Lab #2 - Torsion

EGR 201L

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11/20/2023

Introduction & Objective(s):

This experiment measures the degree of rotation of an aluminum specimen of interest with respect to a known torsion force as applied by a specialized machine. The objective of this laboratory is to introduce the torsion test and to analyze certain material properties and their significance from the data collected in this experiment.

Methodology & Data:

Data was collected by placing the specimen in a torsion machine and analyzing two key variables of interest in real time: torque (kg/cm) and rotation of the specimen (degrees). Some information was collected regarding the sample type (Aluminum 6061), load cell capacity (11,500 kg-cm), gauge length (21.9 cm), and diameter (19.32 mm). Given certain operational constraints with the machine, we relied on data from a video of this experiment which was conducted by an instructor, analyzing values as they occur in real time with respect to torque values and degree of rotation. These values, along with maximum values of interest, are displayed in Appendix A.

Results:

1. The rotation readings can easily be converted from degrees to radians by multiplying its degree value by pi/180. Applying this for all degree values, we get the following radian conversions (next page).

Torque (kg-cm)	Rotation (Radians)	Torque (kg-cm)	Rotation (Radians)
100	0.00872665	2200	0.155334
200	0.0191986	2300	0.16057
300	0.0261799	2400	0.165806
400	0.0331613	2500	0.172788
500	0.0401426	2600	0.1780236
600	0.0471239	2700	0.1850049
700	0.0541052	2800	0.1902409
800	0.0610865	2900	0.1972222
900	0.0680678	3000	0.2042035
1000	0.0750492	3100	0.20944
1100	0.0802851	3200	0.2164208
1200	0.0872665	3300	0.2234021
1300	0.0925025	3400	0.2303835
1400	0.0994838	3500	0.2356194
1500	0.106465	3600	0.244346
1600	0.113446	3700	0.2530727
1700	0.120428	3800	0.2600541
1800	0.127409	3900	0.270526
1900	0.13439	4000	0.29147
2000	0.141372	4100	1.21824
2100	0.148353	4200	2.02458

Finally, at the specimen's sheer angle of 281.6999 degrees, this has an equivalent radian value of 4.9165925.

2. Using the shear-strain equation, we can find γ from φ using $\gamma = c / L * \varphi$, where c is the radius (1.932cm) and L is the gauge length (21.9cm) and φ is the radians previously calculated. Applying this equation for each data point, we get the following results:

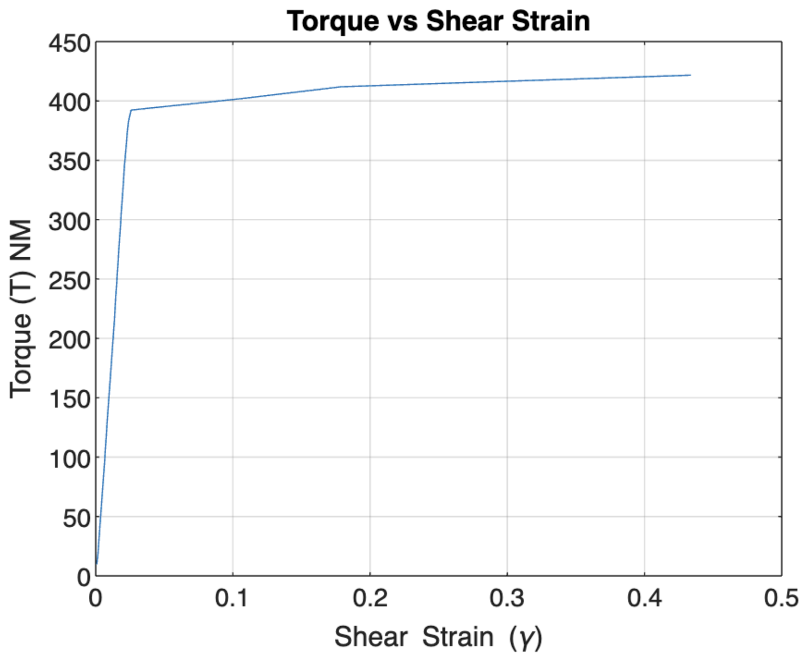
Torque (kg-cm)	Shear/Strain (γ)	Torque (kg-cm)	Shear/Strain (γ)
100	0.0007698578904	2200	0.01370343781
200	0.001693684712	2300	0.01416535342
300	0.00230956926	2400	0.01462726904
400	0.00292546263	2500	0.01524321534
500	0.003541347178	2600	0.01570509567
600	0.004157231726	2700	0.01632098022
700	0.004773116274	2800	0.01678289584
800	0.005389000822	2900	0.01739878038
900	0.00600488537	3000	0.01801466493
1000	0.00662077874	3100	0.01847662466
1100	0.007082685534	3200	0.0190924651
1200	0.007698578904	3300	0.01970834964
1300	0.008160494521	3400	0.02032424301
1400	0.008776379068	3500	0.02078614981
1500	0.009392254795	3600	0.02155600329
1600	0.01000811288	3700	0.02232586559
1700	0.01062405918	3800	0.02294175896
1800	0.01123991726	3900	0.02386558137
1900	0.01185577534	4000	0.02571324384
2000	0.01247172164	4100	0.1074721315
2100	0.01308757973	4200	0.1786067836

