Reactivity of Ethanol

Effects of E-85 on Composite and Aluminum Intake Components

Presented By

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Table of Contents

Figure List

Abstract

The purpose of the project will be to test the effects of ethanol-based E85 on the materials used in the construction of the intake assembly for the Western Washington University Formula SAE race car. The primary materials used are T6061 aluminum for the injector bases and fuel rail mounting, and carbon fiber and epoxy composites for the intake runners, plenum body, and air diffuser.

The fuel injection process allows for E85 to attach to the intake system materials long enough to cause potential damage. The standard injection process, intake reversion, and traction control operation all play a key role in the amount of E85 deposited.

The surface of aluminum is permanently oxidized, but E85 can further promote this oxidation process causing small particles of aluminum oxides to separate. These particles can become trapped between the valve and valve seat, and over time cause a loss of compression which results in power loss and reliability issues.

One byproduct of this oxidation reaction with aluminum is water. This water is soluble in E85, and can be transported by the ethanol into elastomeric polymers. The water is then left behind when the ethanol evaporates, causing swelling of the polymer part. This repeated process eventually breaks down the polymer bonds causing stress cracks and deformation, similar to the process of environmental stress cracking. If this reaction occurs with the polymer bonds in the epoxy resins of the intake system, vacuum leaks and structural weakening can occur.

To determine the true effects ethanol blended fuels have on the components used on the Western Washington University Formula SAE car, a rigorous test schedule will be conducted using 6061-T6 Aluminum in bare alloy form, in addition to a ceramic coating, and a thermal dispersant coating. Three epoxy resins will be tested with carbon fiber reinforcement; JeffCO 1391, Renlam 4017, and West Systems 105.

Over 270 lines of data were analyzed, and it was found that of all the measurements, three are statistically significant, with p-values less than 0.05 for a 95% confidence interval. However, two of these statistically significant data sets, Renlam 4017's reaction with gasoline and West Systems 105 reaction with E-85, both had an inverse correlation with the hypothesis. It was found these two data sets were not practically significant, as it is not plausible that liquid fuel could cause an increase in modulus. The final statistically significant data set, JeffCO 1391's reaction with E-85, showed a decrease of tensile strength. However, the data was measured with a high degree of variance. Although the resulting data response was greater than the standard deviation, the argument can be made that correlation does not equal causation, and that random variation could cause such a result.

It was concluded that there is not enough evidence to support the claim that ethanol blended fuels cause corrosion and physical deterioration of aluminum and polymer based materials. At the same time, there is not enough evidence to assume no potential for problems exists. With these

points in mind, the construction of the intake assembly will be made purely with manufacturing and cost in mind, as no reactivity data can be conclusively used.

Introduction

This last fall, members of the Western Washington University Formula SAE team made the decision to test E-85 as an optional fuel for the 2009 race car, Viking 46. E-85 is composed of 85% ethanol, and 15% regular gasoline, and is considered by many to be a green fuel, as the primary ingredient ethanol is renewable. There are many benefits to running a high ethanol content fuel, including its high octane rating and high latent heat of vaporization (see figure 1). The octane boost can allow for higher peak cylinder pressures before knock occurs, and the latent heat of vaporization causes a cooling affect as the fuel atomizes with the intake air charge, both resulting in more horsepower.

Figure 1 – Comparison Data of Premium Unleaded Gasoline and E-85 Fuel [1]

	Premium Unleaded Gasoline	E-85
Price Per Gallon (March 1, 2009 - US Dollars)	2.46	2.21
Octane Rating (R+M/2 Method)	92	105
Latent Heat of Vaporization (kJ/g)	180	855

After much research, it was found that ethanol is known to react with certain alloys of aluminum and elastomeric polymers [2], [3]. The team concluded that testing was needed in order to justify the use of this fuel, as the primary materials used on the Formula SAE intake system are aluminum and carbon fiber reinforced polymers (CFRP's) (Figure 2).

Figure 2 – 2008 WWU Formula SAE Intake Assembly

It was determined that a rigorous testing schedule was needed to evaluate the materials based on their reactivity with E-85, manufacturability, performance and cost. Aluminum in uncoated form, two coatings for aluminum, and three epoxy resins with carbon fiber reinforcement were chosen for testing. There are two distinct components of the intake assembly, the aluminum injector bases, and the CFRP intake structure, therefore two different design matrices will be used to determine the best suitable material for each component. The injector base matrix will use factors of manufacturing time, material cost, coating cost, performance and reactivity with E-85. The CFRP intake structure matrix will use factors of manufacturing (epoxy process time, epoxy cure time, epoxy cure temperature), epoxy cost, performance, and reactivity with E-85. From these two matrices, the ideal materials can be chosen for the two intake components.

Proposed Solution & Changes Made

Originally, three alloys of aluminum, 2024, 6061 and 7075 were to be tested, as each is molecularly different and are the most commonly available aluminum alloys that are machinable. However, the raw stock of 2024 and 7075 aluminum alloys available for use were very large, and would have created excess waste that was deemed unnecessary. Therefore, only 6061-T6 aluminum was used in both uncoated (Figure 3) and coated forms.

Figure 3 – 6061-T6 Aluminum Discs – Uncoated, Ceramic Coated, Thermal Dispersant Barrier Coated

Various coating options were explored. The first of which by definition is not a coating, is known as anodizing. The anodizing process redistributes the oxidation layer on the surface of aluminum to a more uniform density. Often this layer is much thicker than the original oxidation layer. After a sealant is added, this thick oxidation layer provides protection against abrasion and galling. However, this process is not known for its chemical resistance, and due to supplier issues, anodizing was eliminated from the testing lineup.

The next option explored was a ceramic coating. This high temperature, high chemical resistant coating is applied in liquid form, and oven cured. This is a common coating for temperature critical engine components, but also offers superior abrasion resistance and could potentially act as a chemical barrier (Figure 4).

Figure 4 – Ceramic Coated Aluminum Disc

Solidified Gel Deposition, or Sol-Gel, is a new technology that offers high abrasive and chemical resistant properties. Unfortunately, similar supplier issues forced this coating off of the testing lineup.

Lastly, a Thermal Dispersant Barrier (TDB) was found, and offered by the same supplier as the ceramic coating. This is a thin dry film coating that offers good chemical resistance as well as high heat dispersion. TDB also has a very low surface energy, so dirt, moisture and chemicals have a hard time attaching to the coated component (Figure 5).

Figure 5 – Thermal Dispersant Barrier Coating on Aluminum Disc

The polymer system used on the previous Formula SAE race car was JeffCO 1391, a toughened epoxy resin system. This epoxy system was tested, in addition to Renlam 4017, a tooling and infusion epoxy, and West Systems 105 epoxy resin, a general purpose boat and aircraft epoxy resin.

A carbon fiber reinforced thermoplastic, poly-ether-ether-ketone (PEEK) was also considered, as it is known for its excellent chemical resistance. However, processing limitations prevented this product from being tested.

Originally, all test samples were to be tested at two different temperature levels, as previous data (Figure 6) indicates that the probability and frequency of corrosion spots increases with temperature. Unfortunately, there were safety concerns raised regarding how to heat the fume-hood in the PET lab safely with exposed gasoline and E-85 fumes. Therefore the upper test temperature of 142˚F was removed. These same concerns, coupled with the need for other students to use the fume hood for class projects, resulted in the elimination of the 7 day (168 hour) testing.

Figure 6 – ASM International Chart of Temperature VS Corrosion of Aluminum [4]
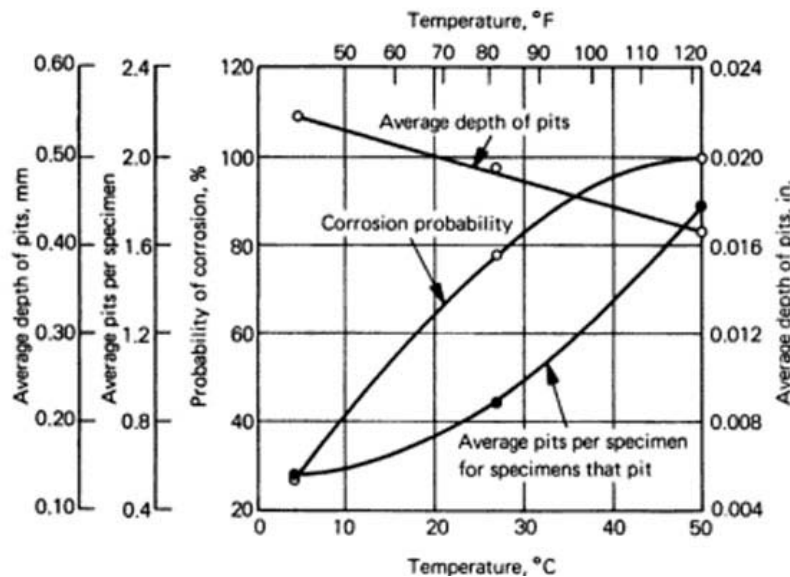
With the various changes to the testing schedule, the original proposed solution and revised solution table differ. Options for continuing investigation using the original plan of action will be touched upon later.

Figure 7 – Original Table Showing Factor and Factor Levels for Experimental Design

Factor	Fuel Type	Temperature (˚F)	Time (hours)	Aluminum Alloys (bare)	Aluminum Coatings	Polymers
Factor Levels	E85	69	0	2024	Anodized	Jeffco 1391

	Premium Unleaded	142	4	6061	Sol-Gel Coating	System B
			24	7075	Ceramic Coating	System C
			168			CFRP - PEEK

Figure 8 – Revised Table Showing Factor and Factor Levels for Experimental Design

Factor	Fuel Type	Temperature (˚F)	Time (hours)	Aluminum Alloys (bare)	Aluminum Coatings	Polymers
Factor Levels	E85	69	0	6061	Ceramic Coating	JeffCO 1391
	Premium Unleaded		4		Thermal Dispersion Barrier	Renlam 4017
			24			West Systems 105

The original test responses remained mostly the same. *Polymer Mass Percentage* was removed due to the difficulty of measurement. It was originally assumed that burnout testing could be used to determine resin mass and fiber mass percentage, but carbon fibers oxidize in flame therefore the results would not be valid. Also, hardness tests were not conducted on the CFRP samples.

Figure 9 – Original Table Showing Factor Class and Responses

Factor Class	Aluminum	Polymers
Responses	Mass (g)	Mass (g)
	Density (g/cm3)	Density (g/cm3)
	Hardness (Rockwell Scale)	Hardness (Rockwell Scale)
	Microscopic Scans	Microscopic Scans
		Polymer Mass Percentage
		Tensile Strength (ksi)
		Modulus (ksi)

Figure 10 – Revised Table Showing Factor Class and Responses

Factor Class	Aluminum	Polymers
Responses	Mass (g)	Mass (g)
	Density (g/cm3)	Density (g/cm3)
	Hardness (Rockwell Scale)	Microscopic Scans

	Microscopic Scans	Tensile Strength (ksi)
		Modulus (ksi)

Methodology & Testing

Aluminum & Coated Aluminum Samples

Testing of the aluminum alloy and coated aluminum was performed using 1 inch diameter discs cut by the MET Water Jet machine (Figure 11). Each disc is 0.20 inches thick, and each was stamped with a number, a total of 72 were made. The uncoated discs were numbered 1-24, and sample numbers 25-72 were sent to the coating supplier.

