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Lithium:
Measurement of Young's Modulus
and Yield Strength

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INTRODUCTION

The Lithium Collection Lens is used for anti-proton collection. In analyzing the structural behavior during operation, various material properties of lithium are often needed. Properties such as density, coefficient of thermal expansion, thermal conductivity, specific heat, compressability, etc; are well known[1]. However, to my knowledge there is only one published source[2] for Young's Modulus. This paper reviews the results from our testing of Young's Modulus and the yield strength of lithium at room temperature.
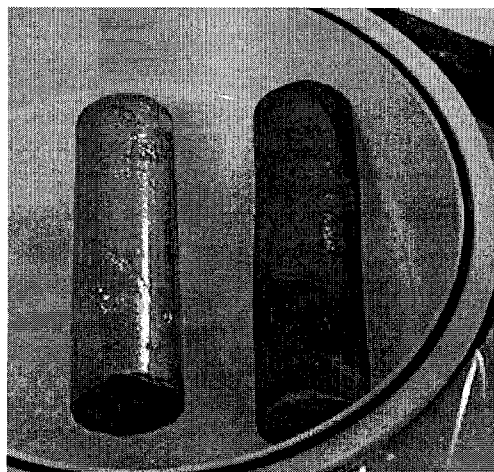
SAMPLE COMPOSITION

Lithium naturally exists at 92.5% Li-7, 7.5% Li-6. The isotopically pure lithium-7 (0.01 % impurities) used for lithium lens production is very expensive. In our tests, we used battery grade lithium (2% impurities). The mechanical properties may vary between battery grade and isotopically pure lithium. We decided, however to conserve our supply of isotopically pure lithium. The battery grade samples were manufactured and purchased back in the early 1980's from Lithco, Inc. The cast size and shape is a 1 - 11/16" (diameter) cylindrical slug 12" long. They have been stored dry, submersed in argon gas, packed within an aluminum envelope, and sealed within a paint can.

MATERIAL HANDLING

While the melting point of lithium is 180.6 °C, it is flammable at about 160 °C. We felt that there was little danger in handling it in open air at room temperature. The lithium will react with oxygen to produce Li_2O, with nitrogen to produce Li_3N, and with water to produce $LiOH$ + H_2 – which is flammable. We were primarily concerned with containment of all the material. While lithium will not chip, small pieces will tear off and stick to any tools that are used. These tools must be cleaned by dousing them in water. While the gases produced are toxic and flammable, we felt there was little danger in reacting the minute amounts found sticking to tools. It was far more dangerous to leave any fragments of lithium than to react them. Refer to the MSDS sheet for a complete explanation for any further safety concerns.

Lithium is a very gummy, sticky substance, much like silly putty or cold caramel. For this reason, it is unfeasible to machine it in any way. The best way we found to cut lithium was with a razor blade and a hammer. It was a very slow and tedious process.
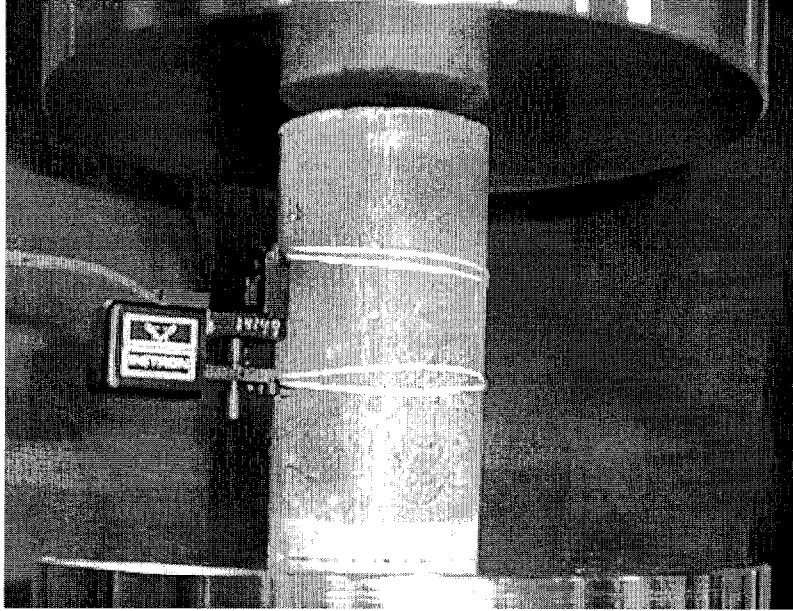
The suggested method for long term storage is submersion in argon gas or mineral oil. Lithium is very corrosive in pure nitrogen or pure oxygen. In air, lithium does oxidize, but at a much slower rate. Noticeable surface corrosion can be seen after an hour or two. Our samples were bright, shiny, almost mirror-like silver at the beginning. After two hours in open air, they had turned to a dull grayish black.

Picture 1 – lithium corrosion

2

TEST SETUP

The original slug was 12" long. When testing in compression, it is best to have an aspect ratio of less than 5 for buckling purposes. We chose to cut our specimen down to about 3.5 inches, which was about the minimum limit for the Instron machine.

Picture 2: Test setup

The Inston machine measures force via a load cell, and strain via an extensometer. The stress can be calculated by measuring the cross sectional area. The top ram will move down at a set displacement rate. The ASTM standard rate for E testing is 0.05 inches per minute. We experimented with rates from 0.005 to 0.15 inches per minute and found that anything equal to or faster than the recommended standard was sufficient to minimize creep.

