DELIVERABLE D2.2:
TEST REPORT ON CHARACTERIZATION PROGRAM

ADVANCED TIDGEN® POWER SYSTEM
US DEPARTMENT OF ENERGY AWARD: DE-EE0007820

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1. Table of Contents

2. Purpose

To fulfill deliverable 2.2: "*Test report on characterization program, composite testing and selected composite Structure"* of Milestone M1.2: "*Characterization testing of composite material sets completed, with selected composite structure delivering > 20-year component life"* for the Advanced TidGen power system project.

3. Introduction

ORPC arranged coupon testing of candidate material sets as part of a larger characterization program. The goal of this testing was to down select the candidate material sets and determine failure mechanisms. This was done by testing both dry and saturated material sets and examining the effects of moisture uptake of the coupons mechanical properties. This test program was completed under a separate DOE funded project (U.S. DOE MHK Composite Materials & Structures Database, FY17) to populate the Marine Hydrokinetic Database (MHK) hosted by Montana State University (MSU) and Sandia National Labs. Due to the limitations of this program we were limited to static tensile testing is longitudinal and transverse directions as well as limited tensile fatigue testing with a loading of R=0.1 (tension - tension). This program did however, allow for a larger spread of material sets including a novel hydrophobic resin that was promoted to resist water uptake, optimized for subsea applications.

Test coupons were cut parallel to the zero's on the mold face (shiny surface) of the supplied material sets panels. Standard coupon dimensions can be seen in Figure 1. Table 1 shows a summary of the manufacturing details for the candidate material set panels.

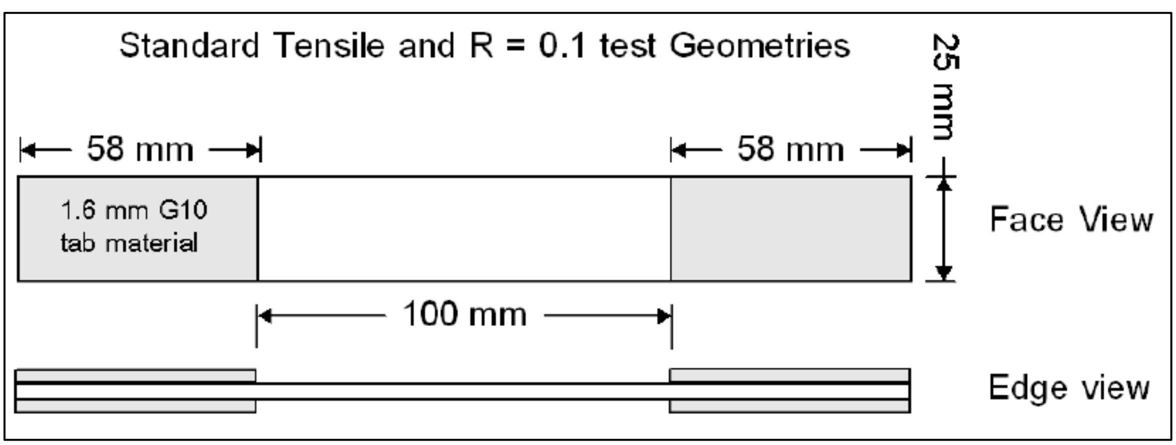

Figure 1: Standard composite coupon dimensions

Table 1: Materials CE1 to CE6 manufacturing summaries.

Material	Layups	Fabrics	Resin	cure
CE1	[V(+/-45)g/0c]s	Veil, E-BX-1700, Zoltek UD600	Pro-set INF 114/211	8h @ 60C
CE2	[V(+/-45)g/0c]s	Veil, E-BX-1700, Vectorply CLA 1812		
CE3	[V(+/-45)g/0c]s	Veil, E-BX-1700, Zoltek UD600	Hexion RIMR 035c/RIMH 0366	12h @ 70C
CE4	[V(+/-45)g/0c]s	Veil, E-BX-1700, Vectorply CLA 1812		
CE5	[V(+/-45)g/0c]s	Veil, E-BX 1700,CLA 1812, E-BX 1700	Crestapol 1250PUL urethane Acrylate	1.3h @ 80C, 1.3h @ 120C
CE6	[V/0/45/-45/0/V]	Veil, E-LT-2900, E-BX 1700, E-LT-2900	AME 6001 VE +1.5% MCP	

4. Description

The tow's visibility seen on the other face (mold top) showed tow angles of up to 2.5 degrees off-axis. This caused some of the test variations seen in static strength and fatigue. Coupon thickness variations also added to the variations, as it introduced out-of-plane waviness in the laminates. The minimum coupon thickness was used for the stress calculations. Table 2 detail some of the manufacturing and dimensional details of this material set.

Table 2: Materials CE1 to CE6 dimensional and layup summaries.

Material	Average thickness all tests, mm	Maximum thickness mm	Minimum thickness mm	Average fiber volume %	Fiber contents			Layup
					% 0's	% +/- 45's	% 90's	
CE1	2.79	3.04	2.49	41.6	57.6 C	42.2 G	0.4 G	[V/(+/-45)g/0c]s
CE2	3.31	3.67	3.06	36.7	56.6 C	43.4 G	0	
CE3	2.80	3.01	2.55	41.7	57.6 C	42.2 G	0.4 G	
CE4	3.33	3.54	3.09	36.5	56.6 C	43.4 G	0	
CE5	3.14	3.52	3.01	36.6	56.6 C	43.4 G	0	
CE6	2.47	2.73	2.18	42.0	69.2 G	22.5 G	8.3 G	[V/0/45/-45/0/V]

The coupon weight gain versus hours soaking in 50 °C ASTM D1141 simulated seawater (without heavy metals) is shown in Figure 2. Figure 3 shows SEM micrographs of the materials cross-sections, showing some of the effects of thickness variations in the lay-ups.

