Tensile, Fatigue, and Impact Testing of Aluminum and Carbon Fiber

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Abstract

Tensile tests, fatigue analysis, and impact tests were run on carbon composite made in house and aluminum 2024 - T3 to determine their physical properties. It was determined that while the carbon fiber performed well, it is not capable of elastic deformation. Instead, carbon fiber fractures, making aluminum the more malleable material. Both materials have their strengths and situations in which they are used.

Nomenclature

A	=	Area
E	=	Young's Modulus
F	=	Uniaxial Load
ϵ	=	Engineering Strain
ν	=	Poisson's Ratio
σ	=	Engineering Stress

I. Introduction

The purpose of this experiment is to observe and analyze material mechanical properties of both aluminum alloy and carbon composite which was fabricated in the lab. Understanding how materials behave when various forces are applied to them is crucial. This includes methods such as tensile strength tests, fatigue analysis, and impact tests. This experiment was conducted in a way to understand how engineers design a physical system that is strong enough as well as the appropriate stiffness. Failure is when a component or system can no longer safely perform its intended function within the specified requirements. This experiment is a useful method to observe such changes to ensure the reliability of the engineering systems subjected to various loading conditions.

II. Methods and Materials

As part of the experiment, carbon-fiber reinforced polymer (CFRP) or also called prepreg, was fabricated in the lab. Note that the prepreg used in the lab is old carbon fiber prepreg donated from companies as it was deemed too old to use. Due to the prolonged age of this prepreg, the material characteristics will differ from that of a fresh prepreg. This material was stored in a freezer to prevent it from curing since the material is embedded in a matrix of epoxy resin. The methods of fabrication consist of preparing the metal base plate, laying down the prepreg, peel ply, release film, and breather fabric, vacuuming, and working the autoclave.

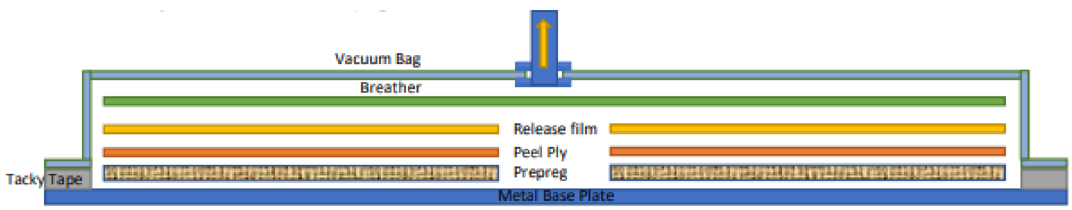

Figure 1. Schematic Diagram of the Final Layup

Before applying the layers, the metal base plate was cleaned thoroughly by sanding and razor blading the surface followed by a few coatings of release agents. Any remaining dust and contamination was chemically wiped away. Tacky tape was placed around the edges of the metal base. The figure above shows the order of layers in order to fabricate the carbon composite. However, one major change in this fabrication was that the release film was positioned right above the metal base plate instead of above the peel ply to ensure a more successful vacuum. The purpose of the peel ply is to absorb the resin matrix as well create a desirable bonding surface. There should not be any creases on the peel ply. Six layers of prepreg were used. Table below shows the dimensions at which the layers were cut.

Table 1. Dimensions of Final Layup Table

Dimensions	
Composite Prepreg	9" x 16.75"
White Peel Ply and Blue Release Film	9.5" x 16.75"
Breather Fabric	4 × (9.5" x 16.75")

The vacuumed material was then processed in the autoclave where it was exposed to a specified pressure and temperature. After the autoclave process, the resulting carbon composite was sliced into given dimensions for impacting and tensile testing. **Figure 2** shows the dimensions and position of the four layups on the metal base plate.

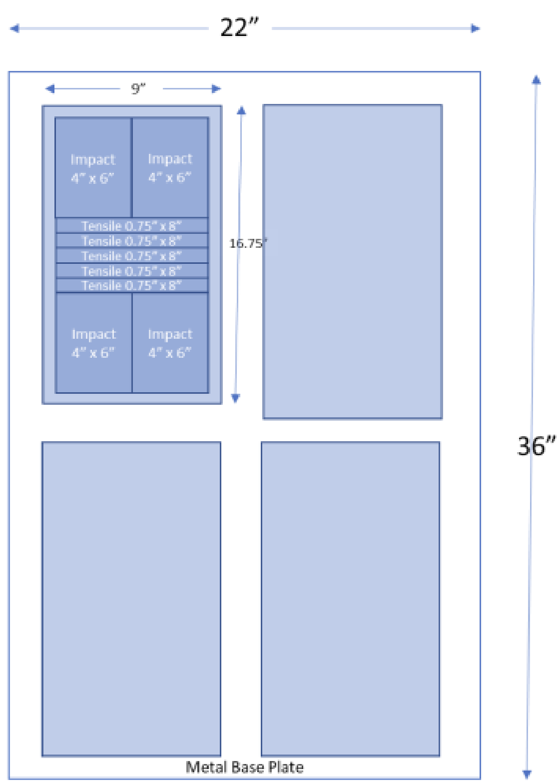

Figure 2. Metal Base Plate and Carbon Specimen Dimensions

Tensile testing was done to understand the stress and strain characteristics of each specimen. Strain gauges were attached to the specimen as a way to measure the change in elongation. To ensure the accuracy of our measurements, the aluminum surface was sanded down and thoroughly cleaned using a degreaser before the strain gauge was attached. Each specimen was tested on the Instron machine where they will undergo a uniaxial load. The relationship between stress and strain is shown in Eq. (1). Definition of engineering stress is also shown in Eq. (2).

