Pressure Vessel Test (Report #3)

Chris Hyde, Kelsey Lawson, Han Cheng Liang, Rochelle Lucero
Group 2, Lab #4, Wednesday, 2-2:50 pm
Friday, December 13th, 2019

Introduction

This lab involved creating a plane strain to analyze Young's modulus (E) and principal strain values, which are very important for mechanical and material properties. To do so, a strain rosette was attached to an air tank to measure strain data when the tank was pressurized (psi). The strain rosette and laptop, running software to a data acquisition system, were connected to record data on the software LabView. Additionally, the pressure gauges on the tank are relative gauges because they aren't exposed to the outside atmosphere. In this report, the methodology of the experiment as well as the results and scrutiny of the recorded data are observed. Through pressure readings, cross-section properties, and strain measurements, the pressure vessel material's Young's modulus will be calculated and compared with the experimental and theoretical E value.

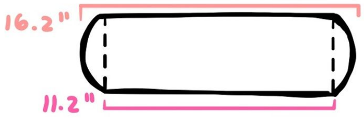
$E = \frac{\sigma\,(tensile\ stress)}{\varepsilon\,(tensile\ strain)} = \frac{F*L}{A*(\Delta L)}$ where F = applied load, L = length, ΔL = change in length, A= area

$Area = \pi r^2$. The tank radius is 11.65 cm, so the area equals to 0.0426 m^2.

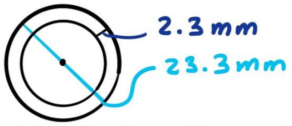
Inner radius = .1142m

Methodology and Procedures

1) Set up the lab such that each strain gauge on the tank is wired to a NI 9944, which is connected with an RJ50 cable plugged into the NI 9237 and the cDAQ 9172. The cDAQ is in turn also connected to a power source and a laptop running LabView.
2) Turn the red handles on the air tank to remove any pressure still within it.
3) Measure the air tank and the sample cut piece provided with calipers and a tape measure. A schematic of the dimensions of the air tank is given below.



Air Tank, Side



Elevated Section View, Front

4) Set LabView ready to record by choosing three channels, a quarter bridge configuration, and the rectangular rosette as well as enabling offset null and shunt calibration.
5) Test/run the data script with data logging off to ensure the strain gauges measure no strain.
6) Turn on data logging, and pressurize the tank to 20, 40, 60, and 80 psi with the air hose, pausing for several seconds every time.
7) Stop data logging and the script, turn the valve to release all of the air, and save the TDMS file as an excel sheet.

Results

Standard 45° Strain Rosette:

(1) $\theta_A = 0°,\quad \theta_B = 45°,\quad \theta_C = 90°$

(2) $\varepsilon_A = \varepsilon_x cos^2\theta_A + \varepsilon_y sin^2\theta_A + \gamma_{xy} sin\theta_A cos\theta_A \Rightarrow \varepsilon_x = \varepsilon_A$

(3) $\varepsilon_B = \varepsilon_x cos^2\theta_B + \varepsilon_y sin^2\theta_B + \gamma_{xy} sin\theta_B cos\theta_B \Rightarrow \gamma_{xy} = 2\varepsilon_B - (\varepsilon_A + \varepsilon_C)$

(4) $\varepsilon_C = \varepsilon_x cos^2\theta_C + \varepsilon_y sin^2\theta_C + \gamma_{xy} sin\theta_C cos\theta_C \Rightarrow \varepsilon_y = \varepsilon_C$

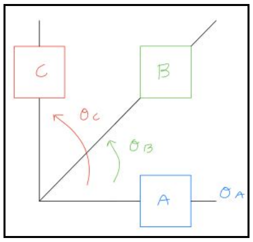
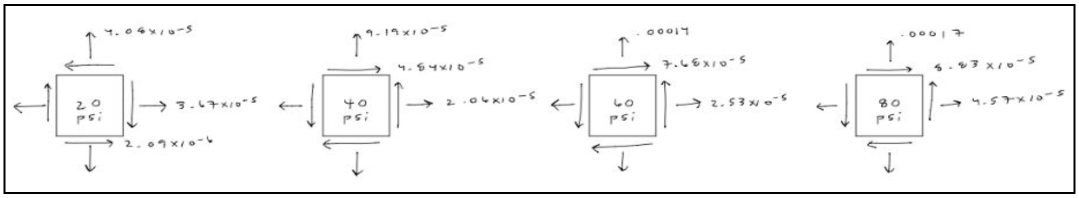


Table 1: Calculated Strain Rosette Measurements

	20.1 psi	**40 psi**	**60 psi**	**78.6 psi**
ε_x	3.86897E-5	2.06151E-5	2.52779E-5	4.56952E-5
ε_y	4.07823E-5	9.1922E-5	.000139242	.000171844
γ_{xy}	-2.0926E-6	4.83555E-5	7.68281E-5	8.83168E-5

Figure 2: Strain Rosette Strain Element



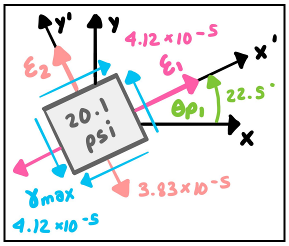
Principal Strains:

$$(5)\ \varepsilon_1 = \frac{\varepsilon_A+\varepsilon_C}{2} + \sqrt{\left(\frac{\varepsilon_A-\varepsilon_C}{2}\right)^2 + \left(\frac{2\varepsilon_B-(\varepsilon_A+\varepsilon_C)}{2}\right)^2},\ \varepsilon_2 = \frac{\varepsilon_A+\varepsilon_C}{2} - \sqrt{\left(\frac{\varepsilon_A-\varepsilon_C}{2}\right)^2 + \left(\frac{2\varepsilon_B-(\varepsilon_A+\varepsilon_C)}{2}\right)^2},$$