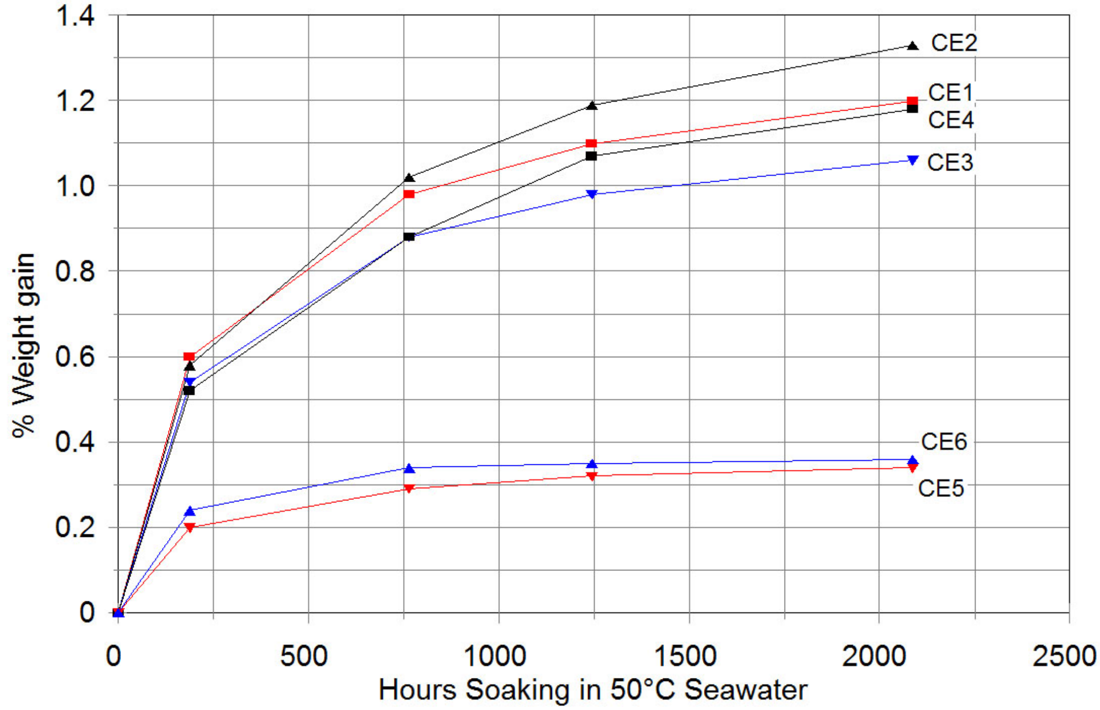

Figure 2: Weight gain versus hours soaking in 50 °C ASTM D1141 simulated seawater (without heavy metals)

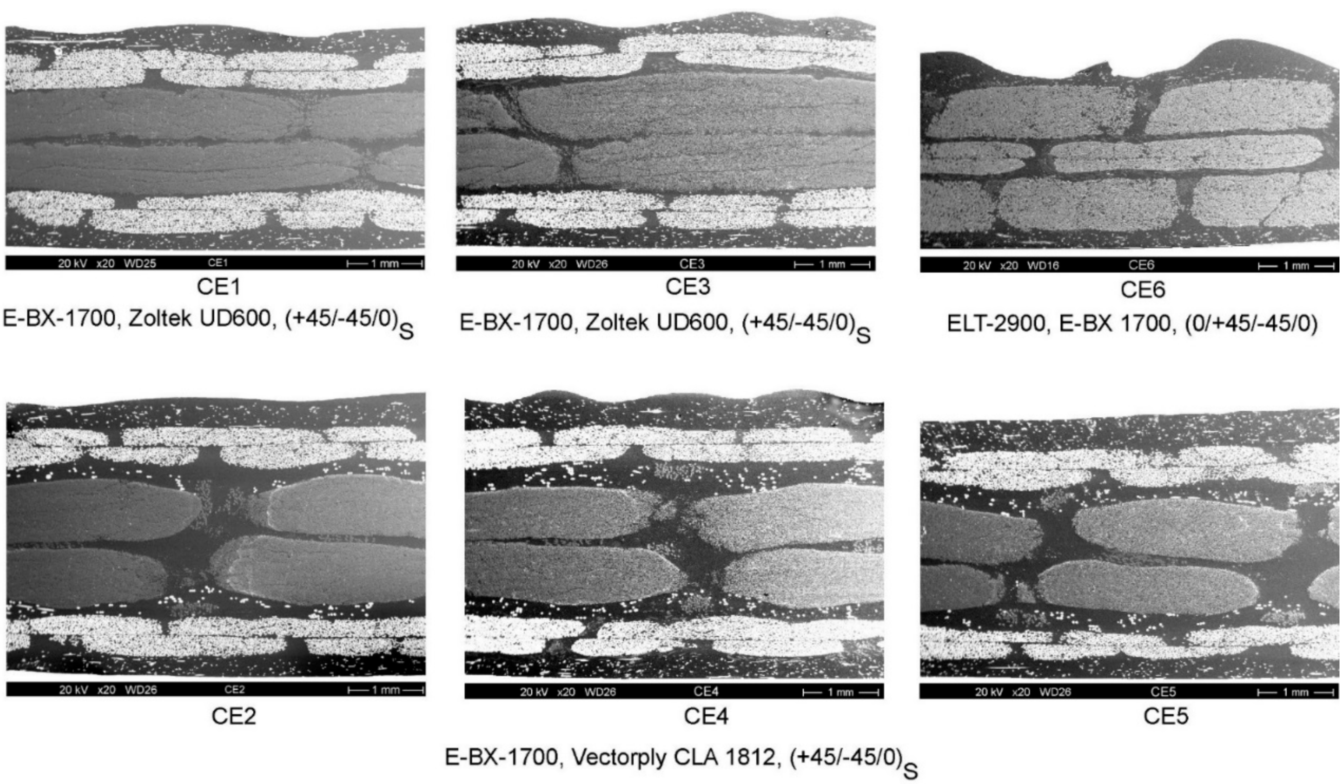

Figure 3: Typical SEM micrograph cross-sections of materials CE1 to CE6.