Figure 11 – 6061-T6 Aluminum Discs Being Cut by MET Water Jet Machine

All samples were measured for mass, density and hardness prior to any testing. The discs were tested in glass containers with lids (Figure 12). Four discs were tested for each time interval, and for both E-85 and gasoline. After each time interval of testing, the samples were allowed to dry for 24 hours before response measurements were taken.

Figure 12 – Glass Container for Aluminum Test Samples

Carbon Fiber Reinforced Polymer Samples

14 inch by 14 inch square laminates were made for each of the composites. Each plaque is capable of producing 18 ASTM composite specific tensile tabs cut by the MET Water Jet machine. Each laminate used two layers of 6k carbon fiber weave, with fiber directions in the 0˚ and 90˚ directions.

Each sample was labeled with a permanent marker and a piece of blue masking tape with the sample number was taped to the one end. To reduce the potential for sample mix-up, the first letter of the epoxy used was included next to the sample number. For example, sample number 8 from the Renlam 4017 epoxy was labeled *8R*. The CFRP samples were placed in the PET lab's 1000ml glass beakers for testing. These were tall enough to ensure that the 13 inch tall ASTM tensile tab could fit in the beaker, while leaving enough room not to stick out the top. The fuel level was approximately one inch below the top of the sample height; this was to prevent the fuel from degrading the label on the blue masking tape on the top portion of the ASTM tensile tab.

Mass Measurement

Mass measurements were taken using the PET lab's Mettler high accuracy balance. Before each measurement, the balance was zeroed, and left to sit for approximately 5 seconds. Once a sample was placed on the balance the sliding doors were closed completely, possible only with the aluminum and coated aluminum samples. The measurement was taken once the displayed mass did not fluctuate by more than +/- 0.0005g. Measurements were recorded to three decimal places, as the fourth decimal place was almost always moving.

Density Measurement

Density samples were taken using the *Archimedes' Principle* method. A structure was made and placed on the balance. An arm on the structure held the sample suspended in water (Figure 13). The balance was zeroed once the structure and arm were secure and placed in the water. The sample was added to the arm, making sure the entire sample was submerged in water. The resulting mass was recorded. To calculate the density, use the following equation:

$$\rho = \frac{m}{(m - m')} \times \varphi$$
$$where\ m = mass\ in\ air$$
$$m' = \ mass\ in\ water$$
$$\varphi = density\ of\ water$$
$$\rho = dnsity\ of sample$$

Figure 13 – Structure and arrangement for Density Measurement
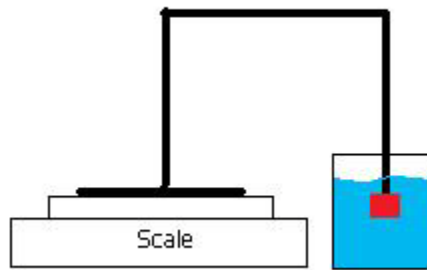
Hardness Measurement

Hardness measurements were taken of the aluminum alloy samples and coated aluminum samples. A 1/8" ball was used, with a 100kg force applied, yielding results in the Rockwell E scale. The samples were placed under the ball, and the test was repeated three times per sample, with the average of the three measurements recorded as the hardness.

Tensile Strength & Modulus Measurement

The PET Lab's MTS tensile tester was used to determine ultimate tensile strength and modulus of the ASTM CFRP tensile tabs. It should be noted that all mass and density measurements should be completed prior to using the tensile tester. The large jaws were used, as the peak loads were in the 3200 pound range, exceeding the limits for the small jaws. Each ASTM tab was placed in the jaws as centered as possible. Peak values of tensile strength and modulus were recorded after each run.

Scanning Electron Microscope Images (SEM)

The scanning electron microscope was used to try and identify changes happening on the surfaces of the samples, specifically changes that would not necessarily change the physical properties of the sample. SEM use requires training by WWU Scientific Technical Services personnel.

Results

6061-T6 Aluminum Alloy & E-85
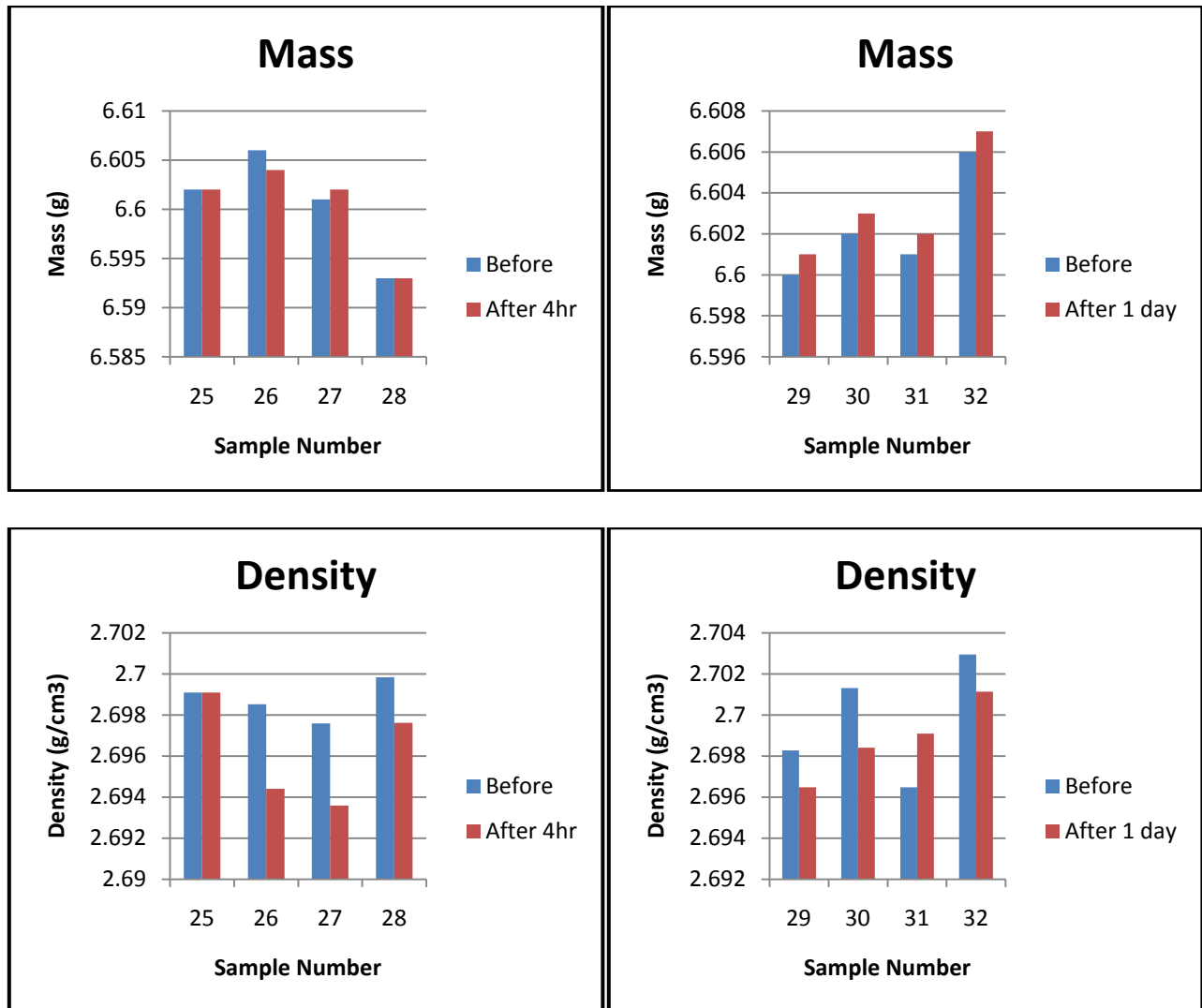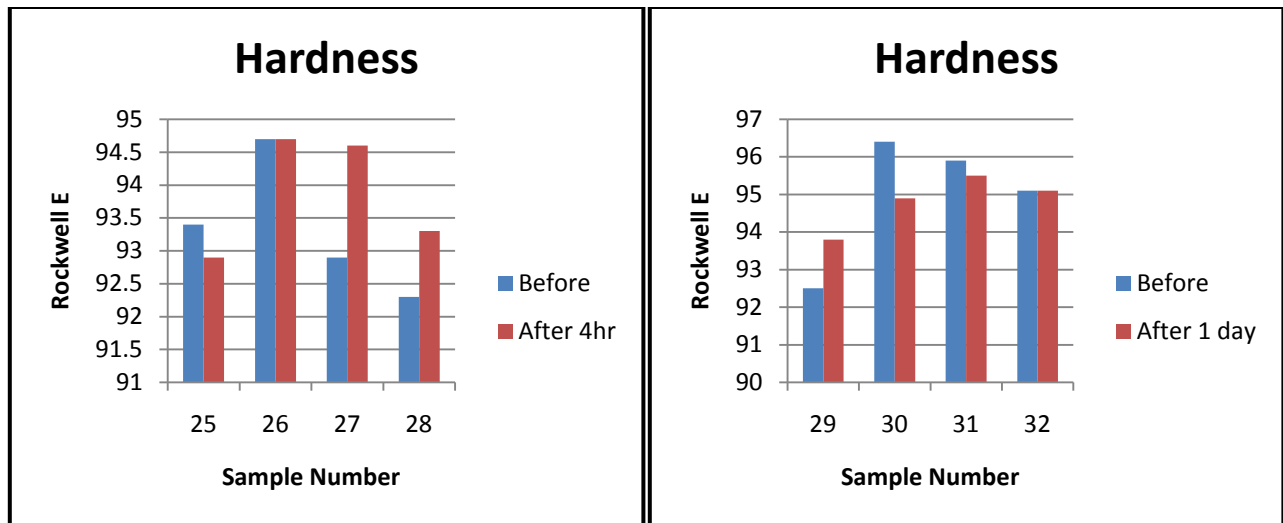
Figure 14 – Summary of 6061-T6 Aluminum Alloy Results

