The Cooper Union for the Advancement of Science and Art

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
STRUCTURAL ENGINEERING LABORATORY

LAB 1

TENSILE TESTING OF AN ALUMINUM ROD

Group 2
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CE-321
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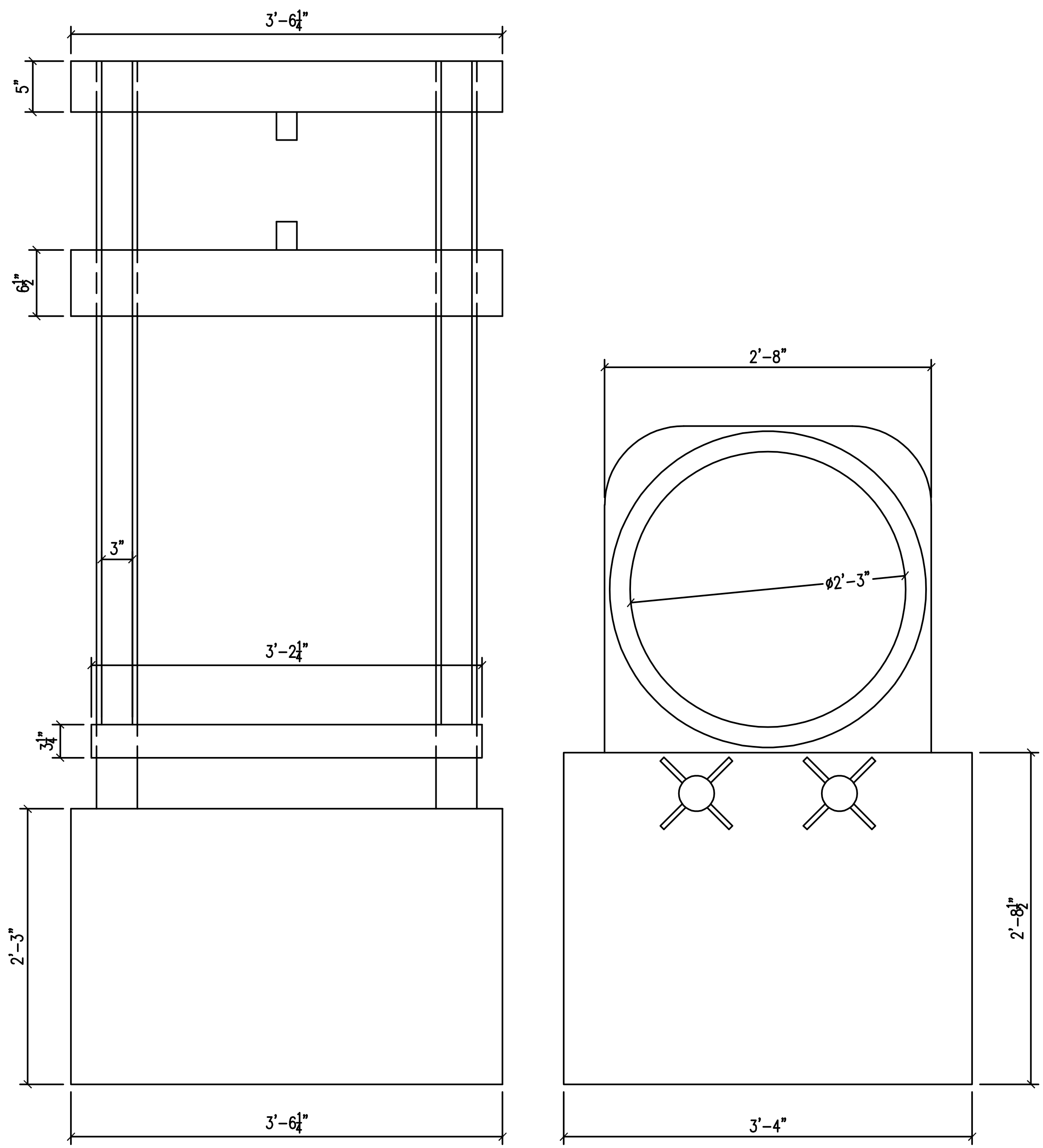
1 Objective

The objective of this experiment was to test the tensile strength of an aluminum rod using a Tinius Olsen material testing device. Force and deflection of the rod are measured and recorded simultaneously until yielding. The rod is unloaded to measure permanent deflection/ set, then reloaded until failure to observe the rod's tensile properties. Testing the tensile strength of a rod has significant engineering importance when considering a material for use. Distinguishing the difference between the experimental and theoretical moduli of elasticity, proportional limits, yield strengths, and ultimate tensile strengths are vital to imposing tolerances during design. Since exceeding an object's yield strength causes permanent deflection, this value must be considered for design since the measurements of a structure are very precise. Even more so, the ultimate tensile strength should be excessively considered during design since the object would theoretically fail after this point. The experiment is conducted in the Civil Engineering Structures Lab at the Cooper Union (room LL220).

