Tensile, Fatigue and Impact Lab Report

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In this study, we investigate the mechanical properties of a material through tensile, fatigue and impact tests. The tensile experiments involve subjecting the material to varying levels of stress to analyze its deformation and ultimate strength. Fatigue tests explore the material's endurance and structural integrity over repeated loading cycles. Impact tests assess the material's response to sudden, dynamic loads, from which we learn about the material's ability to absorb energy and sudden shocks. This report synthesizes the outcomes of these experiments, offering a comprehensive overview of the material's mechanic behaviour.

Nomenclature

a	=	triangle leg length, mm
a_{crit}	=	critical crack length, mm
AS	=	axial strain gauge
c	=	Hypotenuse length, mm
d	=	Hole diameter, mm
D	=	Damage Index
E	=	Elastic Modulus, GPa
EX	=	extensometer
F	=	Load, kN
g	=	gravitational acceleration, $\frac{m}{s^2}$
h	=	height, m
K_{1C}	=	Mode 1 crack initiation fracture toughness, $MPa\sqrt{m}$
K_t	=	Stress Concentration Factor
L_0	=	original length, mm
m	=	mass, kg
S	=	Critical Stress, MPa
t	=	thickness, mm

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TS	=	transverse strain gauge
v	=	velocity, m/s
τ	=	shear stress, MPa
θ	=	Angle, degrees
ν	=	Poisson's ratio
w	=	width, in
ΔL	=	change in length, mm
ϵ	=	strain, mm/mm
σ	=	stress, MPa, GPa

I. Introduction

Understanding these properties of a material is essential, as it provides crucial insights into the material's behavior under various loading conditions, ultimately influencing material selection and design considerations. The background of this research stems from the critical need to comprehend how materials respond to different forms of mechanical stress. Tensile properties, which include parameters such as yield strength and ultimate tensile strength, offer fundamental insights into a material's ability to withstand axial loads.

Fatigue properties, explored through cycle loading, are pertinent to scenarios involving repetitive stress cycles, such as those experienced by components in machinery or infrastructure subjected to regular use. An understanding of a material's fatigue life is important for predicting its longevity and potential failure, ensuring safety and reliability of engineering systems.

Impact resistance, looks at the material's ability to absorb energy and withstand sudden shocks. Industries demand materials with superior impact resistance to ensure the durability and safety of their products.

To achieve these objectives, we will be conducting a series of designed experiments. Through instrumentation and rigorous data analysis, we aim to extract comprehensive and reliable data that we allow us to understand the material's behavior better.

II. Materials and Methods

A. Tensile

Two aluminum alloy (AL 6061 – T6), "dogbone" samples were tested. The composition was designed to be 98% Aluminum with Silicon and Magnesium, having an ultimate tensile strength of 290 MPa, yield strength of 240 MPa, elongation of 8%, and modulus of 67 GPa. The aluminum dogbone sample dimensions are tabulated in Table (1) below.

Table 1 Dimensions of aluminum samples.

	1	2
Overall Length (mm)	200.0	200.0
Overall Width (mm)	12.70	12.70
Gauge Length (mm)	76.20	76.20
Thickness (mm)	1.575	1.422

A carbon composite was created at the beginning of Fall quarter, then cut into five rectangles and tested. The carbon composite dimensions are tabulated in Table (2) below.

Table 2 Dimensions of carbon composite samples.

	1	2	3	4	5
Length (mm)	185.7	203.2	201.6	201.6	201.6
Width (mm)	19.05	15.88	15.88	19.05	15.88
Thickness (mm)	0.9271	0.9779	0.9017	1.257	0.9398

When fabricating the composite, 3501 prepreg was used. The areal weight was 280 g/m^2 and the epoxy-to-carbon fiber volume fraction was 35%. The fiber orientations in the weave was unidirectional (then layered to be bidirectional) and the fabric weave was 5H (a 5 harness satin weave), which has relatively high strength. Note that thicker weave is correlated with higher areal weight. The prepreg has thousands of carbon strands per yarn. According to the specifications, the tensile strength of the neat resin was 6.6 ksi, the carbon filaments were 310 ksi, and the tensile strength of the fiber-matrix composite was 120.0 ksi.

An Instron collected data (mm) on the extension of the cross-head, with strain calculated according to Eq. (1):

$$\epsilon = \frac{\Delta L}{L_0} \tag{1}$$

The original length (ΔL) was either the gauge length (aluminum) or the distance between the Instron jaws (carbon composite). Unfortunately, these strain measurements were not very trustworthy, as some of the extension could be attributed to jaw slippage and lengthening of the Instron equipment itself. Strain was directly measured with strain gauges and an extensometer. Although more accurate than the Instron, these could only gather data to a certain point before falling off or needing to be removed, respectively. (Note that one carbon composite sample did not house any strain gauges, only using the Instron and extensometer data.)

Considering these limitations, the Instron was used to calculate maximum strain and ultimate tensile stress, while the strain gauges and extensometer were used for Elastic Modulus (also known as Young's Modulus) and yield strength. Since a regression line was used to estimate the slope of the curve, the theoretical and calculated Elastic Modulus are the same. Transverse strain gauges supplemented data gathered from the other axially-based instruments, allowing for a calculation of Poisson's ratio.

B. Fatigue

One aluminum 6061-T6 fatigue specimen was tested in the Instron. The specimen had the following properties before testing, outlined in Table (3):

Table 3 Dimensions of aluminum fatigue sample.

Dimension	Value (mm)
Length	103.1367
Width	65.1256
Thickness	3.2385

Additionally, a 6.25 mm diameter hole was drilled into the center of the specimen using a drill press. We use the width and hole diameter as the input parameters, to use the stress concentration factor (Kt). To ensure the fatigue load stays inside the elastic region for the duration of test, the bulk yield strength of the material is divided by this stress concentration factor. The specimen is labeled, inspected, and set up on the instron machine by clamping its top and aligning vertically. We do not use any strain gauges and extensometers for this experiment. We initiate the test using 'Instron Wave Matrix', after specifying project details and parameters. Once we start the experiment, we can see the required graphs on the Instron screen. We will be continuing with the experiment until total fracture (complete separation) occurs. As the machine does not know the point of total fracture, we will manually terminate the test when we reach that point. The experiment is monitored for fracture on the displayed graphs, and after the total fracture point we stop the machine and unclamp the specimen and facilitate data retrieval through a USB drive.

Using our calculated stress concentration factor from the hole width and diameter and max applied stress, we can find the peak stress at the inside edge of the hole where the crack initiated. We measure the length of the flat fracture surface, which would be our critical crack length. We then measure the angle of the shear lip when rapid fracture occured and and draw a Mohr's circle, pointing out the angle of max shear stress and principal stresses.

C. Impact

The subject we used for impact testing was a composite we made in the first six weeks of the lab. Composites are defined as engineering combinations of two or more different materials. The composite that we worked with is carbon-fiber reinforced polymer (CFRP). For our composite, the carbon fibers are embedded in a matrix of epoxy resin, requiring it to be stored in a freezer to ensure the resin would not cure.

As shown in figure (1), our final composite consisted of a metal baseplate, the CFRP, peel ply, a breather material, vacuum bag, and a vacuum connector. To prepare the metal base plate, we used a scraping tool and acetone to clean off any remaining materials from prior usage. We then used blue masking tape around the edges of the metal plate to prevent coating this area with the release agent. Following this, we applied three coats of release agent to the metal plate. To form a cohesive boundary we placed tacky tape around the edges of the mold to ensure that the tape does not overlap at the corners.

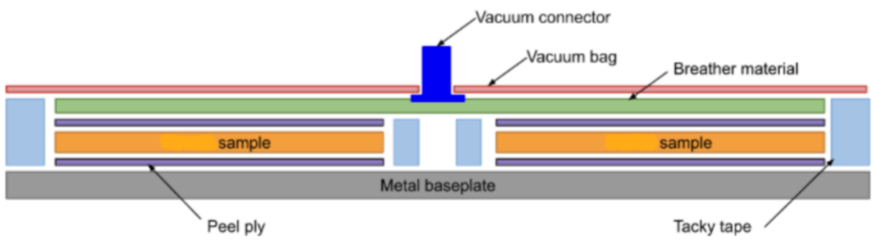


Fig. 1 Schematic of our composite used for impact testing.

In preparation to lay down the various layers, we stack six to eight layers of CFRP in consistent weave orientation with the warp faces (longitudinal, 0 degrees) facing up and the weft faces (lateral, 90 degrees) facing down. We rolled the bubbles out, every time a new layer is placed down. After the stack is created we cut a piece of peel ply covering the entire carbon fiber stack. We then transferred the stack next to the tacky tape and cut breather fabric to cover the composite in order to absorb the resin.

Following this we set our vacuum bag film onto the tacky tape to seal the vacuum. It is also extremely important that there are no air bubbles or creases between the vacuum bag and the tape to ensure a tight seal. We then screwed the parts of the connector together, and once the connector was sealed we checked for leaks. Upon completion, we placed our composite into the autoclave to cure the composite. After following the autoclave directions in the lab manual, we removed the extra layers of our composite: peel ply, release film, vacuum bag, tacky tape, and breather fabric. Finally, we cut our composites into four equal rectangles of dimensions, four inches by six inches.

The Dynatup machine pictured in figure (2) was used for the impact testing on the composites we created. The control panel is used to drop an impactor at various heights. The standard impactor geometry has a blunt, hemi- spherical striker tip. To measure the height of the impactor a tape measure was used to measure the height from the tip of the impactor to the point of impact. For stability during testing, the composite was positioned by sliding it between two metal plates.

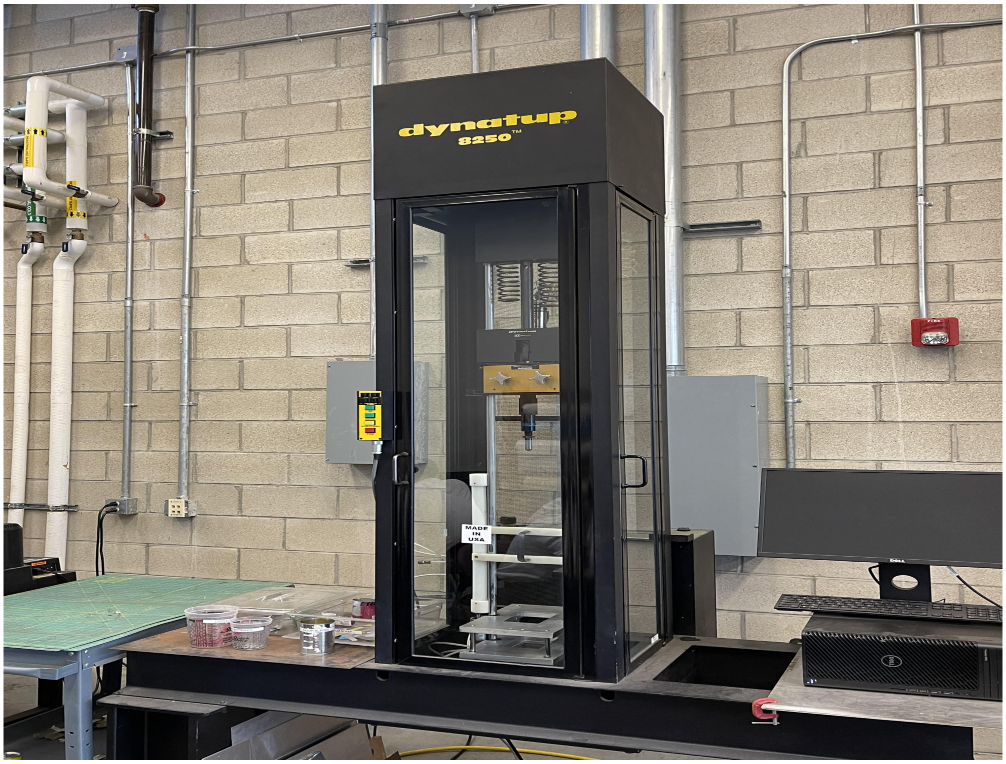


Fig. 2 Dynatup Machine used for composite impact testing.

III. Results

A. Tensile

Note that plots exclude data from pre-tension, post-failure, and after the strain gauges debonded. (i.e. the curves were manually cut off to ignore initial slack and regions where the strain stopped increasing.)

1. Aluminum Alloy

The Instron provided time, extension, load, and stress data. Strain could be computed using equation (1):

$$\epsilon = \frac{\Delta L}{L_0}$$

where ΔL is extension and L_0 is the original measured length. The resulting extension-load and stress-strain relationships were plotted for each of the aluminum samples in Figure (3),

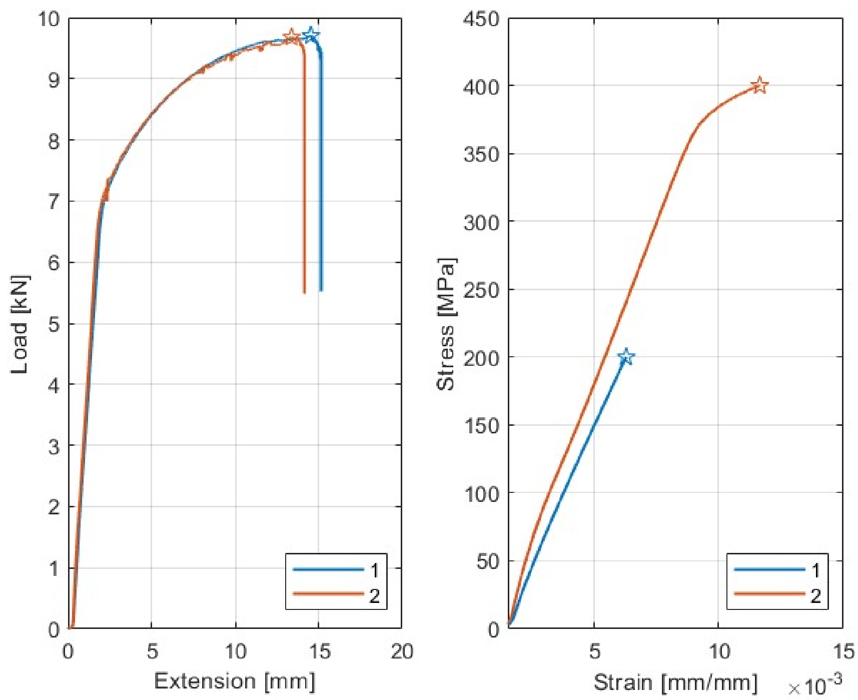


Fig. 3 Extension-load and stress-strain curves from the Instron data.