$$\sigma = E\epsilon \tag{1}$$

$$\sigma = \frac{F}{A} \tag{2}$$

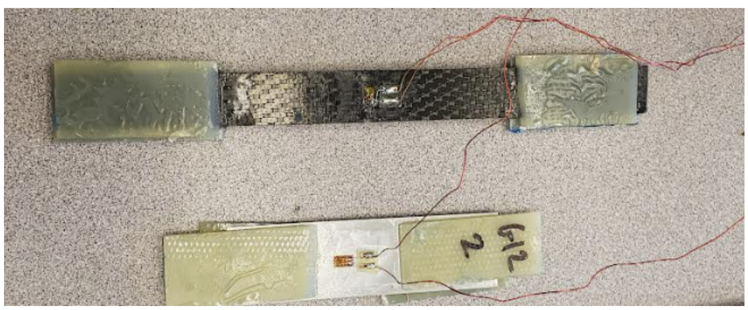

Figure 3. Carbon Composite and Aluminum Specimen

Fatigue testing was done using the Instron 8801. Fatigue is the failure under applied cyclic stress. In this fatigue experiment, the cyclic frequency was 20 Hz. One aluminum specimen was tested with no strain gauge attached. A hole was drilled mid length of the specimen so that the failure would occur at that point due to the stress concentration at the edges of the hole.

For the impact test, the samples were secured at the bottom of the Dynatup machine between its two plates and the weight was raised to a selected drop height for each test. The drop height of the first three impact tests was determined by observing the damage from other groups' impact tests and their associated heights, and using this information to estimate values that would provide minimum, moderate and heavy damage. We decided to leave the fourth drop height to be determined after the conclusion of the first three tests so that we may obtain one of the damage levels if our carbon fiber characteristics were different from other groups', which ended up being the case as our carbon fiber was stiffer and more durable so we had to pick a larger height to get the heaviest damage level. The minimum and maximum diameter of the indentation was measured for each sample, and the impact depth was measured from the top of the sample to the end of the split fibers. The drop heights are listed in table 2 below.

Table 2. Impact test drop heights

Sample	Drop Height [cm]
A	41.91
B	46.99
C	38.10
D	52.71

An extensometer was used during the lab to measure the changes of length of the carbon specimen. It is a useful device to measure and calculate Elastic Modulus and Yield Strength.

III. Results

Table 3 below shows the dimension of each specimen that was tested for tensile stress and strain. It is worth noting that the second specimen failed under buckling during the mounting and calibration setup of the experiment. Therefore, the transverse mounted strain gauge was not recorded. The figures below show the uniaxial load versus extension and tensile stress versus axial mounted strain gauge.

Table 3. Tensile Testing Carbon Specimen Dimensions

	Specimen 1	**Specimen 2**	**Specimen 3**	**Specimen 4**
Length [mm]	195	198	193	199
Thickness [mm]	1.435	1.428	1.41	1.436
Width [mm]	16.64	17.47	16.94	16.6