5. Results

Table 3 summarizes the static test data and Figure 4 through 9 detail the fatigue testing results. Stress vs. cycles, load vs. cycles and Initial maximum strain vs. cycles are presented. Carbon fiber composites have a really flat tensile fatigue response which produces lots of scatter in the data points. This data scatter is increased with other coupon effects like thickness variations, tow waviness and angle misalignments. All these effects increase the frequency of coupon failures in the tab or gripped regions of the coupon. Table 16 in Appendix A summarizes the individual test data.

Table 3: Summary of static test data for control and simulated seawater conditioned coupons.

MSU Material	Layup	Average V_F for static tests %	% moisture	Longitudinal Direction			Transverse Direction		
				E, GPa	UTS, MPa	% strain	E, GPa	UTS, MPa	% strain
CE1	[V/(+/-45)g/0c]s	40.9	0	56.1	786	1.38	10.7	98.3	3.17
			1.2	58.3	787	1.33	8.54	68.3	1.84
CE2		35.8	0	54.8	773	1.40	9.02	83.3	3.26
			1.33	55.3	725	1.30	7.79	58.9	1.84
CE3		40.7	0	54.1	792	1.43	9.96	95.3	3.67
			1.1	52.1	691	1.31	8.62	68	1.92
CE4		36.1	0	53.7	774	1.36	8.91	83.9	3.69
			1.2	53.1	712	1.30	8.18	60.5	1.82
CE5		36.4	0	56.5	733	1.29	9.69	77.8	3.54
			0.34	57.9	695	1.15	8.05	63.6	2.05
CE6	[V/0/45/-45/0/V]	42.3	0	29.2	695	2.69	12.0	109	2.52
			0.36	28.7	590	2.36	16.6	126	2.36

Figure 10 is a summary of the stress showing the maximum tensile stress for fatigue, longitudinal static and transverse static testing. Figure 11 is a summary of the loads showing the maximum tensile loads for fatigue and static testing. Figure 12 is a summary of the thermoset materials tensile strength showing tensile modulus, tensile strength and tensile strain to failure for dry and conditioned material sets CE1 to CE6.

6. Discussion

Summary data graphs are shown in Figure 10 and 11. In looking at materials CE3, CE4 and CE5 for the most likely best material to use for further testing; material CE4 did have some fiber misalignments, up to 2.7 degrees off zero, which if corrected could produce some better strengths and cycles to failure. Material CE3 had lower static and fatigue strengths but had higher transverse strengths. Material CE5 shows the least effect to conditioning and less transverse cracking in tension. MSU rank CE5 as the better system with CE4 next and CE3 holding the number three slot.

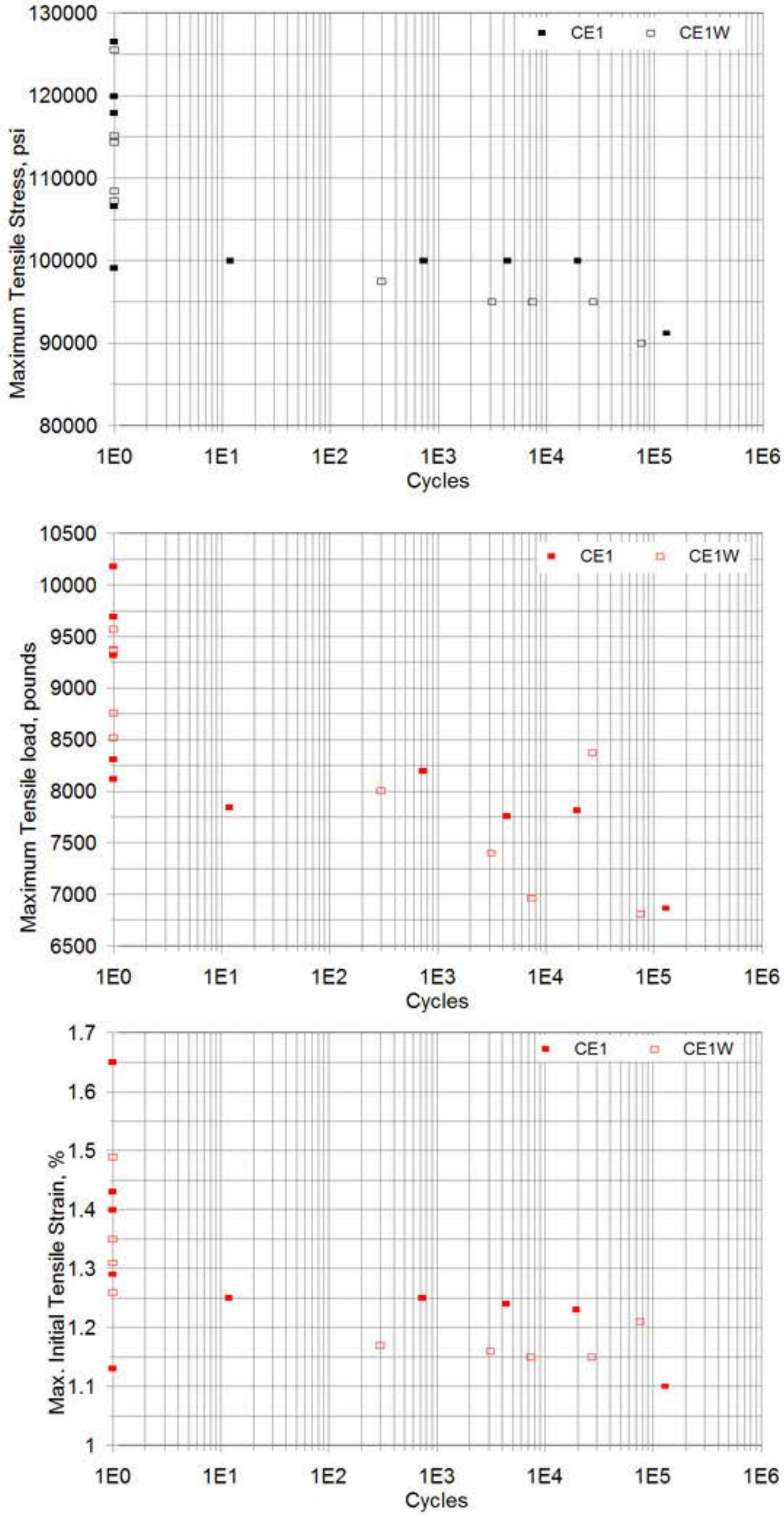

Figure 4: Material CE1 – R=0.1 fatigue data for control and conditioned coupons.

