Load Based Stress-Strain

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***Abstract*—During this lab six different materials were tested in order to produce stress strain diagrams. The first material was a copper wire and the deflection was measured using a LVDT, by adding weights in increments. The second part of the lab involved placing three materials under tensile loading using the Instron Universal Testing Machine. The last two materials were placed under compressive loading in the machine. The first sample placed in the Instron machine was an initially unknown material, and after collecting the data it is concluded that the material was and alloy of Aluminum possibly a 6000 alloy series. The other four materials were known samples, carbon fiber, nylon 6-6, Plaster of Paris and aluminum.**

***Index Terms*— Instron 5967 Universal Testing Machine, Instron Model 2630-116 Extensometer and LDVT.**

I. INTRODUCTION

THE purpose of lab three is to provide stress strain curve diagrams for different materials. The lab is divided into two sections, lab 3a and 3b. Lab 3a consist of loading weight by increments onto an annealed 99.9% copper wire of 32 gauge. The deflection of the material is measured using a LVDT, linear variable differential transformer. It transforms the linear motion of the object to an electrical signal, voltage. This is how the change in length of the copper wire is determined. The LVDT value is tared in order to reduce any noise, and it has a calibration constant of 488 mV/mm ± 0.5%. The data for the first part of the lab was collected using LabVIEW and a DAQ.

In the second part of the lab, an Instron 5967 Universal Testing Machine is used to determine the displacement of an unknown material and four known materials: carbon fiber, nylon 6-6, plaster of paris and aluminum. The machine applies a certain load over the material and measures the extension. For the first material, an extensometer is used to determine the change in length.

In order to determine the strain the material undergoes by the applied load, it is found by the change in the material's length, l. The flowing equation represents strain, ε:

$$\varepsilon = \frac{\Delta l}{l} \qquad (1)$$

Normal stress, σ, is found by multiplying the strain of the material times the Modulus of Elasticity, E, as shown in (2):

$$\sigma = \varepsilon E \qquad (2)$$

II. PROCEDURE

Lab 3a

In order to obtain a stress strain diagram for the copper wire the elongation of the wire must be measured. This is accomplished by wiring the LVDT to the DAQ. The constant is applied in the VI. The copper wire is then set up along tensile fixture and the weight carrier. The weight carrier alone weighed 24.8 g and was accounted for in the VI. Once the LVDT carrier was set up properly measured weights were placed onto the carrier by increments until the copper wire broke. This was repeated three times.

Lab 3b

In the second part of the lab, five materials were placed in the Instron Machine. Before they were placed, each material was measured with a caliper to ensure accuracy. For the first sample, the unknown sample, ten measurements were made by ten different students. For the rest of the materials, only one person had to measure the material's dimension. Afterwards, the materials were labeled with burnish marks in order to determine its elongation after it was placed in the machine. Once the materials' dimensions were recorded they were place onto the Instron Machine by the TA one by one. Three of the materials, samples 1-3, were placed in tensile stress, the last two materials were placed in compressive stress. The initial length between the grips of the machine was also measured. The data collected by the machine is used to create the stress strain curves shown in the Results section below.

III. RESULTS

Part 3a

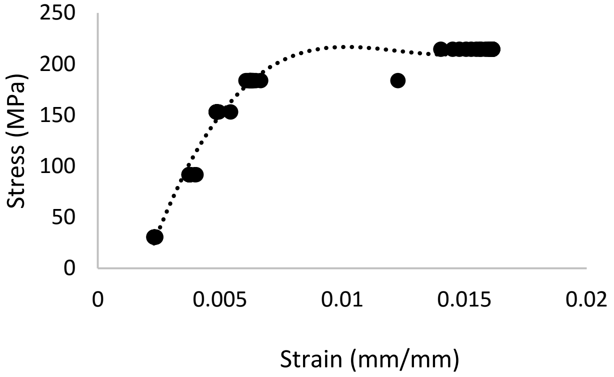

Fig. 1. This is a Stress Strain Diagram of the annealed copper wire when it experienced tensile loading.

The incremental loading experiment was conducted three times. The young's modulus was taken from the second experiment because more data was collected within the elastic region, as shown in Fig. 2.

