Subject: Results of aluminum toughness testing

Foreword

Your company is turning recycled cans into structural grade alloy in an effort to expand your facility and bring much-needed jobs to the area. You believe that your material scientists have developed a method for producing 7075-T651 aluminum alloy and need independent verification that the alloy has the correct composition. Thus, you have asked our firm to perform tensile and fracture testing, following the ASTM 399 standard, on aluminum samples machined to size by an independent machining company. Specifically, you have asked that we provide you with the density, modulus, Poisson's ratio, yield strength, ultimate tensile strength, and fracture toughness of the material. We have completed these tasks. The purpose of this report is to provide you with our findings, conclusions, recommendations, and supporting documentation.

Summary

We have found all the material properties that you have asked for except for the fracture toughness, which we were unable to find due to an inadequate number of fracture specimens. The properties of the alloy you gave us for testing can be found in Table 1 along with the properties of 7075-T651 aluminum alloy. The density, Young's modulus, and Poisson's ratio for the material you provided us are equal to those of 7075-T651 aluminum alloy; however, the yield strength and the ultimate tensile strength do not agree. We have concluded, therefore, that the material supplied to us is not 7075-T651 aluminum alloy.

Table 1: Supplied alloy has the same density, modulus, and Poisson's ratio as 7075-T651 aluminum alloy, but different yield strength and ultimate tensile strength

	Your alloy	7075-T651 aluminum alloy
Density (kg/m^3)	2863 ± 82	2800
Modulus (GPa)	72.0 ± 3.0	71.0
Poisson's ratio	0.314 ± 0.023	0.33
Yield Strength (MPa)	542.68 ± 0.54	603
Ultimate Tensile Strength (MPa)	585.85 ± 0.36	572

Procedure

Your company provided us with a cylindrical tensile bar in tensile testing and four ASTM 399 standard single-edge-notch beam specimens of varying thickness for fracture toughness testing; all specimens were machined to size by an independent machining company.

Figure 1: Tensile bar specimen has diameter d_0 and length l_0

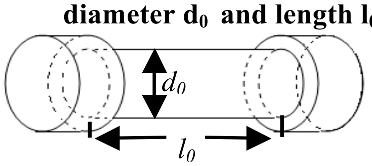
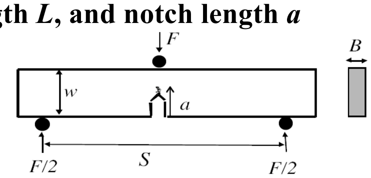


Figure 2: Fracture specimen has thickness *B*, width *w*, length *L*, and notch length *a*



First, using calipers, we measured the gauge length l_0, 9.519 ± .009 cm, and the diameter d_0, 1.286 ± .006 cm, of the tensile specimen (shown in Fig. 1). Then we securely attached the specimen to the Instron 4206 load machine (serial number 514) and ran the tensile test, recording the strain and load data until the strain-gauges failed, after which we continued the test until fracture recording only the load data. The test was done at an extension rate of 2.54 mm/min and a sampling rate of 3 Hz. The data was recorded using LabView 7.2 software.

Next, we measured the dimensions of four fracture samples (dimensions shown in Fig. 2) using calipers. Then we performed the fracture toughness test on each sample using the Instron 8516 machine (system ID 8516·H1099) and the load-versus-displacement data was recorded using Instron Plus 8500 software. To ensure correct results, for each test we calibrated the gauge clip and positioned the specimen so that it was in the middle of the clip gauge and parallel to the front surface of the machine. The test was conducted until the load started to decrease, at which point we stopped the experiment and manually broke the sample in two. Then using calipers and a magnifier, we measured the crack length, *a*, for each of the samples using different points along the pre-crack curve in order to get the uncertainty in the measurement.

All experiments were done at a room temperature of 23.1 ± .05 degrees Celsius, and all of the data was plotted and analyzed using Microsoft Excel.

Findings

Below are results and analysis of the measurements, tensile testing, and fracture toughness testing that we performed on the aluminum specimen.

Density

We found the density of the alloy to be 2863 ± 82 kg/m^3 which agrees with 7075-T651 aluminum alloy's density of 2800 kg/m^3 [1]. The density was calculated by measuring the dimensions of the thinnest fracture sample while taking into account the uncertainties due to resolution and precision errors. As shown in Figure 2, the parameters defining the dimensions of the specimen are the thickness B, width w, length L, mass m, and notch area V. The dimensions and calculated density of the sample can be found with uncertainties in Table 2.