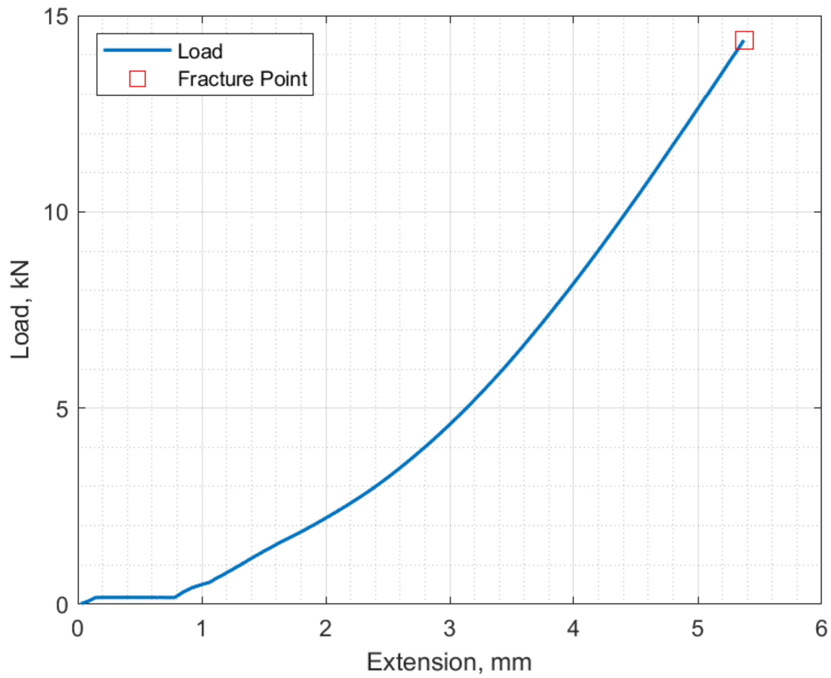

Figure 4. Axial Mounted Strain Gauge, Specimen 1 Load vs. Extension

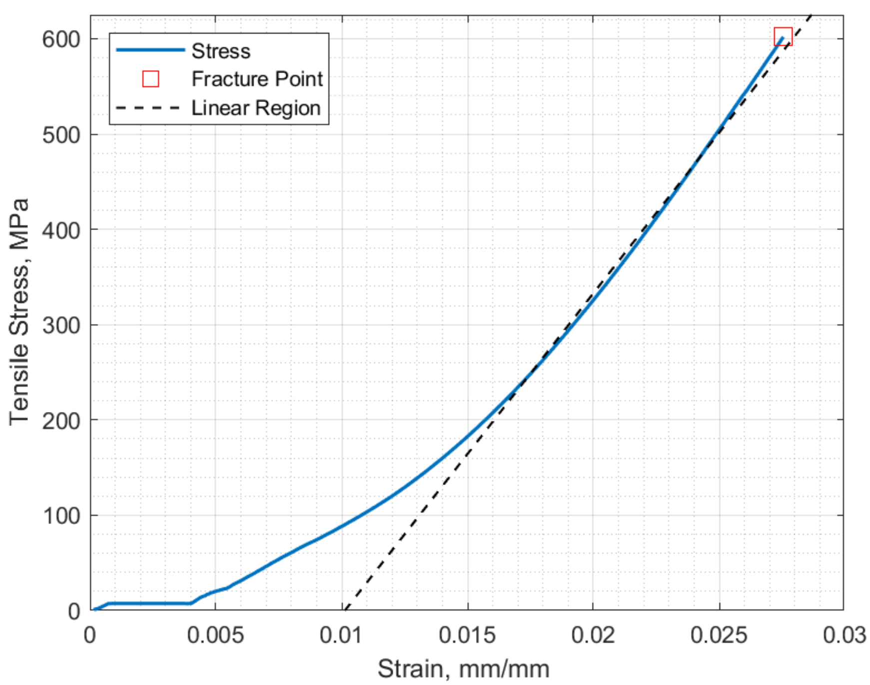

Figure 5. Axial Mounted, Specimen 1 Engineering Stress vs. Strain Curve

Table 4. Carbon Specimen 1 Tensile Data

Instron Strain	Ultimate load [kN]	Ultimate Stress [MPa]	Fracture Stress [MPa]
0.275	14.3	602	602