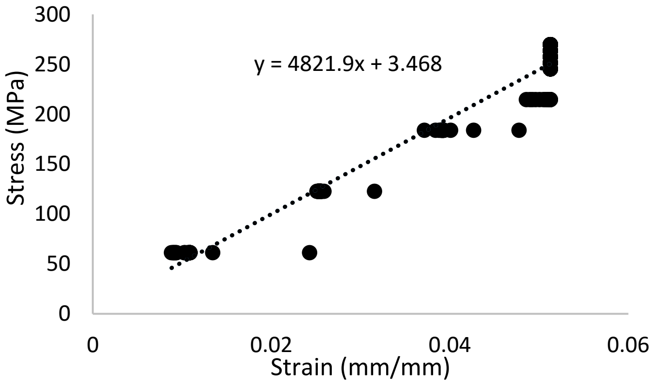

Fig. 2. Stress strain diagram of the copper wire at elasticity. The slope represents the material's modulus of elasticity.

Part 3b

A. *Sample 1*

TABLE I
CLASS MEASUREMENTS OF SAMPLE 1

Width (in.)	Thickness (in.)	Area (in^2.)
0.2589	0.1263	0.032699
0.261	0.1254	0.032729
0.2621	0.1256	0.03292
0.262	0.1261	0.033038
0.2692	0.1258	0.033865
0.2611	0.1251	0.032664
0.2639	0.1257	0.033172
0.2577	0.1256	0.032367
0.2627	0.1258	0.033048
0.2603	0.1259	0.032772
	Average Area:	*0.032927* in^2
		21.24345 mm^2

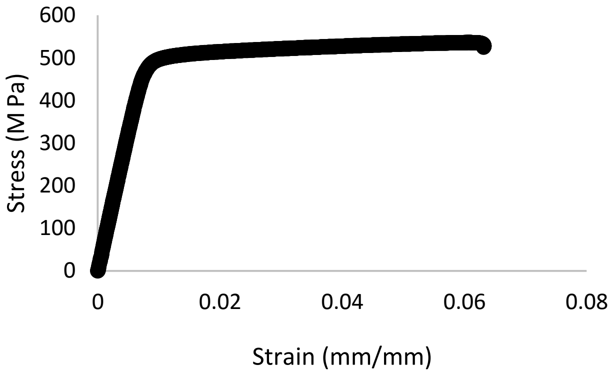

Fig. 3. Stress strain diagram of the unknown material.

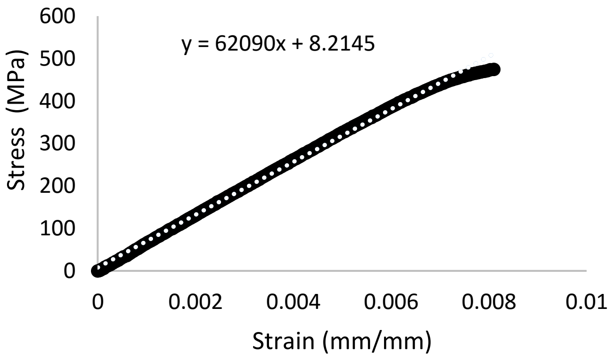

Fig. 4. This is a zoomed in graph of Fig. 3. in order to obtain the Modulus of Elasticity with the use of a trend line.

B. *Sample 2: Carbon Fiber*

TABLE II
MEASUREMENTS OF CARBON FIBER

Length Between Grips	Width (in.)	Thickness (in.)	Area (in^2.)
193 mm	0.8159	0.0148	0.01208
			7.7935 mm^2

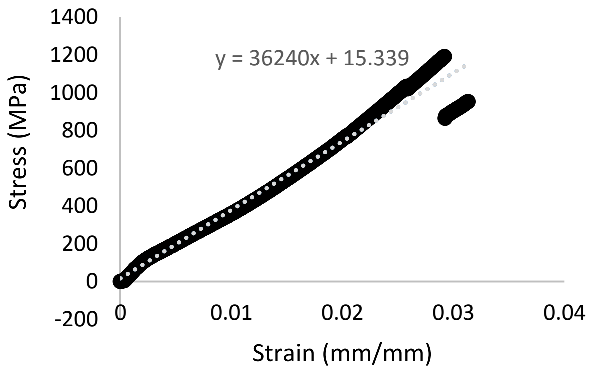

Fig. 5. Stress Strain diagram of carbon fiber when it under goes tensile loading. A trend line is used to determine the Modulus of Elasticity.