	Mass	Density	Hardness
Average of Base Measurements	6.602	2.7	93.742
Average of 4 Hour Measurements	6.6	2.698	93.875
Average of 24 Hour Measurements	6.603	2.699	94.825
Difference Between Base & 4 Hour	0.002	0.002	0.133
Difference Between Base & 24 Hour	0.001	0.001	1.083
Standard Deviation	0.004	0.003	1.569
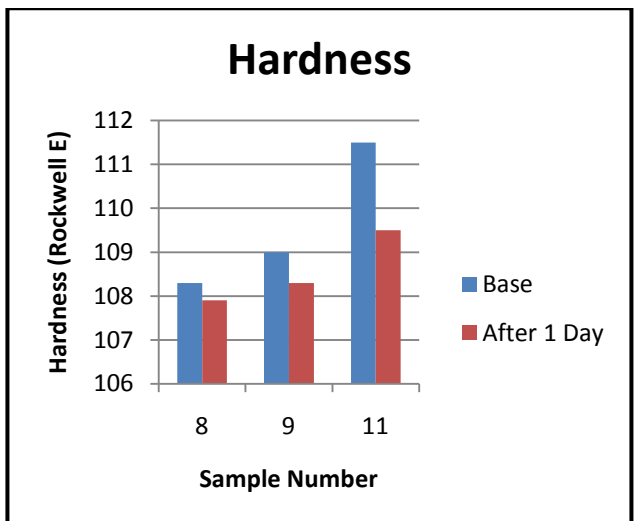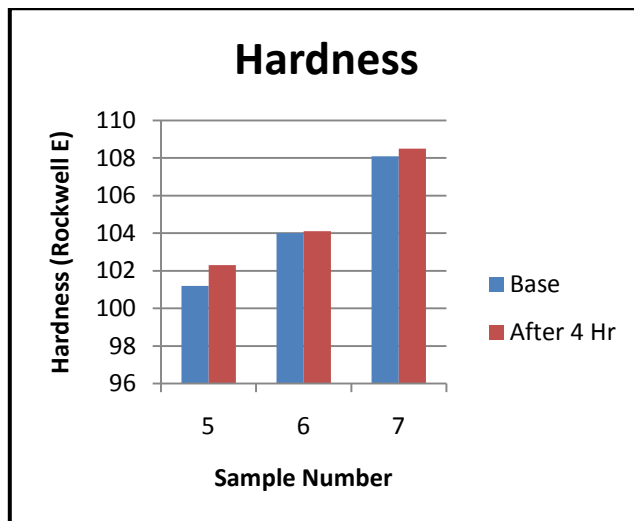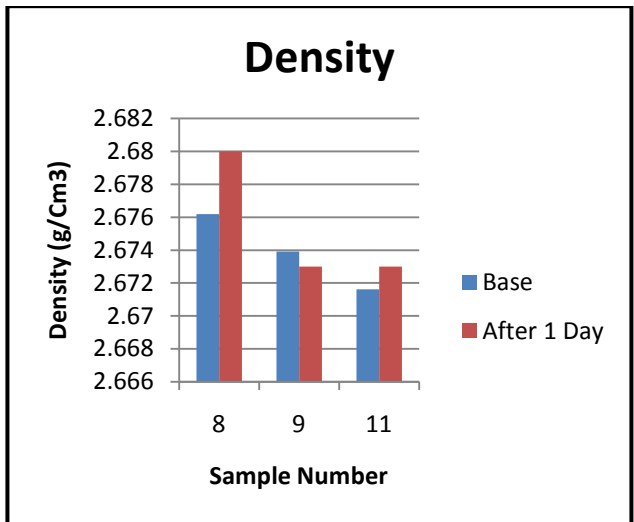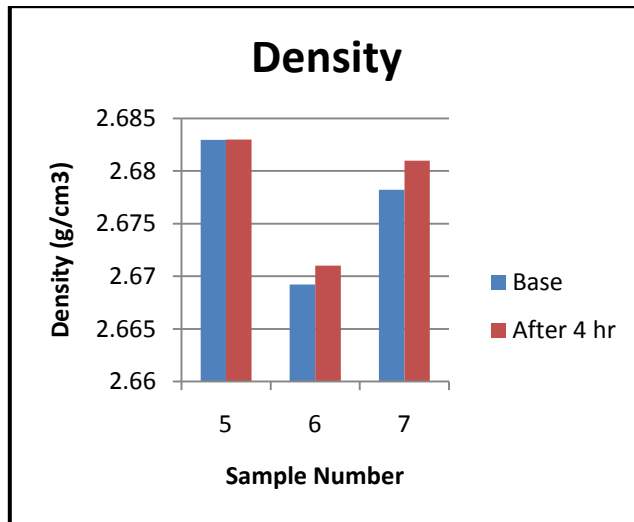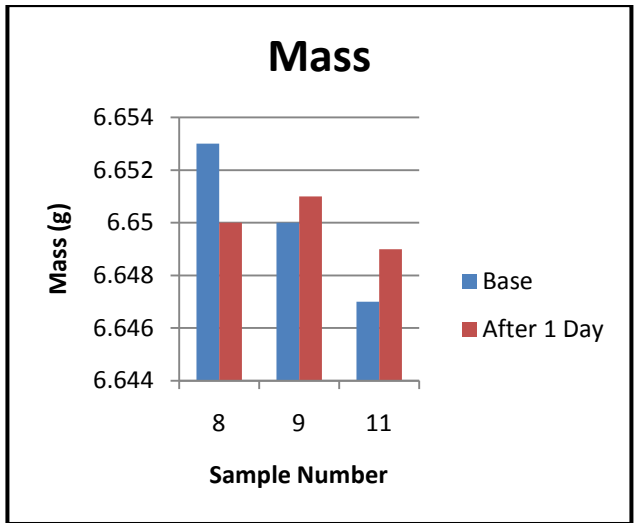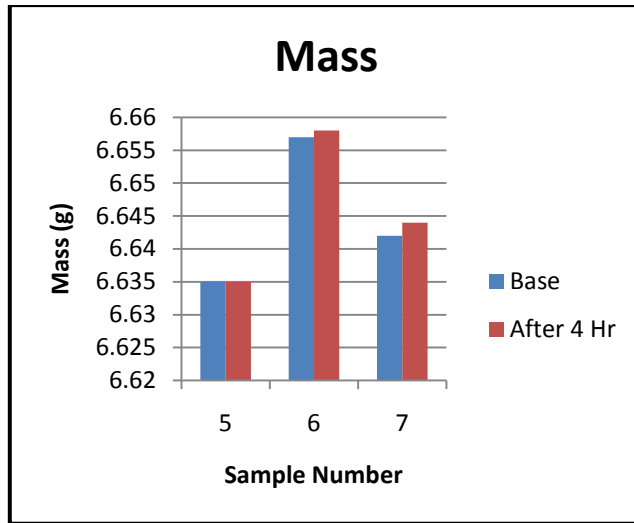
Figure 15 – Summary of Ceramic Coated Aluminum in E-85 Results

	Mass	Density	Hardness
Average of Base Measurements	6.649	2.678	107.500
Average of 4 Hour Measurements	6.646	2.678	104.967
Average of 24 Hour Measurements	6.650	2.675	108.567
Difference Between Base & 4 Hour	0.004	0.000	2.533
Difference Between Base & 24 Hour	0.001	0.003	1.067
Standard Deviation	0.008	0.005	3.242

Thermal Dispersant Barrier Coated Aluminum & E-85
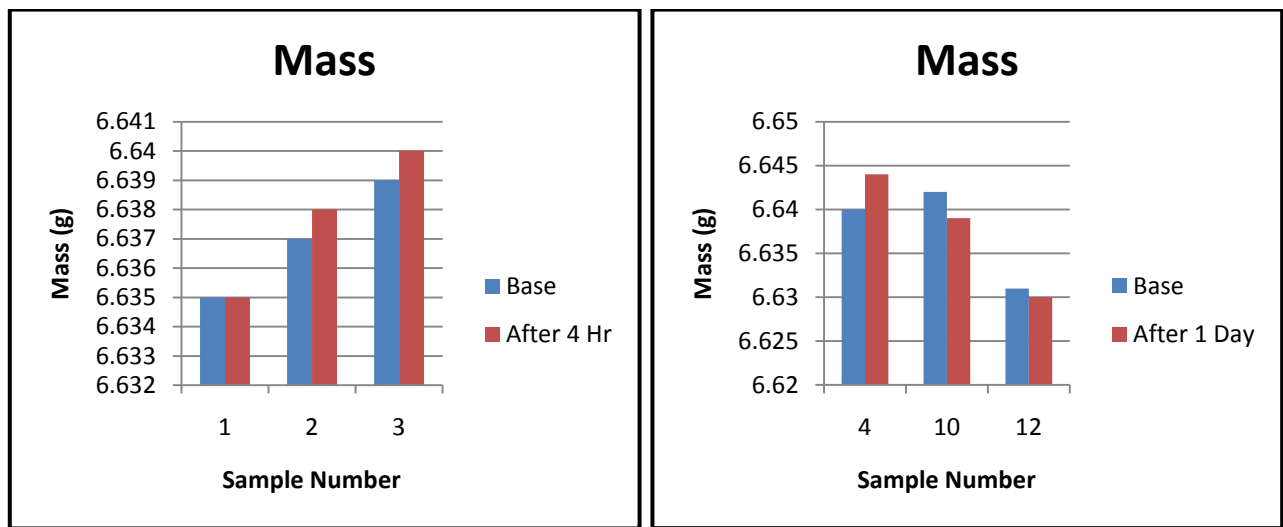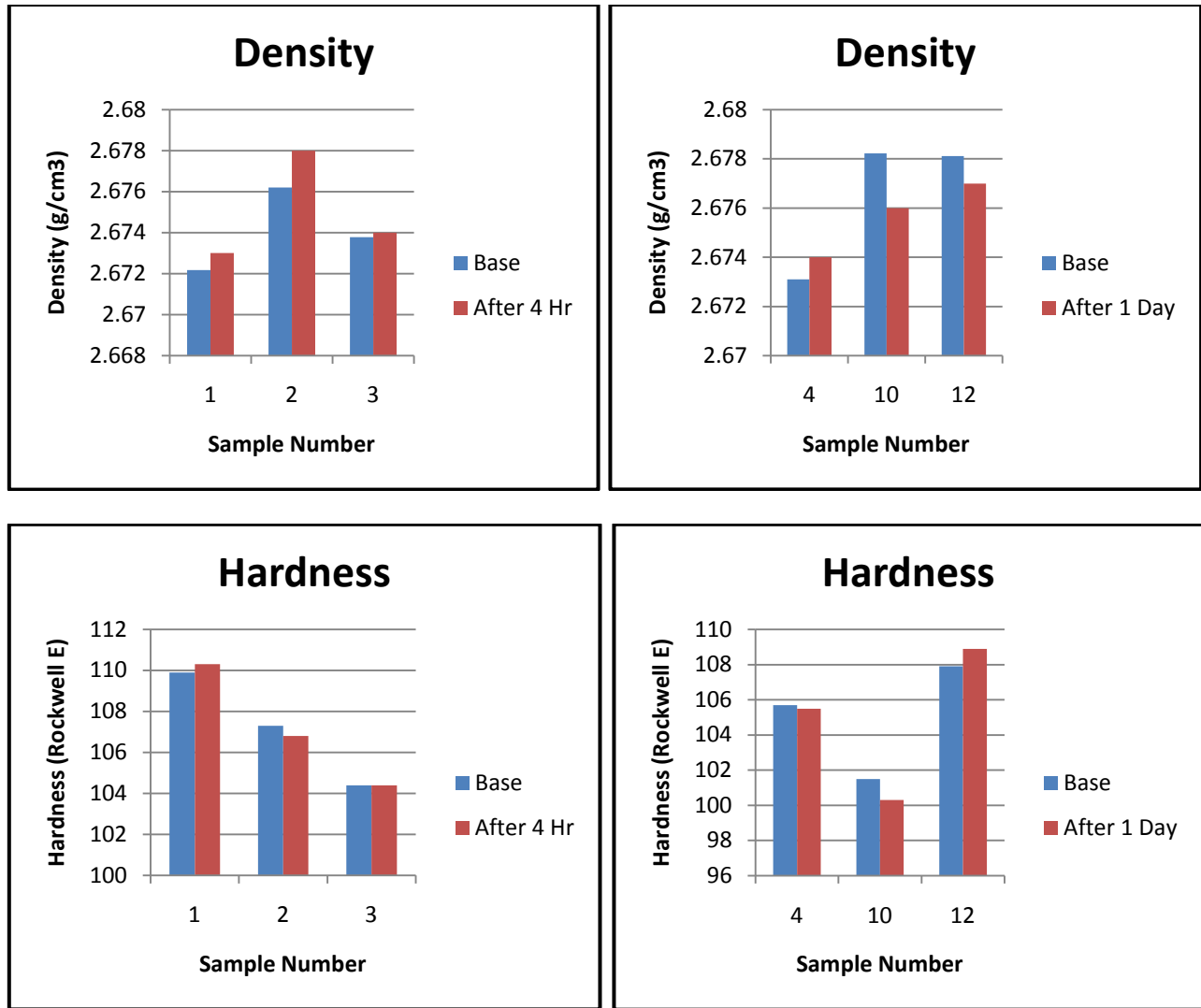
Figure 16 – Summary of Thermal Dispersant Barrier Coating and E-85 Results

