited noticeable plastic deformation (bends) after being tested.

Squeeze-out of the adhesive on the cross bar specimens was not an issue, due to the fixture openings being slightly wider than the aluminum and fiberglass components. Spacing between the supports of the upper and lower test fixtures were 1.26" and 1.27" respectively for all cross bar tests.

Cross-head travel was very minimal, particularly for the lap-shear tests, and there was generally no sound associated with the loading of either type of specimen. (until failure was reached)

All samples were individually bagged after testing to allow for later examination of the failure surfaces.

Adhesive samples ending in the MM designation were not found with the samples provided.

In total, 75 cross-bar samples, and 54 in-line lap-shear samples were tested.

Tester's Notes Continued:

The "Retains from Previous" lap-shear specimens were of a different geometry than the other specimens. These retains were not tested, as the load applied by the wedge-action grips would not have been on the centerline of the bonded area, and the results would not have been comparable to the other specimens.