Table 2: Dimensions of thinnest fracture sample yield an alloy density of 2863 ± 82 kg/m^3

B **(mm)**	***W*** **(mm)**	***L*** **(mm)**	***M*** **(kg)**	***V*** **(mm^3)**	**Density (kg/m^3)**
3.296 ± 0.028	19.006 ± 0.028	95.225 ± 0.043	.0167 ± 1.4E-7	85.7 ± 2.8	2863 ± 82

Poisson's ratio

Poisson's ratio, υ, was found to be 0.314 ± 0.023, which agrees with 7075-T651 aluminum alloy's Poisson's ratio of 0.33 [1]. This value of υ is equal to the slope of the elastic region of the plot of lateral strain against negative transverse strain found in Fig. 3. The lateral and transverse strains for the plot were calculated using Equations 1 thru 5. The normal strains in the x and y directions, ε_{xx}, ε_{yy}, and the shear strain γ_{xy} in the x-y plane were found from Equations 1, 2, and 3. Strains ε_1, ε_1, and ε_1 refer to the data recorded from strain-gauges 1, 2, and 3, respectively, and the strain-gauges were positioned at angles θ_1=0˚, θ_2=45˚, and θ_3=90˚. After solving for ε_{xx}, ε_{yy}, and γ_{xy}, the principal strains in the x-y plane were computed from Equations 4 and 5 (derived from Mohr's circle of strain). The largest of the principal strains is the lateral strain, ε^l, and the smallest is the transverse strain, ε^t.

$$\varepsilon_1 = \varepsilon_{xx}\cos^2(\theta_1) + \varepsilon_{yy}\sin^2(\theta_1) + \gamma_{xy}\cos(\theta_1)\sin(\theta_1) \qquad \text{Equation 1}$$

$$\varepsilon_2 = \varepsilon_{xx}\cos^2(\theta_2) + \varepsilon_{yy}\sin^2(\theta_2) + \gamma_{xy}\cos(\theta_2)\sin(\theta_2) \qquad \text{Equation 2}$$

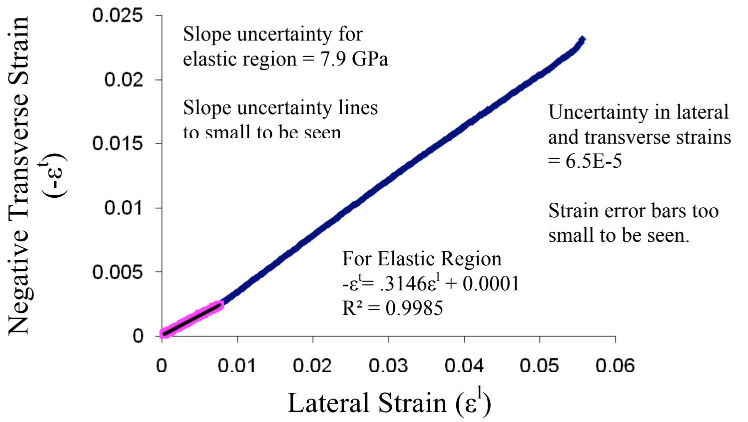
$$\varepsilon_3 = \varepsilon_{xx}\cos^2(\theta_3) + \varepsilon_{yy}\sin^2(\theta_3) + \gamma_{xy}\cos(\theta_3)\sin(\theta_3) \qquad \text{Equation 3}$$

$$\varepsilon^l = (\varepsilon_{xx} + \varepsilon_{yy})/2 + \sqrt{(\varepsilon_{xx} - \varepsilon_{yy}/2)^2 + (\gamma_{xy}/2)^2} \qquad \text{Equation 4}$$

$$\varepsilon^t = (\varepsilon_{xx} + \varepsilon_{yy})/2 - \sqrt{(\varepsilon_{xx} - \varepsilon_{yy}/2)^2 + (\gamma_{xy}/2)^2} \qquad \text{Equation 5}$$

The lateral and transverse strains are related within the elastic region according to the equation $\varepsilon^t = -\upsilon\varepsilon^l$. Thus, Poisson's ratio, υ, is equal to the slope of the elastic region. The uncertainty in υ comes from the precision and resolution errors in the strain data collection equipment.