2 Procedure

The materials used for this lab include an aluminum rod, a Tinius Olsen material testing device, a vernier caliper, a ladder, and protective eyewear. First, the aluminum rod is measured using the vernier caliper to the nearest thousandth of an inch. The shaft diameter and lengths of the rod including and excluding the threaded ends are measured. These would be useful for the yield and tensile strength calculations.

After protective eyewear was issued to the lab technicians, and the initial rod measurements are taken, the aluminum rod is ready for the Tinius Olsen. Clamps are used to fasten the aluminum rod in the material testing device. A ladder is used to reach the clamps as they are located about 10ft from the ground. After fastening the rod tight enough so there's no slack, the wheel on the Tinius Olsen is turned to load the rod with force. The technician turning the force wheel yells out the increasing force values every 500N, while a technician on the ladder yells out the respective deflection values from a dial near the rod. The force dial slowing down indicates that the rod is yielding. The rod is then unloaded, measured for permanent deflections, then reloaded. The tensile strength is tested by loading the rod all the way until failure. When the rod finally snaps in two, the force is recorded and the experiment is concluded.



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PROJECT NAME:

LAB#1
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TINIUS OLSEN
DRAWING

DATE:
10/19/2022

SCALE:
¾"=1'

3 Theory

When an axial load is applied to a member, the stress σ at a specific point in the member is defined by the magnitude of the load P divided by the cross-sectional area A_0 at the point in question.

$$\sigma = \frac{P}{A_0} \tag{1}$$

Similarly, a member under a tensile loading will experience a deflection δ; the percent change in the original length L_0 of the member is defined as the strain ϵ.

$$\epsilon = \frac{\delta}{L_0} \tag{2}$$

Different materials will experience higher or lower deflections at a given load. When the relationship between stress and strain is linear, Hooke's Law applies:

$$\sigma = E\epsilon \tag{3}$$

where E is defined as the *modulus of elasticity* or *Young's modulus* of the material.

Equation 3 is significant as it defines the elastic region of the stress-strain curve; materials undergoing loading will exhibit elastic deformation when Hooke's Law holds. The *proportional limit* of a material is defined as the point where equation 3 no longer holds. This is in contrast to the *yield strength* σ_y, which is the point where permanent set begins. For this laboratory experiment it is assumed that the differences between the proportional limit and yield strength are negligible due to the ductility of metals, and are therefore the same.

Equations 1 and 2 can be substituted into equation 3 to get a direct relationship between the load applied and the deflection observed:

$$\sigma = E\epsilon \Rightarrow \frac{P}{A_0} = E\frac{\delta}{L_0}$$

$$\delta = \frac{PL_0}{A_0E} \tag{4}$$

This equation is especially useful as the input quantities for length, cross-sectional area, and modulus of elasticity can be determined from simple measurements.

When the yield strength is reached, the material experiences permanent offset. This means that when the member is unloaded, it does not return to its original length and thus has been permanently deformed. The permanent offset is also known as *plastic deformation* and once the yield strength is reached the member is said to deform plastically. Hooke's Law as expressed by equations 3 and 4 do not hold in the plastic region of a material. When a ductile material undergoes plastic deformation, it will experience much larger deformation with smaller increases in the load. Eventually, the *ultimate tensile strength* σ_u is reached; this is the maximum load the material can take. Once the ultimate strength is reached, a phenomena can be observed where the cross-sectional area of the member at a point will decrease; this is known as *necking*, and lower loads are sufficient to cause deformation. Rupture occurs when the member can no longer take any stresses. The stress at rupture is defined as the *breaking stress* σ_b.

