Lab 02

The Uniaxial Tensile Test

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Lab Section: 102, Tuesday, 2-5pm

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1 Objective

To demonstrate the basic properties of strength and toughness by using the uniaxial tensile test and observing the necking and yielding behavior of the corresponding stress strain plots generated. To view and understand the micro structure of materials after fracture using the Charpy Impact test and a scanning electron microscope.

2 Experimental Procedures

2.1 Uniaxial Tensile test

First we performed rockwell hardness tests on all three materials. We performed the test once on each end of the materials. Next we measured the initial length of the material as well as the diameter of the cross sectional area. We placed each material into the uniaxial tensile test machine and used the rates of 0.003, 0.001, and 0.003 in/sec for the steel-1018, steel-4340, and Al-Cu alloys. During the test, observe the live data being generated for any signs of necking that occurs.

2.2 Charpy Impact test

Before the start of the lab, we placed a sample of 1018 steel in liquid nitrogen in order to cool the material. First we performed a test run without any sample in the machine and recorded this as the test angle. Next we placed a piece of 1018 steel at room temperature into the machine and ran the test. Finally, we grabbed the liquid nitrogen cooled sample of steel-1018 and ran the same test with this sample. We placed both samples of steel-1018 into a scanning electron microscope in order to observe the surface of fracture.

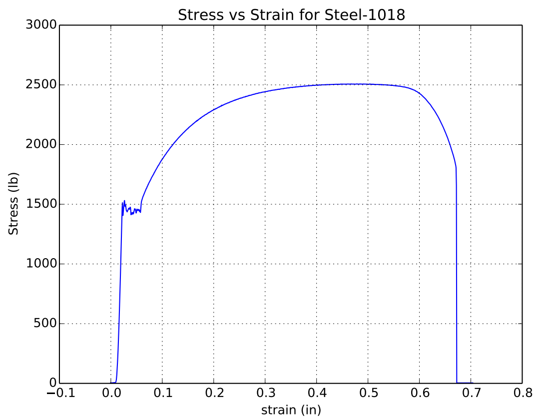
3 Experimental Results

Materials	l_0 (in)	l_f (in)	d_0 (in)	d_f (in)	strain rate (in/s)	Hardness #1 (RHN)	Hardness #2 (RHN)
Al-Cu	1.908	2.275	0.254	0.232	0.005	14	19
Steel-1018	1.884	2.477	0.233	0.206	0.005	31	31
Steel-4340	1.973	2.008	0.235	0.234	0.001	72	74

Figure 1: Uniaxial Tensile test results for all alloys

	angle (θ)
test run (no sample)	159
room temperature	126
liquid nitrogen temperature	156

Figure 2: Charpy test results for Steel-1018



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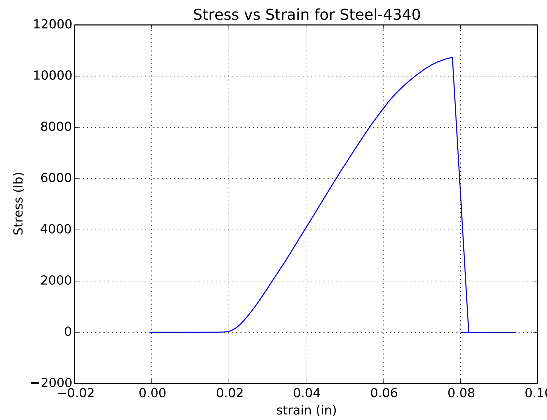

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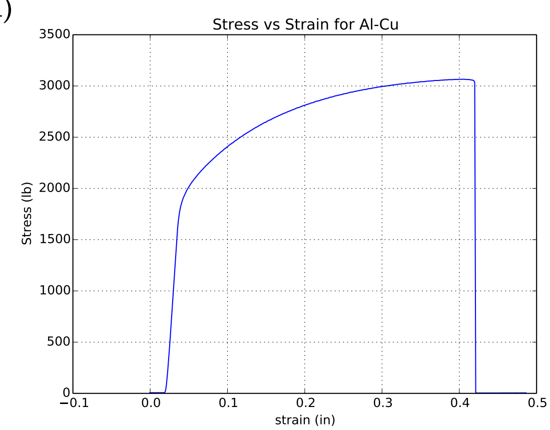