Figure 3: Plot of lateral strain against negative transverse strain gives a Poisson's ratio of 0.314 ± 0.023 for the aluminum sample



Ultimate tensile stren

The ultimate tensile stre ... ound to be 585.85 ± .36 MPa; this value does not match the 7075-T651 alı ... MPa [1]. The ultimate tensile strength of the alloy was found by performin ... the strain-gauge data and the force applied by the crossheads (the load). W ... ominal stress-versus-strain curve found in Fig. 4, page 4. The lateral nomi ... l previously using Equations 1 thru 5, and the nominal stress data was ... in which F is the force and A_0 was the original area of the specimen (A_0=3.1

$$\sigma_n = \frac{F}{A_0} \qquad \text{Equation 6}$$

Fig. 4 only shows the tensile test data until the strain-gauges failed; however, load data was still recorded until fracture. Also, data points with negative strain and/or stress values found at the beginning of the test were not used in the plot as they were not valid (strain and tensile stress cannot be negative); instead, these values were used to calculate the precision error of the data collection equipment. The maximum value of nominal stress, the ultimate tensile strength of the specimen, occurred during the fracture portion of the test (strain-gauges had already failed); hence, the ultimate tensile strength cannot be seen on the nominal stress-versus-strain plot. The uncertainty in the stresses and strains are results of the precision and resolution error of the testing and recording equipment.

Young's modulus of elasticity and yield strength

The Young's modulus and yield strength of the alloy were found to be 72.0 ± 3.0 GPa and 542.68 ± 0.54 MPa, respectively. The modulus of the sample agrees with 7075-T651 aluminum alloy's modulus of 71.0 GPa [1]; however, the yield strength does not agree with 7075-T651's yield strength of 603 MPa [1]. The modulus was found by plotting the true stress-versus-strain curve (shown in Fig. 5) and taking the slope of the elastic region. The yield strength was found using the .2% strain offset method. Both the modulus and yield strength errors are composed of resolution and precision errors from the data collection equipment, but the yield strength error also has a component from human error (from visually finding the intersection of the .2% strain line and the curve).

The nominal stress-versus-strain data (shown graphically in Fig. 2) was used in Equations 7, 8, and 9 to find the true stress-versus-strain data. Equation 7 calculates the true strain, ε_t, Equation 8 gives the true stress, σ_t, within the elastic region, and Equation 9 gives σ_t within the plastic region. D_0 is the original diameter of the tensile specimen and ε^t is the transverse strain defined by Equation 4 on page 3. The true strain, ε_t, is equal to the lateral strain, ε^l, which is defined by Equation 5 on page 3.

$$\sigma_t = B\varepsilon_t^{\,n} \qquad \text{Equation 7}$$

$$\sigma_t = \sigma_n(1+\varepsilon_n) \qquad \text{Equation 8}$$

$$\sigma_t = F/\left[\pi/4(D_0 + D_0 * \varepsilon^t)^2\right] \qquad \text{Equation 9}$$

Figure 4: Nominal stress-strain curve cuts off before ultimate tensile strength of 585.85 ± .36 MPa

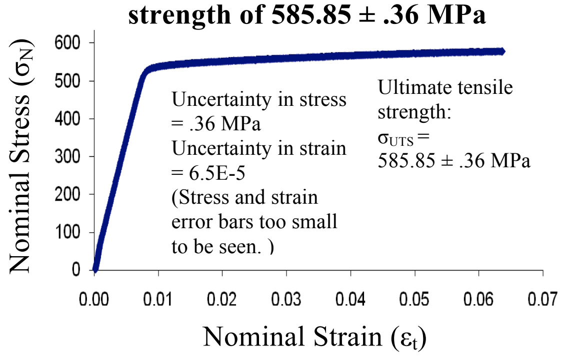
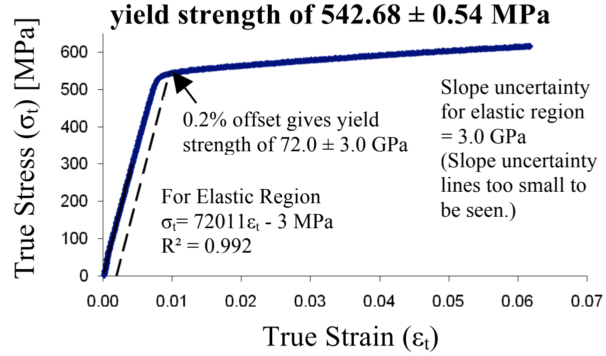


Figure 5: True stress-versus-strain curve yields elastic modulus of 72.0 ± 3.0 GPa and yield strength of 542.68 ± 0.54 MPa