Table 5. Carbon Specimen Extensometer vs. Linear Elastic Modulus

Extensometer Elastic Modulus, GPa	Linear Region, Elastic Modulus, GPa
104	33.717

Table 6. Tensile Testing Aluminum Specimen Dimensions

	Specimen 1	Specimen 2
Thickness [mm]	0.4976	0.4976
Width [mm]	26.10	26.10

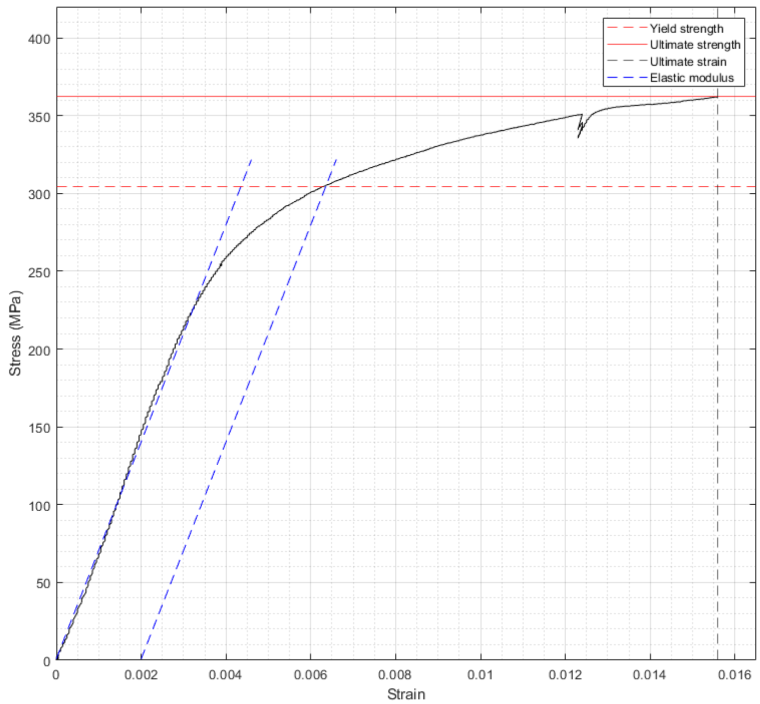

Figure 6. Axial Mounted, Aluminum Specimen 1 Engineering Stress vs. Strain Curve

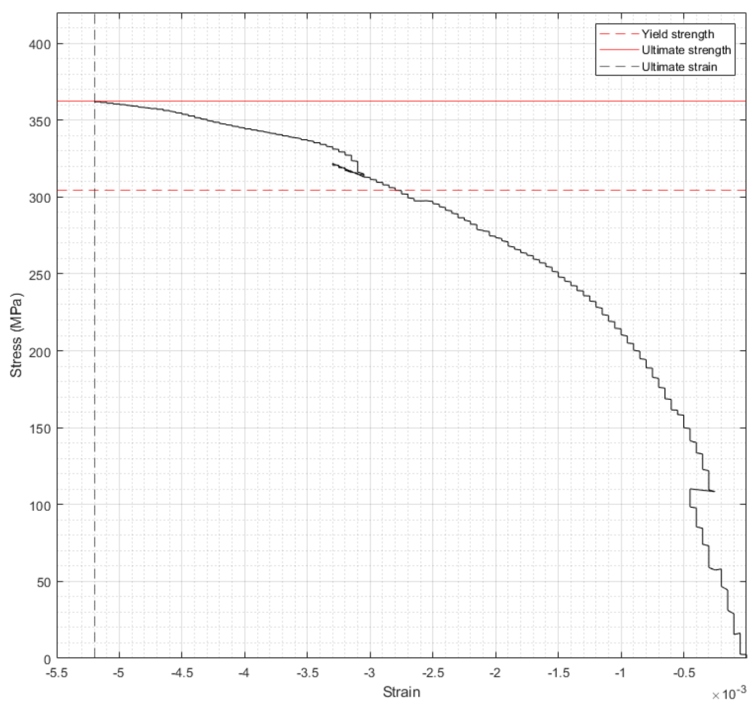

Figure 7. Transverse Mounted, Aluminum Specimen 2 Engineering Stress vs. Strain Curve

Table 7. Aluminum Tensile Data

Ultimate Load [kN]	Yield Strength [MPa]	Ultimate Strength [MPa]	Elastic Modulus [GPa]
4.700	304.1	362.7	69.77

Poisson's ratio is defined as the negative ratio of lateral strain and longitudinal strain shown in Eq. (3)

$$\nu = -\frac{Lateral\ Strain}{Longitudinal\ Strain} \tag{3}$$

$$\begin{aligned} \nu &= -\frac{\epsilon_{lat}}{\epsilon_{long}} \\ &= -\frac{-0.0052}{0.0156} \\ &= 0.3333 \end{aligned}$$

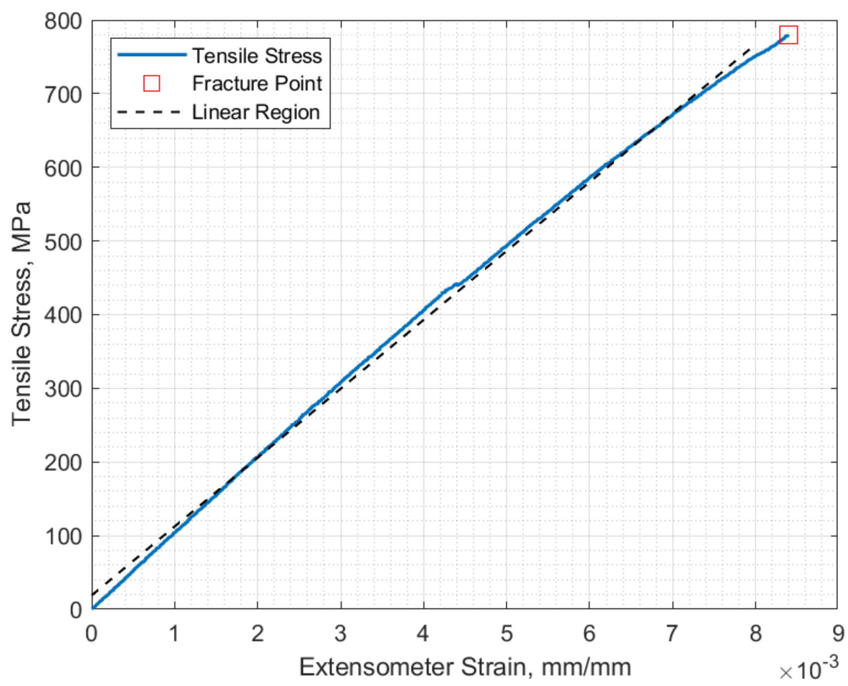

Figure 8. Extensor meter Stress vs. Strain Curve

Table 8. Aluminum Fatigue Testing Data

Characteristic	**Value or Type**
Temperature	69 - 71 ℉
Relative Humidity	24.89 %
Medium Tested In	Air
Material Tested	Aluminum (*Unknown Alloy*)
Tensile Strength	*Unknown*
Yield Point	*Unknown*
Yield Strength	*Unknown*
Elongation in a Specified Gage Length	*Unknown*
Forming Process	*Unknown*
Thermal Treatment	*Unknown*
Surface Treatment	*Unknown*
Stress Concentration	4 mm Center Hole
Testing Machine Model	Instron 8801
Testing Machine Type	Electrohydraulic
Frequency of Force Application	2 Hz
Forcing Function	8800 Waveform Sinusoidal
Type of Test	Axial
Failure Criterion	Catastrophic Fracture
Number of Cycles to Failure Criterion	14605
Failure Surface	Horizontal Separation from Center Hole
Location of Crack Origin	Horizontal Edge of Center Hole
Max Load	12 kN
Minimum Load	0.000114 kN