(6) $tan(2\theta_p) = \frac{2\varepsilon_B-(\varepsilon_A+\varepsilon_C)}{(\varepsilon_A-\varepsilon_C)}$, and $\gamma_{max} = \varepsilon_1$ since ε_1 and ε_2 are positive. Principal angle = θ_p

Table 2: Calculated Principle Strains

	20.1 psi	**40 psi**	**60 psi**	**78.6 psi**
ε_1	4.121569165E-5	9.943500099E-5	1.509810767E-4	1.857653416E-4
ε_2	3.825630835E-5	1.264850901E-5	1.353882327E-5	3.177385839E-5
γ_{max}	4.121569165E-5	9.943500099E-5	1.509810767E-4	1.857653416E-4
θ_p	22.5°	-17.1°	-17.0°	-17.5°



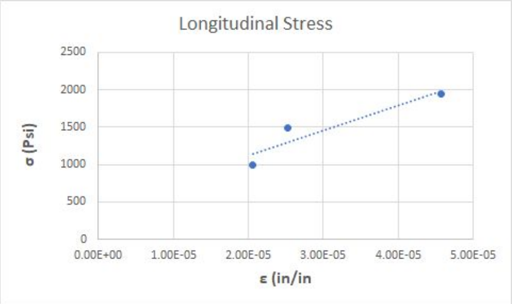
Hoop and Longitudinal Stress:

For cylinders: (where P = pressure, r = inner radius, and t = thickness)

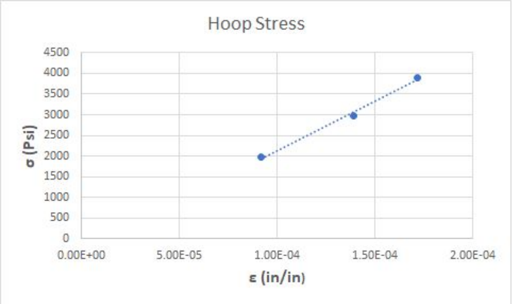
(7) Hoop stress = $\sigma = \frac{Pr}{t}$ (8) Longitudinal stress = $\sigma = \frac{Pr}{2t}$

Table 3: Hoop & Longitudinal Calculated Stress

(lbs)	**20.1 psi**	**40 psi**	**60 psi**	**78.6 psi**
Hoop Stress	998.0085	1986.087	2979.13	3902.66
Longitudinal Stress	499.0042	993.0443	1489.565	1951.33



Graph 1



Graph 2

(9) $E_{Longitudinal} = 38.2 * 10^6$ Psi (10) $E_{Hoop} = 24 * 10^6$ Psi

Young's Modulus:

$$(11)\ E = \frac{\sigma}{\varepsilon}\ and\ \%_{Error} = \frac{|\#_{Experimental} - \#_{Theoretical}|}{\#_{Theoretical}} \times 100\%$$

*A-36 steel Young's Modulus: 29** 10^6 *Psi (theoretical)*

(12) $\%_{Error\ Longitudinal} = 31.7\%$ (13) $\%_{Error\ Hoop} = 17.2\%$

(14) $E_{Average} = \frac{1}{2}(E_{Longitudinal} + E_{Hoop}) = 31.1 * 10^6$ (15) $\%_{Avg.\ Error} = 7.24\ \%$.

Discussion

The state of strain for each loading consists of normal strain in the x and y direction and shear strain in the XY plane. Based on the results, the normal strain in the x-direction decreased between 20.1 and 40 psi (3.86897E-5) but steadily increased as the load became larger. Normal strain in the y-direction had a consistent rise, starting from 4.07823E-5, as the pressure increased. Lastly, the shear strain in the XY plane for a 20.1 psi load was negative (-2.0926E-6), but remained positive as the load became larger.

As for the principal strains, they are ε_1 and ε_2, calculated using the formulas above. For $\varepsilon_{1,}$ it began with 4.121569165E-5 and continued to increase its strain as the load increased as well. On the other hand, ε_2 started with 3.825630835E-5 but diminished to 1.264850901E-5 when the load elevated from 20.1 to 40 psi. However, it began to increase from 40 to 78.6 psi. The principal angle (θ_p) was also calculated. Initially, its angle was 22.5° (counterclockwise), but when the pressure increased, the principal angle switched to a clockwise rotation (-17.1°)

The Young's Modulus, calculated using longitudinal stress, was $E_{Longitudinal} = 38.2 * 10^6$ Psi (*Graph (1)*). Using hoop strain, $E_{Hoop} = 24 * 10^6$ Psi (*Graph (2)*). The percent error for each of the two stresses was found to be: 31.7% for Longitudinal Stress and 17.2% for Hoop Stress. However, once the two Young's Moduli are averaged, shown in (12), the percent error reduces to 7.24%.

Conclusion

This experiment was conducted to observe how different loadings can affect the various types of strains, such as the normal strain, principal strain, and hoop and longitudinal stress. The calculations demonstrated above illustrate how the element diagram is altered based on the mechanical and material properties of the pressure wall vessel. Some of the trends that were observed were: as the loading increased by a 20 psi increment, the hoop, and longitudinal stress also increased, indicating that there is a linear relationship of pressure to stress. As a result, if there is a larger pressure, the material will have higher stress. Although there is a linear relationship of pressure to stress, the stress seen from Hoop Stress (7) will be larger because the Longitudinal Stress (8) is divided by 2 in the formula and therefore it will always be half the Hoop Stress.