The resulting curve could be used to find both maximum (ultimate tensile) and fracture stress. These happened to occur at the same point for each sample (see the stars on the right plot), since no "necking" occurred. Maximum and fracture strain were found similarly, each associated with their corresponding stress value. Maximum load was pulled from the peak of the left curves (see the stars on the plot), with associated extension values documented as well. Percent elongation at failure could be computed by dividing the each sample's extension (just before breaking) by the original length. Gauge length at failure was computed by assuming the majority of extension occurred in the narrow portion of the dogbone and thus adding the extension at failure to the original gauge length. Table (4) includes key metrics for both samples, taken from the Instron data and plots. Again, note that some values are duplicated since maximum and fracture stress and strain occurred at the same points.

Table 4 Instron results.

	1	2
Maximum Stress (MPa)	200.0	400.0
Fracture Stress (MPa)	200.0	400.0
Maximum Strain (mm/mm)	0.00258	0.01203
Fracture Strain (mm/mm)	0.00258	0.01203
Maximum Load (kN)	9.703	9.676
Extension at Maximum Load (mm)	14.54	13.39
Elongation at Failure (%)	7.580	7.079
Gauge Length at Failure (mm)	77.4529	78.5295

Stress-strain curves were also constructed using the strain gauge and extensometer data. Unfortunately, an error occurred during the first run which prevented data acquisition from the Wheatstone bridge for the axial case. Thankfully, this issue was resolved in the second sample and transverse data was successfully obtained.

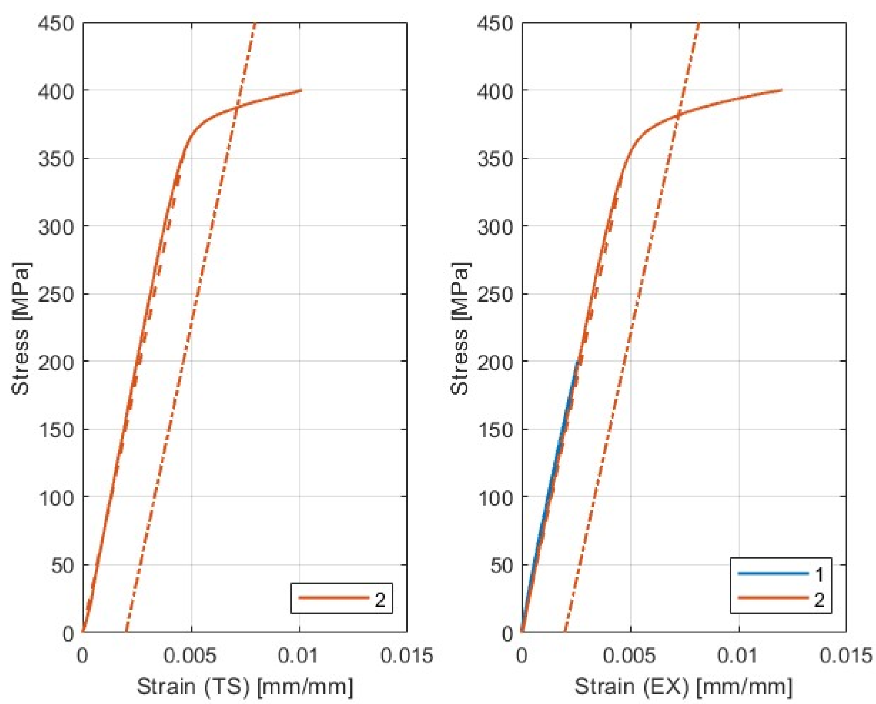


Fig. 4 Stress-strain curves from the strain gauges and extensometer data.

Figure (4) includes regression lines (dashed) for the linear portion of the curves and lines (dash-dotted) to represent the 0.002 strain offset. Note that the first sample failed before yielding, so the strain offset could not be applied and final values were used in the table. (With stain gauge debonding and extensometer limitations, both instruments were removed before failure, so these end values do not necessarily reflect the failure points.) Elastic Modulus (the slope of the linear region of the curve), as well as yield stress and strain (the point of transition from linear to nonlinear, with 0.002 offset) were then compared. Strain at debonding is merely the last value acquired by the strain gauge before falling off; for the extensometer, the equivalent is the last strain value before removal. The values are roughly what one could expect from a literature review on aluminum, with some significantly smaller values for the first sample due to its premature failure.

Table 5 Transverse strain gauge (TS), axial strain gauge (AS), and extensometer (EX) results.

	AS1	TS2	EX1	EX2
Elastic Modulus (GPa)	-	75.4227	77.5136	72.8251
Yield Stress (MPa)	-	388.384	200.0047	381.351
Strain at Yield Stress (mm/mm)	-	0.007368	0.00258	0.00723
Strain at Debonding (mm/mm)	-	0.010131	0.00258	0.01203

Unfortunately, the lack of axial data prevents the calculation of Poisson's ratio.

2. Carbon Composite

The carbon composite specimens underwent similar analysis. Extension-load and stress-strain were plotted for each sample, with data ignored after the strain stopped increasing. Note that the dips in Figure (5) mark when the test was paused and the extensometer was removed.

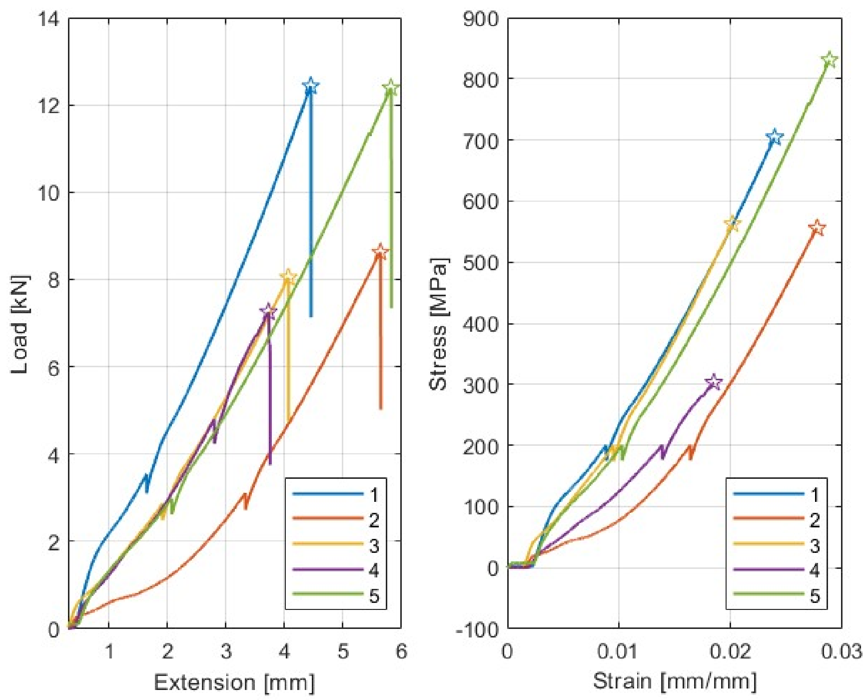


Fig. 5 Extension-load and stress-strain curves from the Instron data.

Again, the maximum and fracture values coincide for all the samples tested, so duplicate tabular values are to be expected. Unlike the aluminum dogbones with a clear gauge length (evidenced by a change in width in the original sample), the composite gauge length was estimated from the distance between the Instron jaws. This value was thus used to calculate gauge length at failure. Table (6) summarizes these results.

Table 6 Instron results.

	1	2	3	4	5
Maximum Stress (MPa)	703.7713	555.4041	562.0419	302.9017	830.3349
Fracture Stress (MPa)	703.7713	555.4041	562.0419	302.9017	830.3349
Maximum Strain (mm/mm)	0.023948	0.02775	0.020174	0.018496	0.028861
Fracture Strain (mm/mm)	0.023948	0.02775	0.020174	0.018496	0.028861
Maximum Load (kN)	12.43	8.622	8.045	7.255	12.39
Extension at Maximum Load (mm)	4.448	5.639	4.067	3.729	5.819
Elongation at Failure (%)	2.398	2.777	2.018	1.863	2.888
Gauge Length at Failure (mm)	140.2	158.8	155.7	155.4	157.4

The stress-strain plot from strain gauge and extensometer readings (with appropriate regression lines) depicted in Figure (6). Each sample had its own axial and transverse strain gauges, so that three separate plots may be produced. The exception is sample 1, which did not have any strain gauges attached and only generated extensometer data.

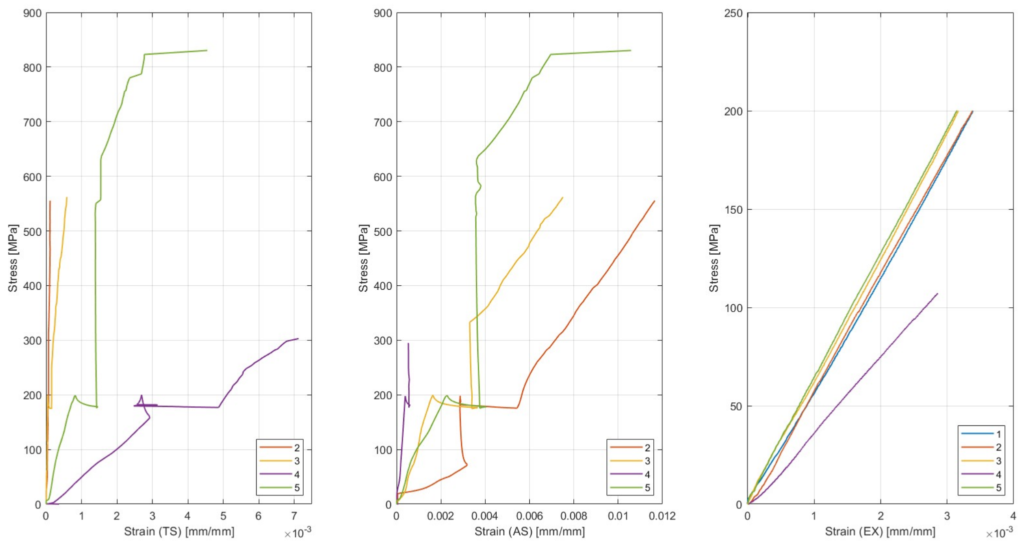


Fig. 6 Stress-strain curves from the strain gauges and extensometer data.

Adding dashed and dash-dotted lines highlight the linear portions for Elastic Modulus calculations and the 0.002 offset, as applicable. Most of the samples yielded after strain gauge debonding and extensometer removal. In fact, the only data beyond the linear region came from the transverse gauge on the fourth sample and both strain gauges on the fifth sample. This information is shown in Figure (7).

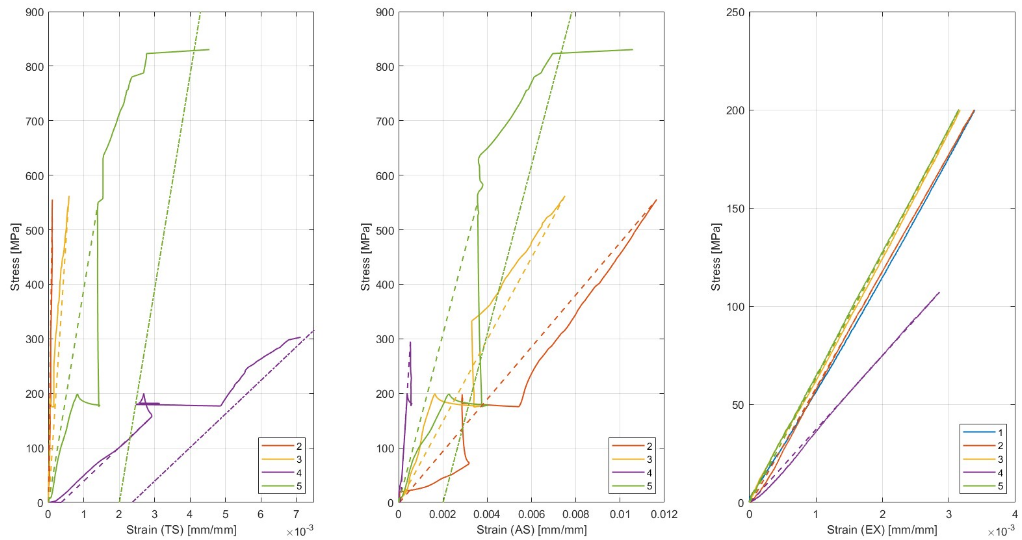


Fig. 7 Stress-strain curves from the strain gauges and extensometer data (with guide lines).

Key parameters are displayed in Tables (7) - (9), noting that duplicate values stem from the fact that debonding and extensometer removal occurred before the yield point for most of the tests.

Table 7 Transverse strain gauge results.

	1	2	3	4	5
Elastic Modulus (GPa)	-	47.84	75.08	649.4	154.7
Yield Stress (MPa)	-	555.4	562.0	302.9	823.8
Strain at Yield Stress (e^{-3}) (mm/mm)	-	11.65	7.507	21.86	7.332
Strain at Debonding (e^{-3}) (mm/mm)	-	11.65	7.507	21.86	10.58

Table 8 Axial strain gauge results.

	1	2	3	4	5
Elastic Modulus (GPa)	-	5190.6	984.3	61.58	393.3
Yield Stress (MPa)	-	555.4	562.0	302.9	828.6
Strain at Yield Stress (e^{-4}) (mm/mm)	-	1.14	5.86	71.2	41.2
Strain at Debonding (e^{-4}) (mm/mm)	-	1.14	5.86	71.2	45.5

Table 9 Extensometer results.

	1	2	3	4	5
Elastic Modulus (GPa)	58.99	59.49	63.09	37.59	63.49
Yield Stress (MPa)	200.0	199.9	200.0	107.1	200.0
Strain at Yield Stress (e^{-3}) (mm/mm)	3.39	3.38	3.17	2.86	3.15
Strain at Removal (e^{-3}) (mm/mm)	3.39	3.38	3.17	2.86	3.15

Using the strains (at yield stress) from the tables above, Poisson's ratio could be calculated with the following equation

$$v = \frac{\epsilon_{transverse}}{\epsilon_{axial}}$$

which outputs are documented in the Table (10).

Table 10 Poisson's ratio from strain gauge results.

	1	2	3	4	5
Poisson's ratio	-	0.0097829	0.07806	0.32572	0.56124

These values should fall between -1 and 0.5, so sample 5 is automatically flagged as incorrect.