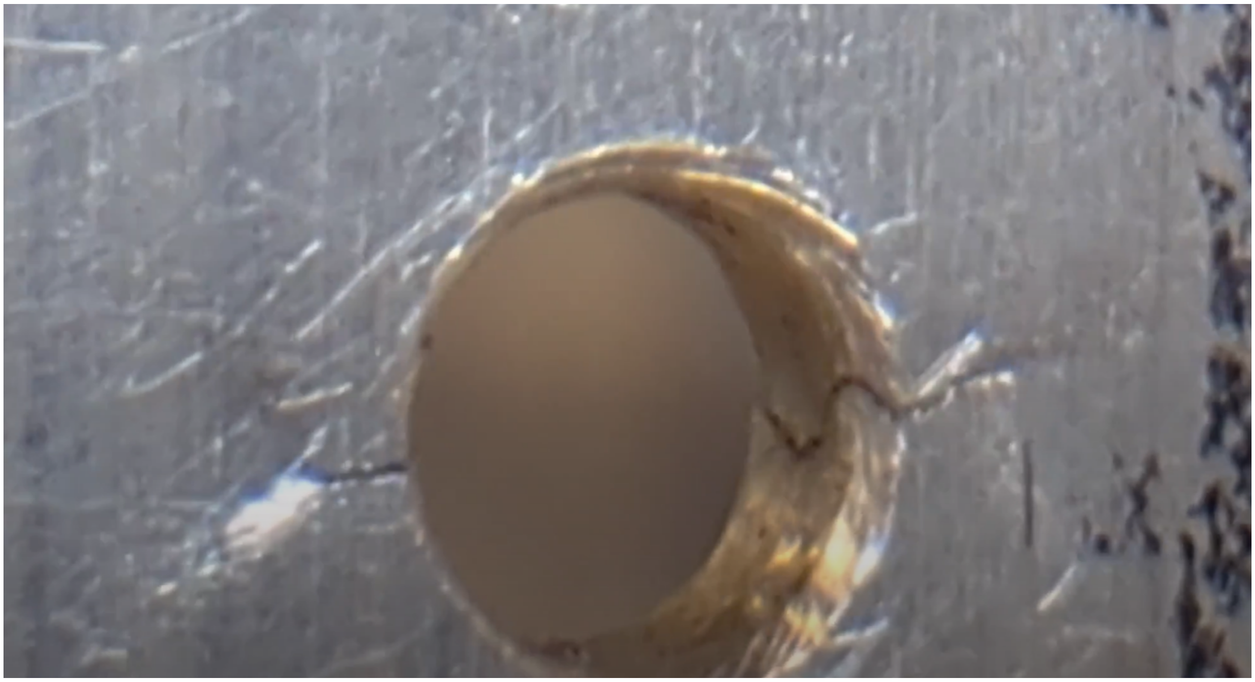

Figure 9. Aluminum Sample Before Fatigue Failure - Fatigue lines visible

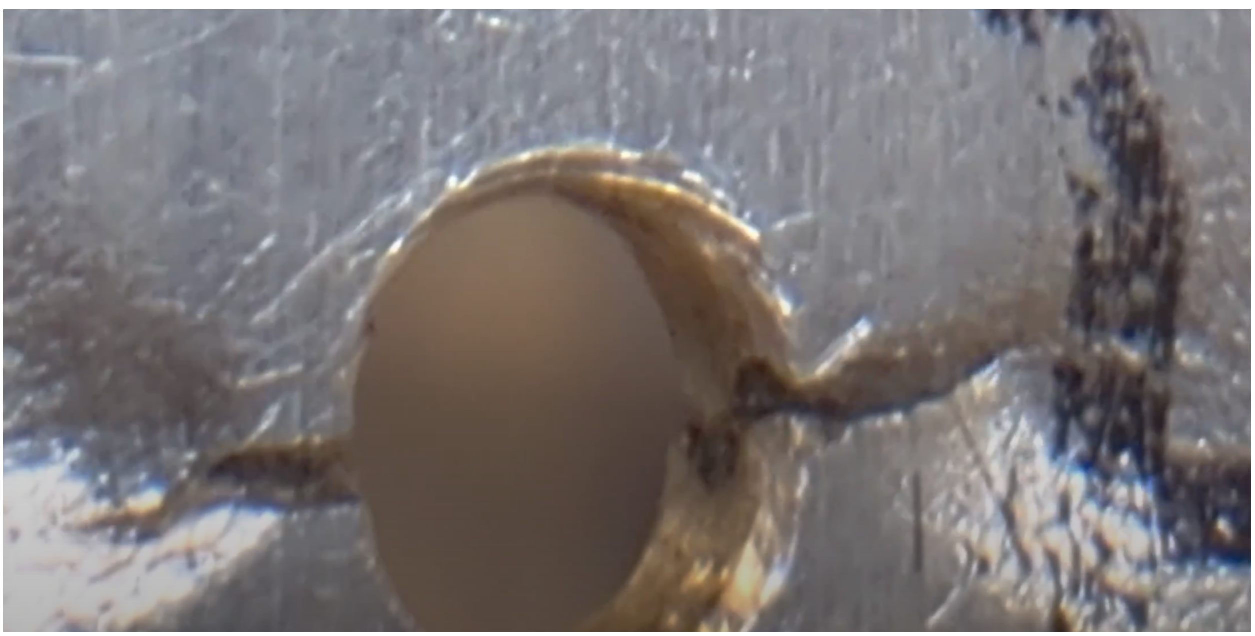

Figure 10. Aluminum Sample During Fatigue Failure - Fatigue failure visible, catastrophic fracture starting

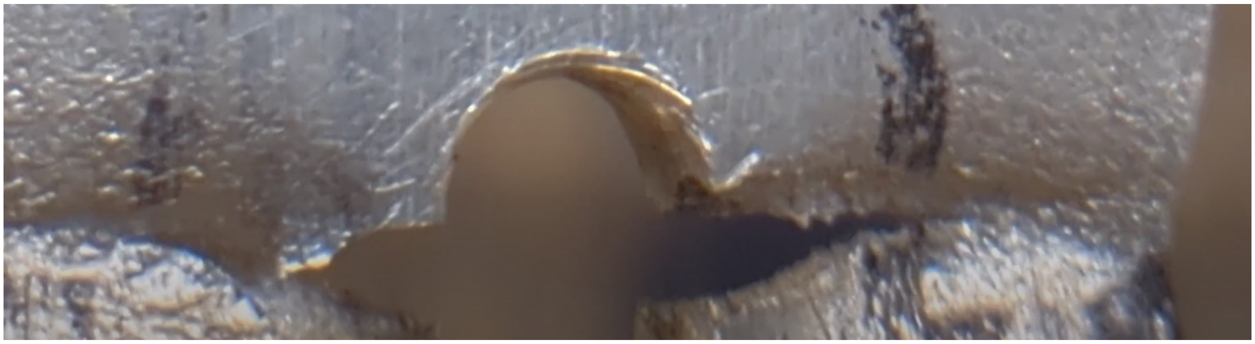

Figure 11. Aluminum Sample During Catastrophic Failure - Catastrophic fracture occurring

