I. INTRODUCTION

This report examines the tensile strength of plastic, steel, and aluminum. Tensile strength is defined as the ability of an object to resist breaking under forces of tension. Stress is quantified as the tensile force enacting on an object per unit area. The result of stress produces a deformation, known as strain, which is measured as the change in length divided by its original length. For adequately low stress and strain, they increase proportionally on a linear trend (Figure 1). The Young's modulus (E), is this constant of proportionality and depends on the type of material. Objects which experience stress and strain within this range will revert to its original length when the stress is removed. For larger stresses, the stress and strain relationship will no longer be linear (E will change), and the resulting deformation will be permanent. E is defined as:

$$E = \frac{\sigma}{\varepsilon} = \frac{F/A}{\Delta L/L_i}$$

where σ is the stress, with the force F applied to the cross-sectional area A and where ε is the strain, with the change in length ΔL over the initial length L_i.

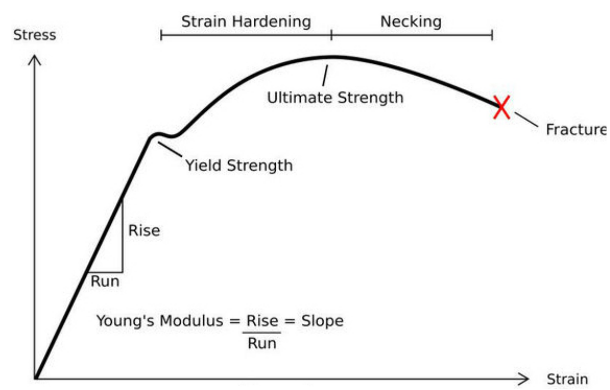

Figure 1: *A stress-strain curve where stress is in MPa and strain is in mm/mm. The initial graph is linear, and its slope is the Young's modulus. For this experiment, objects will break once the ultimate strength is reached since stress is constrained so that it can only increase. (Philipfigari 2015)*

The Pasco Scientific Stress/Strain apparatus will stretch various test coupons until breakage while collecting force and displacement data. With measurements on the dimensions of the coupons, the Capstone software is used to generate a stress-strain graph for each material. The objective of this experiment is thus, to find Young's modulus of the plastic, steel, and aluminum coupons.

II. PROCEDURE

To set up the Pasco Scientific Stress/Strain apparatus (Figure 2), the rotary motion sensor[1] [1] and the force sensor[2] [2] are connected to the Universal Interface and are then connected to a computer

[1] Uncertainty: ±0.002 rad
[2] Uncertainty: ±0.03 N

that runs the Capstone software. Data collection of force and angle is set to automatically start and end when the force registered is greater than 1.00 N and smaller than 50.00 N. The collection frequency of both sensors is set to 1kHz and the tare calibration button on the force sensor is pressed before the start of every test. During testing, the crank is turned clockwise at a slow but steady pace to lengthen the coupon clamps [9] and thus, apply tensile force onto the firmly mounted test coupon. The coupons are secured by clips and nuts to prevent slipping during the test. After each test, signalled by the breaking of the coupon, the crank is returned to its original position to allow the next coupon to be mounted. Since the apparatus may also exhibit displacement when stretching coupons, a calibration bar is first mounted to the coupon clamps [9] and tested to isolate this calibration coefficient. This coefficient will be used to find the calibrated displacement of only the coupons due to stretching. The cross-sectional dimensions of the steel and aluminum coupons measure 4.33 by 0.07±0.01 mm with an initial length of 100.11±0.01 mm using a digital Vernier Caliper (±0.01 mm). The plastic coupon has a midspan that is cylindrical instead of rectangular with a diameter of 1.78±0.01 mm with an initial length of 25.43±0.01 mm. Using the equations for areas of a rectangle[3] and circle[4], the cross-sectional area is $A = bh = 4.33 \times 0.07 = \mathbf{0.30\ mm^2}$ and $\pi r^2 = \pi \left(\frac{1.78}{2}\right)^2 = \mathbf{2.49\ mm^2}$, respectively, with percentage uncertainty[5] $U_P = A\left(\frac{\Delta a}{a} - \frac{\Delta b}{b}\right) = 0.30\left(\frac{0.01}{4.33} + \frac{0.01}{0.07}\right) = \mathbf{\pm 0.04\ mm^2}$ and $2.49\left(\frac{0.01}{1.78} + \frac{0.01}{1.78}\right) = \mathbf{\pm 0.03\ mm^2}$, respectively.