Equations 1 and 2 define the *engineering* stress and strain of a material undergoing axial loading. However, this consideration only takes into account the original length L_0 and original cross-sectional area A_0, and not the fact that the length and cross-sectional area of the members changes with loading. Thus, a more accurate measure for stress and strain accounts for these changes; this is known as *true stress* σ_t and *true strain* ϵ_t For true stress:

$$\sigma_t = \frac{P}{A} \tag{5}$$

where A is the cross-sectional area of the member at the specific loading. For true strain, every recorded length for every specific loading is considered as an integral:

$$\epsilon_t = \int_{L_0}^{L} \frac{dL}{L} \tag{6}$$

where L is the length of the member at a specific loading. The true stress and true strain are a more accurate measure than the engineering stress; however, they will not be used in this experiment as the cross-sectional area changes cannot be determined by simple measurement.

The stress-strain curves for a material undergoing tensile loading are highly relevant to structural engineering, primarily for the determination of the yield strength of a specific member to prevent plastic deformation. However, the yield strength must never be reached and therefore safety factors must be introduced to prevent yielding, which lends itself to two crucial methodologies of structural design (Load and Resistance Factor Design vs Allowable Stress Design). Thus, the material properties determined by a tensile test (and by extension a compression test) are invaluable to structural design.

4 Sample Calculations

4.1 Cross-Sectional Area

$$A = \frac{\pi}{4} \times d^2$$

$$A = \frac{\pi}{4} \times (0.505 \text{ in})^2 = \boxed{0.2 \text{ in}^2}$$

4.2 Stress

$$\sigma = \frac{P}{A}$$

$$\sigma = \frac{11500 \text{ lb}}{0.2 \text{ in}^2} = \boxed{57500 \text{ psi}}$$

4.3 Strain

$$\varepsilon = \frac{\delta}{L}$$

$$\varepsilon = \frac{0.143 \text{ in}}{4.519 \text{ in}} = \boxed{0.0316}$$

4.4 Modulus of Elasticity

$$E = \frac{P \times L}{A \times \delta}$$

$$E = \frac{11500 \text{ lb} \times 4.519 \text{ in}}{0.2 \text{ in}^2 \times (0.143 \text{ in} - 0.101 \text{ in})} = \boxed{6177578 \text{ psi}}$$

4.5 Error

$$\%_{\text{Error}} = \frac{|\text{Theoretical} - \text{Experimental}|}{\text{Theoretical}} \times 100\%$$

$$\%_{\text{Error}} = \frac{|10600000 \text{ psi} - 6177578 \text{ psi}|}{10600000 \text{ psi}} \times 100\% = \boxed{41.72\%}$$

5 Results

Table 1: Measured and Observed Data

Measured		Observed	
Diameter	0.505 in	Yield Deflection	0.102 in
Rod Length	4.519 in	Yield Force	10500 lbs
Inner Rod Length	2.45 in	Ultimate Yield Force	13500 lbs

Table 2: Experimental and Theoretical Results

Modulus of Elasticity	Theoretical	10600 ksi
	Experimental	6177.58 ksi
Ultimate Tensile Strength	Theoretical	68000 psi
	Experimental	67400.19 psi
Proportional Limit	Theoretical	47000 psi
	Experimental	52000 psi

Table 3: Initial Loading

P (lb)	δ (in)	σ (psi)	ε	P (lb)	δ (in)	σ (psi)	ε
0	0.000	0.0000	0.0000	6000	0.039	29955.6407	0.0086
500	0.005	2496.3034	0.0011	6500	0.044	32451.9441	0.0097
1000	0.008	4992.6068	0.0018	7000	0.048	34948.2475	0.0106
1500	0.011	7488.9102	0.0024	7500	0.053	37444.5509	0.0117
2000	0.015	9985.2136	0.0033	8000	0.058	39940.8543	0.0128
2500	0.017	12481.5170	0.0038	8500	0.063	42437.1577	0.0139
3000	0.019	14977.8203	0.0042	9000	0.068	44933.4610	0.0150
3500	0.021	17474.1237	0.0046	9500	0.072	47429.7644	0.0159
4000	0.023	19970.4271	0.0051	10000	0.078	49926.0678	0.0173
4500	0.025	22466.7305	0.0055	10500	0.102	52422.3712	0.0226
5000	0.029	24963.0339	0.0064	10750	0.115	53670.5229	0.0254
5500	0.034	27459.3373	0.0075	11000	0.124	54918.6746	0.0274