Figure 12. Aluminum Sample After Fatigue Failure - Axial View

Figure 13. Aluminum Sample After Fatigue Failure - Horizontal View Edge Details

Figure 14. Aluminum Sample After Fatigue Failure - Horizontal View Axial Details

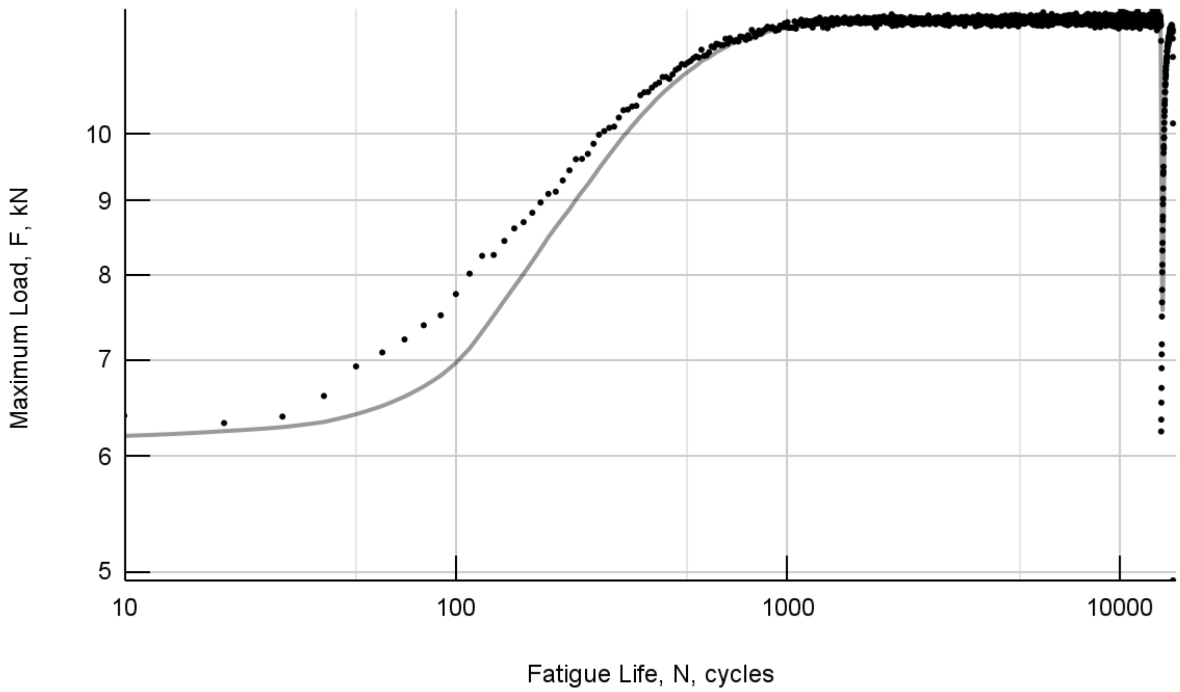

Figure 15. S-N Diagram for Aluminum in Fatigue Testing on Instron 8801 at 2 Hz in air at room temperature