	Mass	Density	Hardness
Average of Base Measurements	6.645833333	2.674563346	106.2
Average of 4 Hour Measurements	6.637666667	2.675	107.1666667
Average of 24 Hour Measurements	6.637666667	2.675666667	104.9
Difference Between Base & 4 Hour	0.008166667	-0.000436654	0.966666667
Difference Between Base & 24 Hour	0.008166667	0.00110332	1.3
Standard Deviation	0.011312369	0.002483196	3.170316875

JeffCO 1391 Epoxy Resin & E-85

JeffCO 1391 Epoxy Resin & Gasoline

Average Density

Average Tensile Strength

Average Modulus
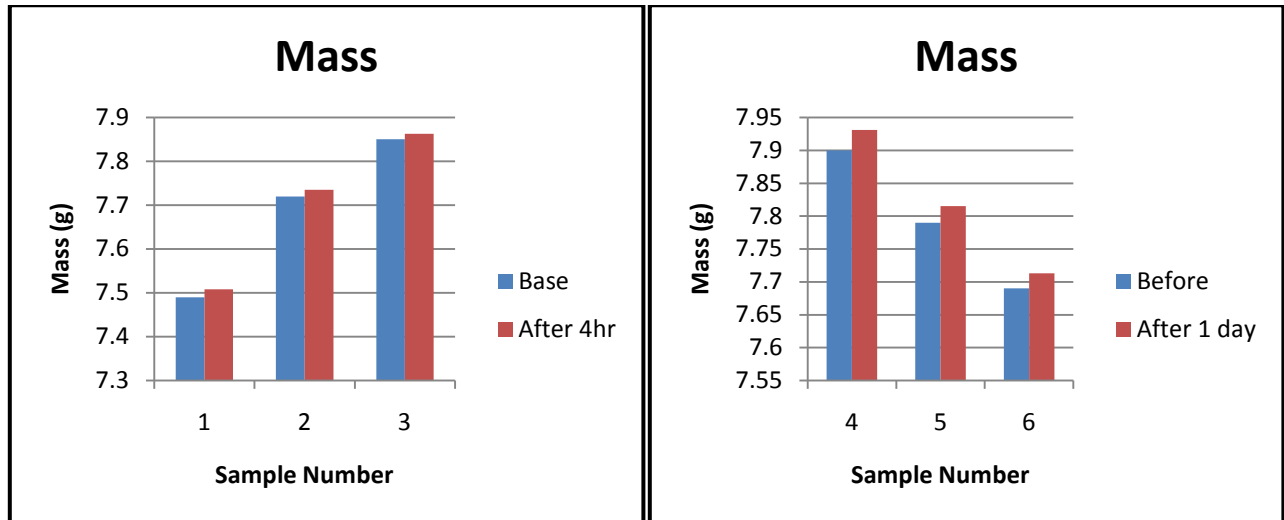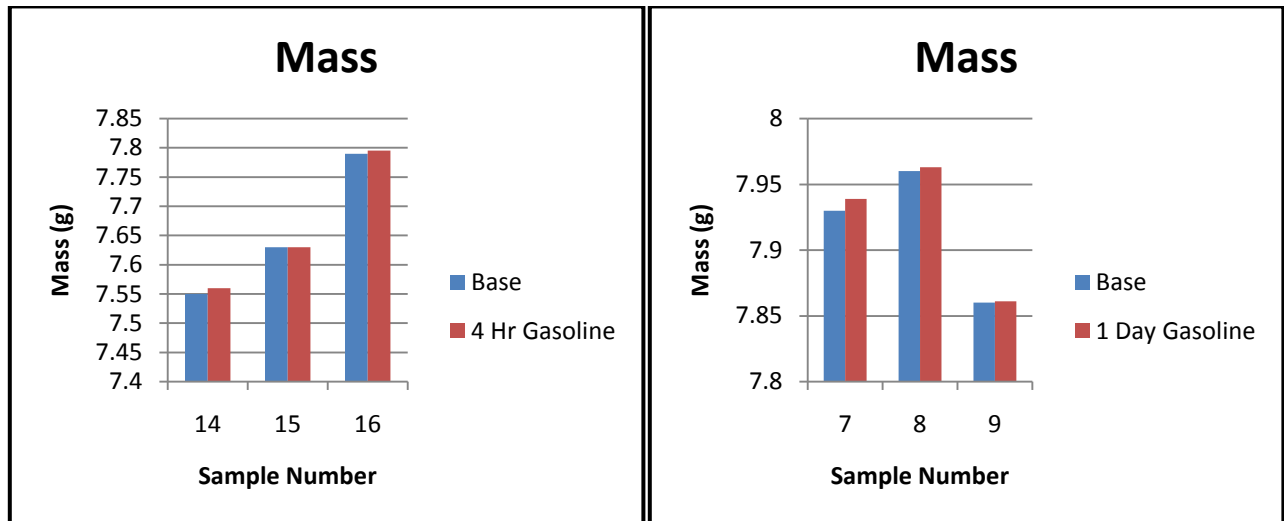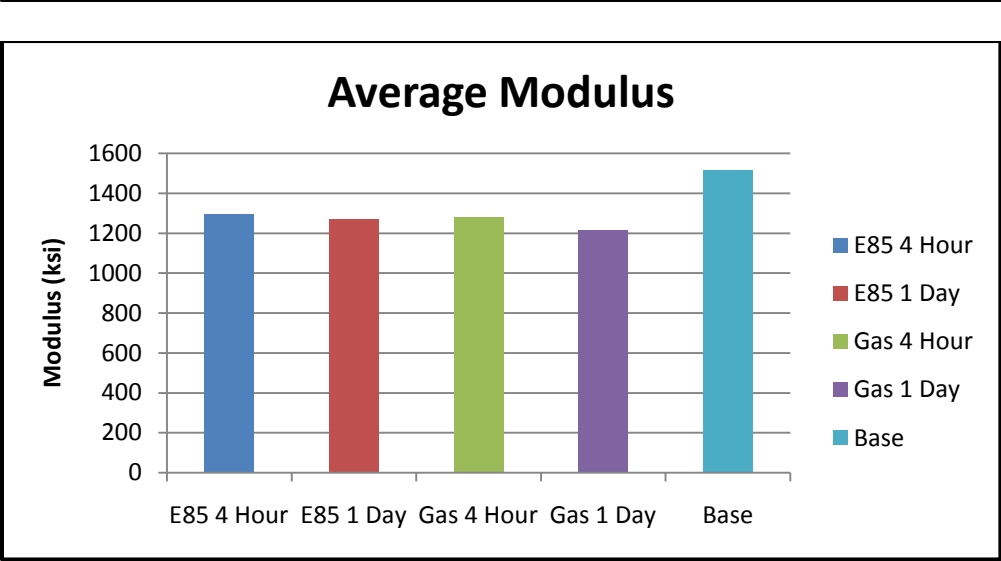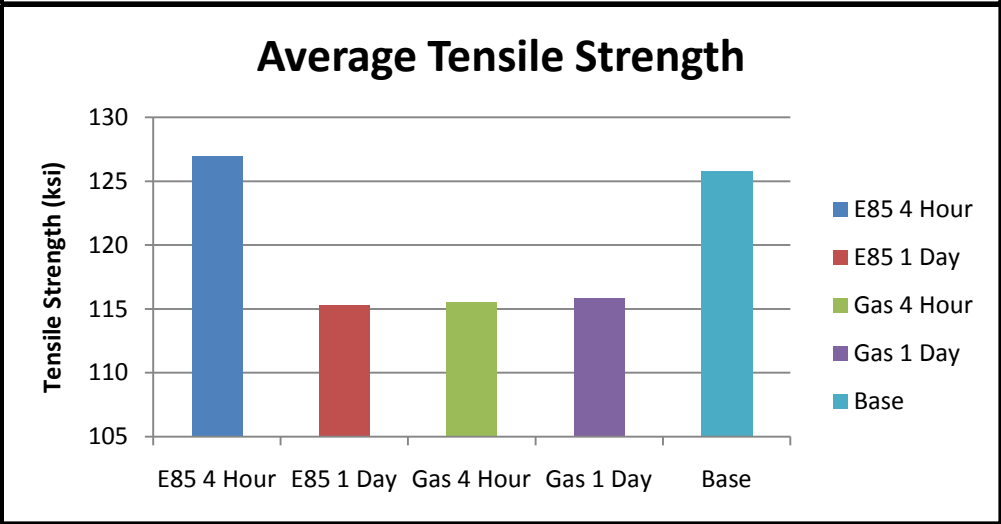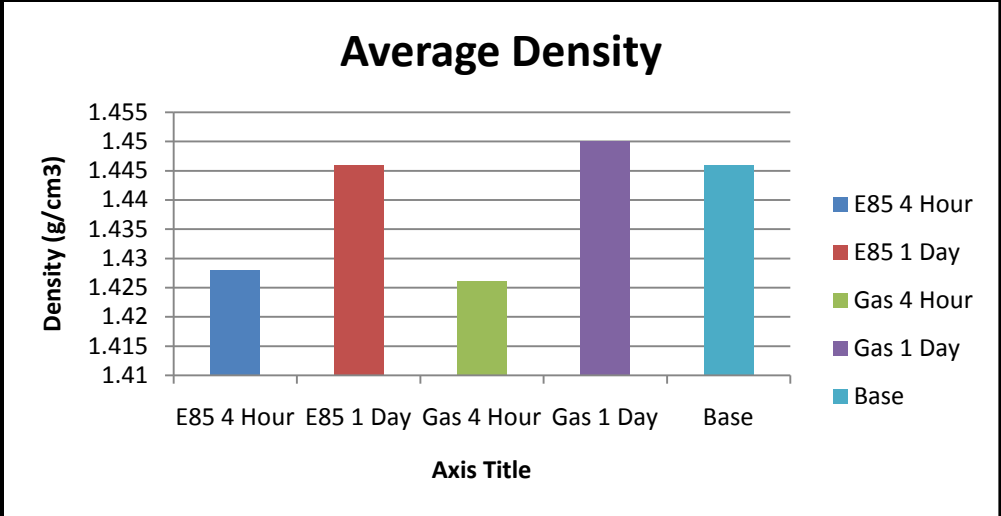
Figure 17 – SEM of JeffCO 1391 CFRP Pre Soak
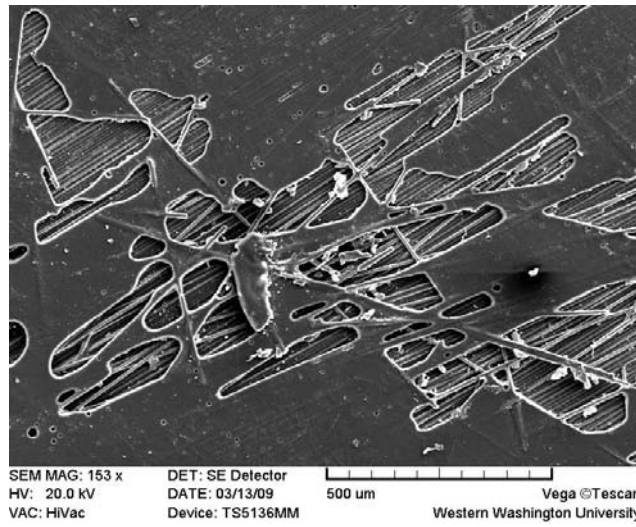
Figure 18 – SEM of JeffCO 1391 CFRP after 1 Day E-85 Soak