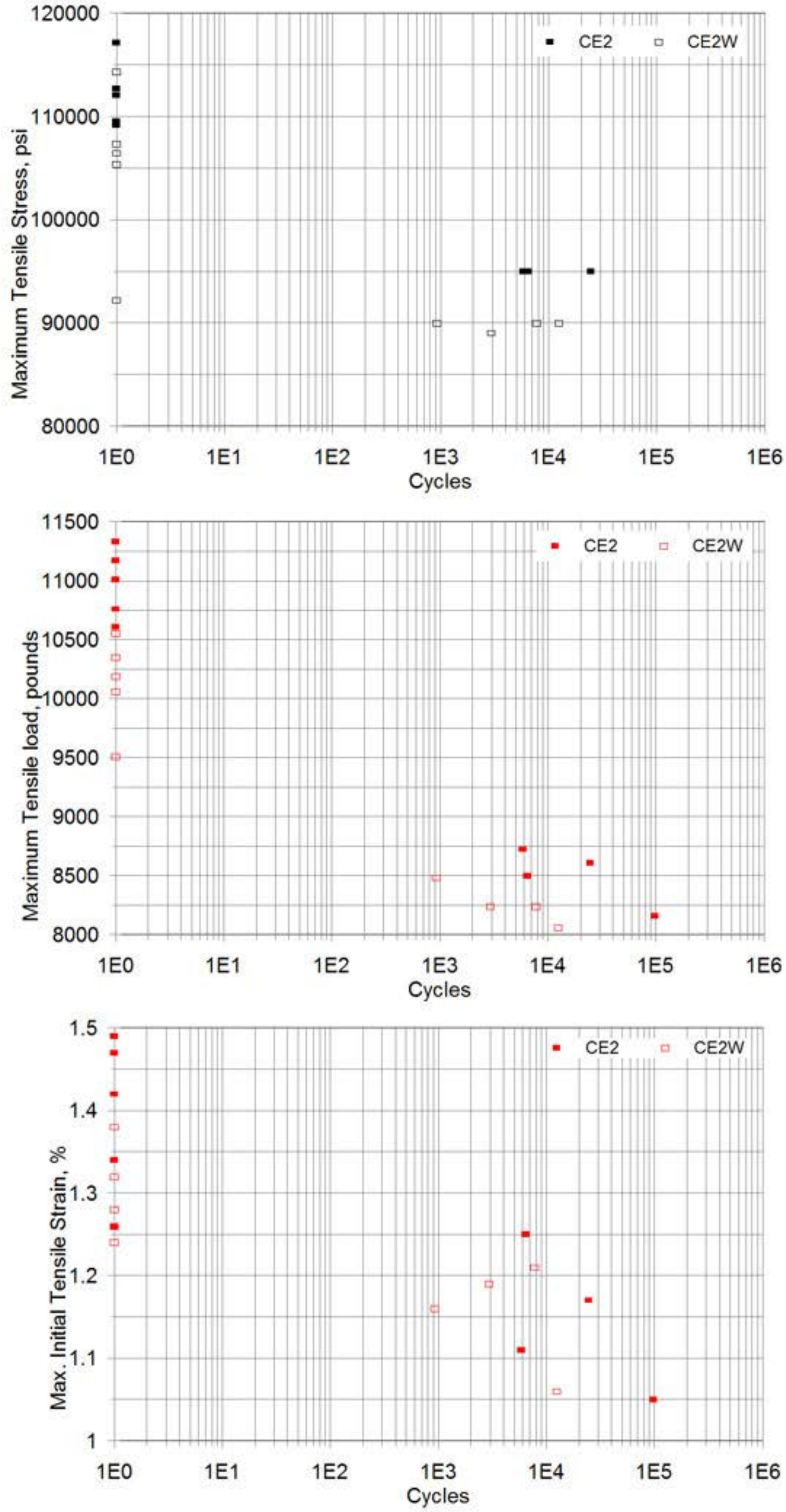

Figure 5: Material CE2 – R=0.1 fatigue data for control and conditioned coupons.