ASTM and other literature on S-N Diagrams does not follow the observed trends from the aluminum sample tested with a 4 mm hole drilled through the center. The test conditions appear to be very similar to other recorded samples but the test performed was done without known material properties or cross-section. The data shows the maximum load (without a known cross-section an analog for stress) is continuously rising until the catastrophic fracture failure.

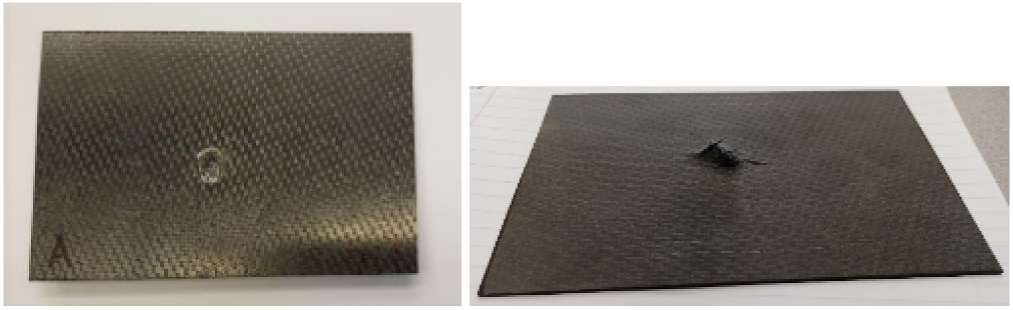

Figure 16. Sample A after impact test

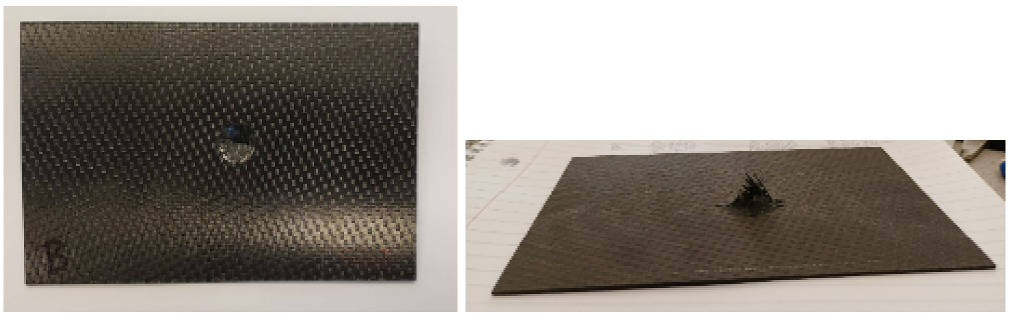

Figure 17. Sample B after impact test

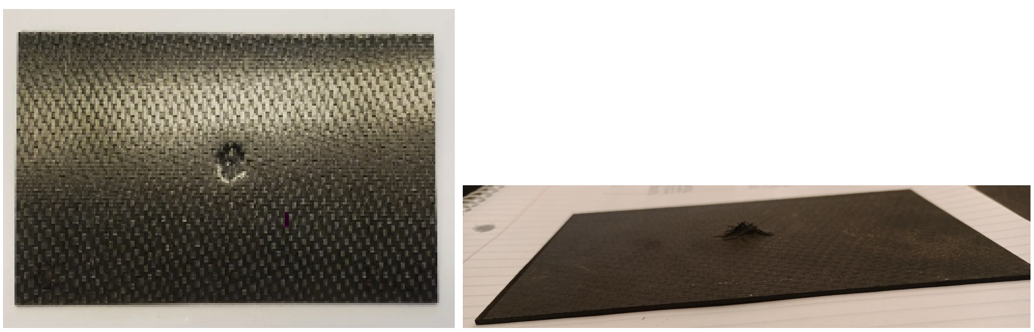

Figure 18. Sample C after impact test

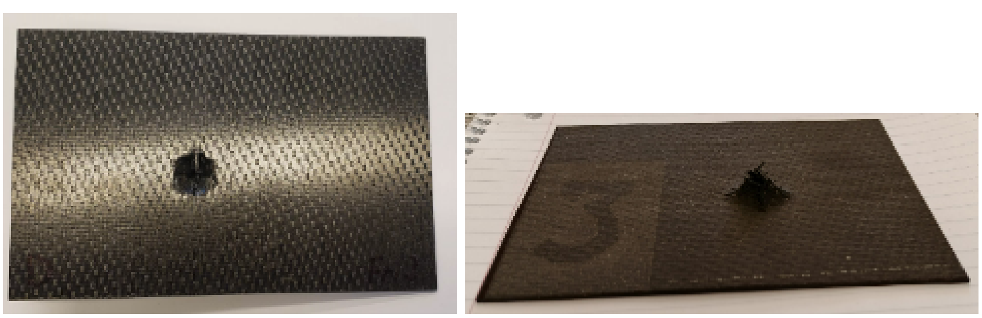

Figure 19. Sample D after impact test

Table 8. Impact test Data

Sample	A	B	C	D
Thickness [mm]	1.440	1.442	1.437	1.436
Drop Height [cm]	41.91	46.99	38.10	52.71
Velocity [m/s]	2.867	3.036	2.734	3.215
Kinetic Energy [J]	10.686	11.981	9.714	13.440
Specific Ratio [J/mm]	7.421	8.309	6.760	9.359
Minimum Diameter [mm]	11.299	14.101	10.257	15.905
Maximum Diameter [mm]	14.995	16.057	13.496	17.678
Impact Depth [mm]	1.698	5.165	1.139	6.841

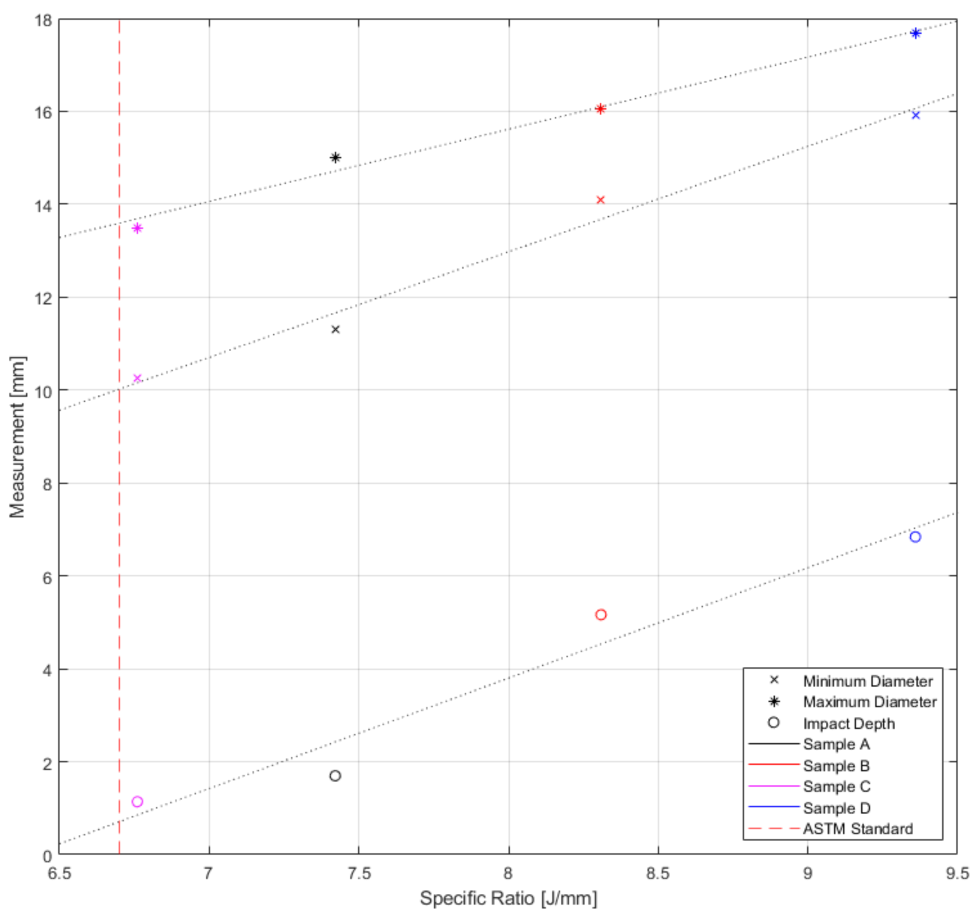

Figure 20. Impact test measurements versus specific ratio for each sample

IV. Conclusion

The Engineering stress and strain curves from the carbon specimens shows that the material cannot deform elastically under uniaxial load in comparison to the aluminum since the carbon fractures right at the end of the linear portion of the curve. The Elastic modulus found using the extensometer is higher than the Elastic modulus determined using the strain gauges for carbon specimens. In regards to the comparison between the carbon fiber and the aluminum, the carbon fiber has a higher Elastic Modulus. By observation, carbon is a brittle material while aluminum is malleable as from the plots.

Each impact test had a specific ratio higher than the ASTM standard of 6.7 J/mm [x]. Sample C was the closest to ASTM standard with a specific ratio of 6.76 J/mm, and the specific ratio increased up to a value of 9.359 J/mm for sample D. All samples experienced cracks, fiber splitting, indentation and delamination with the size of the indent increasing linearly with the specific ratio. Samples B and D were the only samples that the impactor fully punctured.

Overall, both the carbon fiber samples and the aluminum samples have proven that they have their place in modern engineering. If a sturdy but lightweight material is needed, carbon fiber may fill that role. However, carbon fiber may be too rigid a material, in which case aluminum can be used, a much more elastic material.

V. References

[1] ASTM D7136/D7136M, Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event