C. Sample 3: Nylon 6-6

TABLE III
MEASUREMENTS OF NYLON 6-6

Length Between Grips	Width (in.)	Thickness (in.)	Area (in^2.)
120 mm	0.5208	0.1432	0.07458
			48.116 mm^2

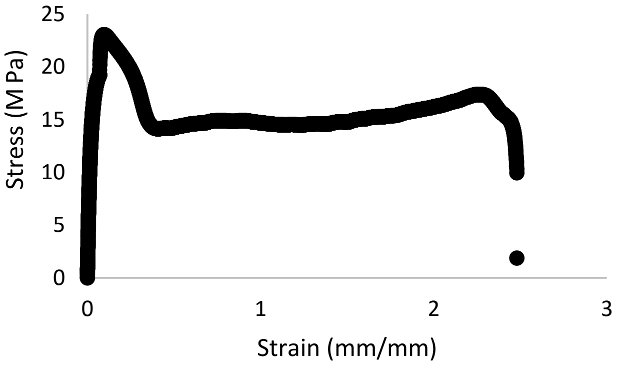

Fig. 6. Stress strain diagram of Nylon 6-6 when it undergoes tension.

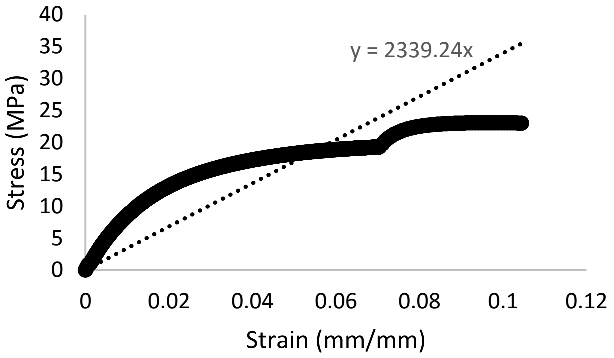

Fig. 7. Stress strain diagram of Nylon 6-6. This is a zoomed in graph of Fig. 6. This was used to determine the Modulus of Elasticity.

D. Sample 4: Plaster of Paris

TABLE IV
MEASUREMENTS OF THE PLASTER

Diameter (in.)	Height (in.)	Area (in^2.)
2.052	2.815	3.307
		2133.5 mm^2

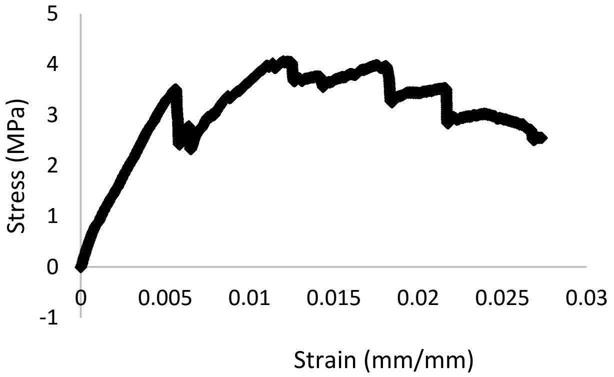

Fig. 8. Stress strain diagram of Plaster of Paris when it is placed in compression.

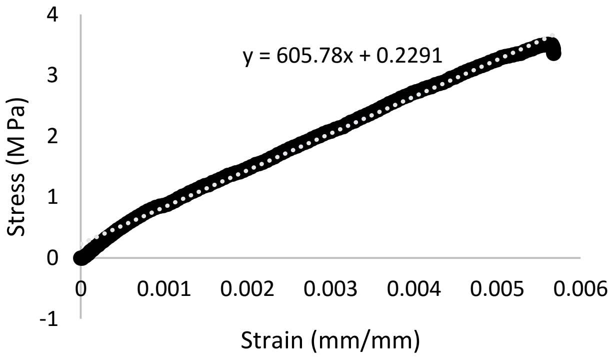

Fig. 9. Stress strain diagram of the zoomed in graph of Fig. 8. in the elastic region. This is used to determine the modulus.

E. Sample 5: Aluminum

TABLE V
MEASUREMENTS OF THE PLASTER

Diameter (in.)	Height (in.)	Area (in^2.)
0.3744	0.8382	0.110
		70.968 mm^2

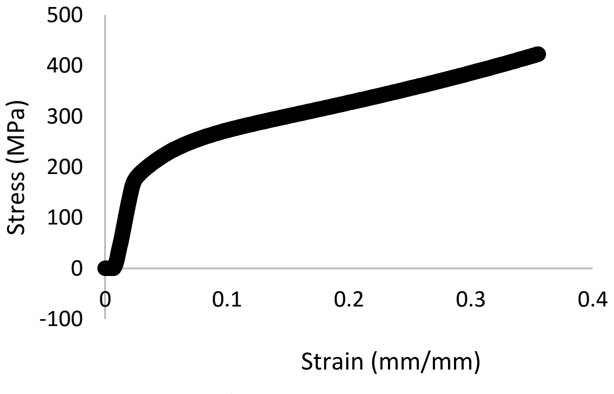

Fig. 10. Stress strain diagram of Aluminum when a compression load is applied.