Table 4: Unloading

P (lb)	δ (in)	σ (psi)	ε	P (lb)	δ (in)	σ (psi)	ε
10500	0.138	52422.3712	0.0305	5000	0.124	24963.0339	0.0274
10000	0.137	49926.0678	0.0303	4500	0.123	22466.7305	0.0272
9500	0.136	47429.7644	0.0301	4000	0.121	19970.4271	0.0268
9000	0.134	44933.4610	0.0297	3500	0.12	17474.1237	0.0266
8500	0.133	42437.1577	0.0294	3000	0.118	14977.8203	0.0261
8000	0.132	39940.8543	0.0292	2500	0.116	12481.5170	0.0257
7500	0.131	37444.5509	0.0290	2000	0.114	9985.2136	0.0252
7000	0.129	34948.2475	0.0285	1500	0.112	7488.9102	0.0248
6500	0.128	32451.9441	0.0283	1000	0.108	4992.6068	0.0239
6000	0.127	29955.6407	0.0281	500	0.103	2496.3034	0.0228
5500	0.125	27459.3373	0.0277	0	0.056	0.0000	0.0124

Table 5: Reloading

P (lb)	δ (in)	σ (psi)	ε	P (lb)	δ (in)	σ (psi)	ε
0	0.056	0.0000	0.0124	7000	0.126	34948.2475	0.0279
500	0.101	2496.3034	0.0224	7500	0.127	37444.5509	0.0281
1000	0.104	4992.6068	0.0230	8000	0.128	39940.8543	0.0283
1500	0.106	7488.9102	0.0235	8500	0.13	42437.1577	0.0288
2000	0.11	9985.2136	0.0243	9000	0.132	44933.4610	0.0292
2500	0.112	12481.5170	0.0248	9500	0.133	47429.7644	0.0294
3000	0.114	14977.8203	0.0252	10000	0.135	49926.0678	0.0299
3500	0.115	17474.1237	0.0254	10500	0.136	52422.3712	0.0301
4000	0.117	19970.4271	0.0259	11000	0.139	54918.6746	0.0308
4500	0.118	22466.7305	0.0261	11500	0.143	57414.9780	0.0316
5000	0.12	24963.0339	0.0266	12000	0.192	59911.2814	0.0425
5500	0.121	27459.3373	0.0268	12500	0.224	62407.5848	0.0496
6000	0.123	29955.6407	0.0272	13000	0.295	64903.8882	0.0653
6500	0.124	32451.9441	0.0274	13500	0.4	67400.1916	0.0885

Table 6: Theoretical Data

P (lb)	**δ (in)**	**σ (psi)**	ε	**P (lb)**	**δ (in)**	**σ (psi)**	ε
0	0	0	0	7000	0.014899	34948.25	0.003297004
500	0.001064	2496.303	0.0002355	7500	0.015963	37444.55	0.003532505
1000	0.002128	4992.607	0.000471001	8000	0.017028	39940.85	0.003768005
1500	0.003193	7488.91	0.000706501	8500	0.018092	42437.16	0.004003505
2000	0.004257	9985.214	0.000942001	9000	0.019156	44933.46	0.004239006
2500	0.005321	12481.52	0.001177502	9500	0.02022	47429.76	0.004474506
3000	0.006385	14977.82	0.001413002	10000	0.021285	49926.07	0.004710006
3500	0.00745	17474.12	0.001648502	10500	0.022349	52422.37	0.004945507
4000	0.008514	19970.43	0.001884003	11000	0.023413	54918.67	0.005181007
4500	0.009578	22466.73	0.002119503	11500	0.024477	57414.98	0.005416507
5000	0.010642	24963.03	0.002355003	12000	0.025541	59911.28	0.005652008
5500	0.011706	27459.34	0.002590504	12500	0.026606	62407.58	0.005887508
6000	0.012771	29955.64	0.002826004	13000	0.02767	64903.89	0.006123008
6500	0.013835	32451.94	0.003061504	13500	0.028734	67400.19	0.006358509