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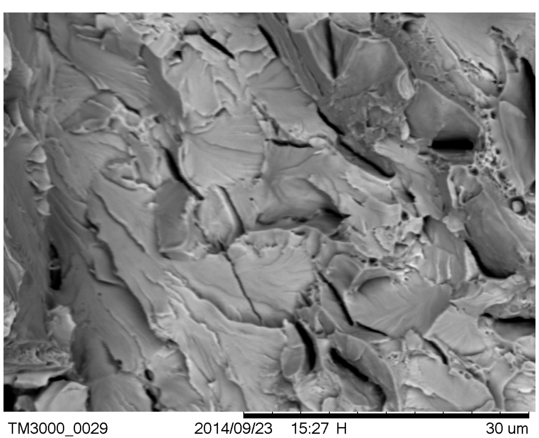
Figure 3: **(a)** Stress-Strain plot results for Steel-1018 using the uniaxial tensile test. **(b)** Stress-Strain plot for results for Steel-4340 using the uniaxial tensile test. **(c)** Stress-Strain plot results for Al-Cu alloy using the uniaxial tensile test.



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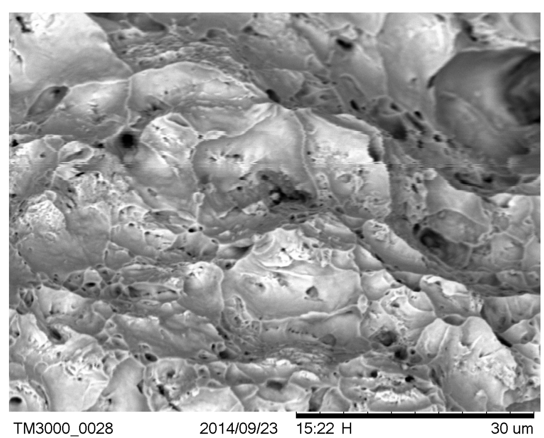

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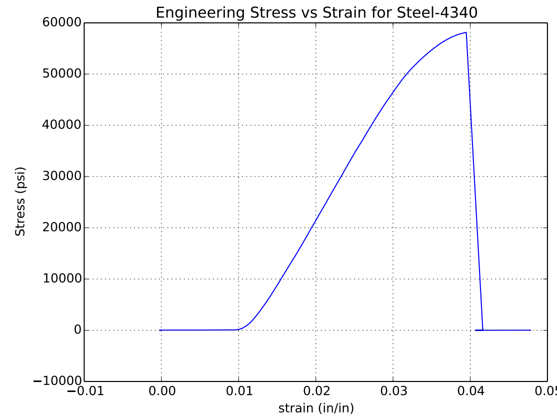
Figure 4: **(a)** SEM picture for liquid nitrogen cooled Steel-1018. **(b)** SEM picture for room temperature Steel-1018

4 Discussion

1) How can you plot an "engineering stress-strain curve" from "applied load" vs "elongation" data. Using your own data, plot engineering stress-strain curves for all three samples and explain.

Since we want an engineering stress-strain curve and not just a stress-strain, we need to calculate the initial cross sectional area of the material, A_0 and the initial length l_0. Next divide these by the 'applied load' and 'elongation' data points in order to get engineering stress-strain data points. Finally plot this new data with your plotting tool of choice. In this case, python.