3. Comparison

Several metrics are especially important when comparing the mechanical behavior of an aluminum alloy versus carbon composite. Sample 2 of the aluminum and sample 3 of the carbon composite are chosen as representatives, with their relevant outputs reiterated in Tables (11)-(13).

Table 11 Key metric comparison from Instron results.

	Aluminum (Instron)	Aluminum (Standard)	Composite (Instron)	Composite (Standard) [1]
Maximum Stress (MPa)	400.0	290	562.0419	3790
Maximum Strain (mm/mm)	0.01203	-	0.020174	-
Maximum Load (kN)	9.676	-	8.045	-
Extension at Maximum Load (mm)	13.39	-	4.067	-
Elongation at Failure (%)	7.079	8	2.018	11
Gauge Length at Failure (mm)	78.5295	-	155.7	-

Since the data are limited by debonding or extensometer removal, final values are used for a few of the parameters. Toughness was added as a metric by finding the area under the strain gauge stress-strain curve

Table 12 Key metric comparison from transverse strain gauge and extensometer results.

	Aluminum (TS)	Composite (TS)	Aluminum (EX)	Composite (EX)	Aluminum (Standard)	Composite (Standard) [1]
Elastic Modulus (GPa)	75.4227	75.08	72.8251	63.09	67	520
Yield (or Final) Stress (MPa)	388.384	562.0	381.351	200.0	240	3220
Yield (or Final) Strain (mm/mm)	0.010131	0.007507	0.01203	0.00317	-	-
Maximum Strain (mm/mm)	0.01013	0.007507	0.01203	0.00317	-	-
Toughness (MPa)	-	-	2.406	0.89084	-	-

While the plastic region was clearly seen in a few of the plots, there is not enough information to fully discuss plasticity across the samples.

Finally, an assessment of Poisson's Ratio is necessary to complete the comparison.

Table 13 Poisson's ratio from strain gauge results.

	Aluminum (Strain Gauges)	Composite (Strain Gauges)	Aluminum (Standard)	Composite (Standard)
Poisson's ratio	-	0.07806	0.33 [2]	0.10 [3]

B. Fatigue

The stress concentration factor for a hole is extracted from a graph of K_t vs. $\frac{d}{w}$ [4]:

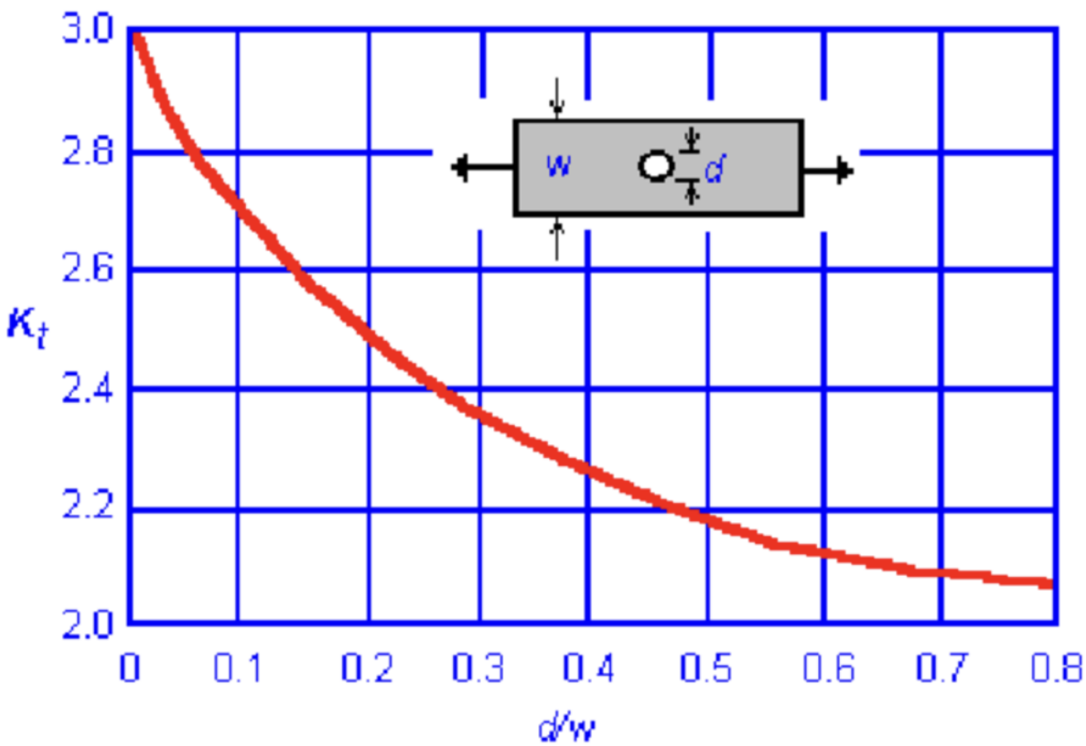


Fig. 8 Stress concentration factor based on geometry

From the graph, for d = 6.25 mm and w = 65.1265 mm, K_t = 2.75. Because the Instron 8801 applies a maximum force of 9 kN, the nominal stress can be calculated as

$$\begin{aligned}
\sigma_{nom} &= \frac{w}{w-d}\sigma_{applied} \\
\sigma_{nom} &= \left(\frac{65.1265}{65.1265-6.25}\right)\left(\frac{9}{65.1265(3.2385)}\right) \\
\sigma_{nom} &= \underline{47.2\ MPa}
\end{aligned} \tag{2}$$

Knowing both the nominal stress near the hole and the stress concentration factor, the peak stress at the hole can be computed as

$$\begin{aligned}
\sigma_{peak} &= \sigma_{nom}(K_t) \\
\sigma_{peak} &= 47.2(2.75) \\
\sigma_{peak} &= \underline{129.804\ MPa}
\end{aligned} \tag{3}$$

As seen from Eq.(3), applying the stress concentration factor increases the stress experienced at the hole. As the load path travels through the specimen, it must divert its course around the hole, meaning that the thinner cross sections around the hole drastically increase in stress. There is a concentration of force in a smaller area.

The stress should concentrate near the hole and then dissipate in an equally distributed pattern as distance away from the hole increases. Figure (9) below depicts the expected stress distribution around the hole:

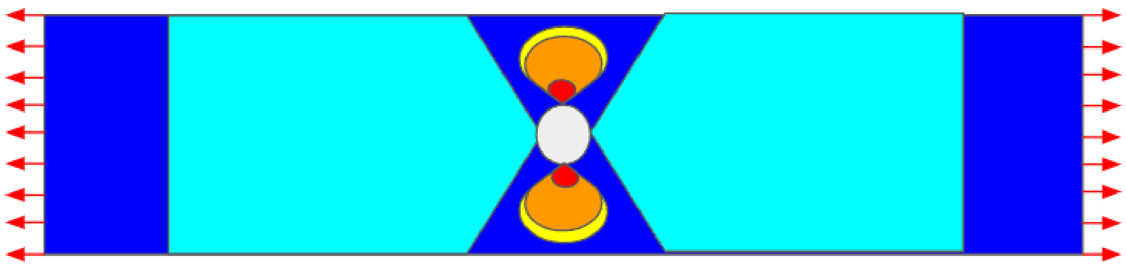


Fig. 9 Stress distribution near hole

The critical crack length of the sample was measured as the flat portion of the fracture surface. Figure (10) below shows the measurement of the critical fracture surface to be approximately 3mm on each side of the hole.

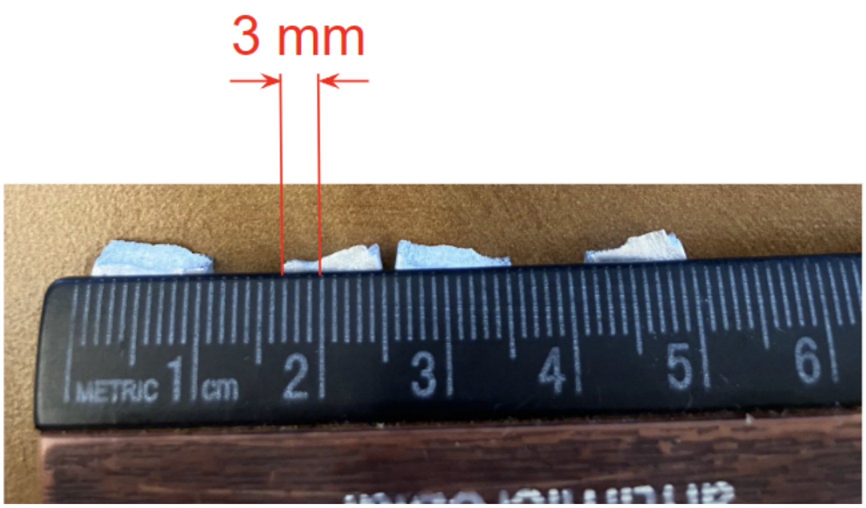


Fig. 10 Critical crack length measurement

This is the maximum length of the initial crack before onset of catastrophic failure. The theoretical fracture toughness for mode 1 crack initiation of an aluminum alloy, K_{1C}, is 37 $MPa\sqrt{m}$ [5]. Using this theoretical fracture toughness, the theoretical critical crack length can be computed as

$$a_{crit_T} = \left(\frac{K_{1C}}{S_{crit}(\pi)}\right)^2 \tag{4}$$

From [6], the critical stress is $S_{crit} = \frac{\sigma_{yield}}{2} = 155.5\ MPa$ for Al 6061-T6. From Eq. (4), the theoretical critical crack length is therefore 5.736 mm. In comparison to the measured critical crack length of 3 mm, we find that the percent difference between theoretical and practical measurements is 62.6%. Differences may be attributed to imperfections in the dogbone alloy and possible asymmetric loading of the fatigue specimen due to angling in the machine.

Figure (11) below depicts the regions of fatigue cyclic failure in blue and the regions of catastrophic, rapid failure in red.

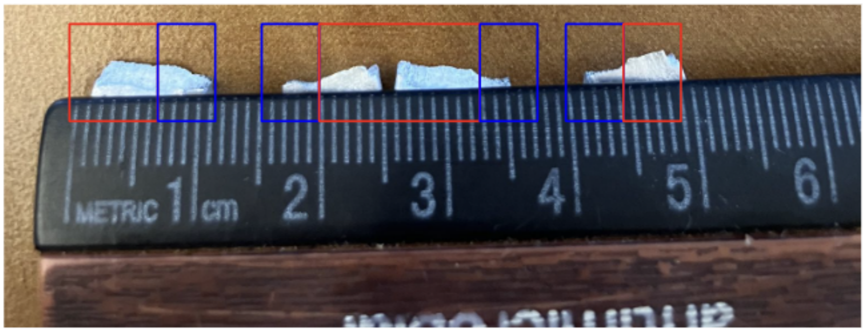


Fig. 11 Cyclic and catastrophic regions of failure

The regions of rapid failure show fracturing on the lines of greatest stress; therefore, they are angled away from the horizontal. Figure (12) below depicts the angularity for each specimen modelled as triangles.

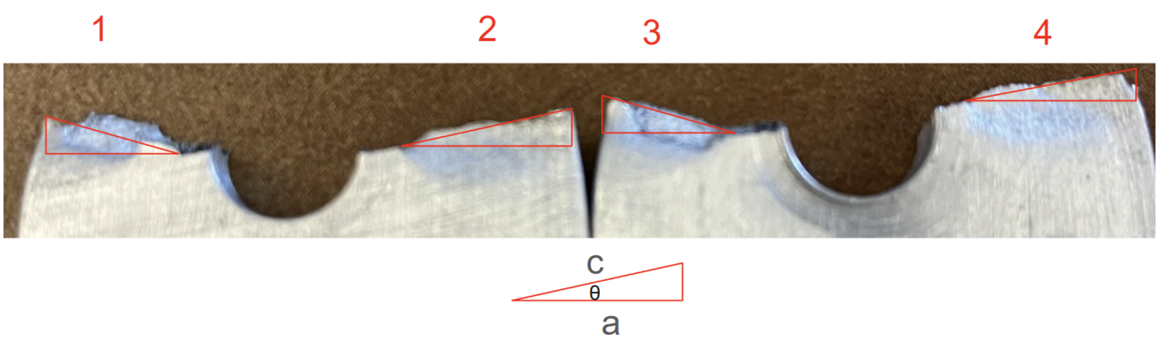


Fig. 12 Angularity of failure path

The measurements for a, c, and θ ae tabulated in Table (14) below.

Table 14 Shear Lip Measurements

	Angle 1	Angle 2	Angle 3	Angle 4
a (mm)	5	7	4	7
c (mm)	5.5	8	5	8
θ (deg)	42.274	41.186	38.660	41.186

In order to validate these angles, the theoretical value for maximum shear stress can be depicted on Mohr's circle. The principal stresses due to uniaxial loading are $\sigma_2 = 0MPa$ in the *yy* direction and $\sigma_1 = \sigma_{peak} = 129.804\ MPa$ in the *xx* direction. Because there is no applied shear force, it is evident that the angle of maximum stress lies at 45° from the horizontal, because this is where shear stress is maximum:

$$\tau_{x'y'} = -\frac{(\sigma_x - \sigma_y)}{2} sin(2\theta) + \tau_{xy} cos(2\theta) \tag{5}$$

With no shear forces, and no *yy* axial stress, we have

$$\begin{aligned} \tau_{x'y'} &= \left| -\frac{129.804MPa}{2} sin(2(45°)) \right| \\ \tau_{max} &= \underline{64.902\ MPa} \end{aligned} \tag{6}$$

This can be illustrated on Mohr's circle as follows in Figure (13).