Finally, the shear angle has a γ of 0.4337377493.

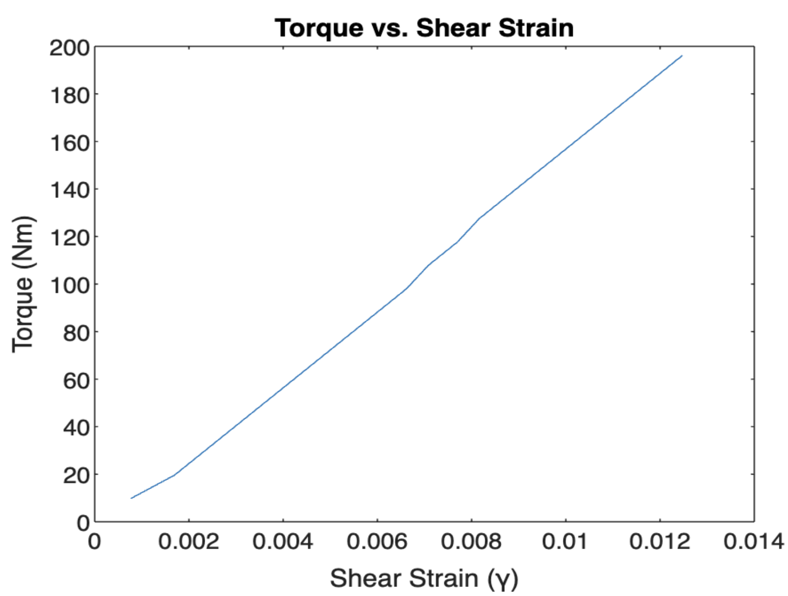
3. To convert the torque values from kg-cm to Nm, we use the following equation: 1 kg-cm = 0.09807 N-m. Multiplying this constant for each relevant torque value (below 4300 kg-cm), we get the following result:

Torque (kg-cm)	Torque (Nm)	Torque (kg-cm)	Torque (Nm)
100	9.807	2200	215.754
200	19.614	2300	225.561
300	29.421	2400	235.368
400	39.228	2500	245.175
500	49.035	2600	254.982
600	58.842	2700	264.789
700	68.649	2800	274.596
800	78.456	2900	284.403
900	88.263	3000	294.21
1000	98.07	3100	304.017
1100	107.877	3200	313.824
1200	117.684	3300	323.631
1300	127.491	3400	333.438
1400	137.298	3500	343.245
1500	147.105	3600	353.052
1600	156.912	3700	362.859
1700	166.719	3800	372.666
1800	176.526	3900	382.473
1900	186.333	4000	392.28
2000	196.14	4100	402.087
2100	205.947	4200	411.894

4. The graph of the full range of torque vs strain is displayed below using a MATLAB computation. The torque values are in Nm as opposed to kg-cm.



A second graph is shown below with the reduced range of strain from zero to just past the yield strain at 0.012.