Fracture Tou

We were not ab ... cal fracture toughness, K_{IC}, be ... gh
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These quantities are recorded in Table 3. The thinnest sample (B = 3.296 ± 0.028 mm) cannot be used for the analysis of K_Q because it does not fulfill the requirements for plain strain (it responds to load in plane stress). Fig. 6 shows the force-displacement curves for the specimens 2, 3, and 4. For each plot we found where a line from the origin with a slope 95% of the linear region slope intersects the actual curve, and this point gave us the critical load value, P_Q (Table 3). We then used P_Q values in Equation 10 (for Mode I loading) to find K_Q for each specimen.

$$K_Q = P_Q S/\left[Bw^{3/2}\right] f(a/w) \qquad \text{Equation 10}$$

Table 3: *B*, *w*, and *a* values give values of *f(a/w)* ranging from 2.56 to 2.39

Specimen #	**1**	**2**	**3**	**4**
a [mm]	9.23 ± 0.95	9.29 ± 0.69	9.28 ± 0.43	8.85 ± 0.46
B [mm]	3.296 ± 0.028	6.389 ± 0.038	6.7327 ± 0.082	6.8755 ± 0.065
P_Q [kN]	~~---------~~	5.782 ± 0.029	7.980 ± 0.023	9.567 ± 0.079
w [mm]	19.006 ± 0.025	19.05 ± 0.18	19.038 ± 0.026	19.016 ± 0.079

f(a/w)	-------------------	2.56 ± 0.19	2.56 ± 0.19	2.39 ± 0.18

Figure 6: 95% slope method gives P_Q values that increase as thickness B increases

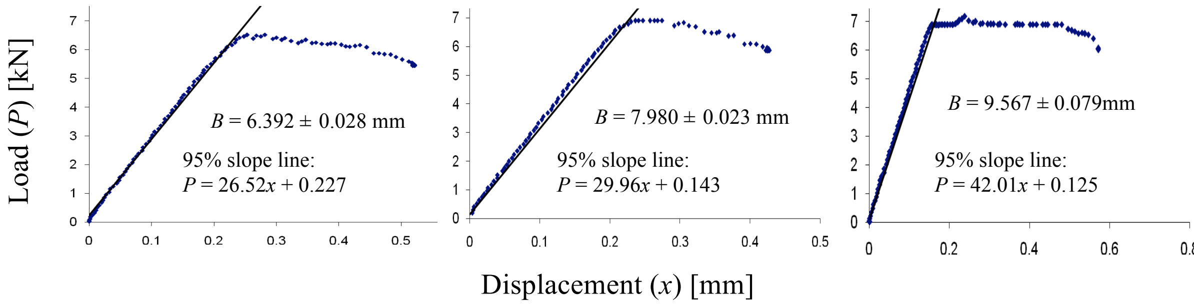
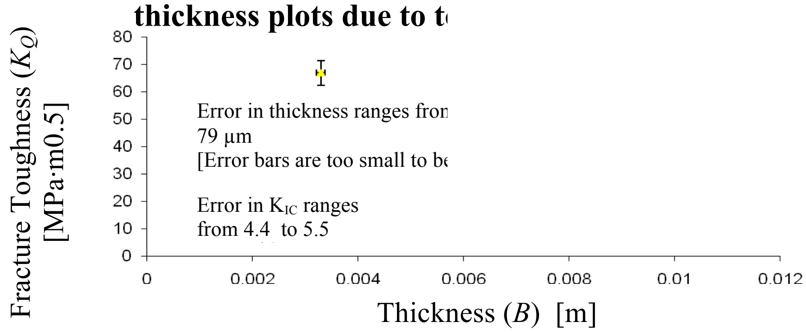


Figure 7: Critical fracture tough m fracture toughness-versus- thickness plots due to t



Conclusions and Reco

The density, modulus, and Poi the values for 7075-T651 alloy; however, the values of yield strength an agree (shown in Table 1). These results lead me to the conclusion that is not 7075-T651 aluminum alloy; it is a 7075 aluminum alloy of a diff nce the yield strength and ultimate tensile strength of your alloy is highe u will likely still be able to use this alloy in the applications that you ha at you inspect the method of heat treatment of the alloy to deter and re-test the fracture toughness with more samples to further investigate and understand the properties of the alloy you have produced.

References

[1] ASM Handbook, 2003, ASM International. Granta Design Limited.

[2] ASTM Standard E399, 2007, "Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness KIc of Metallic Materials," ASTM International, West Conshohocken, PA, www.astm.org.