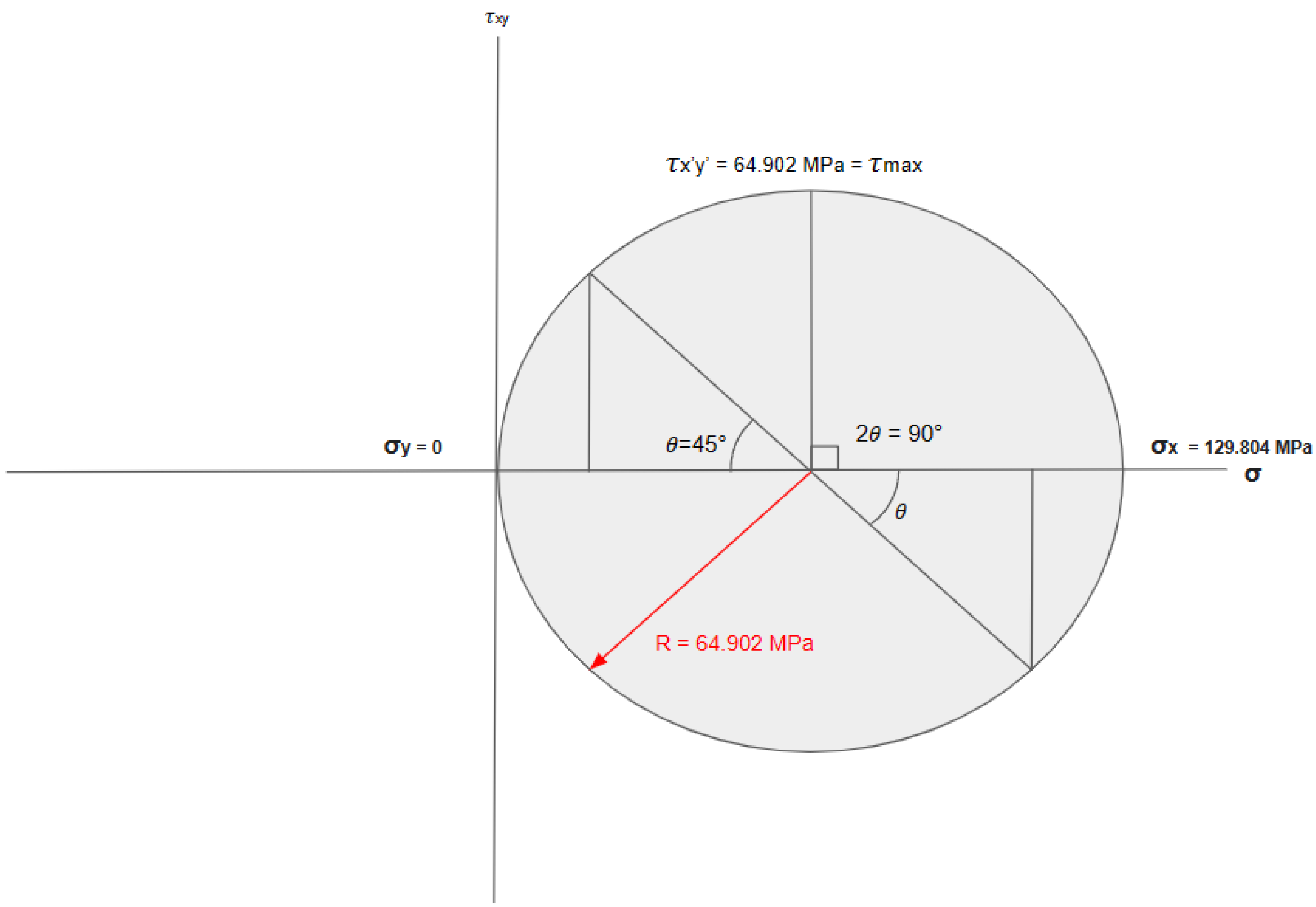
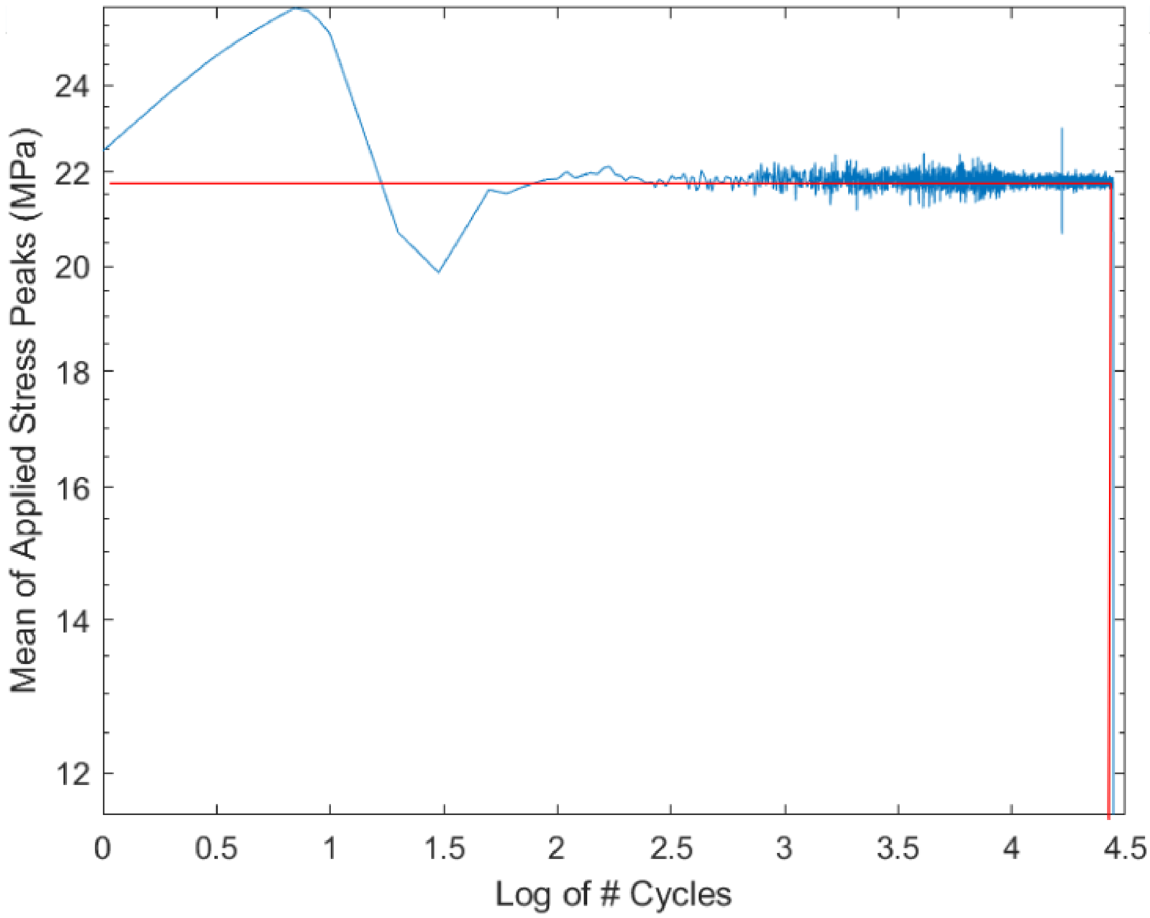


Fig. 13 Mohr's circle depiction of maximum shear stress

The angles in Table (14) averaged to 40.827°, about 4° lower than the expected line of maximum shear. This error is primarily due to measurement errors, but is also likely due to the fact that some material continued to be stretched and moved after the failure had occurred, distorting the line of maximum shear stress.

The failure of the specimen due to fatigue can be modelled as a stress vs. number of cycles curve (S-N Curve). The data from the Instron machine was overlaid onto an S-N curve for aluminum 6061-T6 from [7]. In the source, the aluminum plate has 4 holes drilled into the center, and therefore the graph depicts a modified 6061 curve. This application for the S-N curve is similar to the lab, where a plate has had a hole drilled into the center. As seen in Figure (14) below, the ramp time to reach steady cyclic loading is approximately 50 cycles. The load ratio averaged to 217.3 across the entire test time, taken as the average ratio between maximum and minimum loading.



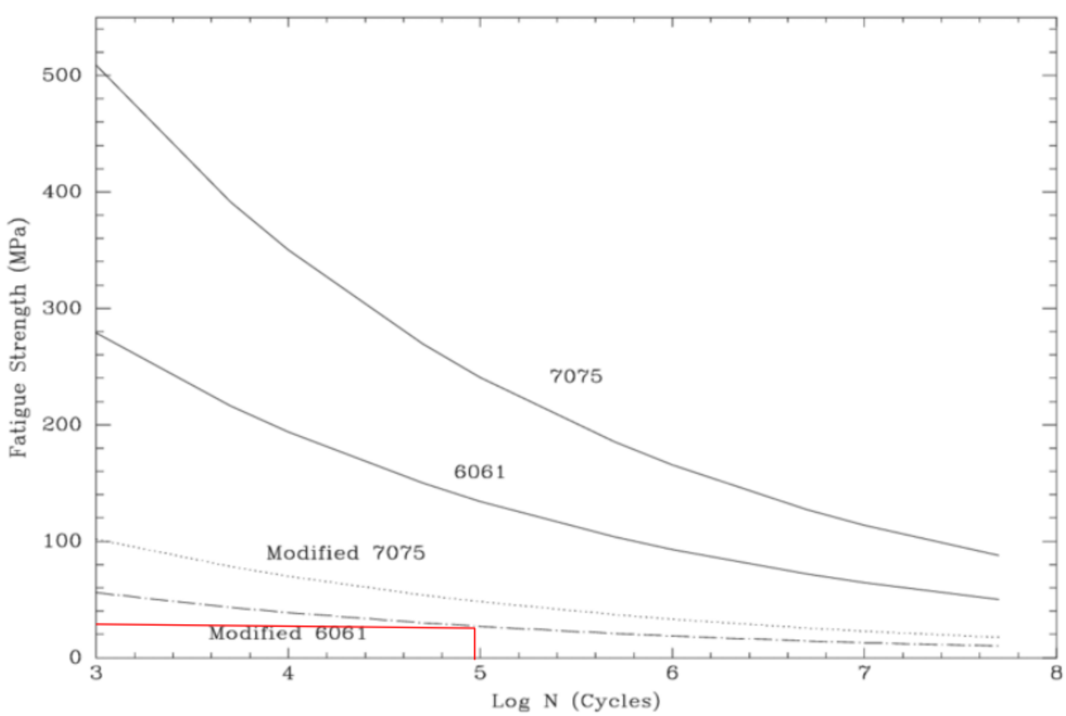


Fig. 14 Measured S-N curve (top) vs. literature modified Al 6061-T6 S-N Curve (bottom)

Miner's law characterizes damage due to fatigue on a scale with 0 being loaded with zero cycles, and 1 being loaded with the required cycles to failure [8]. This scale is computed by comparing the number of cycles experienced through time under a constant cyclical stress to a known S-N curve that runs until failure. The loading mean of peaks was taken as the loading for the fatigue specimen, and divided by the full cross-sectional area of the specimen to compute the applied mean stress. This value was then plotted against the base 10 log of the elapsed number of cycles to determine the top S-N curve in Figure (14).

From this point forward, the number of cycles from the lab will be referred to as n, and the number of cycles from literature will be referred to as N. It can be seen that the lab specimen fails when $log_{10}(n) = 4.45$. This corresponds to a value of $n = 28183.6$ cycles. Additionally, the mean of peaks stress from the lab averages to 21.33 MPa.

The literature S-N curve is analyzed at the 21.33 MPa average stress load from the lab measurements. It is seen that the corresponding number of cycles from literature, shown by the red lines in the bottom plot in Figure (14), is such that $log_{10}(N) = 4.97$. Therefore, the corresponding number of cycles for the literature at an average cyclic loading of 21.33 MPa is $N = 93325.4$ cycles.

Miner's Law dictates that damage is calculated as follows:

$$D = \frac{n}{N} \tag{7}$$

where D is the damage index, n is the number of measured cycles, and N is the corresponding number of cycles on a known S-N graph. When the damage index reaches 1, ultimate failure occurs. From the above analysis, it is evident that

$$D = \frac{28183.6}{93325.4} = 0.3 \tag{8}$$

From this analysis, it can be seen that the damage index is $\frac{1}{3}$ of the way to failure. This means that according to the literature, the specimen should not have failed at the number of cycles that it did. There are a number of reasons literature may contradict lab results. First, the literature example used here was for a circular aluminum 6061-T6 plate that had a different geometry than the lab specimen. Secondly, the fatigue test was not conducted at a truly constant cyclic loading, meaning that approximations of a constant cyclic loading inevitably lead to erroneous results. Finally, the orientation of the fatigue sample in the machine may not have been truly vertical, leading to stresses more closely aligned with the angle of maximum shear and lowering the fatigue life. Any pre-existing material flaws or scratches may have led to a decrease in expected fatigue life.

To mitigate fatigue damage in the specimen, we can shot-peen the surface, leaving compressive stresses in the metal that attempt to close cracks before they can reach to critical crack length. Additionally, loading the specimen horizontally would have increased the applied area and therefore decreased the applied stress, leading to a longer fatigue life. Chamfering or countersinking the hole would have distributed the load divergence more slowly as the load approached the hole, leading to a decreased stress concentration factor and a longer fatigue life.

C. Impact

The length, width, thickness, crater depth, crater diameter is listed in table (15). As well as the corresponding drop height and velocity associated with the impactor.

As shown in figure (15) there are varying levels of crater depth and diameter depending on the drop height of the impactor. As expected, as the drop height of the impactor increases the more evident the impact is. This was not true for all cases though. For specimen two, the drop height was changed from 5.5-12 inches, but the impact was less evident in the second specimen than it was for the first specimen. It was not until a final drop height of 31.5 inches where the impactor went completely through the composite specimen. From Figure (16), we see that all four specimens experience dents and depressions. In specimen 3 and 4 there was a combination of large cracks with fiber breakage and indentations.

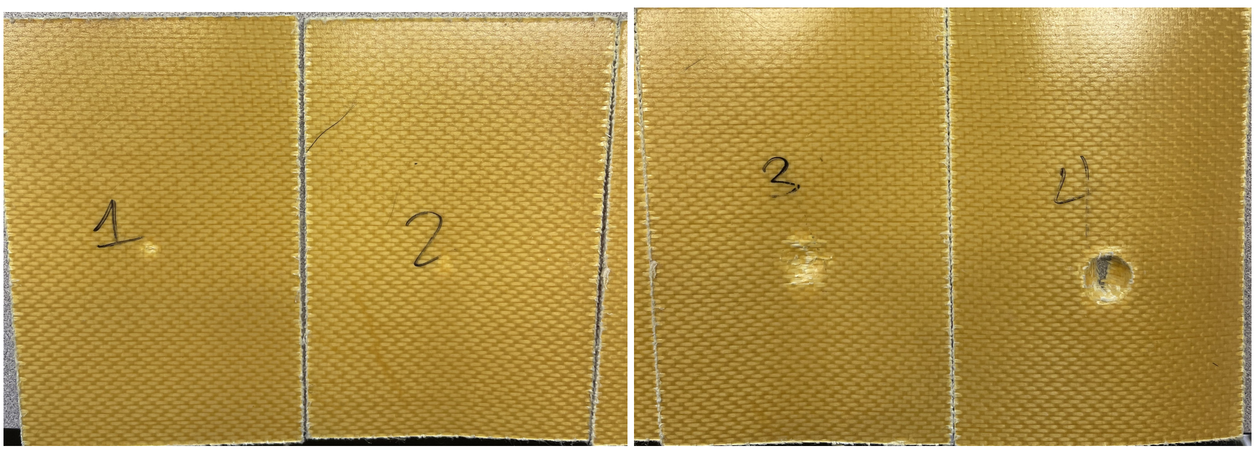


Fig. 15 Specimens after impact testing at various heights.