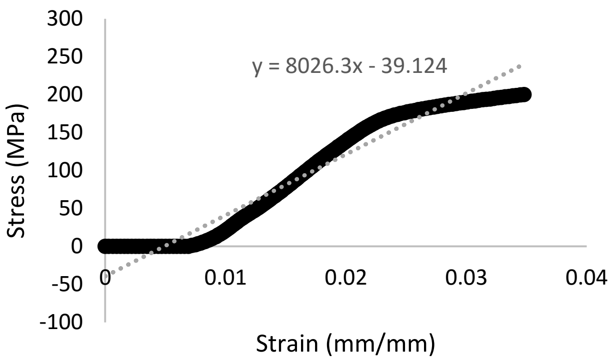

Fig. 11. Zoomed in graph of Fig. 10. elastic region used to determine the Modulus of Elasticity.

TABLE VI
MATERIAL PROPERTIES

Sample	Modulus of Elasticity (MPa)	Yield Strength (MPa)	Ultimate Strength (MPa)	Breaking Strength (MPa)
1	62090	450.8	536.1643	527.343
2	36240	1191.23	1191.23	1191.23
3	2339.24	192.674	230.624	173.9909

TABLE VII
MATERIAL PROPERTIES CONTINUED

Sample	Percent Elongation by Strain	Toughness (MPa)	Density (g/cm^3)	Specific Strength (m^2/s^2)	Specific Stiffness (m^2/s^2)
1	6.74	30.8235	2.7	166.7	22996.3*
2	2.14	17.39	1.262	943.92*	28716
3	248.07	43.5	1.14	0.592	2975.8

*Denotes the highest specific property out of the three samples.

IV. DISCUSSION

Part 3a

The young's modulus was found using the slope in Fig. 2. Which varies from the modulus found online. This could be a result of the uncertainty in calibrating the weight holder and any possible measurement errors. The yield strength was found by analyzing Fig. 1 and Fig. 2 and determining at what point the graph was no longer linear. This was accomplished by taking the maximum stress in Fig. 2 because the strain value was not changing but the stress was increasing, therefore it was the yield point.

The ultimate strength is the maximum stress the material undergoes. Because I conducted this experiment three times, I took the average of each maximum.

TABLE VIII
MATERIAL PROPERTIES OF THE COPPER WIRE

Property	Value
Modulus of Elasticity	4821.9 MPa
Elastic Limit	183.94 MPa
Yield Point	269.775 MPa
Ultimate Strength	273.8625 MPa

The uncertainty in the copper's young modulus was found by using a Monte-Carlo simulation on the slope from Fig. 2. The uncertainty in the strain and stress was also calculated, refer to Table IX for the values and Appendix A for the uncertainty equations.

TABLE IX
CALCULATED UNCERTAINTIES

Symbol	Uncertainty of	Value
U_{ε}	Strain	±0.109 m/m
U_{σ}	Stress	±6.52 MPa
U_{LVDT}	LVDT constant	±24.4 mV/mm
U_{m}	Weighed mass	±2.5g
U_{l}	Length	±0.5 mm
U_{E}	Modulus of Elasticity	±42.1 MPa

Part 3b

A. *Sample 1*

The unknown material's modulus of elasticity was determined by finding the slope of the elastic region. The uncertainty in the slope was found through a Monte-Carlo simulation.

There is some discrepancy in the data for the first sample because the fracture of the sample material was located above the extensometer. Because the change in length was not measured where the fracture occurred, the data past the yield point has inconsistency. Therefore, the ultimate strength, breaking strength, and toughness will be inaccurate.

The extensometer was used to measure strain on ductile material. Cross head displacement was not used because it also measures the machine grip deflection and machine deflection. By not using the cross head displacement error is reduced and one does not have to take into account if there was slipping. Which is an advantage of using the extensometer instead of cross head displacement. Extensometer is also preferable for measuring local deflection.