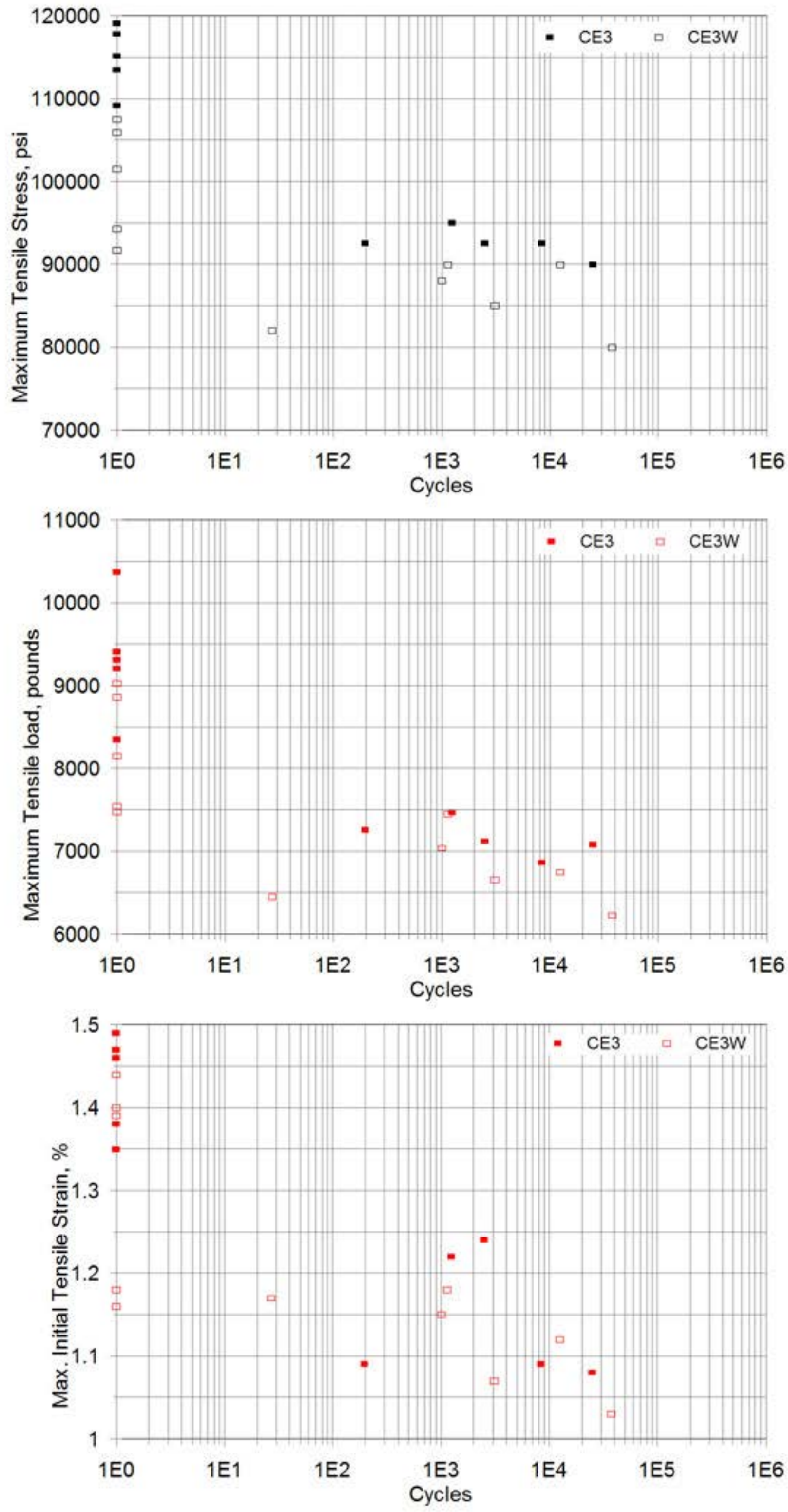

Figure 6: Material CE3 - R=0.1 fatigue data for control and conditioned coupons.

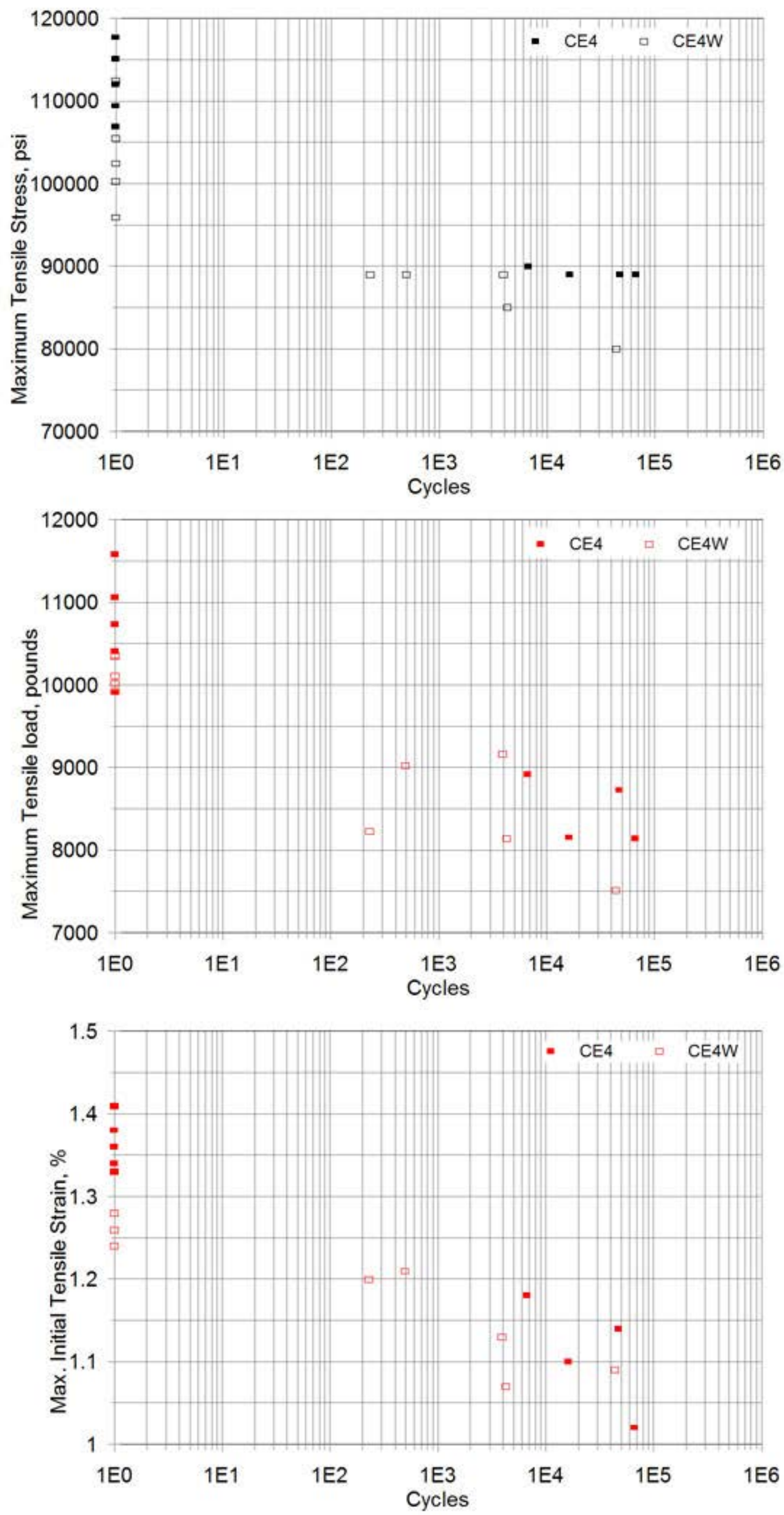

Figure 7: Material CE4 – R=0.1 fatigue data for control and conditioned coupons.