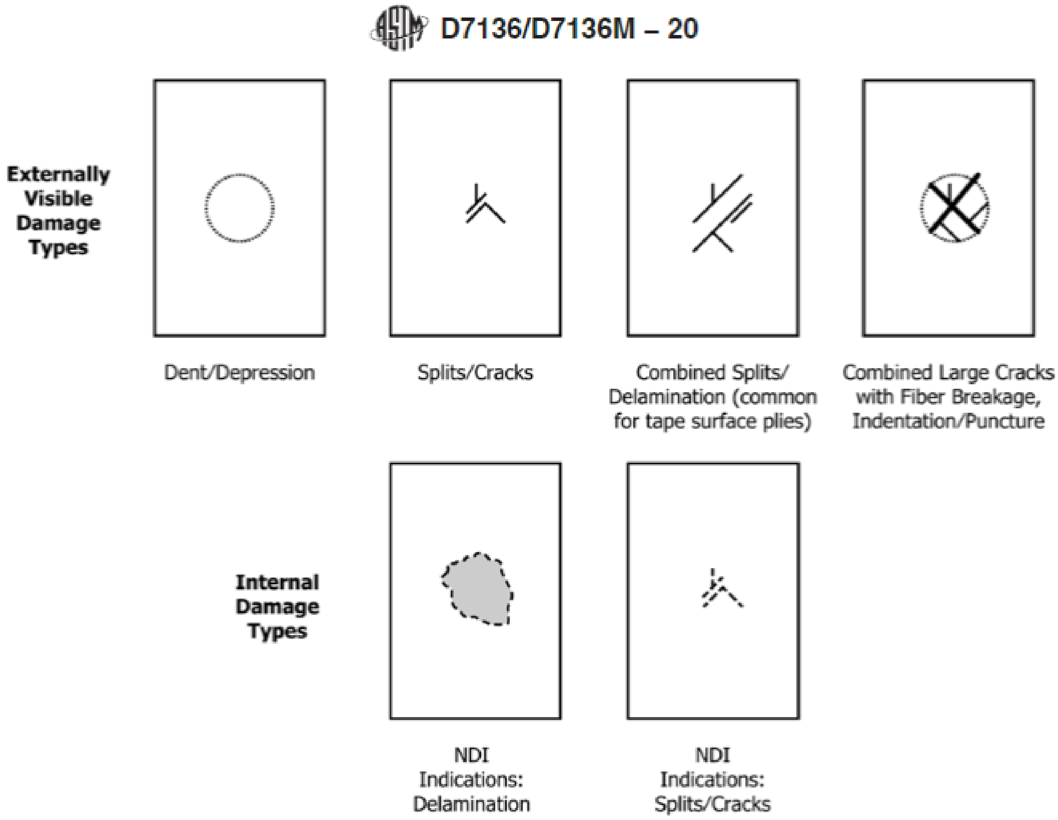


Fig. 16 Common modes of damage from drop-weight impact from ASTM D7136/D7136M [9]

.

To calculate the velocity of the impactor for the various heights, we used Eq. **??** for the conservation of mechanical energy.

$$
\begin{aligned}
E_i &= E_f \\
\frac{1}{2}mv_i^2 + mgh_i &= \frac{1}{2}mv_f^2 + mgh_f
\end{aligned}
\tag{9}
$$

Since the impactor starts from rest and the final position of the impactor is at a height of zero, the resulting equation becomes

$$mgh_i = \frac{1}{2}mv_f^2$$

$$gh = \frac{1}{2}v_f^2$$

Assuming no friction, this shows that the impactor's initial potential energy is equal to the impactor's velocity at impact. The final equation for velocity is then solely a function of height as the masses cancel out.

$$V_f = \sqrt{2gh}$$

Table 15 Dimensions and data from impact testing.

	Specimen 1	Specimen 2	Specimen 3	Specimen 4
Length (in)	6	$5\frac{14}{16}$	$5\frac{15}{16}$	6
Width (in)	4	4	$3\frac{15}{16}$	$3\frac{15}{16}$
Thickness (in)	0.0445	0.0405	0.0405	0.052
Drop Height (in)	5.5	12	20	31.5
Velocity (m/s)	1.6556	2.4454	3.1571	3.9621
Crater Depth (mm)	0.4	0.3	1.123	1.3208
Crater Diameter (mm)	4.81	5.55	13.915	15.03
Potential Energy of Impactor (J)	3.5632	7.7742	12.9571	20.4074
Kinetic Energy of Impactor (J)	3.5632	7.7742	12.9571	20.4074

IV. Discussion

A. Tensile

The results from the tensile test for the dogbone specimens were generally in accordance with the literature. With the exception of the prematurely failed first test, the dogbone passed through the elastic regime and showed a clearly defined plastic regime before ultimate failure. For the carbon composite specimens, Extension-load and stress-strain plots were generated for each sample. Unlike aluminum dogbones with a clear gauge length, the composite gauge length was estimated from the Instron jaws' distance. Table (6) summarized the results, indicating that the gauge length at failure was calculated based on the estimated distance. Figure (6) showed the stress-strain curves, with separate plots for axial and transverse strain gauges for most samples except sample 1. Most samples yielded post-strain gauge debonding and extensometer removal, except for the transverse gauge on the fourth sample and both strain gauges on the fifth sample. We then calculated for Poisson's ratio and theoretically since the value should be ranging from -1 to 0.5, sample 5 is clearly incorrect.

The aluminum and carbon fiber appeared to have brittle fracture patterns across all samples, as evidenced by the stress-strain curves. Using information from ASTM D3039, the failure code for all carbon composites tested would be lateral-gage-middle, or LGM (since these were the same for each sample, no table was produced).

All in all, aluminum would be better for aircraft or spacecraft applications because of its superior performance.

B. Fatigue

In our fatigue test, we are centered on the analysis of stress concentrations near the hole in our specimen subjected to a maximum force of 9kN. The calculated nominal stress near the hole, accounting for the dimensions of the specimen was calculated to be around 47.2 MPa.

Upon introducing the stress concentration factor computed as 2.75, the peak stress at the hole was found to be 129.804 MPa. This notable increase in stress at the hole highlights the impact of stress concentration on the material, emphazising the significance of load path diversion around the hole.

Equation (2) shows that the stress concentration factor amplifies the stress experienced at the hole. As the load path diverts around the hole, the thinner cross sections near the hole experience a substantial increase in stress.

C. Impact

The relationship between the height of the impactor and various impactor-related parameters, such as velocity, composite crater depth, diameter, as well as potential and kinetic energy, is illustrated in Table (15). This is expected as the drop height is an important factor into calculating the mechanical energy of the impactor. The increase in mechanical energy of the impactor led to a larger crater depth/diameter as well as overall physical damage of the composites.

The published specific ratio of impact energy to specimen thickness in ASTM D7136 was $6.7\frac{J}{mm}$. This is derived from taking the specimen's energy and dividing by the thickness of the specimen. To attain this value, there were multiple impact experiments done at a designated height. We did our impact experiments at varying heights so we had four different values for specified ratio of impact energy to specimen thickness (C_e). Using the values from Table (15) for specimens 1-4 their respective C_e were: 3.0832, 7.5573, 12.5956, 15.4508. Resulting in a mean C_e of 9.6717. Using the equations in the impact results section, a drop height of 10.6385 inches will result in a C_e of 6.7.

V. Conclusion

Our experimental stress analysis encompassing tensile, impact and fatigue testing yielded valuable insights into the mechanical properties of carbon fiber and aluminum specimens. The tensile tests conducted on carbon fiber strips, using the Instron 5969 provided data for elastic modulus, yield strength, max tensile strength and ultimate tensile strength. The impact tests allows us to assess damage resistance of the carbon fiber specimen under varying heights. Our fatigue tests on aluminum tensile bars offered an understanding of fatigue behaviour, including nominal stress, peak stress and the number of cycles till failure. These findings contribute to our understanding of material performance and structural integrity in real world applications.

Appendix

Please see attached Matlab code.

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aluminum

```
close all; clear all; clc

% INSTRON
Al1 = readmatrix('Al_1.csv');             Al2 = readmatrix('Al_2.csv');
      % import data

L0_Al1 = (7 + 7/8)*25.4;                  L0_Al2 = (7 + 7/8)*25.4;
      % original length, mm

time_Al1 = Al1(:,1);                      time_Al2 = Al2(:,1);
      % time, s
extension_Al1 = Al1(:,2);                 extension_Al2 = Al2(:,2);
      % extension, mm
strain_Al1 = extension_Al1(1:378)/L0_Al1; strain_Al2 = extension_Al2(1:468)/
L0_Al2; % strain
load_Al1 = Al1(:,3)/1000;                 load_Al2 = Al2(:,3)/1000;
      % load, kN
stress_Al1 = Al1(1:378,4);                stress_Al2 = Al2(1:468,4);
      % tensile stress, MPa

ix1 = find(load_Al1==max(load_Al1)); ix2 = find(load_Al2==max(load_Al2));

figure
subplot(1,2,1)
plot(extension_Al1, load_Al1, 'LineWidth', 1.2, Color=[0 0.4470 0.7410])
hold on
plot(extension_Al2, load_Al2, 'LineWidth', 1.2, Color=[0.8500 0.3250 0.0980])
plot(extension_Al1(ix1), max(load_Al1), 'pentagram', 'MarkerSize', 8, Color=[0
 0.4470 0.7410])
plot(extension_Al2(ix2), max(load_Al2), 'pentagram', 'MarkerSize', 8,
 Color=[0.8500 0.3250 0.0980])
xlim([0 20])
xlabel('Extension [mm]')
ylabel('Load [kN]')
legend('1', '2', Location='southeast')
grid on

subplot(1,2,2)
plot(strain_Al1, stress_Al1, 'LineWidth', 1.2, Color=[0 0.4470 0.7410])
hold on
plot(strain_Al2, stress_Al2, 'LineWidth', 1.2, Color=[0.8500 0.3250 0.0980])
plot(strain_Al1(end), stress_Al1(end), 'pentagram', 'MarkerSize', 8, Color=[0
 0.4470 0.7410])
plot(strain_Al2(end), stress_Al2(end), 'pentagram', 'MarkerSize', 8,
 Color=[0.8500 0.3250 0.0980])
xlim([0.0015 0.015])
xlabel('Strain [mm/mm]')
ylabel('Stress [MPa]')
legend('1', '2', Location='southeast')
% sgtitle('Aluminum')
```

```
hold on
grid on

per_elong_Al1 = extension_Al1(end)/L0_Al1;
per_elong_Al2 = extension_Al2(end)/L0_Al2;

g_len0 = 76.20; % mm
in1 = length(strain_Al1); % fails at the end
g_len_Al1 = (g_len0 + extension_Al1(in1)); % index is at failure
in2 = length(strain_Al2); % fails at the end
g_len_Al2 = (g_len0 + extension_Al2(in2)); % index is at failure

disp("Aluminum")
disp("INSTRON")
disp("Sample 1")
disp("max strain: " + strain_Al1(end))
disp("max stress: " + stress_Al1(end))
disp("max load: " + max(load_Al1))
disp("extension at max load: " + extension_Al1(ix1))
disp("percent elongation: " + per_elong_Al1)
disp("gauge length at failure: " + g_len_Al1)
disp("Sample 2")
disp("max strain: " + strain_Al2(end))
disp("max stress: " + stress_Al2(end))
disp("max load: " + max(load_Al2))
disp("extension at max load: " + extension_Al2(ix2))
disp("percent elongation: " + per_elong_Al2)
disp("gauge length at failure: " + g_len_Al2)

% TS / AS / EX
Al2ws = readmatrix('Al_ws2.txt');
strain_Al2ts = Al2ws(:,2)/1000000; % strain gauge
index = find(strain_Al2ts == max(strain_Al2ts));
strain_Al2ts = strain_Al2ts(1:index);
index1 = round(linspace(1,length(stress_Al2),index));
stress_Al2_ = stress_Al2(index1); % tensile stress, MPa
strain_Al1ex = Al1(1:378,5); strain_Al2ex = Al2(1:468,5); % strain
 (extensometer), mm/mm

in = find(stress_Al2_ == 355.62238); % find second point for linear region
x = [strain_Al2ts(1), strain_Al2ts(in)]; y = [stress_Al2_(1),
 stress_Al2_(in)]; % two points to define the linear region
x_offset = x + 0.002; % 0.002 offset
x_offset_interp = x_offset(1) + (450 - y(1)) * (x_offset(2) - x_offset(1)) /
 (y(2) - y(1)); % interpolate to extend the offset line
x_offset = [x_offset, x_offset_interp]; y_offset = [y, 450]; % attach the
 interpolated value to define three points for the offset linear region
E_Al = (y(2)-y(1)) / (x(2)-x(1)) / 10^3; % rise/run, GPa

x1 = [strain_Al1ex(1), strain_Al1ex(end)]; y1 = [stress_Al1(1),
 stress_Al1(end)];
x1_offset = x1 + 0.002;
E_Al1 = (y1(2)-y1(1)) / (x1(2)-x1(1)) / 10^3; % rise/run, GPa
```

```
in2 = find(stress_Al2 == 340.82578); % find second point for linear region
x2 = [strain_Al2ex(1), strain_Al2ex(in2)]; y2 = [stress_Al2(1),
 stress_Al2(in2)]; % two points to define the linear region
x2_offset = x2 + 0.002; % 0.002 offset
x2_offset_interp = x2_offset(1) + (450 - y2(1)) * (x2_offset(2) -
 x2_offset(1)) / (y2(2) - y2(1)); % interpolate to extend the offset line
x2_offset = [x2_offset, x2_offset_interp]; y2_offset = [y2, 450]; % attach the
 interpolated value to define three points for the offset linear region
E_Al2 = (y2(2)-y2(1)) / (x2(2)-x2(1)) / 10^3; % rise/run, GPa

figure
subplot(1,2,1)
plot(strain_Al2ts, stress_Al2_, 'LineWidth', 1.2, Color=[0.8500 0.3250
 0.0980])
hold on
plot(x, y, '--', 'LineWidth', 1.2, Color=[0.8500 0.3250 0.0980])
plot(x_offset, y_offset, '-.', 'LineWidth', 1.2, Color=[0.8500 0.3250 0.0980])
% plot(strain_Al2ts(end), stress_Al2_(end), 'pentagram', 'MarkerSize', 8,
 Color=[0.8500 0.3250 0.0980])
xlim([0 0.015])
xlabel('Strain (TS) [mm/mm]')
ylabel('Stress [MPa]')
legend('2', Location='southeast')
grid on

subplot(1,2,2)
plot(strain_Al1ex, stress_Al1, 'LineWidth', 1.2, Color=[0 0.4470 0.7410])
hold on
plot(strain_Al2ex, stress_Al2, 'LineWidth', 1.2, Color=[0.8500 0.3250 0.0980])
% plot(strain_Al1ex(end), stress_Al1(end), 'pentagram', 'MarkerSize', 8,
 Color=[0 0.4470 0.7410])
% plot(strain_Al2ex(end), stress_Al2(end), 'pentagram', 'MarkerSize', 8,
 Color=[0.8500 0.3250 0.0980])
plot(x1, y1, '--', 'LineWidth', 1.2, Color=[0 0.4470 0.7410])
% plot(x1_offset, y1, '-.', 'LineWidth', 1.2, Color=[0 0.4470 0.7410])
plot(x2, y2, '--', 'LineWidth', 1.2, Color=[0.8500 0.3250 0.0980])
plot(x2_offset, y2_offset, '-.', 'LineWidth', 1.2, Color=[0.8500 0.3250
 0.0980])
xlim([0 0.015])
xlabel('Strain (EX) [mm/mm]')
ylabel('Stress [MPa]')
legend('1', '2', Location='southeast')
grid on

strain_yieldts = 0.007368; stress_yieldts = 388.384; % from plot
strain2_yieldex = 0.00723; stress2_yieldex = 381.351; % from plot

disp("TS")
disp("Sample 2")
disp("elastic modulus (GPa): " + E_Al)
disp("yield stress (MPa): " + stress_yieldts)
disp("strain at yield stress (mm/mm): " + strain_yieldts)
disp("strain at debonding (mm/mm): " + strain_Al2ts(end))
disp("EX")
```

```
disp("Sample 1")
disp("elastic modulus (GPa): " + E_Al1)
disp("yield stress (MPa): " + stress_Al1(end))
disp("strain at yield stress (mm/mm): " + strain_Al1ex(end))
disp("strain at debonding (mm/mm): " + strain_Al1ex(end))
disp("Sample 2")
disp("elastic modulus (GPa): " + E_Al2)
disp("yield stress (MPa): " + stress2_yieldex)
disp("strain at yield stress (mm/mm): " + strain2_yieldex)
disp("strain at debonding (mm/mm): " + strain_Al2ex(end))

disp("MAX STRAIN COMPARISON VALS")
disp("TS")
disp("Sample 2")
disp("max strain: " + max(strain_Al2ts))
disp("EX")
disp("Sample 1")
disp("max strain: " + max(strain_Al1ex))
disp("Sample 2")
disp("max strain: " + max(strain_Al2ex))
disp("toughness: " + max(strain_Al2ex)*max(stress_Al2)/2)
```