SEM MAG: 153 x | DET: SE Detector
HV: 20.0 kV | DATE: 03/13/09 | 500 um | Vega ©Tescan
VAC: HiVac | Device: TS5136MM | Western Washington University

SEM MAG: 132 x | DET: SE Detector
HV: 20.0 kV | DATE: 03/13/09 | 500 um | Vega ©Tescan
VAC: HiVac | Device: TS5136MM | Western Washington University
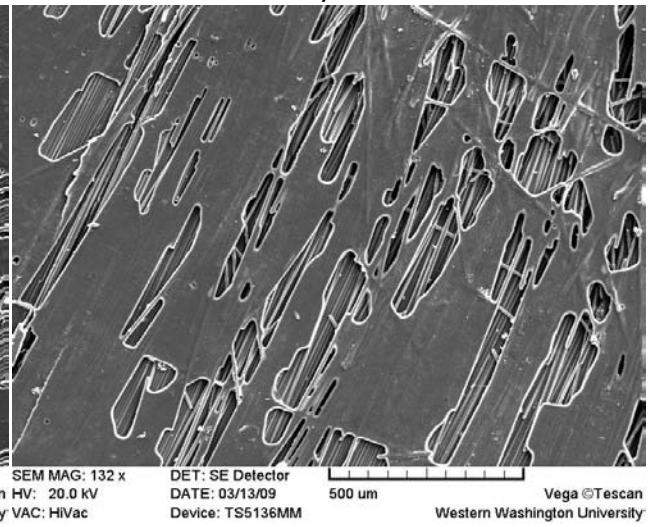
Figure 19 – SEM of JeffCO 1391 CFRP after 1 Day Gasoline Soak

SEM MAG: 150 x | DET: SE Detector
HV: 20.0 kV | DATE: 03/13/09 | 500 um | Vega ©Tescan
VAC: HiVac | Device: TS5136MM | Western Washington University
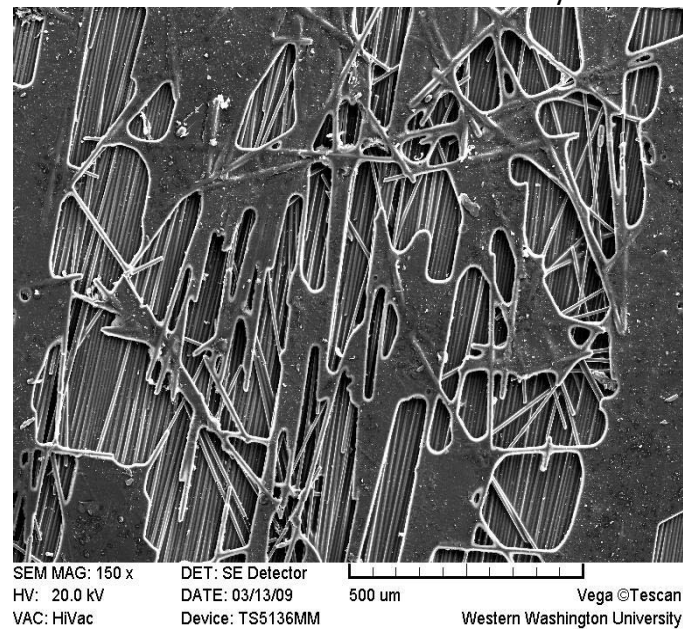
Figure 20 – Summary of JeffCO 1391 CFRP & E-85 Results

	Mass	Density	Tensile Strength	Modulus
Average of Base Measurements	7.723	1.45	125.8	1516.225
Average of 4 Hour Measurements	7.702	1.428	126.933	1294.9
Average of 24 Hour Measurements	7.82	1.446	115.267	1267.4
Difference Between Base & 4 Hour	0.02	0.022	1.133	221.325
Difference Between Base & 24 Hour	0.097	0.004	10.533	27.5
Standard Deviation	0.173	0.025	5.43	137.293

Figure 21 – Regression Analysis of JeffCO 1391 CFRP in E-85:
Factor – Time
Response – Tensile Strength

Regression Statistics	
Multiple R	0.73896
R Square	0.54605
Adjusted R Square	0.48931
Standard Error	5.00451
Observations	10

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	241.015	241.015	9.62325	0.014618405
Residual	8	200.361	25.0451		
Total	9	441.376			

Figure 22 – Regression Analysis of JeffCO 1391 CFRP in E-85:
Factor – Time
Response – Modulus

Regression Statistics	
Multiple R	0.60693

R Square	0.36837	
Adjusted R Square	0.28941	
Standard Error	123.443	
Observations	10	

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	71094.7	71094.7	4.66558	0.062789895
Residual	8	121905	15238.1		
Total	9	193000			

Figure 23 – Summary of JeffCO 1391 CFRP & Gasoline Results

	Mass	Density	Tensile Strength	Modulus
Average of Base Measurements	7.723	1.45	125.8	1516.225
Average of 4 Hour Measurements	7.662	1.446	115.867	1217.067
Average of 24 Hour Measurements	7.921	1.426	115.533	1282.2
Difference Between Base & 4 Hour	0.061	0.004	9.933	299.158
Difference Between Base & 24 Hour	0.149	0.023	10.267	234.025
Standard Deviation	0.173	0.025	5.43	137.293

Figure 24 – Regression Analysis of JeffCO 1391 CFRP in Gasoline:
Factor – Time
Response – Tensile Strength

Regression Statistics	
Multiple R	0.47052
R Square	0.22139
Adjusted R Square	0.12406
Standard Error	7.08007
Observations	10

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	114.025	114.025	2.27471	0.169932188
Residual	8	401.019	50.1274		
Total	9	515.044			

Figure 25 – Regression Analysis of JeffCO 1391 CFRP in Gasoline:
Factor – Time
Response – Tensile Strength

Regression Statistics	
Multiple R	0.35057
R Square	0.1229
Adjusted R Square	0.01326
Standard Error	202.184
Observations	10

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	45822.8	45822.8	1.12096	0.320629673
Residual	8	327026	40878.2		
Total	9	372848			