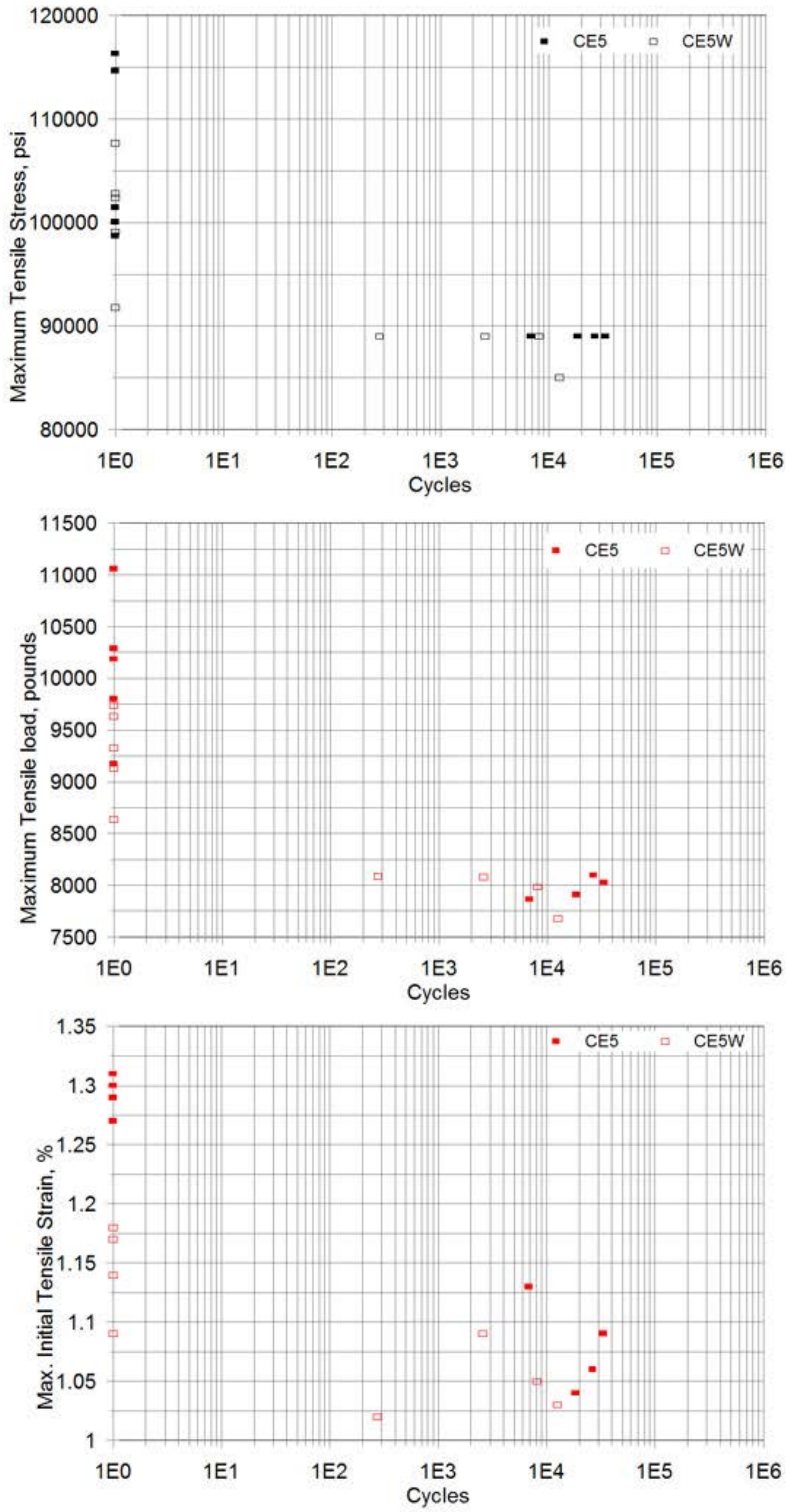

Figure 8: Material CE5 - R=0.1 fatigue data for control and conditioned coupons.