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composite

```
close all; clear all; clc

% INSTRON
c1 = readmatrix('composite_1.csv');
c2 = readmatrix('composite_2.csv');
c3 = readmatrix('composite_3.csv');
c4 = readmatrix('composite_4.csv');
c5 = readmatrix('composite_5.csv');

L0_c1 = (7 + 5/16)*25.4; L0_c2 = (8)*25.4; L0_c3 = (7 + 15/16)*25.4; L0_c4 =
 (7 + 15/16)*25.4; L0_c5 = (7 + 15/16)*25.4; % original length, mm

% test
% extension = c1(:,2);
% strain = extension(1:end)/L0_c1; stress = c1(1:end,4);
% figure
% plot(strain, stress)

time_c1 = c1(:,1);        time_c2 = c2(:,1);        time_c3 = c3(:,1);
 time_c4 = c4(:,1);        time_c5 = c5(:,1);       % time, s
extension_c1 = c1(:,2);   extension_c2 = c2(:,2);   extension_c3 = c3(:,2);
 extension_c4 = c4(:,2);   extension_c5 = c5(:,2);  % extension, mm
strain_c1 = extension_c1(1:end)/L0_c1; strain_c2 = extension_c2(1:end)/L0_c2;
 strain_c3 = extension_c3(1:end)/L0_c3; strain_c4 = extension_c4(1:end)/L0_c4;
 strain_c5 = extension_c5(1:end)/L0_c5; % strain
load_c1 = c1(:,3)/1000;   load_c2 = c2(:,3)/1000;   load_c3 = c3(:,3)/1000;
 load_c4 = c4(:,3)/1000;   load_c5 = c5(:,3)/1000;  % load, kN
stress_c1 = c1(1:end,4);  stress_c2 = c2(1:end,4);  stress_c3 = c3(1:end,4);
 stress_c4 = c4(1:end,4);  stress_c5 = c5(1:end,4); % tensile stress, MPa

ix1a = find(load_c1==max(load_c1)); ix2a = find(load_c2==max(load_c2)); ix3a
 = find(load_c3==max(load_c3)); ix4a = find(load_c4==max(load_c4)); ix5a =
 find(load_c5==max(load_c5));
ix1b = find(stress_c1==max(stress_c1)); ix2b =
 find(stress_c2==max(stress_c2)); ix3b = find(stress_c3==max(stress_c3)); ix4b
 = find(stress_c4==max(stress_c4)); ix5b = find(stress_c5==max(stress_c5));

strain_c1 = strain_c1(1:ix1b); strain_c2 = strain_c2(1:ix2b); strain_c3
 = strain_c3(1:ix3b); strain_c4 = strain_c4(1:ix4b); strain_c5 =
 strain_c5(1:ix5b); % strain
stress_c1 = stress_c1(1:ix1b); stress_c2 = stress_c2(1:ix2b); stress_c3
 = stress_c3(1:ix3b); stress_c4 = stress_c4(1:ix4b); stress_c5 =
 stress_c5(1:ix5b); % tensile stress, MPa

% set plot colors
color1 = [0 0.4470 0.7410]; color2 = [0.8500 0.3250 0.0980]; color3 = [0.9290
 0.6940 0.1250]; color4 = [0.4940 0.1840 0.5560]; color5 = [0.4660 0.6740
 0.1880];

figure
```

```
subplot(1,2,1)
plot(extension_c1, load_c1, 'LineWidth', 1.2, Color=color1)
hold on
plot(extension_c2, load_c2, 'LineWidth', 1.2, Color=color2)
plot(extension_c3, load_c3, 'LineWidth', 1.2, Color=color3)
plot(extension_c4, load_c4, 'LineWidth', 1.2, Color=color4)
plot(extension_c5, load_c5, 'LineWidth', 1.2, Color=color5)
plot(extension_c1(ix1a), max(load_c1), 'pentagram', 'MarkerSize', 8,
 Color=color1)
plot(extension_c2(ix2a), max(load_c2), 'pentagram', 'MarkerSize', 8,
 Color=color2)
plot(extension_c3(ix3a), max(load_c3), 'pentagram', 'MarkerSize', 8,
 Color=color3)
plot(extension_c4(ix4a), max(load_c4), 'pentagram', 'MarkerSize', 8,
 Color=color4)
plot(extension_c5(ix5a), max(load_c5), 'pentagram', 'MarkerSize', 8,
 Color=color5)
xlim([0.3,6])
xlabel('Extension [mm]')
ylabel('Load [kN]')
legend('1', '2', '3', '4', '5', Location='southeast')
grid on

subplot(1,2,2)
plot(strain_c1, stress_c1, 'LineWidth', 1.2, Color=color1)
hold on
plot(strain_c2, stress_c2, 'LineWidth', 1.2, Color=color2)
plot(strain_c3, stress_c3, 'LineWidth', 1.2, Color=color3)
plot(strain_c4, stress_c4, 'LineWidth', 1.2, Color=color4)
plot(strain_c5, stress_c5, 'LineWidth', 1.2, Color=color5)
plot(strain_c1(ix1b), max(stress_c1), 'pentagram', 'MarkerSize', 8,
 Color=color1)
plot(strain_c2(ix2b), max(stress_c2), 'pentagram', 'MarkerSize', 8,
 Color=color2)
plot(strain_c3(ix3b), max(stress_c3), 'pentagram', 'MarkerSize', 8,
 Color=color3)
plot(strain_c4(ix4b), max(stress_c4), 'pentagram', 'MarkerSize', 8,
 Color=color4)
plot(strain_c5(ix5b), max(stress_c5), 'pentagram', 'MarkerSize', 8,
 Color=color5)
% xlim([0.0015,0.018])
% ylim([0,220])
xlabel('Strain [mm/mm]')
ylabel('Stress [MPa]')
legend('1', '2', '3', '4', '5', Location='southeast')
% sgtitle('Composite')
hold on
grid on

% percent elongation
per_elong_c1 = extension_c1(end)/L0_c1*100;
per_elong_c2 = extension_c2(end)/L0_c2*100;
per_elong_c3 = extension_c3(end)/L0_c3*100;
per_elong_c4 = extension_c4(end)/L0_c4*100;
```

```
per_elong_c5 = extension_c5(end)/L0_c5*100;

% original gauge length, mm
Lg0_c1 = L0_c1 - 50;
Lg0_c2 = L0_c2 - 50;
Lg0_c3 = L0_c3 - 50;
Lg0_c4 = L0_c4 - 50;
Lg0_c5 = L0_c5 - 50;

% index is at failure
g_len_c1 = (Lg0_c1 + extension_c1(ix1b));
g_len_c2 = (Lg0_c2 + extension_c2(ix2b));
g_len_c3 = (Lg0_c3 + extension_c3(ix3b));
g_len_c4 = (Lg0_c4 + extension_c4(ix4b));
g_len_c5 = (Lg0_c5 + extension_c5(ix5b));

disp("Composite")
disp("INSTRON")
disp("Sample 1")
disp("max strain: " + strain_c1(ix1b))
disp("max stress: " + max(stress_c1))
disp("max load: " + max(load_c1))
disp("extension at max load: " + extension_c1(ix1a))
disp("percent elongation: " + per_elong_c1)
disp("gauge length at failure: " + g_len_c1)
disp("Sample 2")
disp("max strain: " + strain_c2(ix2b))
disp("max stress: " + max(stress_c2))
disp("max load: " + max(load_c2))
disp("extension at max load: " + extension_c2(ix2a))
disp("percent elongation: " + per_elong_c2)
disp("gauge length at failure: " + g_len_c2)
disp("Sample 3")
disp("max strain: " + strain_c3(ix3b))
disp("max stress: " + max(stress_c3))
disp("max load: " + max(load_c3))
disp("extension at max load: " + extension_c3(ix3a))
disp("percent elongation: " + per_elong_c3)
disp("gauge length at failure: " + g_len_c3)
disp("Sample 4")
disp("max strain: " + strain_c4(ix4b))
disp("max stress: " + max(stress_c4))
disp("max load: " + max(load_c4))
disp("extension at max load: " + extension_c4(ix4a))
disp("percent elongation: " + per_elong_c4)
disp("gauge length at failure: " + g_len_c4)
disp("Sample 5")
disp("max strain: " + strain_c5(ix5b))
disp("max stress: " + max(stress_c5))
disp("max load: " + max(load_c5))
disp("extension at max load: " + extension_c5(ix5a))
disp("percent elongation: " + per_elong_c5)
disp("gauge length at failure: " + g_len_c5)
```

```
% TS / AS / EX
c1ws = readmatrix('composite_ws1.txt'); strain_c1as = abs(c1ws(:,2))/1000000;
 strain_c1ts = abs(c1ws(:,3))/1000000; % strain gauge
c2ws = readmatrix('composite_ws2.txt'); strain_c2as = abs(c2ws(:,2))/1000000;
 strain_c2ts = abs(c2ws(:,3))/1000000; % strain gauge
c3ws = readmatrix('composite_ws3.txt'); strain_c3as = abs(c3ws(:,2))/1000000;
 strain_c3ts = abs(c3ws(:,3))/1000000; % strain gauge
c4ws = readmatrix('composite_ws4.txt'); strain_c4as = abs(c4ws(:,2))/1000000;
 strain_c4ts = abs(c4ws(:,3))/1000000; % strain gauge
c5ws = readmatrix('composite_ws5.txt'); strain_c5as = abs(c5ws(:,2))/1000000;
 strain_c5ts = abs(c5ws(:,3))/1000000; % strain gauge

% cut off bad strain gauge values, match Instron stress to strain gauge data
ixts = find(strain_c1ts == max(strain_c1ts)); ixts = ixts(end); ixas =
 find(strain_c1as == max(strain_c1as)); ixas = ixas(end);
strain_c1ts = strain_c1ts(1:ixts); strain_c1as = strain_c1as(1:ixas);
ixts = round(linspace(1,length(stress_c1),ixts)); ixas =
 round(linspace(1,length(stress_c1),ixas));
stress_c1ts = stress_c1(ixts); stress_c1as = stress_c1(ixas); % tensile
 stress, MPa

ixts = find(strain_c2ts == max(strain_c2ts)); ixts = ixts(end); ixas =
 find(strain_c2as == max(strain_c2as)); ixas = ixas(end);
strain_c2ts = strain_c2ts(1:ixts); strain_c2as = strain_c2as(1:ixas);
ixts = round(linspace(1,length(stress_c2),ixts)); ixas =
 round(linspace(1,length(stress_c2),ixas));
stress_c2ts = stress_c2(ixts); stress_c2as = stress_c2(ixas); % tensile
 stress, MPa

ixts = find(strain_c3ts == max(strain_c3ts)); ixts = ixts(end); ixas =
 find(strain_c3as == max(strain_c3as)); ixas = ixas(end);
strain_c3ts = strain_c3ts(1:ixts); strain_c3as = strain_c3as(1:ixas);
ixts = round(linspace(1,length(stress_c3),ixts)); ixas =
 round(linspace(1,length(stress_c3),ixas));
stress_c3ts = stress_c3(ixts); stress_c3as = stress_c3(ixas); % tensile
 stress, MPa

ixts = find(strain_c4ts == max(strain_c4ts)); ixts = ixts(end); ixas =
 find(strain_c4as == max(strain_c4as)); ixas = ixas(end);
strain_c4ts = strain_c4ts(1:ixts); strain_c4as = strain_c4as(1:ixas);
ixts = round(linspace(1,length(stress_c4),ixts)); ixas =
 round(linspace(1,length(stress_c4),ixas));
stress_c4ts = stress_c4(ixts); stress_c4as = stress_c4(ixas); % tensile
 stress, MPa

ixts = find(strain_c5ts == max(strain_c5ts)); ixts = ixts(end); ixas =
 find(strain_c5as == max(strain_c5as)); ixas = ixas(end);
strain_c5ts = strain_c5ts(1:ixts); strain_c5as = strain_c5as(1:ixas);
ixts = round(linspace(1,length(stress_c5),ixts)); ixas =
 round(linspace(1,length(stress_c5),ixas));
stress_c5ts = stress_c5(ixts); stress_c5as = stress_c5(ixas); % tensile
 stress, MPa

% strain (extensometer), mm/mm
```

```
strain_c1ex = c1(1:495,5);  strain_c2ex = c2(1:1001,5);  strain_c3ex =
 c3(1:577,5);  strain_c4ex = c4(1:544,5);  strain_c5ex = c5(1:625,5);
% tensile stress (extensometer), MPa
stress_c1ex = stress_c1(1:495); stress_c2ex = stress_c2(1:1001); stress_c3ex
 = stress_c3(1:577); stress_c4ex = stress_c4(1:544); stress_c5ex =
 stress_c5(1:625);

% regression lines (TS)
x2ts = [strain_c2ts(1), strain_c2ts(end)]; y2ts = [stress_c2ts(1),
 stress_c2ts(end)]; % two points to define the linear region
x2ts_offset = x2ts + 0.002; % 0.002 offset
x2ts_offset_interp = x2ts_offset(1) + (900 - y2ts(1)) * (x2ts_offset(2) -
 x2ts_offset(1)) / (y2ts(2) - y2ts(1)); % interpolate to extend the offset
 line
x2ts_offset = [x2ts_offset, x2ts_offset_interp]; y2ts_offset = [y2ts, 900]; %
 attach the interpolated value to define three points for the offset linear
 region
E2ts = (y2ts(2)-y2ts(1)) / (x2ts(2)-x2ts(1)) / 10^3; % rise/run, GPa

x3ts = [strain_c3ts(1), strain_c3ts(end)]; y3ts = [stress_c3ts(1),
 stress_c3ts(end)]; % two points to define the linear region
x3ts_offset = x3ts + 0.002; % 0.002 offset
x3ts_offset_interp = x3ts_offset(1) + (900 - y3ts(1)) * (x3ts_offset(2) -
 x3ts_offset(1)) / (y3ts(2) - y3ts(1)); % interpolate to extend the offset
 line
x3ts_offset = [x3ts_offset, x3ts_offset_interp]; y3ts_offset = [y3ts, 900]; %
 attach the interpolated value to define three points for the offset linear
 region
E3ts = (y3ts(2)-y3ts(1)) / (x3ts(2)-x3ts(1)) / 10^3; % rise/run, GPa

x4ts = [strain_c4ts(1), strain_c4ts(end-1)]; y4ts = [stress_c4ts(1),
 stress_c4ts(end-1)]; % two points to define the linear region
x4ts_offset = x4ts + 0.002; % 0.002 offset
x4ts_offset_interp = x4ts_offset(1) + (900 - y4ts(1)) * (x4ts_offset(2) -
 x4ts_offset(1)) / (y4ts(2) - y4ts(1)); % interpolate to extend the offset
 line
x4ts_offset = [x4ts_offset, x4ts_offset_interp]; y4ts_offset = [y4ts, 900]; %
 attach the interpolated value to define three points for the offset linear
 region
E4ts = (y4ts(2)-y4ts(1)) / (x4ts(2)-x4ts(1)) / 10^3; % rise/run, GPa

in = find(stress_c5ts == 550.26794); % find second point for linear region
x5ts = [strain_c5ts(1), strain_c5ts(in)]; y5ts = [stress_c5ts(1),
 stress_c5ts(in)]; % two points to define the linear region
x5ts_offset = x5ts + 0.002; % 0.002 offset
x5ts_offset_interp = x5ts_offset(1) + (900 - y5ts(1)) * (x5ts_offset(2) -
 x5ts_offset(1)) / (y5ts(2) - y5ts(1)); % interpolate to extend the offset
 line
x5ts_offset = [x5ts_offset, x5ts_offset_interp]; y5ts_offset = [y5ts, 900]; %
 attach the interpolated value to define three points for the offset linear
 region
E5ts = (y5ts(2)-y5ts(1)) / (x5ts(2)-x5ts(1)) / 10^3; % rise/run, GPa

% regression lines (AS)
```

```
x2as = [strain_c2as(1), strain_c2as(end)]; y2as = [stress_c2as(1),
 stress_c2as(end)]; % two points to define the linear region
x2as_offset = x2as + 0.002; % 0.002 offset
x2as_offset_interp = x2as_offset(1) + (900 - y2as(1)) * (x2as_offset(2) -
 x2as_offset(1)) / (y2as(2) - y2as(1)); % interpolate to extend the offset
 line
x2as_offset = [x2as_offset, x2as_offset_interp]; y2as_offset = [y2as, 900]; %
 attach the interpolated value to define three points for the offset linear
 region
E2as = (y2as(2)-y2as(1)) / (x2as(2)-x2as(1)) / 10^3; % rise/run, GPa

x3as = [strain_c3as(1), strain_c3as(end)]; y3as = [stress_c3as(1),
 stress_c3as(end)]; % two points to define the linear region
x3as_offset = x3as + 0.002; % 0.002 offset
x3as_offset_interp = x3as_offset(1) + (900 - y3as(1)) * (x3as_offset(2) -
 x3as_offset(1)) / (y3as(2) - y3as(1)); % interpolate to extend the offset
 line
x3as_offset = [x3as_offset, x3as_offset_interp]; y3as_offset = [y3as, 900]; %
 attach the interpolated value to define three points for the offset linear
 region
E3as = (y3as(2)-y3as(1)) / (x3as(2)-x3as(1)) / 10^3; % rise/run, GPa

% x4as = [strain_c4as(1), strain_c4as(end)]; y4as = [stress_c4as(1),
 stress_c4as(end)]; % two points to define the linear region
% x4as_offset = x4as + 0.002; % 0.002 offset
% x4as_offset_interp = x4as_offset(1) + (900 - y4as(1)) * (x4as_offset(2) -
 x4as_offset(1)) / (y4as(2) - y4as(1)); % interpolate to extend the offset
 line