Renlam 4017 Epoxy Resin & E-85

Renlam 4017 Epoxy Resin & Gasoline

Average Density

Average Tensile Strength

Average Modulus
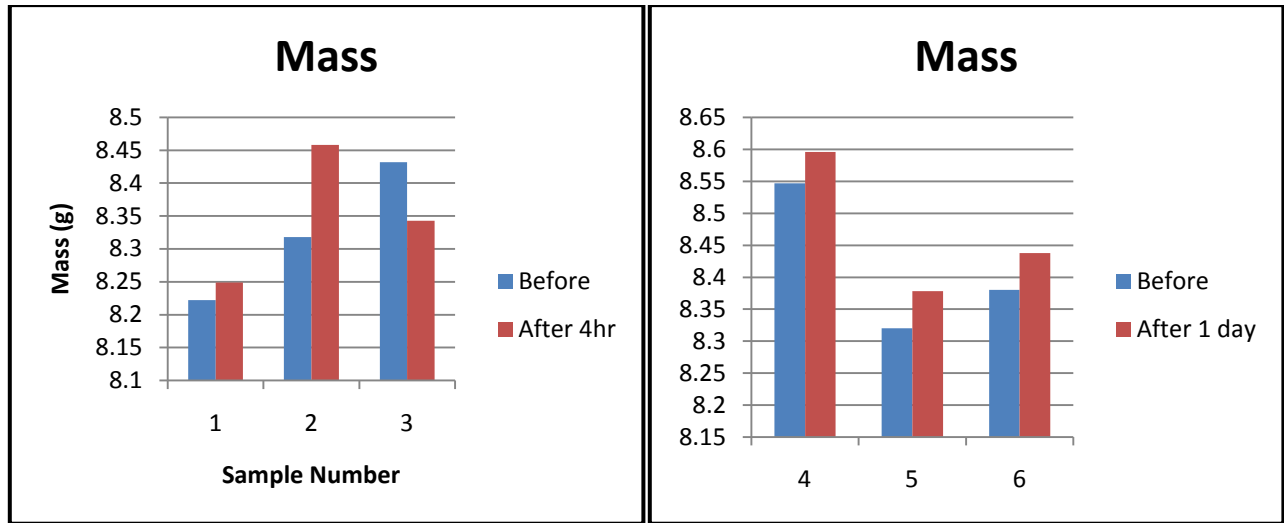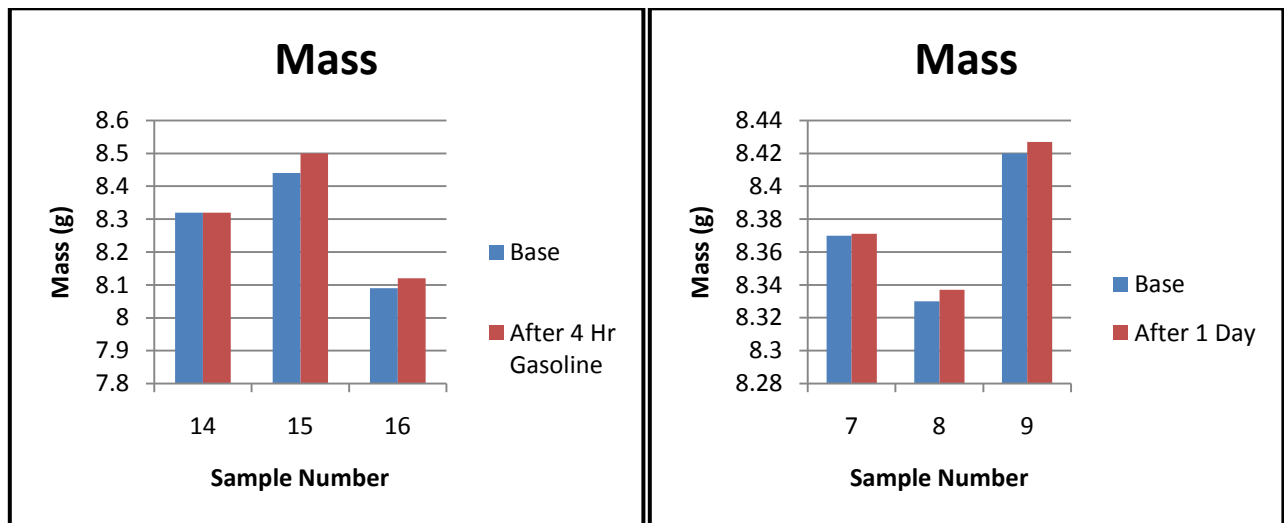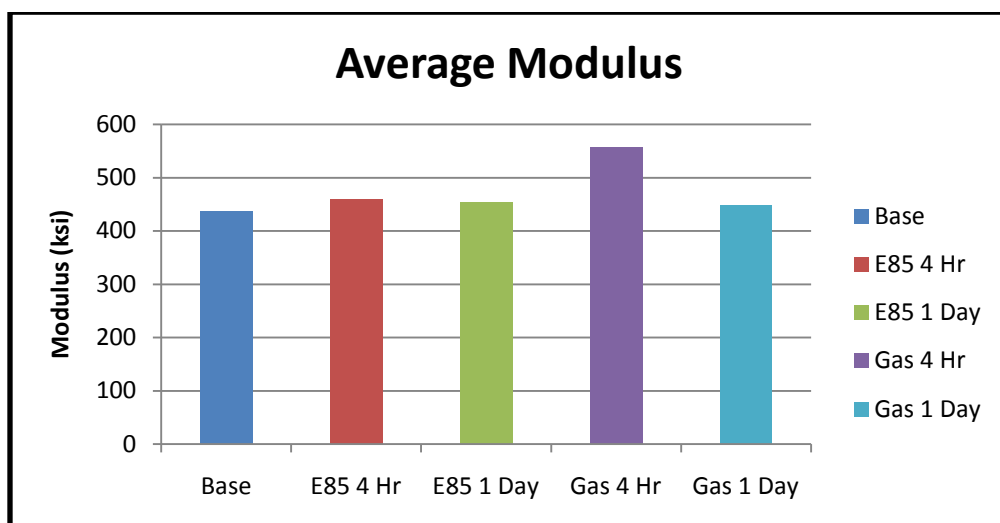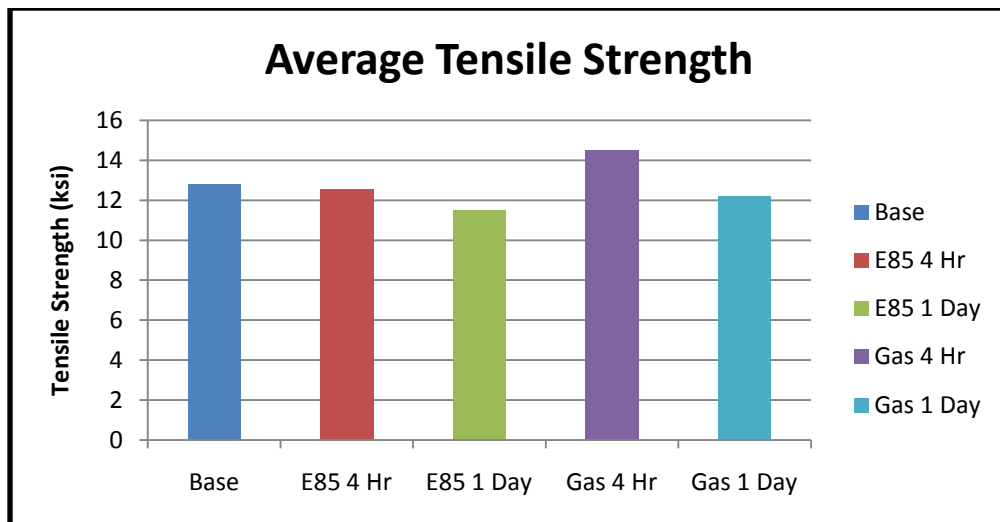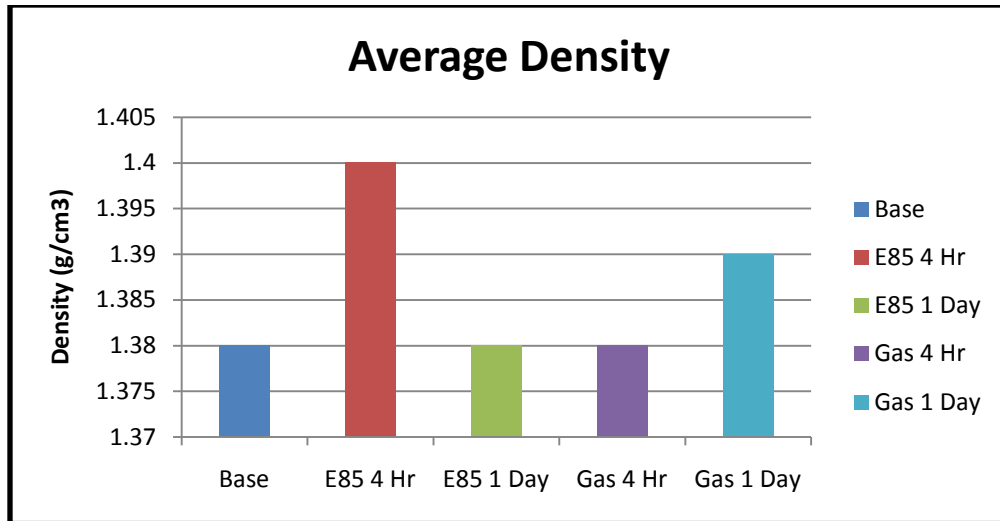
Figure 26 – SEM of Renlam 4017 CFRP Pre Soak   Figure 27 – SEM of Renlam 4017 CFRP After 1 Day in E-85
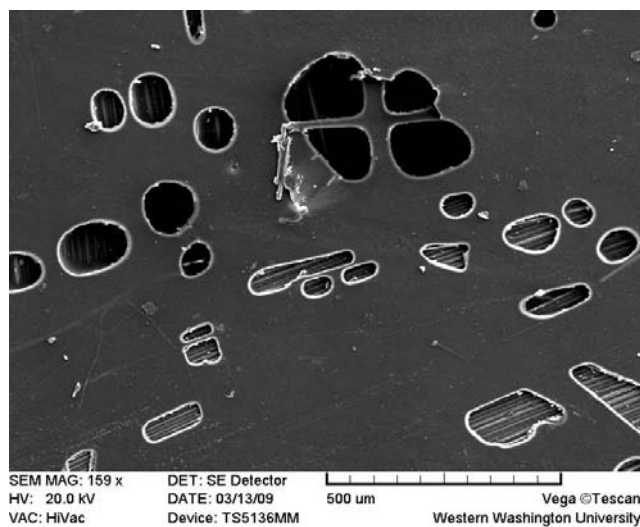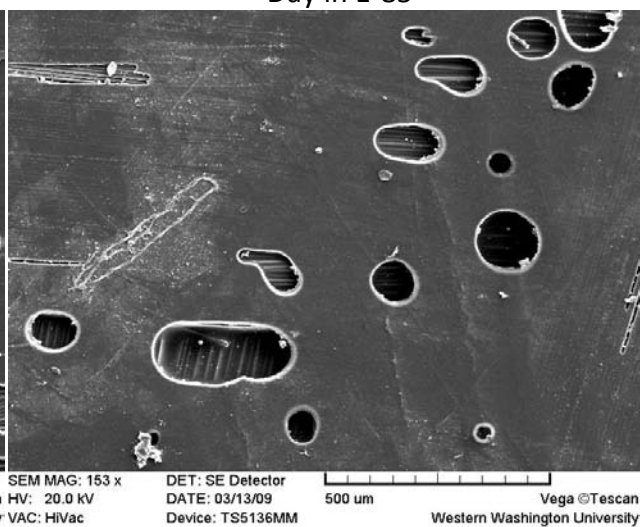
Figure 28 – SEM of Renlam 4017 CFRP After 1 Day in Gasoline
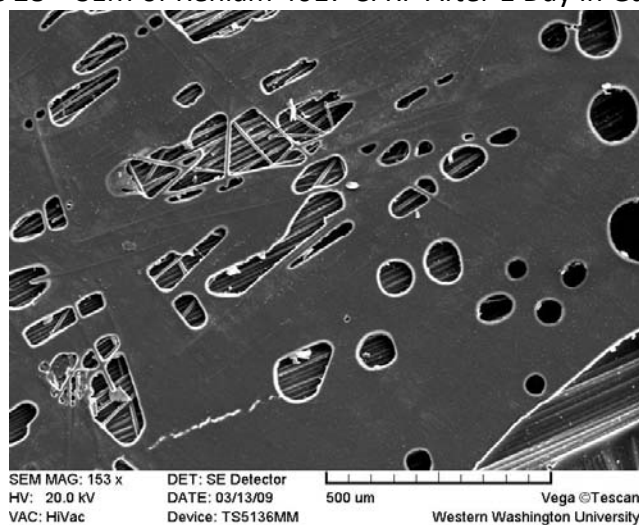
Figure 29 – Summary of Renlam 4017 CFRP & E-85 Results

	Mass	Density	Tensile Strength	Modulus
Average of Base Measurements	7.808	1.381	12.775	436
Average of 4 Hour Measurements	8.35	1.403	12.533	458.1
Average of 24 Hour Measurements	8.471	1.383	11.467	452.533
Difference Between Base & 4 Hour	0.543	0.022	0.242	22.1
Difference Between Base & 24 Hour	0.663	0.002	1.308	5.567
Standard Deviation	0.484	0.03	1.038	22.997

Figure 30 – Regression Analysis of Renlam 4017 CFRP in E-85:
Factor – Time
Response – Mass

Regression Statistics	
Multiple R	0.39373
R Square	0.15502
Adjusted R Square	0.0494
Standard Error	0.60235
Observations	10