Figure 1: Stress vs. Strain Curve

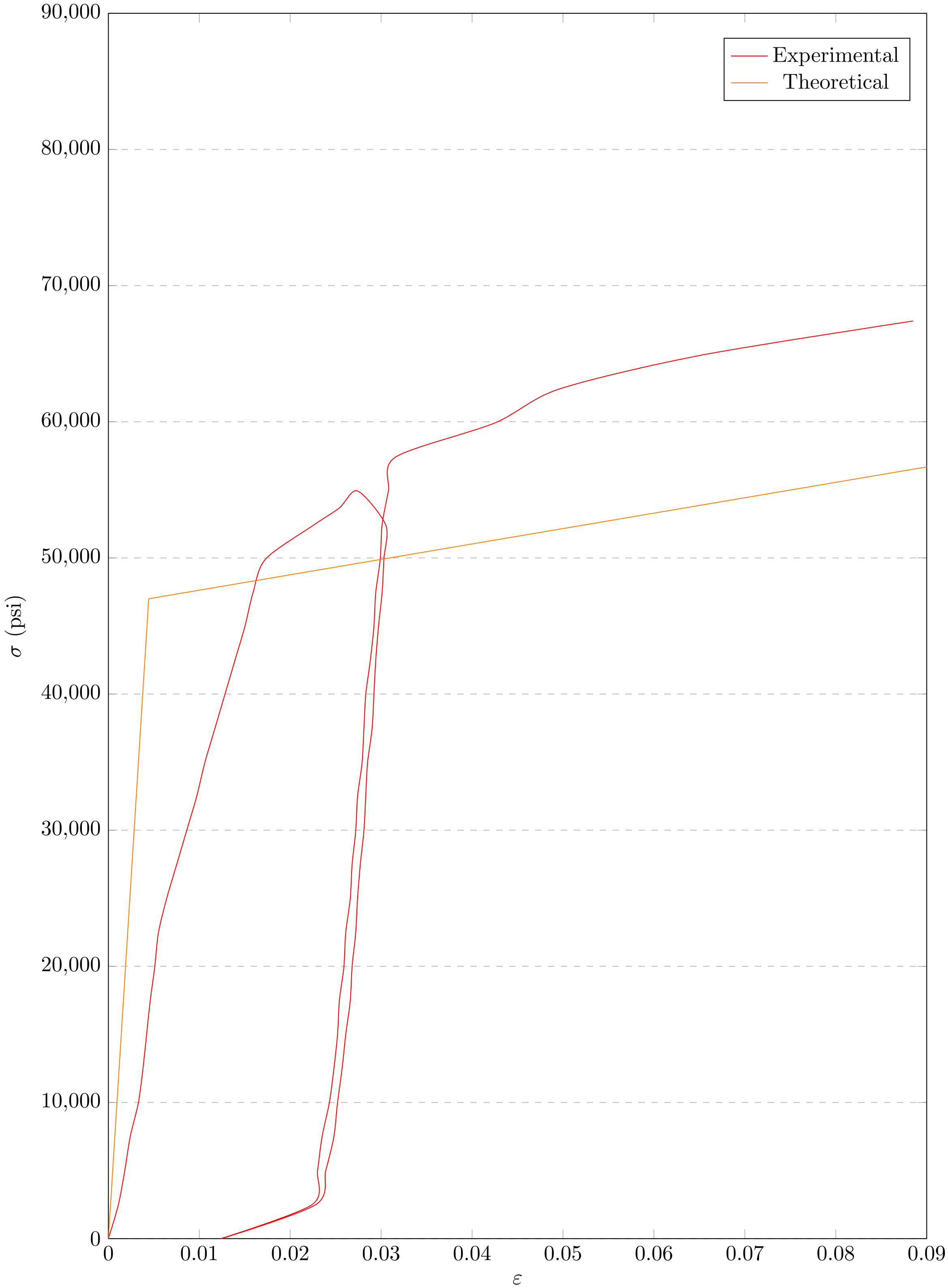


Figure 2: Experimental Stress