% x4as_offset = [x4as_offset, x4as_offset_interp]; y4as_offset = [y4as, 900];
 % attach the interpolated value to define three points for the offset linear
 region
% E4as = (y4as(2)-y4as(1)) / (x4as(2)-x4as(1)) / 10^3; % rise/run, GPa

in = find(stress_c4as == 157.63519); % find second point for linear region
x4as = [strain_c4as(1), strain_c4as(in)]; y4as = [stress_c4as(1),
 stress_c4as(in)]; % two points to define the linear region
x4as_offset = x4as + 0.002; % 0.002 offset
x4as_offset_interp = x4as_offset(1) + (900 - y4as(1)) * (x4as_offset(2) -
 x4as_offset(1)) / (y4as(2) - y4as(1)); % interpolate to extend the offset
 line
x4as_offset = [x4as_offset, x4as_offset_interp]; y4as_offset = [y4as, 900]; %
 attach the interpolated value to define three points for the offset linear
 region
E4as = (y4as(2)-y4as(1)) / (x4as(2)-x4as(1)) / 10^3; % rise/run, GPa

% x5as = [strain_c5as(1), strain_c5as(end)]; y5as = [stress_c5as(1),
 stress_c5as(end)]; % two points to define the linear region
% x5as_offset = x5as + 0.002; % 0.002 offset
% x5as_offset_interp = x5as_offset(1) + (900 - y5as(1)) * (x5as_offset(2) -
 x5as_offset(1)) / (y5as(2) - y5as(1)); % interpolate to extend the offset
 line
% x5as_offset = [x5as_offset, x5as_offset_interp]; y5as_offset = [y5as, 900];
 % attach the interpolated value to define three points for the offset linear
 region
```

```
% E5as = (y5as(2)-y5as(1)) / (x5as(2)-x5as(1)) / 10^3; % rise/run, GPa

in = find(stress_c5as == 550.26794); % find second point for linear region
x5as = [strain_c5as(1), strain_c5as(in)]; y5as = [stress_c5as(1),
 stress_c5as(in)]; % two points to define the linear region
x5as_offset = x5as + 0.002; % 0.002 offset
x5as_offset_interp = x5as_offset(1) + (900 - y5as(1)) * (x5as_offset(2) -
 x5as_offset(1)) / (y5as(2) - y5as(1)); % interpolate to extend the offset
 line
x5as_offset = [x5as_offset, x5as_offset_interp]; y5as_offset = [y5as, 900]; %
 attach the interpolated value to define three points for the offset linear
 region
E5as = (y5as(2)-y5as(1)) / (x5as(2)-x5as(1)) / 10^3; % rise/run, GPa

% regression lines (EX)
x1ex = [strain_c1ex(1), strain_c1ex(end)]; y1ex = [stress_c1ex(1),
 stress_c1ex(end)]; % two points to define the linear region
x1ex_offset = x1ex + 0.002; % 0.002 offset
x1ex_offset_interp = x1ex_offset(1) + (900 - y1ex(1)) * (x1ex_offset(2) -
 x1ex_offset(1)) / (y1ex(2) - y1ex(1)); % interpolate to extend the offset
 line
x1ex_offset = [x1ex_offset, x1ex_offset_interp]; y1ex_offset = [y1ex, 900]; %
 attach the interpolated value to define three points for the offset linear
 region
E1ex = (y1ex(2)-y1ex(1)) / (x1ex(2)-x1ex(1)) / 10^3; % rise/run, GPa

x2ex = [strain_c2ex(1), strain_c2ex(end)]; y2ex = [stress_c2ex(1),
 stress_c2ex(end)]; % two points to define the linear region
x2ex_offset = x2ex + 0.002; % 0.002 offset
x2ex_offset_interp = x2ex_offset(1) + (900 - y2ex(1)) * (x2ex_offset(2) -
 x2ex_offset(1)) / (y2ex(2) - y2ex(1)); % interpolate to extend the offset
 line
x2ex_offset = [x2ex_offset, x2ex_offset_interp]; y2ex_offset = [y2ex, 900]; %
 attach the interpolated value to define three points for the offset linear
 region
E2ex = (y2ex(2)-y2ex(1)) / (x2ex(2)-x2ex(1)) / 10^3; % rise/run, GPa

x3ex = [strain_c3ex(1), strain_c3ex(end)]; y3ex = [stress_c3ex(1),
 stress_c3ex(end)]; % two points to define the linear region
x3ex_offset = x3ex + 0.002; % 0.002 offset
x3ex_offset_interp = x3ex_offset(1) + (900 - y3ex(1)) * (x3ex_offset(2) -
 x3ex_offset(1)) / (y3ex(2) - y3ex(1)); % interpolate to extend the offset
 line
x3ex_offset = [x3ex_offset, x3ex_offset_interp]; y3ex_offset = [y3ex, 900]; %
 attach the interpolated value to define three points for the offset linear
 region
E3ex = (y3ex(2)-y3ex(1)) / (x3ex(2)-x3ex(1)) / 10^3; % rise/run, GPa

x4ex = [strain_c4ex(1), strain_c4ex(end)]; y4ex = [stress_c4ex(1),
 stress_c4ex(end)]; % two points to define the linear region
x4ex_offset = x4ex + 0.002; % 0.002 offset
x4ex_offset_interp = x4ex_offset(1) + (900 - y4ex(1)) * (x4ex_offset(2) -
 x4ex_offset(1)) / (y4ex(2) - y4ex(1)); % interpolate to extend the offset
 line
```

```
x4ex_offset = [x4ex_offset, x4ex_offset_interp]; y4ex_offset = [y4ex, 900]; %
 attach the interpolated value to define three poinex for the offset linear
 region
E4ex = (y4ex(2)-y4ex(1)) / (x4ex(2)-x4ex(1)) / 10^3; % rise/run, GPa

x5ex = [strain_c5ex(1), strain_c5ex(end)]; y5ex = [stress_c5ex(1),
 stress_c5ex(end)]; % two points to define the linear region
x5ex_offset = x5ex + 0.002; % 0.002 offset
x5ex_offset_interp = x5ex_offset(1) + (900 - y5ex(1)) * (x5ex_offset(2) -
 x5ex_offset(1)) / (y5ex(2) - y5ex(1)); % interpolate to extend the offset
 line
x5ex_offset = [x5ex_offset, x5ex_offset_interp]; y5ex_offset = [y5ex, 900]; %
 attach the interpolated value to define three poinex for the offset linear
 region
E5ex = (y5ex(2)-y5ex(1)) / (x5ex(2)-x5ex(1)) / 10^3; % rise/run, GPa

% without linear regression lines
figure
subplot(1,3,1)
% plot(strain_c1as, stress_c1as, 'LineWidth', 1.2, Color=color1)
plot(strain_c2as, stress_c2as, 'LineWidth', 1.2, Color=color2)
hold on
plot(strain_c3as, stress_c3as, 'LineWidth', 1.2, Color=color3)
plot(strain_c4as, stress_c4as, 'LineWidth', 1.2, Color=color4)
plot(strain_c5as, stress_c5as, 'LineWidth', 1.2, Color=color5)
xlim([0 0.0075])
ylim([0 900])
xlabel('Strain (TS) [mm/mm]')
ylabel('Stress [MPa]')
legend('2','3','4','5', Location='southeast')
grid on

subplot(1,3,2)
% plot(strain_c1ts, stress_c1ts, 'LineWidth', 1.2, Color=color1)
plot(strain_c2ts, stress_c2ts, 'LineWidth', 1.2, Color=color2)
hold on
plot(strain_c3ts, stress_c3ts, 'LineWidth', 1.2, Color=color3)
plot(strain_c4ts(1:end-1), stress_c4ts(1:end-1), 'LineWidth', 1.2,
 Color=color4)
plot(strain_c5ts, stress_c5ts, 'LineWidth', 1.2, Color=color5)
xlim([0 0.012])
ylim([0 900])
xlabel('Strain (AS) [mm/mm]')
ylabel('Stress [MPa]')
legend('2','3','4','5', Location='southeast')
grid on

subplot(1,3,3)
plot(strain_c1ex, stress_c1ex, 'LineWidth', 1.2, Color=color1)
hold on
plot(strain_c2ex, stress_c2ex, 'LineWidth', 1.2, Color=color2)
plot(strain_c3ex, stress_c3ex, 'LineWidth', 1.2, Color=color3)
plot(strain_c4ex, stress_c4ex, 'LineWidth', 1.2, Color=color4)
plot(strain_c5ex, stress_c5ex, 'LineWidth', 1.2, Color=color5)
```

```
ylim([0 250])
xlabel('Strain (EX) [mm/mm]')
ylabel('Stress [MPa]')
legend('1','2','3','4','5', Location='southeast')
grid on


% with linear regression lines
figure
subplot(1,3,1)
% plot(strain_c1as, stress_c1as, 'LineWidth', 1.2, Color=color1)
plot(strain_c2as, stress_c2as, 'LineWidth', 1.2, Color=color2)
hold on
plot(strain_c3as, stress_c3as, 'LineWidth', 1.2, Color=color3)
plot(strain_c4as, stress_c4as, 'LineWidth', 1.2, Color=color4)
plot(strain_c5as, stress_c5as, 'LineWidth', 1.2, Color=color5)
% plot(x1as, y1as, '--', 'LineWidth', 1.2, Color=color1)
% plot(x1as_offset, y1as_offset, '-.', 'LineWidth', 1.2, Color=color1)
plot(x2as, y2as, '--', 'LineWidth', 1.2, Color=color2)
% plot(x2as_offset, y2as_offset, '-.', 'LineWidth', 1.2, Color=color2)
plot(x3as, y3as, '--', 'LineWidth', 1.2, Color=color3)
% plot(x3as_offset, y3as_offset, '-.', 'LineWidth', 1.2, Color=color3)
plot(x4as, y4as, '--', 'LineWidth', 1.2, Color=color4)
plot(x4as_offset, y4as_offset, '-.', 'LineWidth', 1.2, Color=color4)
plot(x5as, y5as, '--', 'LineWidth', 1.2, Color=color5)
plot(x5as_offset, y5as_offset, '-.', 'LineWidth', 1.2, Color=color5)
xlim([0 0.0075])
ylim([0 900])
xlabel('Strain (TS) [mm/mm]')
ylabel('Stress [MPa]')
legend('2','3','4','5', Location='southeast')
grid on

subplot(1,3,2)
% plot(strain_c1ts, stress_c1ts, 'LineWidth', 1.2, Color=color1)
plot(strain_c2ts, stress_c2ts, 'LineWidth', 1.2, Color=color2)
hold on
plot(strain_c3ts, stress_c3ts, 'LineWidth', 1.2, Color=color3)
plot(strain_c4ts(1:end-1), stress_c4ts(1:end-1), 'LineWidth', 1.2,
 Color=color4)
plot(strain_c5ts, stress_c5ts, 'LineWidth', 1.2, Color=color5)
% plot(x1ts, y1ts, '--', 'LineWidth', 1.2, Color=color1)
% plot(x1ts_offset, y1ts_offset, '-.', 'LineWidth', 1.2, Color=color1)
plot(x2ts, y2ts, '--', 'LineWidth', 1.2, Color=color2)
% plot(x2ts_offset, y2ts_offset, '-.', 'LineWidth', 1.2, Color=color2)
plot(x3ts, y3ts, '--', 'LineWidth', 1.2, Color=color3)
% plot(x3ts_offset, y3ts_offset, '-.', 'LineWidth', 1.2, Color=color3)
plot(x4ts, y4ts, '--', 'LineWidth', 1.2, Color=color4)
% plot(x4ts_offset, y4ts_offset, '-.', 'LineWidth', 1.2, Color=color4)
plot(x5ts, y5ts, '--', 'LineWidth', 1.2, Color=color5)
plot(x5ts_offset, y5ts_offset, '-.', 'LineWidth', 1.2, Color=color5)
xlim([0 0.012])
ylim([0 900])
xlabel('Strain (AS) [mm/mm]')
```

```
ylabel('Stress [MPa]')
legend('2','3','4','5', Location='southeast')
grid on

subplot(1,3,3)
plot(strain_c1ex, stress_c1ex, 'LineWidth', 1.2, Color=color1)
hold on
plot(strain_c2ex, stress_c2ex, 'LineWidth', 1.2, Color=color2)
plot(strain_c3ex, stress_c3ex, 'LineWidth', 1.2, Color=color3)
plot(strain_c4ex, stress_c4ex, 'LineWidth', 1.2, Color=color4)
plot(strain_c5ex, stress_c5ex, 'LineWidth', 1.2, Color=color5)
plot(x2ex, y2ex, '--', 'LineWidth', 1.2, Color=color2)
plot(x3ex, y3ex, '--', 'LineWidth', 1.2, Color=color3)
plot(x4ex, y4ex, '--', 'LineWidth', 1.2, Color=color4)
plot(x5ex, y5ex, '--', 'LineWidth', 1.2, Color=color5)
ylim([0 250])
xlabel('Strain (EX) [mm/mm]')
ylabel('Stress [MPa]')
legend('1','2','3','4','5', Location='southeast')
grid on

strain_yield5ts = 0.007332; stress_yield5ts = 823.8; % from plot
strain_yield5as = 0.004115; stress_yield5as = 828.6; % from plot

disp("TS")
disp("Sample 2")
disp("elastic modulus (GPa): " + E2ts)
disp("yield stress (MPa): " + stress_c2ts(end))
disp("strain at yield stress (mm/mm): " + strain_c2ts(end))
disp("strain at debonding (mm/mm): " + strain_c2ts(end))
disp("Sample 3")
disp("elastic modulus (GPa): " + E3ts)
disp("yield stress (MPa): " + stress_c3ts(end))
disp("strain at yield stress (mm/mm): " + strain_c3ts(end))
disp("strain at debonding (mm/mm): " + strain_c3ts(end))
disp("Sample 4")
disp("elastic modulus (GPa): " + E4ts)
disp("yield stress (MPa): " + stress_c4ts(end))
disp("strain at yield stress (mm/mm): " + strain_c4ts(end))
disp("strain at debonding (mm/mm): " + strain_c4ts(end))
disp("Sample 5")
disp("elastic modulus (GPa): " + E5ts)
disp("yield stress (MPa): " + stress_yield5ts)
disp("strain at yield stress (mm/mm): " + strain_yield5ts)
disp("strain at debonding (mm/mm): " + strain_c5ts(end))

disp("AS")
disp("Sample 2")
disp("elastic modulus (GPa): " + E2as)
disp("yield stress (MPa): " + stress_c2as(end))
disp("strain at yield stress (mm/mm): " + strain_c2as(end))
disp("strain at debonding (mm/mm): " + strain_c2as(end))
disp("Sample 3")
disp("elastic modulus (GPa): " + E3as)
```

```
disp("yield stress (MPa): " + stress_c3as(end))
disp("strain at yield stress (mm/mm): " + strain_c3as(end))
disp("strain at debonding (mm/mm): " + strain_c3as(end))
disp("Sample 4")
disp("elastic modulus (GPa): " + E4as)
disp("yield stress (MPa): " + stress_c4as(end))
disp("strain at yield stress (mm/mm): " + strain_c4as(end))
disp("strain at debonding (mm/mm): " + strain_c4as(end))
disp("Sample 5")
disp("elastic modulus (GPa): " + E5as)
disp("yield stress (MPa): " + stress_yield5as)
disp("strain at yield stress (mm/mm): " + strain_yield5as)
disp("strain at debonding (mm/mm): " + strain_c5as(end))

disp("EX")
disp("Sample 1")
disp("elastic modulus (GPa): " + E1ex)
disp("yield stress (MPa): " + stress_c1ex(end))
disp("strain at yield stress (mm/mm): " + strain_c1ex(end))
disp("strain at debonding (mm/mm): " + strain_c1ex(end))
disp("Sample 2")
disp("elastic modulus (GPa): " + E2ex)
disp("yield stress (MPa): " + stress_c2ex(end))
disp("strain at yield stress (mm/mm): " + strain_c2ex(end))
disp("strain at debonding (mm/mm): " + strain_c2ex(end))
disp("Sample 3")
disp("elastic modulus (GPa): " + E3ex)
disp("yield stress (MPa): " + stress_c3ex(end))
disp("strain at yield stress (mm/mm): " + strain_c3ex(end))
disp("strain at debonding (mm/mm): " + strain_c3ex(end))
disp("Sample 4")
disp("elastic modulus (GPa): " + E4ex)
disp("yield stress (MPa): " + stress_c4ex(end))
disp("strain at yield stress (mm/mm): " + strain_c4ex(end))
disp("strain at debonding (mm/mm): " + strain_c4ex(end))
disp("Sample 5")
disp("elastic modulus (GPa): " + E5ex)
disp("yield stress (MPa): " + stress_c5ex(end))
disp("strain at yield stress (mm/mm): " + strain_c5ex(end))
disp("strain at debonding (mm/mm): " + strain_c5ex(end))

% poisson's ratio at yield strain
v2 = -strain_c2as(end)/strain_c2ts(end);
v3 = -strain_c3as(end)/strain_c3ts(end);
v4 = -strain_c4as(end)/strain_c4ts(end);
v5 = -strain_yield5as/strain_yield5ts;

disp("POISSON'S RATIO")
disp("Sample 2 " + v2)
disp("Sample 3 " + v3)
disp("Sample 4 " + v4)
disp("Sample 5 " + v5)

disp("MAX STRAIN COMPARISON VALS")
```

```
disp("TS")
disp("Sample 3")
disp("max strain: " + max(strain_c3ts))
disp("EX")
disp("Sample 3")
disp("max strain: " + max(strain_c3ex))
disp("toughness: " + max(strain_c3ex)*max(stress_c3)/2)
```