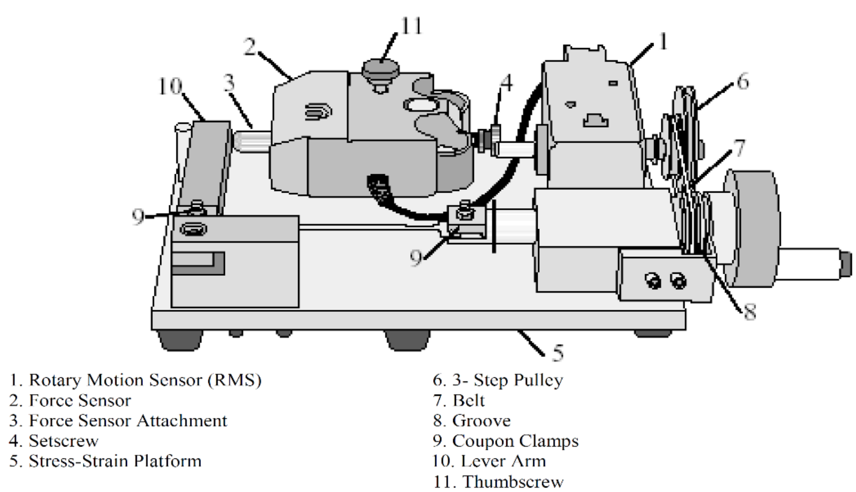

Figure 2: *Labelled diagram depicting the Pasco Scientific Stress/Strain apparatus. Turning the crank clockwise moves the right coupon clamp [9] to the right and stretches the mounted coupon. In turn, a force is exerted on the lever arm. The pivoting of the lever arm generates a force on the force sensor [2] to be collected as raw data.*

[3] Where A is the area, b is the base length, and h is the height length.
[4] Where A is the area, r is the radius which is half of d, the diameter.
[5] Where U_P is the percentage uncertainty, a and b are side lengths, and Δa and Δb are corresponding measurement uncertainties.

Since the force sensor is positioned further away down the lever arm away from its pivot than the coupon clamps, the actual tensile force exerted on the coupon is calculated using: $F_2 = \frac{L_2}{L_1} F_1$, where F_2 is the force exerted on the coupon, L_2 is the length between the point of contact of the force sensor on the lever arm and its pivot, L_1 is the length between the point of contact of the coupon clamps on the lever arm and its pivot, and F_1 is the force registered by the force sensor. L_1 and L_2 are measured using the caliper to be 18.80 and 100.93±0.01 mm, respectively. For example, for a 50 N registered force, the force exerted on the coupon is: $F_2 = \frac{100.93}{18.80}(50.00) = 268.4\text{N}$. The uncertainty for this applied force data is irrelevant since it is processed through the Capstone Software by plotting displacement over it (Figure 3) and fitted using a linear function. Displacement (mm) is attained by dividing the recorded angle data by 2π since each revolution of the rotary motion sensor yields 1.00 mm.