vs. Strain Curve

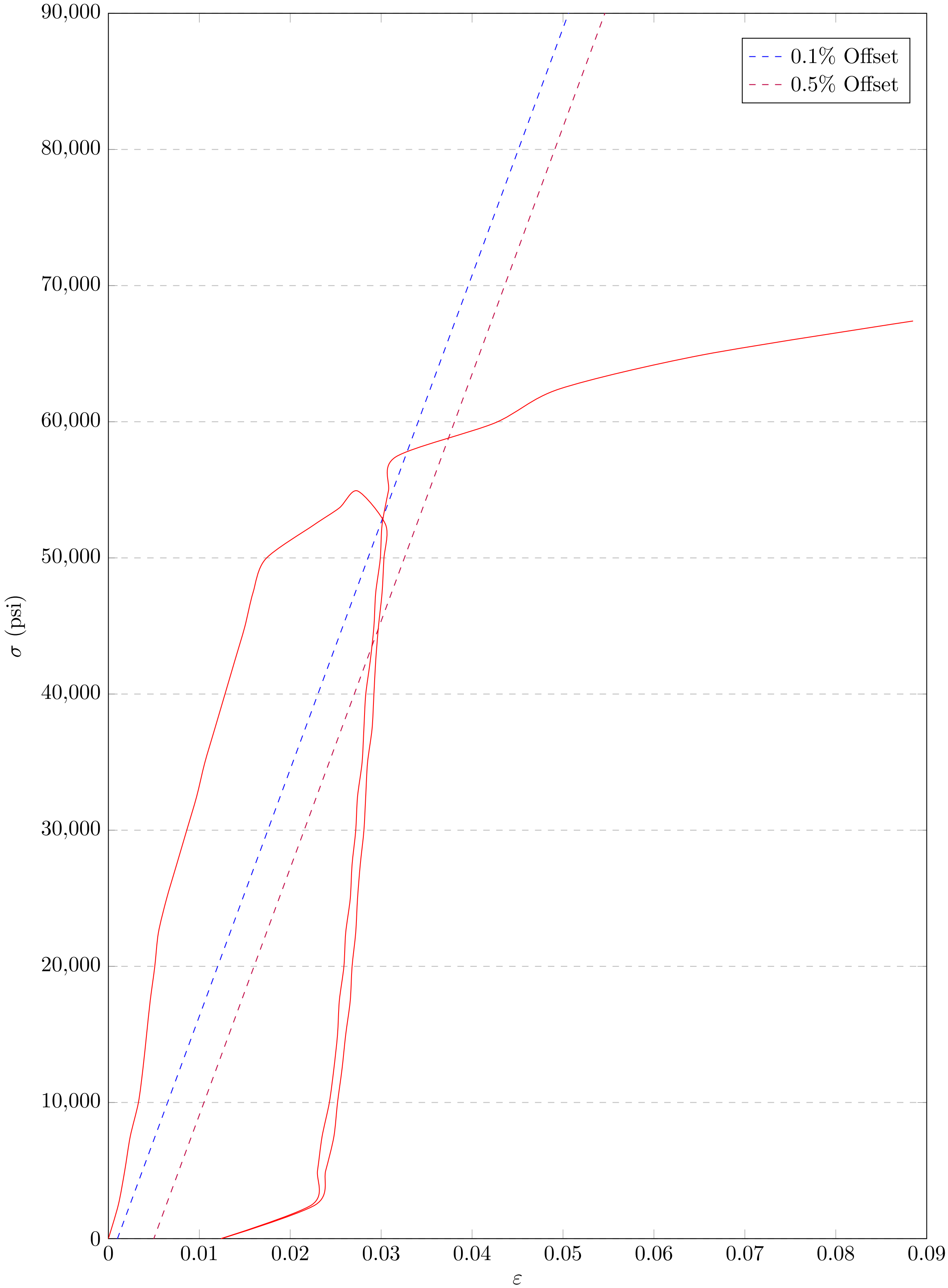
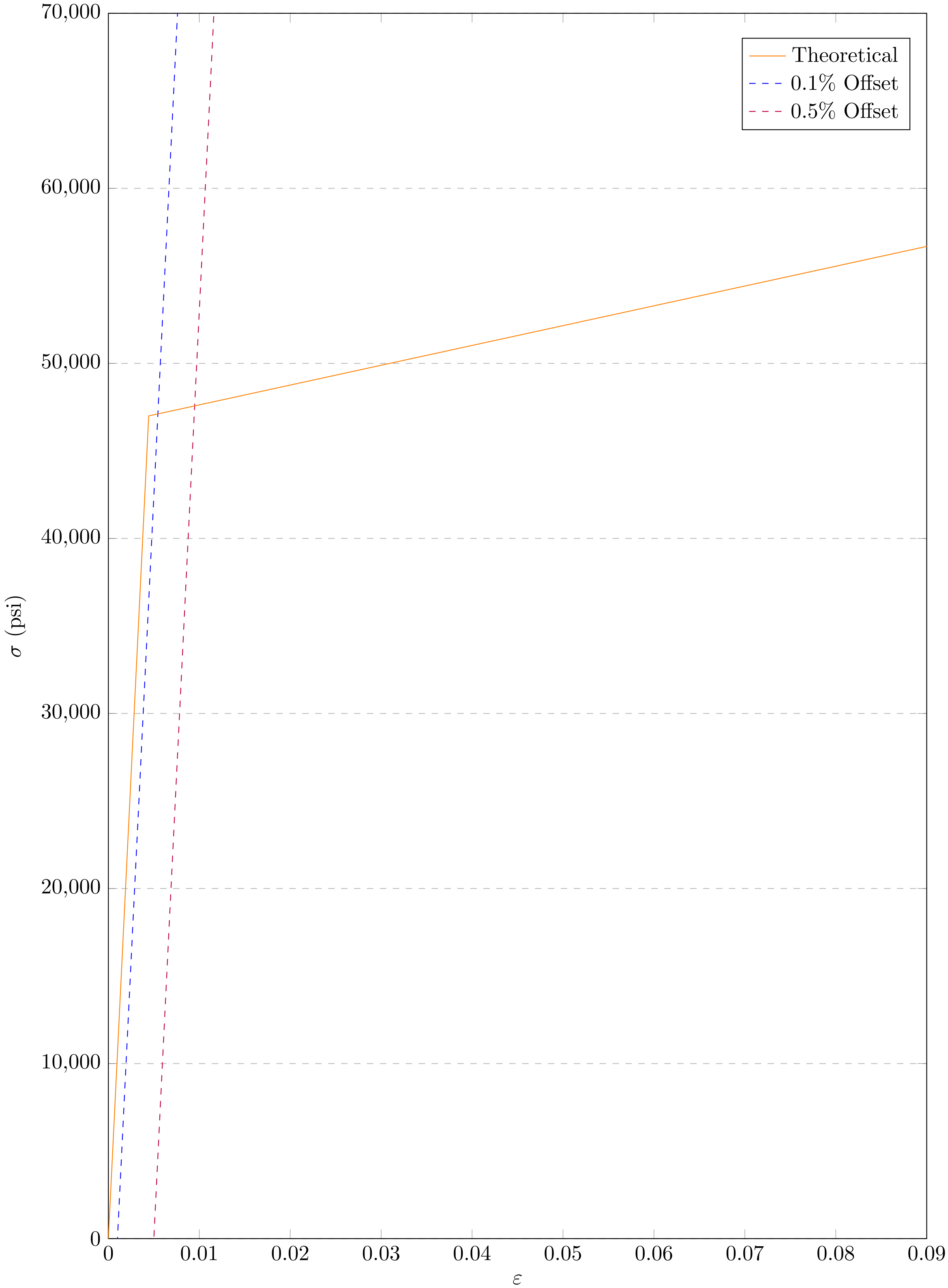