(a)



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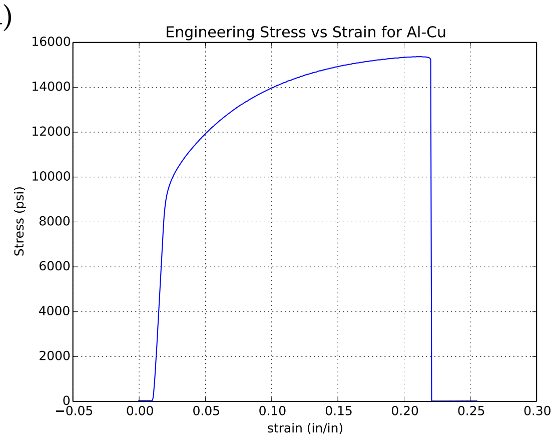

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Figure 5: **(a)** Engineering Stress-Strain plot results for Steel-1018 using the uniaxial tensile test. **(b)** Engineering Stress-Strain plot for results Steel-4340 using the uniaxial tensile test. **(c)** Engineering Stress-Strain plot results for Al-Cu alloy using the uniaxial tensile test.

2) From this curve calculate the following for each of the samples: (a) Young's modulus (slope of elastic portion of the curve); (b) yield strength (lower yield strength for steel, 0.2% offset for aluminum alloy); (c) ultimate tensile strength; (d) fracture stress; (e) percent reduction in area at fracture; (f) total elongation; and (g) toughness (approximated as area under the curve). Explain any anomalies in your results.

The results all seem to be reasonable. No anomalies that stick out.

Material	Young's modulus (psi)	yield strength (psi)	ultimate tensile strength (psi)	fracture stress (psi)	% reduction in area at fracture	total elongation (in/in)	toughness (in^2)
Steel-1018	1.433629×10^6	7.821898×10^3	1.370663×10^4	1.12×10^4	88.4	0.315	4.311251×10^3
Steel-4340	2.624936×10^6	52.25604×10^3	5.812479×10^4	5.84×10^4	99.6	0.0177	1.006291×10^3
Al-Cu	1.057670×10^6	9.127436×10^3	1.536832×10^4	1.67×10^4	91.3	0.192	2.819101×10^3

Figure 6: Table shows the key mechanic properties of a tensile test for two types of steel and a Al-Cu alloy. Some of the results has 7 sig figs because the uniaxial test data provided 7 sig figs of accuracy. The measurements of area and length were done in 3 sig figs because this was measured with a scaliper. Toughness was calculated using simpson's rule of integration. Young's modulus was calculated by doing a linear fit on the elastic portion of the data. Yiled strength was calculated by plotting the 0.2% offset and finding the point of intersection. Tensile strength was found by finding the largest value of stress in the data set.

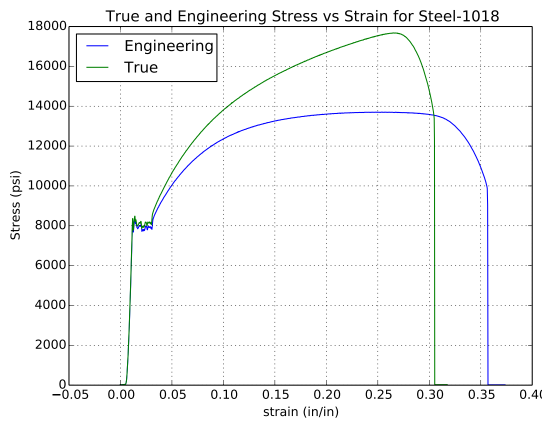
3) During the tensile test the volume of the material remains constant, which can be expressed mathematically as, $l_0 A_0 = l_i A_i =$ constant. Using this relation and the definitions of engineering stress, engineering strain, true stress, and true strain, derive the following relationship between true stress and engineering stress, $\sigma_{\textbf{true}} = \sigma_e(1+\epsilon_e)$, and the relationship between true strain and engineering strain, $te\epsilon_{\textbf{true}} = \sigma_e(1+\epsilon_e)$.

$$\sigma_{\text{true}} = \frac{P}{A_i} = \frac{Pl_i}{A_0 l_0} = \sigma_e \frac{l_i}{l_0} = \sigma_e \frac{l_0 + l_0\epsilon_e}{l_0} = \sigma_e(1+\epsilon_e) \tag{1}$$