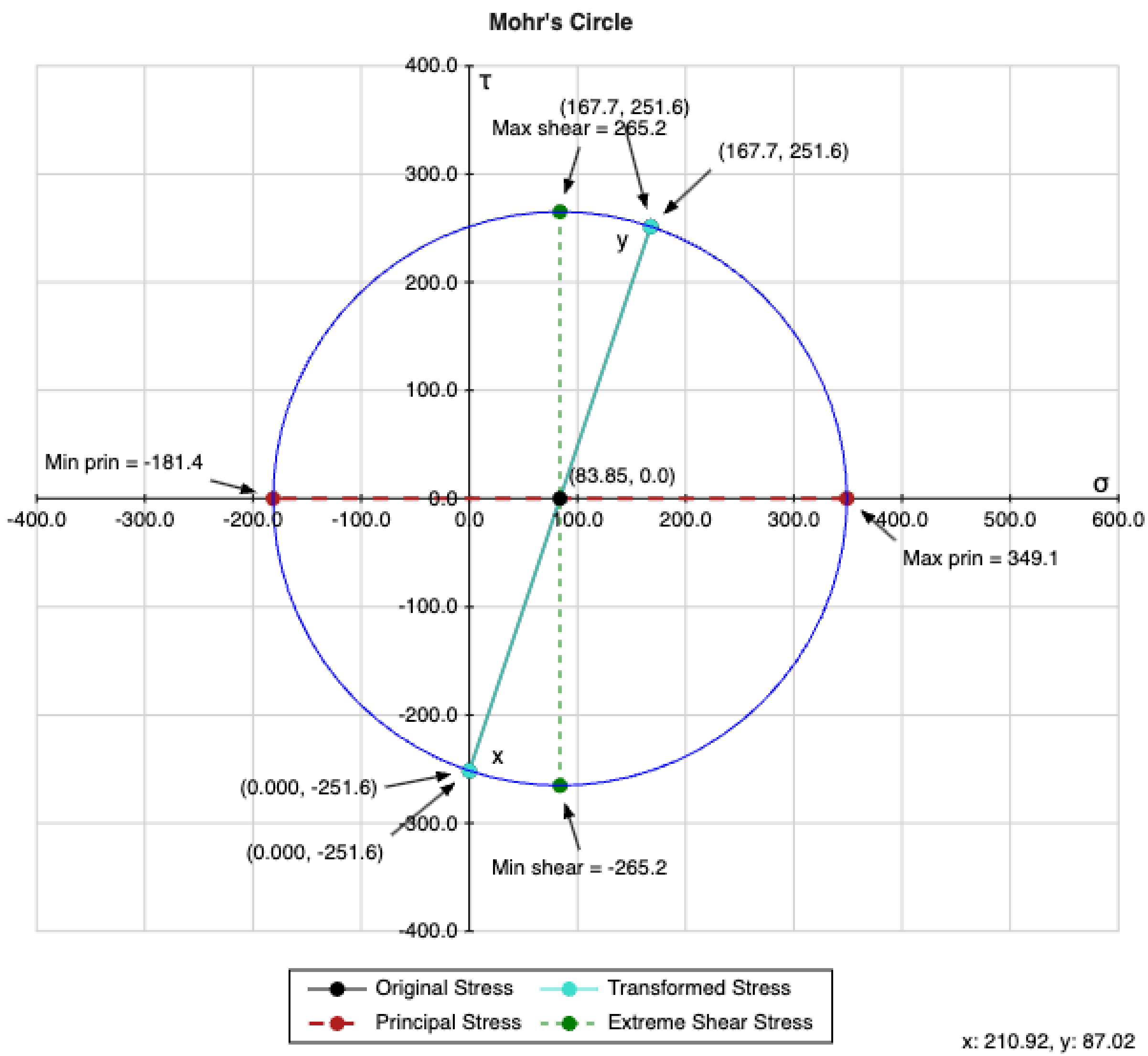
5. The estimated ratio T/γ is 16,397, as calculated using a MATLAB function to estimate the slope of the initial portion of the reduced range torque vs shear-strength graph.

Given the equation for the polar moment of inertia for the specimen, $J = pi/2\ c^4$, we can substitute known value $c = 1.932$ cm to get $J = 21.885$. The yield torque associated with the aforementioned yield strength of 0.012 is 190 Nm. Plugging this into the yield stress equation, we get yield stress $=167.7\ c/J$.