ANOVA	df	SS	MS	F	Significance F
Regression	1	0.53254	0.53254	1.46773	0.260272541
Residual	8	2.90264	0.36283		
Total	9	3.43517			

Figure 31 – Regression Analysis of Renlam 4017 CFRP in E-85:
Factor – Time
Response – Tensile Strength

Regression Statistics	

Multiple R	0.4097
R Square	0.16785
Adjusted R Square	0.06384
Standard Error	1.39651
Observations	10

ANOVA

	df	SS	MS	F	Significance F
Regression	1	3.14709	3.14709	1.61369	0.239670945
Residual	8	15.6019	1.95024		
Total	9	18.749			

Figure 32 – Summary of Renlam 4017 CFRP & Gasoline Results

	Mass	Density	Tensile Strength	Modulus
Average of Base Measurements	7.808	1.381	12.775	436
Average of 4 Hour Measurements	8.313	1.41	12.167	447.167
Average of 24 Hour Measurements	8.378	1.383	14.467	557.4
Difference Between Base & 4 Hour	0.496	0.029	0.608	11.167
Difference Between Base & 24 Hour	0.571	0.002	1.692	121.4
Standard Deviation	0.484	0.03	1.038	22.997

Figure 33 – Regression Analysis of Renlam 4017 CFRP in Gasoline:
Factor – Time
Response – Mass

Regression Statistics	
Multiple R	0.33858
R Square	0.11464
Adjusted R Square	0.00397

	Standard Error	0.60177
	Observations	10

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	0.37511	0.37511	1.03586	0.338575379
Residual	8	2.89702	0.36213		
Total	9	3.27214			

Figure 34 – Regression Analysis of Renlam 4017 CFRP in Gasoline:
Factor – Time
Response – Tensile Strength

Regression Statistics	
Multiple R	0.53759
R Square	0.28901
Adjusted R Square	0.20013
Standard Error	1.47802
Observations	10

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	7.10374	7.10374	3.25183	0.109004425
Residual	8	17.4763	2.18453		
Total	9	24.58			

Figure 35 – Regression Analysis of Renlam 4017 CFRP in Gasoline:
Factor – Time
Response – Modulus

Regression Statistics	
Multiple R	0.93405
R Square	0.87246
Adjusted R Square	0.85651

Standard Error	22.8659				
Observations	10				

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	28612.2	28612.2	54.7237	7.64E-05
Residual	8	4182.79	522.849		
Total	9	32795			

West Systems 105 Epoxy Resin & E-85

Average Tensile Strength (ksi)

Tensile Strength (ksi)

106
104 — 104.06
102 — 102.18
100
98
96 — 96.48
94
92

Averages

■ Base   ■ 4 Hour Soak   ■ 1 Day Soak

Average Modulus (ksi)

1400
1200 — 1161.92
1000 — 969.42
800 — 881.16
600
400
200
0

Averages

■ Base   ■ 4 Hour Soak   ■ 1 Day Soak

Average Density (g/cm3)

Density (g/cm3)

1.4
1.38
1.36
1.34
1.32
1.3
1.28

Base   4 Hr Soak   1 Day Soak

■ Base
■ 4 Hr Soak
■ 1 Day Soak

31
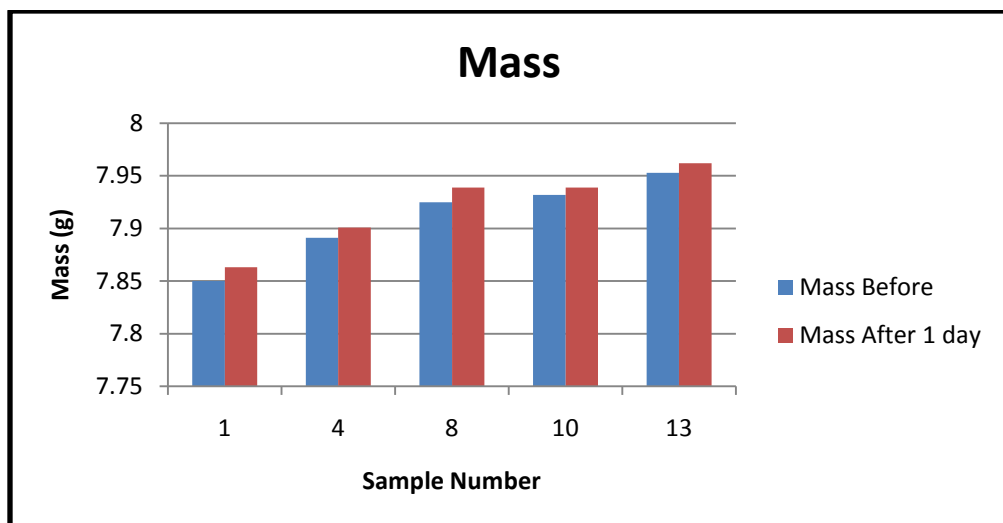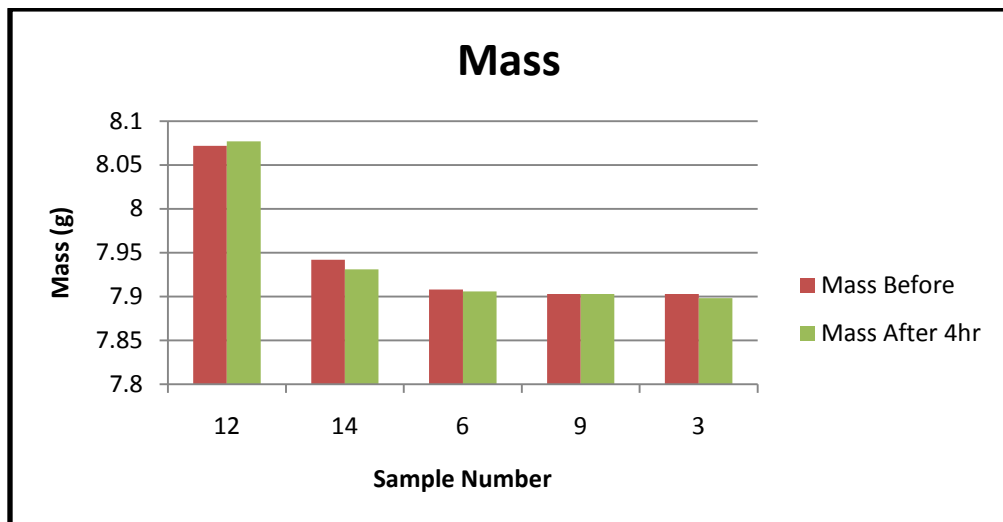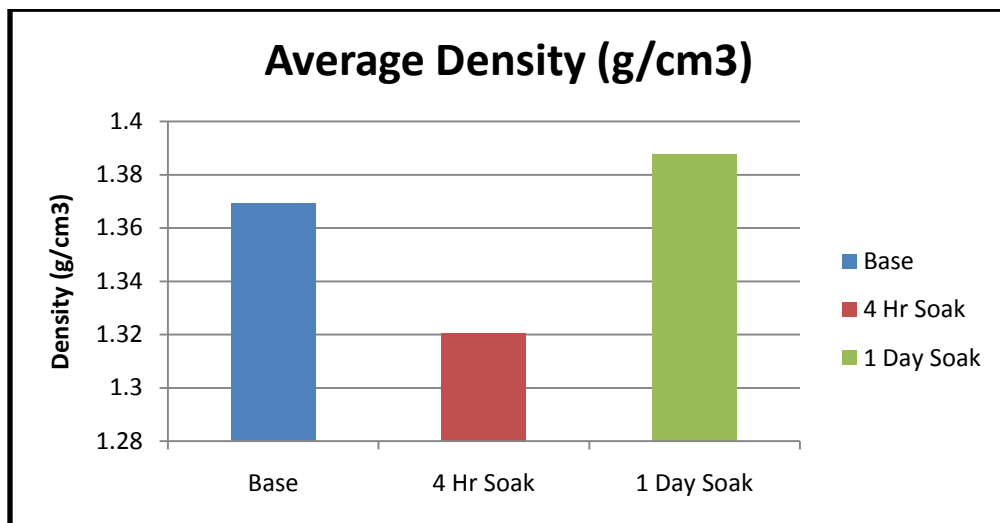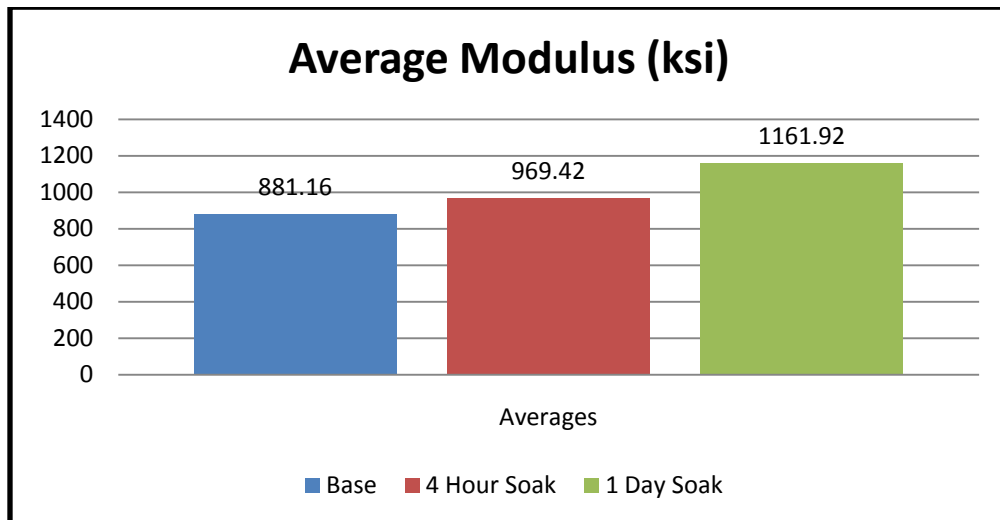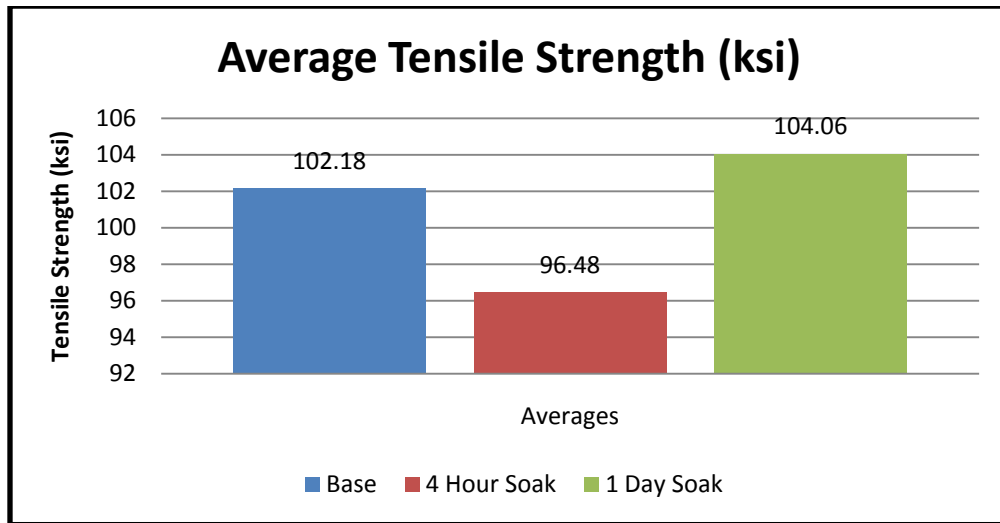
Figure 36 – Summary of West Systems 105 CFRP & E-85 Results