THE MODULUS OF ELASTICITY

Young's Modulus (E) is a constant, defined as stress divided by strain. The Instron machine will output a Force vs. Strain curve. The stress-strain curve can be calculated once the cross sectional area is known. In the elastic region, the slope of this curve is equivalent to Young's Modulus. See Figure 1.
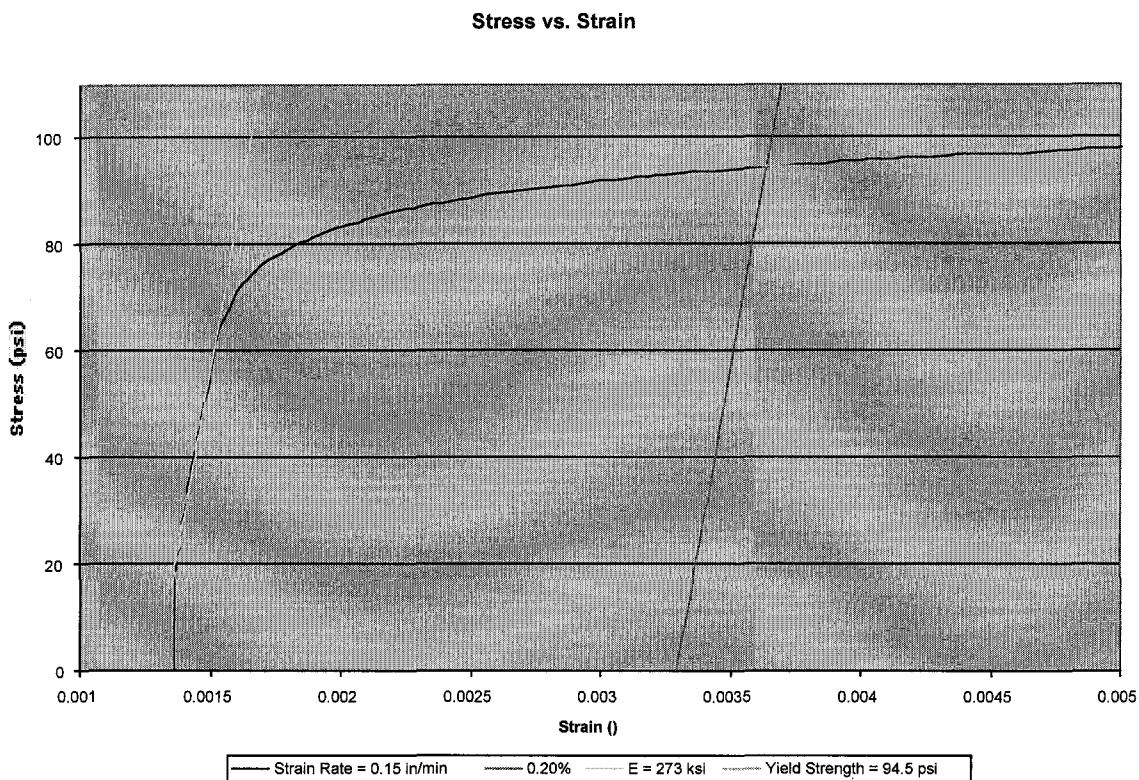
Stress vs. Strain

Figure 1 – Typical Stress-Strain curve

Strain Rate (strain per minute)	Young's Modulus (ksi)
0.05	267
0.05	271
0.08	306
0.10	263
0.15	273
Average	**276**

Table 1 – Young's Modulus Results

Our results show an average of 276 ksi. The only published value[2] that I found for the Young's Modulus of lithium is listed as E = 712 ksi. Any differences in the impurity level or casting conditions could result in a stiffer substance. It is also possible that they measured a different modulus (i.e. bulk or shear) and then back calculated to determine the Elastic Modulus.

4

YIELD STRENGTH

The yield strength (σ_y) is determined by using the 0.2% offset rule[6] (see Figure 1). The point on the curve where the 0.2% offset line intersects the data is known as the yield point. The 0.2% offset rule is an arbitrary standard that is generally accepted for most materials. While 0.2% is the most commonly used value, 0.01, 0.1, and 0.5% are also sometimes used. It may be better to use a smaller offset for ductile materials such as lithium. The results for both 0.1% and 0.2% are listed in Table 2:

Strain Rate (strain/min)	σ_y (psi) – 0.1% offset	σ_y (psi) – 0.2% offset
0.05	66	70
0.05	67.0	72
0.08	72.5	76
0.10	88	93
0.15	89.7	94.5
Average	**76.6**	**81**

Table 2 – Yield Strength Results

The only value[4] I found for the strength of lithium is published as the ultimate strength, often referred to as the tensile strength. This is listed as $\sigma_U < 2200$ psi. It is unclear why the published value is an inequality. While the difference between the ultimate strength and the yield strength of a material is usually not this great, it is possible that highly ductile materials like lithium could behave this way.

CONCLUSIONS
Data sets were taken from two different portions of the same sample and produced similar results. While it would be better to test multiple samples from different castings, the cost to acquire testable samples of lithium is high. It may be necessary in the future to produce an isotopically pure sample for further testing.

Since lithium is not used as a structural material there is very little need for such data. Our application and the composition of our lithium is unique. While the factor of three difference between our results and the published value of Young's Modulus is puzzling, it does not suggest that either of the results are flawed. Quite the contrary, it is very possible that the circumstances between the published data and our results are different enough that they should not be compared. It is likely that they had a different composition or purity level. It is also possible that the value published was not actually measured, but rather was calculated from some other property or theory. Unfortunately, we do not know the circumstances behind the published value of Young's Modulus.

The yield strength of lithium was determined by testing our sample in compression. While it is valid to test the yield strength of a material in either tension or compression, we did not have the capabilities to produce a sample for testing in tension. It is probable that the published ultimate strength value was determined by testing in tension. It is unlikely that we could have obtained meaningful results by testing our sample to failure in compression because of the extremely ductile nature of the material.

ACKNOWLEDGMENTS

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