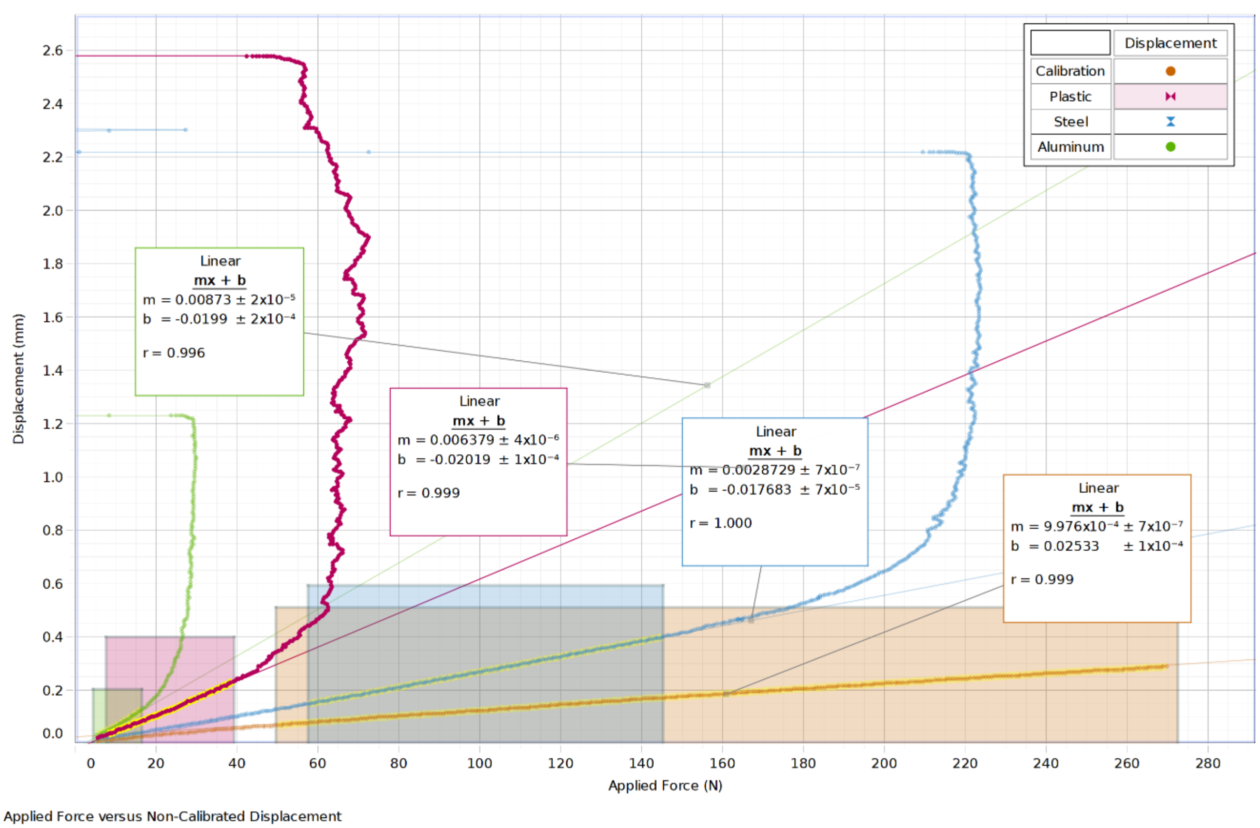

Figure 3: *Applied force versus non-calibrated displacement graph showcasing the curves for calibration (yellow), plastic (magenta), steel (blue), and aluminum (green). The range of the linear fit is applied to the initial sections since this graph is analogous to the stress-strain graph where the initial section pertains a linear trend.*

III. RESULTS AND DISCUSSION

The slope of the calibration curve from Figure 3 is extracted as the calibration coefficient to calculate the calibrated displacement: $D_c = D_{nc} - mF_A$, where D_c is the calibrated displacement, D_{nc} is the non-calibrated displacement, m is the slope of the calibration curve, and F_A is the applied force. This equation is applied to calibrate the displacements of each of the three materials point by point. Calibration is necessary to remove the additional displacement of the apparatus itself during testing.

Stress is the quotient of the applied force over the area corresponding to the cross-sectional shape. Strain is the quotient of the calibrated displacement over the initial length of the coupon. Stress and strain are calculated for each coupon and is graphed and linear fitted in Figure 4. The Young's modulus is the slope of the linear fit and is 203 000±100, 47 200±100, and 2100±2 MPa for the steel, aluminum, and plastic coupons, respectively. Coupons which can withstand the greatest force does not necessarily mean that it can withstand the greatest stress or strain since it depends on the cross-sectional surface area and the value of E for that material.