After comparing data in aerospacematerials.com I have estimated the sample material 1with a modulus of 62 GPa to be Aluminum 6061. After looking through material properties Aluminum has a modulus around the 60's GPa. Therefore I believe the material is Aluminum. Looking further into what specific alloy, the 62 GPa is close to the aluminum 6000 series, which have a modulus of 68.9 GPa [1]. However, because the fracture occurred above the extensometer the data collected is not as accurate, therefore, one cannot definitively identify the Aluminum alloy. Data from Aluminum 6061-T4; 6061-T451 is used to determine the specific strength and stiffness, shown in Table VII.

The material's percent elongation was determined by using (4). The toughness of a material is found by calculating the area under the stress strain curve. For each material, the area was calculated by estimating it to polygons. For sample 1, a triangle and a rectangle were used to estimate the toughness.

To find specific strength, the yield strength is divided by the material's density, ρ, which can be found by equating it to:

$$\rho = \frac{m}{V} \qquad (3)$$

Where mass is m, and volume is V. Density is also used to find specific stiffness (5), which is young's modulus divided by density. Sample 1 has the highest specific stiffness. Specific strength and stiffness for each material can be found in Table VII.

The failure surface of material 1 was a clean fracture at what appears to cut the material at an angle, possibly at a 45 degree angle, a characteristic of ductile materials. Image of the fracture is seen in Fig. 12. The material failed at the maximum shear stress.

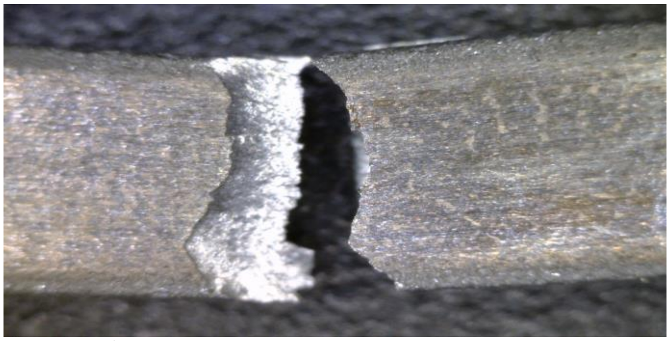

Fig. 12. The fractured metal taken by [2].

B. *Sample 2: Carbon Fiber*

The carbon fiber was placed in the Instron machine and it experienced tensile load. Carbon fiber is a brittle material and from the data collected it measured to have the highest specific strength. The failure surface of the material began to fracture vertically. Pieces of the material would fly out. In Fig. 13. The carbon fiber can be seen to have fractured in long vertical strands that were parallel to the tension load applied. Carbon fiber failed at the plane of maximum tension stress.

Fig. 13. Image of the fractured carbon fiber [2].

C. *Sample 3: Nylon 6-6*

Nylon 6-6 experienced tension and it elongated and began to neck. The machine was first placed at a rate of 10 mm/min and was then changed to 50 mm/min. Nylon took the longest to fracture. The material underwent necking before it finally broke. The cut was at a more defined angle than sample 1.

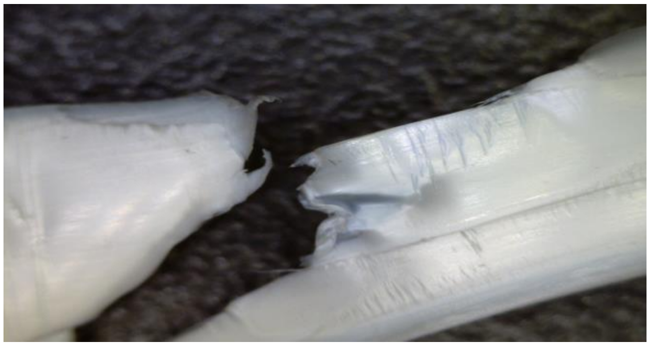

Fig. 14. Image of the fractured Nylon 6-6 that underwent tensile loading [2].

D. *Sample 4: Plaster of Paris*

The Plaster of Paris was placed in a compression load in the Instron Machine. It was placed at a small angle, instead of 90 degrees exact, otherwise it would not have fractured. The cracks began to occur vertically in the outer part of the material, refer to Fig. 15. As the load increased more cracks formed. Once it was unloaded the material was still together, but it was easy to break apart by hand at that point. Fractures had also reached the inner part of the material. Because it is a brittle material, it experienced failure parallel to the load, it failed at minimum normal stress.

Fig. 15. Image of the Plaster of Paris experienced compressive loading [2].