Figure 3: Theoretical Stress vs. Strain Curve



6 Conclusion

Tensile properties of a material are best characterized by subjecting a material specimen to tensile forces in a controlled testing environment. Material tensile properties carry significant importance in engineering design considerations; loads exceeding the yield strength of material cause permanent deflections and eventually failure and as such must be chosen particularly for the intended use.

There are several variables that can affect tensile strengths of aluminum alloys: alloy composition, casting conditions, heat treatment, geometry of specimens, and test conditions some of those variables. There are other experiments and research that analyze and compare tensile properties considering the effects of alloying and heat treatment, and still others that consider casting conditions and alloy compositions. Such experiments are useful in determining the best casting methods and allow compositions. This experiment used a single specimen, with the intent of comparing experimental values to theoretical values for the same metrics. The tensile test conducted placed a specimen of known dimensions between clamps, and keeping one end fixed, load (force) is applied to the material at the other end; the load is increased and the change in length of the sample is measured. Using these data, both engineering stress and strain is calculated, and the relation between the two determines the Youngs' modulus of the material. Youngs' modulus can be used to compare strengths between different materials; a stress-strain curve as displayed above is a simple method for comparing materials. Loading a specimen to breaking point allows one to determine both elastic and plastic tensile deformation properties.

Looking at the graphs produced from the experimental data, the T351 sample was observed as yielding at approximately 10,500 lbs in the initial loading, and between 9,000 and 10,000 lbs in the reloading. For calculating yield strength (stress), more accurate results are obtained by using data from the reloading; the reason for this is because there was some observable slipping at the start of the initial loading. At 9,000 lbs of load the calculated stress is 45,000 psi, at 9,500 lbs the calculated stress is 47,500 psi, and at 10,000 lbs the stress is 50,000 psi. Because it is difficult to tell precisely where yielding began, it is reasonable to assume that 9,500 lbs is the approximate load above which plastic deformation begins. Failure occurred at approximately 13,500 lbs, giving a calculated ultimate tensile strength of 67,500 psi.