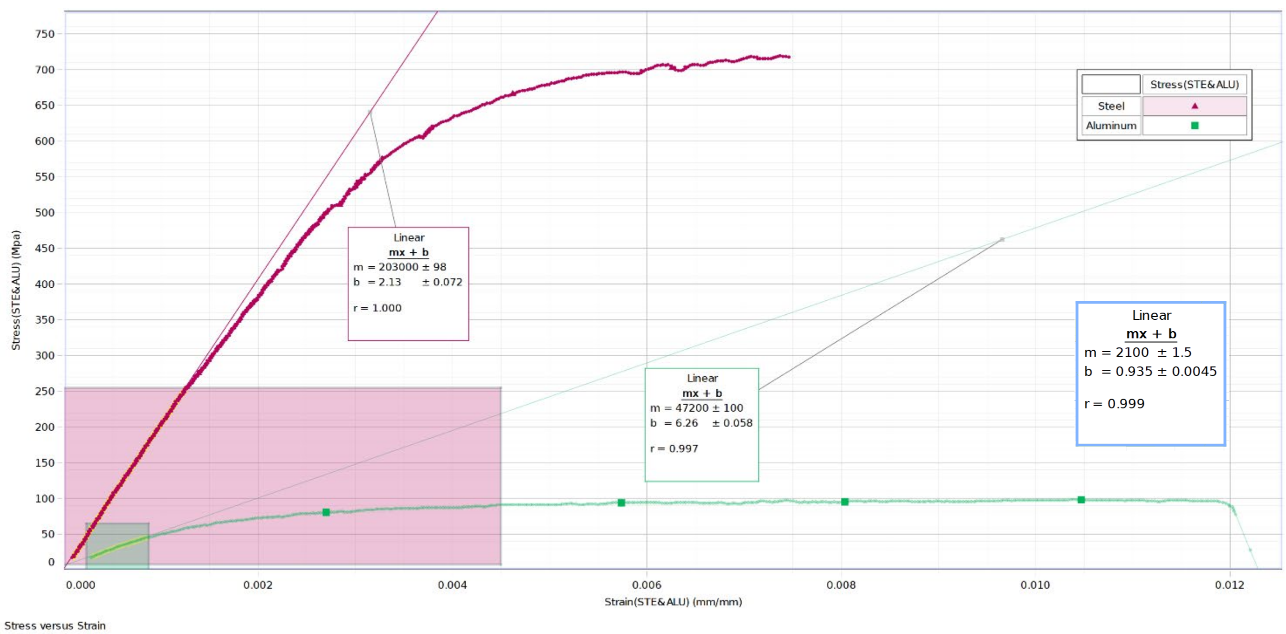

Figure 4: *Stress versus strain graph showcasing the curves for steel (magenta) and aluminum (green) with their linear fits. The curve for plastic is not included to save space from another graph. However, the linear fit for plastic is identified in the blue box.*

The uncertainties of this experiment consist of the measurement uncertainties associated with the dimensions of the three coupons from the caliper (±0.01 mm) and the force (±0.03 N) and angle (±0.002 rad) data from the two sensors. Statistical uncertainties originate from the linear fits that determine the calibration coefficient and E. The dominant uncertainty is likely the latter since E is obtained through two linear fits where the range of the linear fit is set by inspection each time. This is an example of random error. In consequence, the error bars from the measurement uncertainties are not included in the above graphs since it is assumed that the statistical uncertainties are much larger.

IV. CONCLUSION

The experiment has succeeded in identifying the stress and strain relationship between the three coupons. The objective of the experiment has been met by experimentally determining E of the steel, aluminum, and plastic coupons which corresponds to 203 000±100, 47 200±100, and 2100±2 MPa, respectively. The E values from Pasco's Instruction Sheets are 200 000, 69 000, and 19 000 MPa, respectively as reference (Pasco 2017). Although outside of uncertainty, the experimentally determined E are relatively close to the specified values. This inconsistency is primarily blamed on the random error of the linear fits which are performed by inspection during data processing to find E.

The method to experimentally determine E involved collecting angle and force data when stretching the calibration bar and the coupons. The calibration coefficient is obtained through a linear fit of the calibration curve and used to calibrate the displacement of the coupons due to stretching. By calculating the cross-sectional area of the coupons and using their original lengths, their stress-strain curves are generated. The initial linear section of the curves is linear fitted, whereby its slope is E.

While more accurate calipers and sensors can be explored to improve the experiment's accuracy, the execution of more trials per type of coupon can likely produce significantly more consistent E values. For reference, only one trial was conducted per material for this experiment.

The experiment can be extended by heating the coupons before testing and finding their E values. The heated E values can be compared with those of room temperature to determine the relationship of temperature on E. Since E is a measure of stiffness, an initial hypothesis is that E of the heated coupons will decrease, especially for metals, due to increases in their malleability and ductility.

References

Pasco. (2017, June 08). Metal Test Coupons [PDF]. Roseville: Pasco.

Pasco. (2017, June 08). Plastic Test Coupons [PDF]. Roseville: Pasco.

Philipfigari. (2015). Stress/Strain Curve [Digital image]. Retrieved November 18, 2017, from http://www.instructables.com/id/Steps-to-Analyzing-a-Materials-Properties-from-its/