6. The ultimate torque T_u is visually estimated to be $T_u = 380$ Nm based on the maximum torque value that can be seen prior to the rapid decrease in the slope value of the first graph. From this, τ_u is estimated from the equation $\tau_u = 3c/(4J)\ T_u$, where $c = 1.932$ cm, $J = 21.885$, and $T_u = 380$ Nm. The substitution of these values gives us $\tau_u = 251.6$.

7. According to a research platform with various physical listing information about the tested specimen, the shear modulus (G) is 26 GPa, a yield stress of 276 MPa (τ_y), and a τ_u value of 310 MPa (MatWeb). The percent difference between our G of 16 GPa and the expected G of 26 GPa is 47.62%. The percent difference of the expected yield stress 276 MPa vs our value of 167.7 is 48.82%. The percent difference of the expected τ_u value of 310 and our value of 251.6 is 20.80%. These differences are best explained by known deviances in materials being tested, measurement error, and deviances with the machine's true application of force.

Using a graphing tool, the expected Mohr's circle is as pictured:



8. The failure plane is anticipated to be roughly perpendicular with a slight offset as seen in the Mohr's circle pictured above, which is essentially consistent with the results of the experiment.

Discussion:

The results of this study are somewhat expected. We would anticipate that the failure plane to be the same as we experienced in this test. With respect to other measurements, there were more deviations. To an extent, our findings were off with the literature referenced for the expected findings of this experiment. We saw no more than a 50% deviation in our principal results, which is significant. Numerous factors may have played into this outcome including a bad sample, testing errors, and inaccurate data measurements or computations. This can be rectified by testing multiple samples for consistencies and eliminating outliers and testing equipment with known benchmarks to ensure accuracy.

Feedback:

I was most fascinated by just how "perfect" the shear plane was for the sample. Watching the sample twist at an increasingly greater rate with time as more torsional force was applied was my personal highlight of this experiment. Without being able to pinpoint the root causes of the deviations in the data we collected, it is impossible to give feedback to improve this experiment, and seems to be satisfactory for what it is trying to convey.

Conclusions:

This lab analyzed the impact of torsional force applied to an aluminum-6061 specimen of diameter 1.9cm. Analyzing the values of the torque applied with respect to the angle of rotation, we were able to derive the gamma value and plot this with respect to the converted torque values. From there, we were able to compare information about this test and sample to known information and offer explanations to any deviances therein.

References:

ASM material data sheet. (n.d.).

https://asm.matweb.com/search/SpecificMaterial.asp?bassnum=ma6061t6

Duke Engineering 201 Lab 1 Manual

MechaniCalc, Inc. (n.d.). Stress transformations & mohr’s circle. MechaniCalc.

https://mechanicalc.com/calculators/mohrs-circle/

Appendix A - Torsion Lab Data

Torque (kg-cm)	Rotation (degrees)	Torque (kg-cm)	Rotation (degrees)
		4000	16.7
100	0.5	4100	69.8
200	1.1	4200	116
300	1.5	4300	0
400	1.9	4400	0
500	2.3	4500	0
600	2.7	4600	0
700	3.1	4700	0
800	3.5	4800	0
900	3.9	4900	0
1000	4.3	5000	0
1100	4.6	5100	0
1200	5	5200	0
1300	5.3	5300	0
1400	5.7	5400	0
1500	6.1	5500	0
1600	6.5	5600	0
1700	6.9	5700	0
1800	7.3	5800	0
1900	7.7	5900	0
2000	8.1	6000	0
2100	8.5	6100	0
2200	8.9	6200	0
2300	9.2	6300	0
2400	9.5	6400	0
2500	9.9	6500	0
2600	10.2	6600	0
2700	10.6	6700	0
2800	10.9	6800	0
2900	11.3	6900	0
3000	11.7	7000	0
3100	12	7100	0
3200	12.4	7200	0
3300	12.8	7300	0
3400	13.2	7400	0
3500	13.5	7500	0
3600	14	7600	0
3700	14.5	7700	0
3800	14.9	7800	0
3900	15.5	7900	0
	Maximum torque:	4289.0 kg/cm	max twist: 281.7 degrees

Table 2: Torsion Test Data Sheet