E. *Sample 5: Aluminum*

Aluminum was placed in compressive loading. No visible fractures were seen. However, the material did experience deflection. It was slightly squished down in the direction of the load. The aluminum began to deform into a barrel shape.

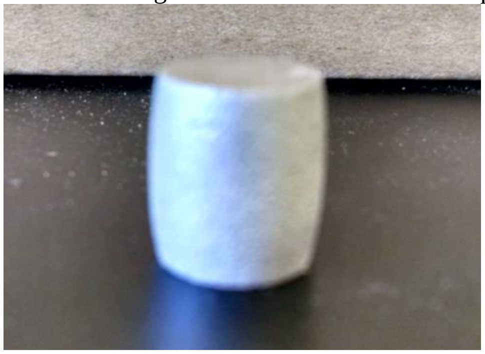

Fig. 16. Image of the aluminum that underwent compressive loading [2].

V. CONCLUSION

Lab three consisted of two sections. The first part required creating a stress strain diagram of a copper wire. This was accomplished by adding weight in increments and the displacement was measured using a LVDT.

The second part of the lab was testing five materials in the Instron machine. Three materials were placed in tensile loading: sample 1, carbon fiber and Nylon 6-6. After graphing each material's stress strain diagram the material's properties were determined, Sample 1 was then concluded to be an alloy of Aluminum because the modulus of elasticity is close in range to Aluminum.

Two materials were placed in compression load. These were Plaster of Paris and aluminum. The aluminum did not fracture but the plaster did, it had vertical cracks parallel to the load.

Stress strain diagrams have been provided for the six materials tested in lab three. Material properties have also been listed that were derived from the diagrams.

APPENDIX A

$$\% \, Elongation = 100 * \frac{L - L_o}{L_o} \tag{4}$$

$$Specific \; Stiffness = \frac{E}{\rho} \tag{5}$$

$$Specific \; Strength = \frac{\sigma}{\rho} \tag{6}$$

$$U_\sigma = \sqrt{\left(\frac{g}{A}\right)^2 * (U_m) + \left(\frac{F}{A^2}\right)^2 * (U_A)^2} \tag{7}$$

$$U_\sigma = \sqrt{\left(\frac{1}{A}\right)^2 * (U_F)^2 + \left(\frac{F}{A^2}\right)^2 * (U_A)^2} \tag{8}$$

$$U_\epsilon = \sqrt{\left(\frac{1}{L}\right)^2 * (U_C)^2 + \left(\frac{\Delta L}{L^2}\right)^2 * (U_L)^2} \tag{9}$$

$$U_\epsilon = \sqrt{\left(\frac{V_o - V_i}{L_o}\right)^2 * (U_c)^2 + * \left(\frac{c}{L_o}\right)^2 * (U_{Vo})^2 * \left(\frac{c * (V_o - V_i)}{L_o^2}\right)^2 * (U_{Lo}^2)^2 + \left(\frac{c}{L_o}\right)^2 * (U_{Vi})^2} \tag{10}$$

APPENDIX B

TABLE X
CALCULATED UNCERTAINTIES

Symbol	Uncertainty of	Value
$U_{\varepsilon 1}$	Strain of Sample 1	±178.9 mm/mm
$U_{\sigma 1}$	Stress of Sample 1	±456.2 MPa
$U_{\varepsilon 2}$	Strain of Sample 2	±13.45 mm/mm
$U_{\sigma 2}$	Stress of Sample 2	±231.2 MPa
$U_{\sigma 3}$	Stress of Sample 3	±103.62 MPa
$U_{\varepsilon 3}$	Strain of Sample 3	±0.879 mm/mm
$U_{\sigma 4}$	Stress of Sample 4	±4.2 MPa
$U_{\varepsilon 4}$	Strain of Sample 4	±0.879 mm/mm
U_t	Thickness	±0.0005 mm
U_b	Base Width	±0.005 mm
U_{E1}	Modulus of Elasticity 1	±98.89 MPa
U_{E2}	Modulus of Elasticity 2	±17.23 MPa
U_{E3}	Modulus of Elasticity 3	±25.87 MPa
U_{E4}	Modulus of Elasticity 4	±65.33 MPa
U_{E5}	Modulus of Elasticity 5	±27.35 MPa
U_{lg}	Length between Grips	±0.3 cm
U_h	Height	±0.5 mm
U_d	Diameter	±0.25 mm

REFERENCES

[1] Aerospace Specification Metals. Website: http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA6061T4H.

[2] Ridgeway, Shannon, Images, unpublished.