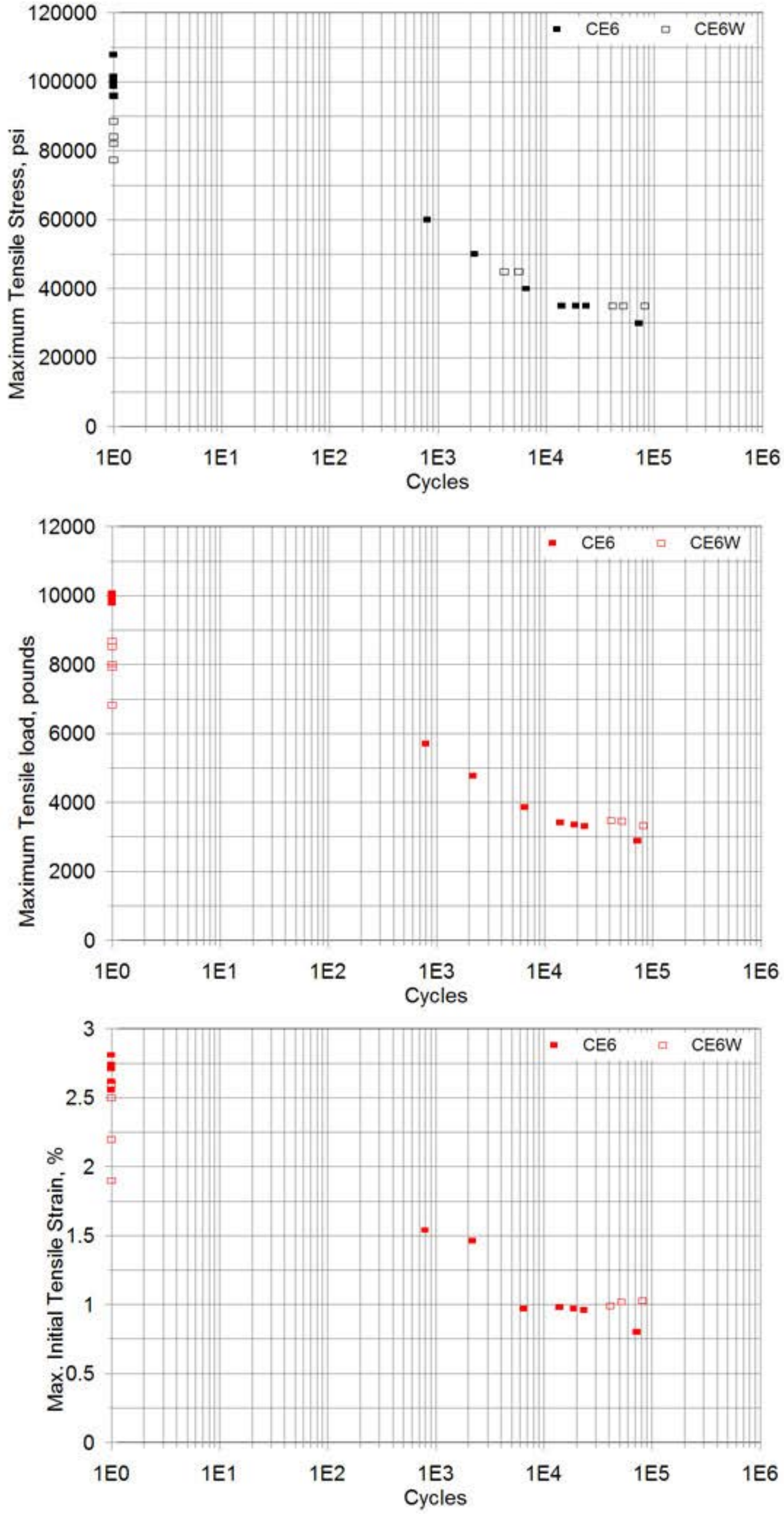

Figure 9: Material CE6 - R=0.1 fatigue data for control and conditioned coupons.