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```
%Initial measurements
% c = composite
% d = dogbone
%f = fatigue Sample
% measurements in english units

%t = thickness
%L = length
%w = width
%g = gage length

c1 = struct;
c2 = struct;
c3 = struct;
c4 = struct;
c5 = struct;
d1 = struct;
d2 = struct;
f = struct;

c1.t = .0365;
c2.t = .0385;
c3.t = .0355;
c4.t = .0495;
c5.t = .0370;
d1.t = .0620;
d2.t = .0560;

c1.L = 7 + 5/16;
c2.L = 8;
c3.L = 7 + 15/16;
c4.L = 7 + 15/16;
c5.L = 7 + 15/16;
d1.L = 7 + 7/8;
d2.L = 7 + 7/8;

d1.g = 3;
d2.g = 3;

c1.w = .75;
c2.w = 5/8;
c3.w = 5/8;
c4.w = .75;
c5.w = 5/8;
d1.w = .5;
d2.w = .5;

f.t = .1275 *25.4;
f.l = 4.0605* 25.4;
f.w = 2.564* 25.4;
f.d = 6.25;
```

```
A = f.t*f.w;
```

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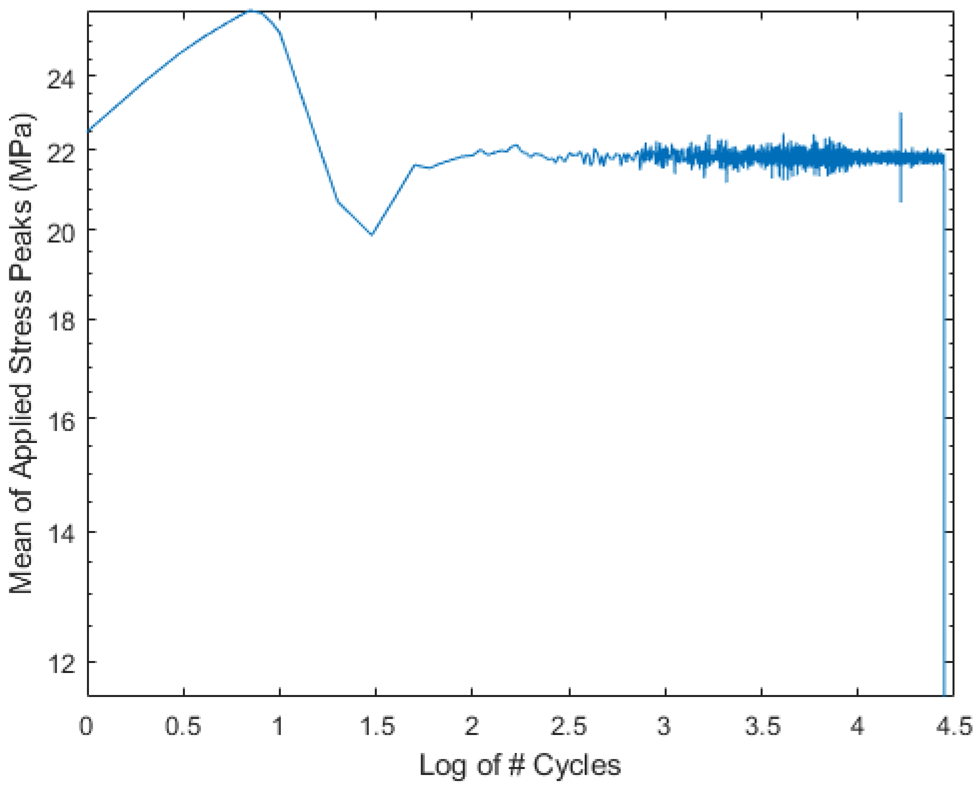
```
clc
clear all
close all

data = readtable("Test1.steps.trends.csv");
data = table2array(data);

A = 210.9093; %mm^2
F = data(:,9); %Mean of peaks (kN)

stress = ((F./A).*1e9)./1e6; %MPa
meanstress = mean(stress);
mans = mean(stress(1:40));
cycles = log10(data(:,1));

figure
semilogy(cycles,stress)
xlabel('Log of # Cycles')
ylabel('Mean of Applied Stress Peaks (MPa)')
```

Warning: Column headers from the file were modified to make them valid MATLAB identifiers before creating variable names for the table. The original column headers are saved in the VariableDescriptions property.
Set 'VariableNamingRule' to 'preserve' to use the original column headers as table variable names.



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