	Mass	Density	Tensile Strength	Modulus
Average of Base Measurements	7.929	1.359	102.18	881.16
Average of 4 Hour Measurements	7.943	1.369	99.48	969.42
Average of 24 Hour Measurements	7.921	1.321	104.06	1161.92
Difference Between Base & 4 Hour	0.014	0.01	2.7	88.26
Difference Between Base & 24 Hour	0.009	0.039	1.88	280.76
Standard Deviation	0.057	0.04	4.164	157.21

Figure 37 – Regression Analysis of West Systems 105 CFRP in E-85:
Factor – Time
Response – Modulus

Regression Statistics	
Multiple R	0.61701
R Square	0.3807
Adjusted R Square	0.33306
Standard Error	158.644
Observations	15

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	201128	201128	7.99148	0.01427458
Residual	13	327182	25167.9		
Total	14	528311			

Timeline

Figure 38 – Initial Timeline

Task	Start	End	Duration	Fall Quarter			Winter Quarter		
				October	November	December	January	February	March
Project Proposal	10/1/2008	12/8/2008	63						
Project Proposal Due	12/8/2008	12/8/2008							
Materials Acquisition	11/1/2008	12/20/2008	47						
Polymer Test Material Fabrication	12/18/2008	1/16/2009	26						
Aluminum Test Material Fabrication	12/18/2008	1/23/2009	32						
Polymer Testing	1/16/2009	2/1/2009	15						
Aluminum Testing	1/23/2009	2/7/2009	15						
Analysis of Results	2/7/2009	2/14/2009	7						
Final Report Write-up	2/14/2009	3/16/2009	28						
Final Report Write-up Due	3/16/2009	3/16/2009							

Figure 39 – Revised Timeline

Task	Start	End	Duration	Fall Quarter			Winter Quarter		
				October	November	December	January	February	March
Project Proposal	10/1/2008	12/8/2008	68						
Project Proposal Due	12/8/2008	12/8/2008							
Materials Acquisition	11/1/2008	3/9/2009	128						
Polymer Test Material Fabrication	12/18/2008	1/16/2009	29						
Aluminum Test Material Fabrication	12/18/2008	1/23/2009	36						
Polymer Testing	1/16/2009	2/13/2009	28						
Aluminum Testing	1/23/2009	3/17/2009	53						
Analysis of Results	2/7/2009	3/17/2009	38						
Final Report Write-up	2/14/2009	3/16/2009	30						
Final Report Write-up Due	3/16/2009	3/16/2009							

Cost Information

Figure 40 – PET Lab Materials Used

Item	Qty
Stir Sticks	11
Chip Brushes	10

33

JeffCO 1391 Epoxy Resin	148g
JeffCO Hardener	24g
Renlam 4017 Epoxy Resin	133g
Renlam Hardener	18 g
Peel Ply	8 ft^2
Bleeder	16 ft^2
Vacuum Bag Material	20 ft^2
Yellow Sealant Tape	0.5 Roll
MTS Use	3.5 Hrs

Figure 41– Itemized Purchases and Costs

Item	Date	Location	Qty	Price (ea)	Tax	Total
92 Octane Fuel (for testing)	3/5/2009	Super V Gas, Bellingham, WA	2.008	2.589	N/A	$5.20
E85 Fuel (for testing)	3/1/2009	Shell Gas, Marysville, WA	5.216	2.279	N/A	$11.89
Poly Gas Can (5gal)	3/5/2009	Hardware Sales, Bellingham, WA	1	9.49	1.085	$10.30
West Systems Epoxy	3/5/2009	Hardware Sales, Bellingham, WA	1	93.99	1.085	$101.98
West Systems Epoxy Hardener	3/5/2009	Hardware Sales, Bellingham, WA	1	39.99	1.085	$43.39
SeaFin Varnish/Protectant	3/5/2009	Hardware Sales, Bellingham, WA	1	16.99	1.085	$18.43
Poly Gas Can (5gal)	2/27/2009	Hardware Sales, Bellingham, WA	1	9.49	1.085	$10.30
Stainless Steel Hemostat	2/27/2009	Hardware Sales, Bellingham, WA	1	7.49	1.085	$8.13
Masking Tape (blue)	2/27/2009	Hardware Sales, Bellingham, WA	2	3.29	1.085	$7.14
Water Jet Fee	1/2009 - 2/2009	Western Washington University	N/A	N/A	N/A	TBD
PET Lab Use Fee	9/2008 - 3/2009	Western Washington University	N/A	N/A	N/A	TBD
FedEX Shipping		From: Performance Coatings, Auburn, WA To: WWU				TBD
					TOTAL	$216.75

Analysis

Implementation

The original timeline was designed to give a buffer for any problems that may arise. As should be expected when dealing with outside suppliers, there were a couple supplier setbacks that held back the progress of the testing.

First, the original company that was contacted to perform anodizing coatings sent back the parts without the process performed. After a few exchanges, it was decided the lead time to send back the parts for anodizing was too long, and thus anodized aluminum was removed from the test schedule.

Secondly, the supplier that performed the ceramic coating estimated a lead time of 2 weeks for their thermal dispersant barrier coating, however it ended up being a 5 week lead time. Since the materials were going to be received the week before the final report deadline, it was determined that a brief extension would allow for the testing of said materials. Due to the unexpected shortened time for testing after receiving the coated aluminum materials, only E-85 testing was performed.

Data

For the aluminum samples, once the data was recorded, comparisons were made between base measurements and post-soak data. Due to the tungsten filament requiring replacement, the aluminum SEM images were limited to ~500 µm, and no useful conclusions could be made, so results and analysis is omitted for lack of clutter.

For the CFRP samples, averages of base measurements were compared to averages of soaked samples. This is due to the fact that it is not possible to pre-test a sample for properties such as tensile strength and modulus and then retest them after the soak period. Once the sample is tested, it is in fact destroyed.

The Data was summarized for each sample type and for each fuel. Comparisons were made between the base measurements and the four and twenty-four hour soak periods. These differences were then viewed in relation the standard deviation of the test. If the differences were greater than the standard deviation, further regression analysis was conducted to determine statistical significance.

Of the ten differences in measured responses, only three of these were statistically significant. A statistically significant measurement was one that had a *p-value* of less than 0.05 (regression analysis was performed with a confidence interval of 95%).

Figures 19, 33, and 35 outline the regression analysis for the three statistically significant data sets. According to the data, JeffCO 1391 Epoxy Resin in E-85 has a significant effect on tensile strength,

Renlam 4017 Epoxy Resin in gasoline has a significant effect on modulus, and West Systems 105 Epoxy Resin has in E-85 has a significant effect on modulus.

However, closer examination of this data suggests that some are not practically significant. For both the reaction of Renlam 4017 and West Systems 105, the modulus increased after the soaking period. This suggests that the material increases in physical strength when exposed to liquid fuels, which is obviously not the hypothesized result, nor practically relevant. Therefore, those two data sets are dismissed.

Lastly, it must be noted that the statistically significant reaction between JeffCO 1391 and E-85 with an effect on tensile strength was measured on a machine with high variance. Even though the difference in measured response is outside the standard deviation, there is always variance in measurement processes. Additionally, correlation does not equal causation, and this should always be remembered when analyzing data of this sort.

Ethics

There are not many ethical considerations when dealing with race cars and internal combustion engines. However, if the Western Washington University decides to switch to E-85 fuel, the principal ingredient, the ethanol, is created in the United States. Since energy independence is fast becoming a serious national security threat, the more we can sustain our own needs, the less we need to rely on an unstable middle-east.

Recommendations for Future Work

There is strong supporting evidence that temperature has a significant affect on corrosion of aluminum. It would be ideal to setup a room where the temperature can be raised safely without concern for combustion of the fuel vapors. Once idea, is use an electric heating blanket or a secondary heating source, where the heating elements are not in the same enclosure as the test samples. Ideal upper level of temperature would be roughly 142°F, which is the approximate maximum temperature the intake assembly will see (via datalogging of the intake-air temperature sensor + saturation estimate in 100°F ambient conditions).

Additional materials should be tested, specifically polymers. It would be worth the effort to try and test different resins. One idea would be to test only the resins, and not include the carbon reinforcement. Test methods would remain mostly the same, as tensile molds can be used to cure resin. This would isolate the reaction to just the epoxy or resin.

It would be interesting to see the reaction PEEK has with E-85 and gasoline, as it is known for its chemical resistance. Processing could be accomplished by using heating elements on the aluminum compression molder tensile bar molds. Temperatures much reach approximately 800°F for the PEEK to successfully cure.

It would also be useful to perform a *Measurement System Analysis* on the Mettler Balance and MTS Tensile Tester station. From this Six-Sigma tool, actual metrics for measurement repeatability and reproducibility could be quantified and used to more precise conclusion making.

Most importantly, longer testing times are going to be required to see substantial results. Test periods of up to three to four weeks should be used to truly examine how E-85 can cause corrosion of the test samples. The painting room has optimum shelf space that is not in general use, so test samples can remain without getting in the way of other students' projects.

Conclusion

Initially, a set of matrices were going to be the deciding factor in the selection of materials suitable for an E-85 operating environment. However, since the testing had no practical or definitive result, there is not enough evidence to support the use of E-85 when used with aluminum and composite intake structures. At the same time, there is not enough evidence to support the claim that ethanol blended fuels corrode aluminum or polymer based composites. With this known, the Western Washington University Formula SAE team could potentially test E-85 in their 2009 car. However, the true effects of ethanol blended fuels are unknown at this point in time, and caution should be used, including frequent inspection of intake components.

With this in mind, there was some valuable data collected from the testing process. JeffCO 1391 Epoxy Resin and West Systems 105 Epoxy Resin had nearly equal physical properties, however the West Systems resin had a cure nearly half of the JeffCO. Additionally, the Renlam 4017 Epoxy Resin had horrible physical properties, on a scale of about 10% that of JeffCO or West Systems. Due to these facts alone, it was determined to begin construction of intake components using West Systems 105 Epoxy Resin.

The aluminum injector base component is going to remain the same, as a carryover item from the 2008 car, Viking 43. Since the supplier of the coatings for this testing is a sponsor of the Formula SAE team, the coatings they offer are free. Since the thermal dispersant barrier coating has advertised cooling properties that would be ideal in a high-performance vehicle, this coating will be used.

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