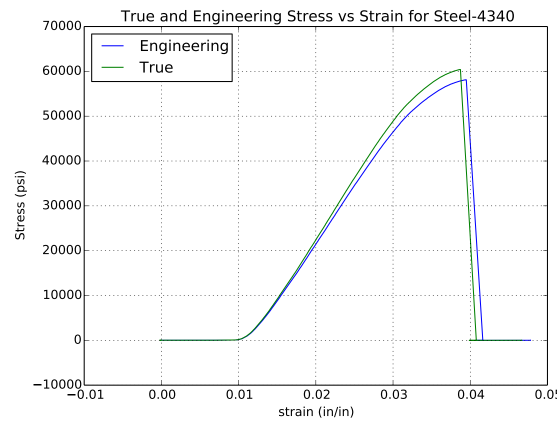
$$\epsilon_{\text{true}} = \ln \frac{l_i}{l_0} = \ln \frac{l_0 + l_0\epsilon_e}{l_0} = \ln(1+\epsilon_e) \tag{2}$$

4) Convert your engineering stress-strain curves to true stress-strain curves.

See figure 7 below.



(a)



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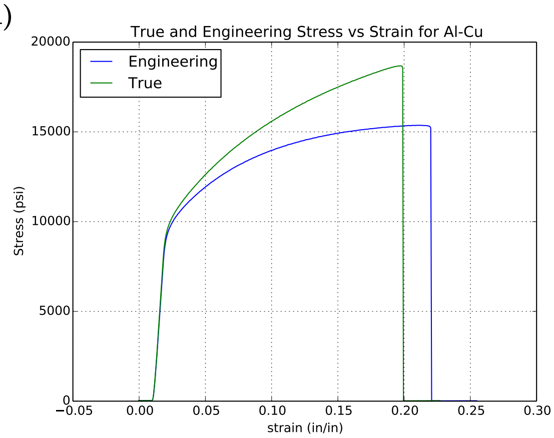

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Figure 7: Both true and engineering plots were overlayed in order to better see the comparation between the two. **(a)** True and Engineering Stress-Strain plot results for Steel-1018 using the uniaxial tensile test. **(b)** True and Engineering Stress-Strain plot for results Steel-4340 using the uniaxial tensile test. **(c)** Engineering Stress-Strain plot results for Al-Cu alloy using the uniaxial tensile test.

5) Where (physical location) on each sample did you observe "necking" to occur? Is this where you expected to see it? Explain.

I expected necking as well as fracture to occur where the initial rockwell tests were done, near the ends of the materials. For the Al-Cu alloy necking and fracture did occur at the end of the material, but for the two steel samples, necking and fracture occuring more towards the center than the ends. There was much more necking (clearly visible in Figure 8) on the Steel-1018 sample than the Steel-4340 sample; this is also verified by looking at the plots in Figure 7.

Figure 8: Samples used for the uniaxial tensile test. From left to right: steel-1018, Al-Cu, steel-4340. Note the necking in steel-1018 is clearly visible in this picture.

6) Compare and contrast the scanning electron "fractographs" recorded during your lab experiments. What are the distinctive features of the fracture surface? How do these features differ from sample to sample? Do these observations make physical sense with respect to their observed strength and toughness? Explain.

Both pictures seem to have dark holes present; this is magnesium sulfide impurities in the metals. The liquid nitrogen sample surface is a lot more flat and smooth as this fracture was done while the metal was in its brittle stage. The room temperature sample has a lot more crack and fracture points as this was stretched more because of its high toughness.

5 Conclusions

As a result of this investigation, the following conclusions can be drawn.

1. Of the three alloys tested, Steel-1018 had the largest toughness.
2. Steel-4340 had almost no plastic region meaning that it cannot deform very well and was very brittle at room temperature.
3. Temperature change of materials can cause a drastic change in its toughness, making the material very brittle at low temperatures.
4. The microstructure of brittle materials at fracture is much more smooth and flat than that of non brittle materials.

6 References

1. James F. Shackelford, Introduction to Materials Science for Engineers, Seventh Edition, Pearson Higher Education, Inc., Upper Saddle River, New Jersey (2009).