The expected maximum load before yield was determined as 9,400 lbs, using the theoretical yield stress of 47,000 psi and the calculated cross-sectional area of 0.2 in^2. Theoretical ultimate tensile strength is published as 68,000 psi. The calculated values for tensile yield strength, maximum load before yielding, and ultimate tensile strengths are reasonably close to the theoretical values: the percent error for tensile yield strength was 1.06%, for ultimate yield strength 0.88%, and for the 0.1% and 0.5% offset yield strengths, percent error was 23.4% and 22.9% respectively. The observed yield load was 100 lbs greater than the theoretical yield load. The experimental yield strength was 500 lbs greater than the theoretical yield strength. Experimental ultimate tensile strength was 500 lbs below the theoretical value. In all calculated values, including maximum load before yielding, and stress (strength) values, error is introduced from instrumental error of the Vernier calipers used to determine the cross-sectional diameter of the specimen. In stress calculations, error is introduced from procedural errors: data points were recorded at approximately every 500 lbs, which is subject to instrumental error in readings and human error by way of delay in calling the load values. Additionally, because data was recorded at increments of 500 lbs, if critical loading is at some point not in increments of 500, the yield point will not be read with complete accuracy, and the experimental yield stress will thus be different as well.

Deformation of the specimen was calculated at every data point; there was a permanent deformation at the end of the unloading stage of 0.056 in; this is due to the fact that the initial loading was not stopped at the precise point of yield, and was instead stopped at 11,000 lbs. Graphically, this results in the reloading curve being offset from the initial load curve. Engineering strain is calculated as a ratio of the deformation to original length; at the observed yield load of 9,500 lbs, the theoretical strain is 0.00447, and the calculated experimental strain is 0.0294. The discrepancy in strain value is due to the deformations being larger experimentally than theoretically. There are several reasons the deformations may be large: human/procedural error, instrumental error, different temperature conditions, slipping of the rod between the grips. To discuss these individually, an error in the readings may have occurred due to the fact that there is a delay between the load being called out, and the deformation being called and read; there is also instrumental error in reading the deformations, as there is a limit on the precision of the instrument. Different temperature conditions make a material more and less ductile – if the experiment conditions were warm, the material may have experienced more ductility and thus more deformation than otherwise. Lastly, there was noticeable slipping at the start of the loading procedure, which resulted in load being applied without deformation occurring; it is not unreasonable to assume there might have been slipping, though unnoticeable in observation, during the reloading procedure. The discrepancy in deformation values leads to strain values such that the modulus of elasticity will be different as well. This is reflected in the percent error of 41.72%.

The specimen failed at values very close to the theoretical values, indicating that the theoretical values hold. The modulus of elasticity was calculated at a value much smaller than the theoretical; this can be attributed to error as described above. Graphically, the experimental modulus of elasticity (slope of the linear portion of the stress-strain curve) looks to be approximately equal to the theoretical value; this is due to the scaling of the graph. To improve this experiment, the area of concern should be the deformations; it would be wise to take measures to ensure little to no slippage during loading.

7 References

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8 Appendix

Rod Diameter, D (in): 0.505

Rod Length, L (in): 4.519

Inner Rod Length, L_{inner} (in): 2.45

Rod Cross-Sectional Area, A $\left(\text{in}^2\right)$: 0.2

	Theoretical	**Experimental**
Modulus of Elasticity, E (psi)	10600000	6177578
Proportional Limit, σ_{PL} (psi)	47000	47500
0.1% Offset Yield Strength, $\sigma_{\text{y0.1\%}}$ (psi)	47000	58000
0.5% Offset Yield Strength, $\sigma_{\text{y0.5\%}}$ (psi)	48000	59000
Ultimate Tensile Strength, σ_{UTS} (psi)	68000	67400.19

Modulus of Elasticity Percentage Error, Error E (%): 41.72

Proportional Limit Percentage Error, Error σ_{PL} (%): 1.06

0.1% Offset Yield Strength, Error $\sigma_{\text{y0.1\%}}$ (%): 23.4

0.5% Offset Yield Strength, Error $\sigma_{\text{y0.5\%}}$ (%): 22.9

Ultimate Tensile Strength, Error σ_{UTS} (%): 0.88