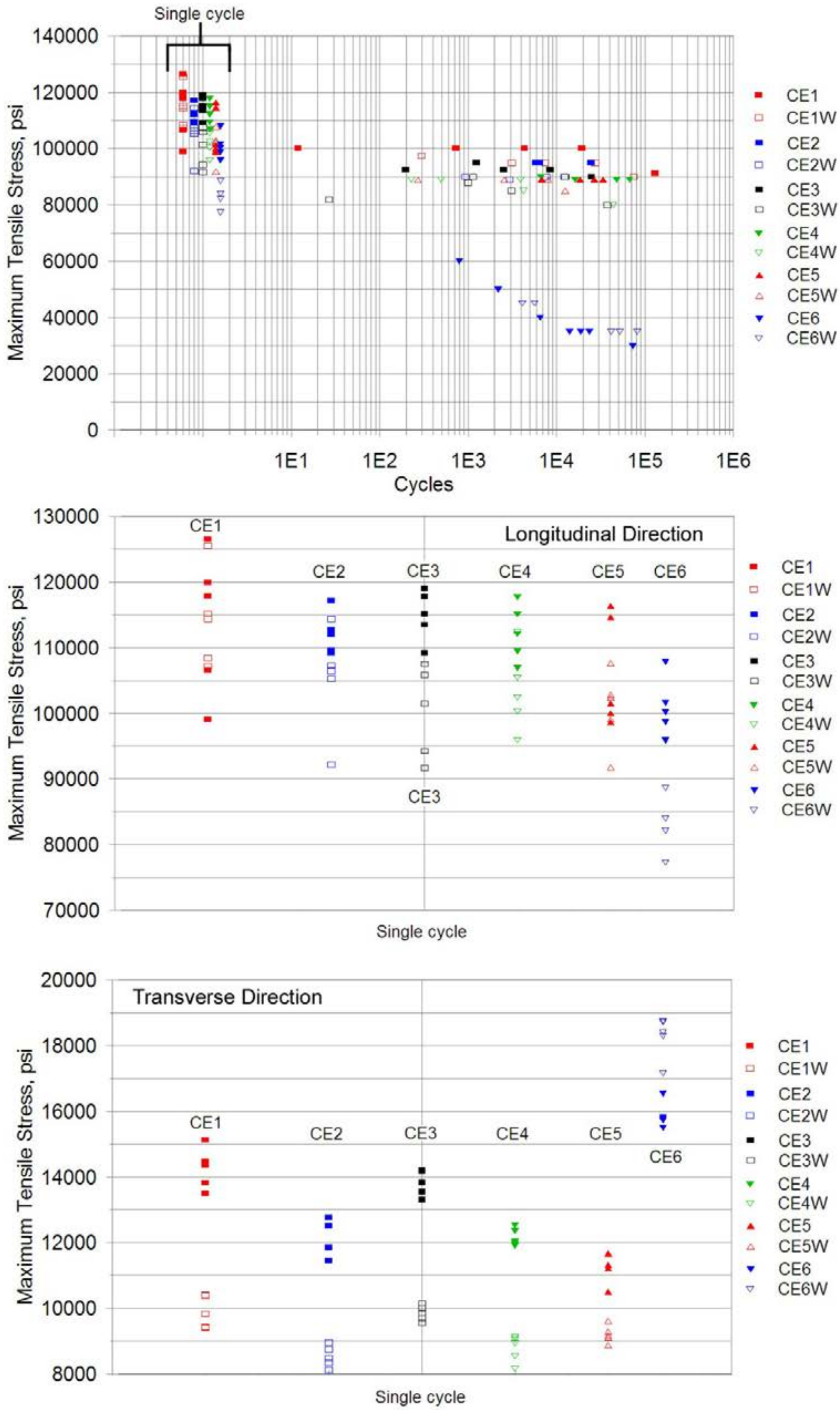

Figure 10: Summary stress graphs

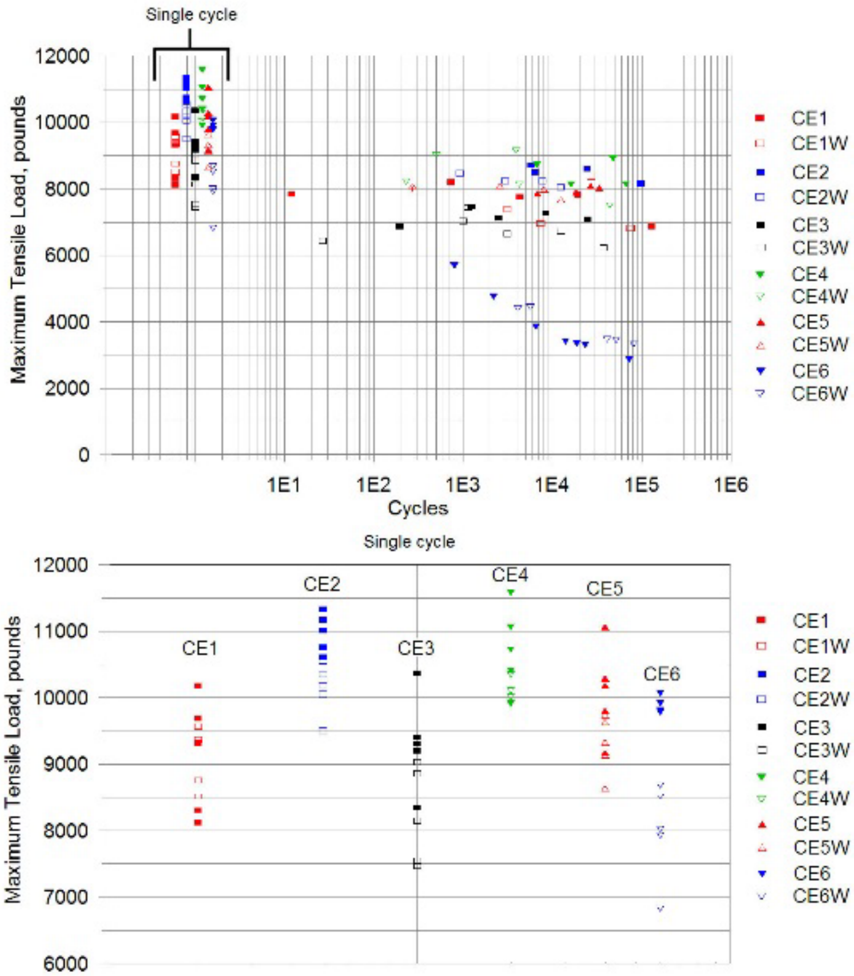

Figure 11: Summary load graphs

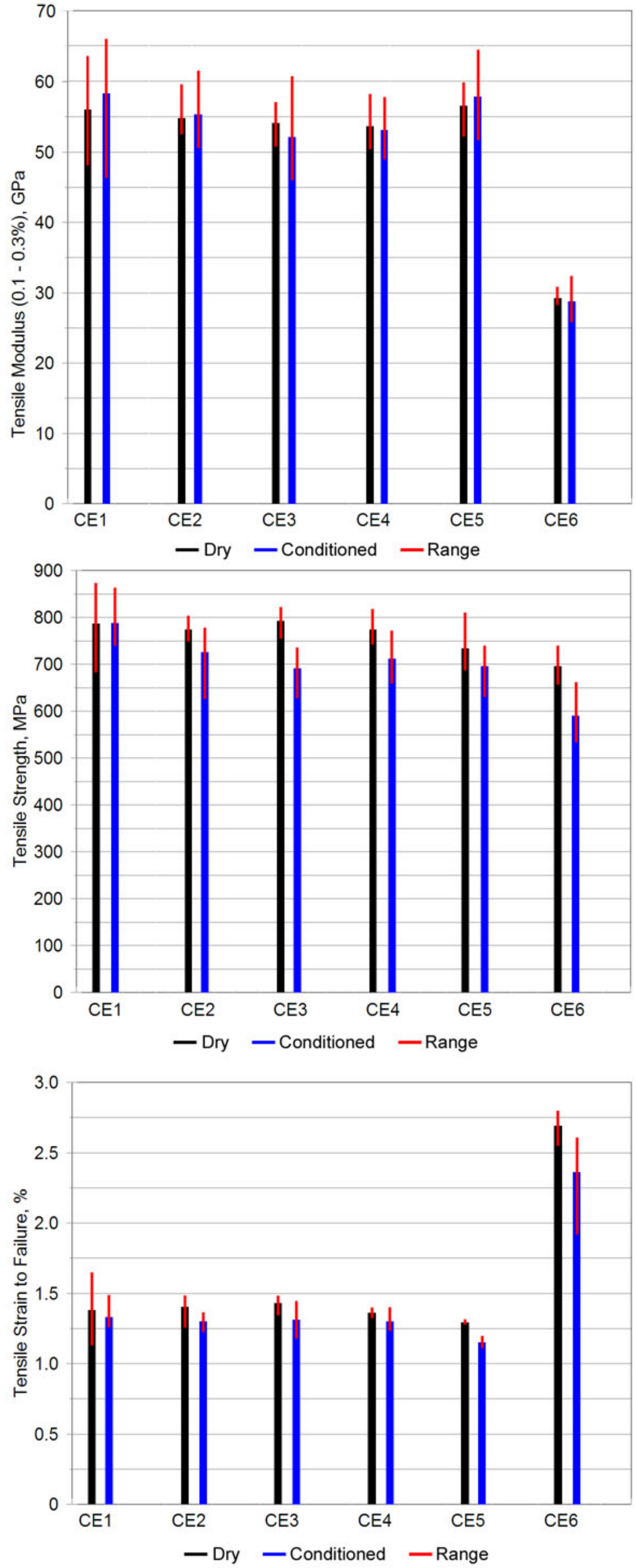

Figure 12: Summary of Thermoset Materials Tensile Strengths.

7. REVISION HISTORY

Revision	Date	Description	Author	Reviewer
R00	04/09/18	Initial	MEB	C. Marnagh