Lab #1
Static Analysis of a Plate

The City College of New York
Department of Mechanical Engineering

ME 37100 Computer Aided Design
Section 1EF
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Abstract

This lab looked to see various parameters that affects the maximum von Mises stress in a FEA analysis. Various mesh coarseness was used to show effects of elements and DOF in the

accuracy of a FEA analysis. Various materials, plate thickness and hole diameter in a hollow plate was used to examine both geometric and material choices on the maximum stress. FEA was used for other mechanical properties determination including strain and displacement. A method to reduce the von Mises maximum stress was also determined with the use of FEA. The plate analyzed in the lab has the dimensions 200 mm x 100 mm with a applied load of 100,000 N.

Introduction

Finite element analysis (FEA) is a tool that is used in many fields of engineering and mathematical physics to help design various tools, parts, infrastructure that we see in our everyday lives. The software simplifies calculations without having to use as many resources as possible to test for different mechanical properties and failure modes of a prototype.

Finite element analysis (FEA) is a tool commonly used in engineering and mathematical physics to simulate mechanical properties and failure modes in designs. By discretizing models into smaller elements, FEA allows for an analysis to be done without an physical trial in the initial phase (though additional testing is up to the demands of a project). The software helps predict stress distribution, displacement, and strain, making it a critical step in optimizing designs for safety and efficiency. FEA can be used for rapid prototyping in an initial design phase to determine material, geometry, and how a loading conditions will affect performance.

In this lab, FEA was used to study how varying parameters such as mesh size and geometry will affect mechanical properties and plot distributions. Mesh refinement is a key factor in FEA accuracy, and as seen in this experiment, a finer mesh generally leads to more accurate results by allowing the stress to converge more closely to the theoretical value. However, other factors including computational time and cost may also play a role in the need for finer mesh settings. Comparison of the stress concentration factors (SCF) of different materials (ABS, steel, brass and aluminum) will also be done to examine how material properties also affect the same properties.

Theoretical Background

The finite element method is used within FEA which looks to discretize an model into small finite elements, dependent on the user specified mesh settings. Parameters such as number of nodes, element size and number of elements are based upon the mesh and the overall dimensions of the model. The FEM looks to solve for different inputs such as stress, flux, displacement within each element through a numerical approach.

The Von mises stress is the conventional stress values used by many (including SolidWorks) FEAS software's as it can determine if a material will yield. Yielding will occur when the distortion energy reaches the critical value for the material, determined through tensile testing. Graphically, the yielding can be seen when the stress values are out of bounds of the (Figure A2).

The Stress concentration factor determines the localization of the maximum stress at the critical points compared with the average/nominal stress experienced by a specimen. SCF is geometrically dependent, meaning the locations of the stress concentration will change and therefore your SCF [5].

Materials play a key role in determining how stress is distributed and concentrated. Different materials exhibit different stress-strain behaviors, yield strengths, and stress concentration tendencies. A geometrical discontinuity in a material will experience an increase the stress values in the area of the discontinuities [6]

Manual Analysis and Calculations

In this lab, the result of the FEA is compared to theoretical values, specifically the stress concentration factor (SCF).

The equation for the SCF is as follows:

$$k = \frac{\sigma_{max}}{\sigma_{nominal}} \text{ (eq. 1)}$$

for the analysis of the FEA plates. The k value through theoretical means utilizes (Figure A1), where r is 20 mm and d is 60 mm in this lab. The SCF in this lab is found to be around $K_t =$ 2.24.
The values used to determine the SCF in the FEA plate utilizes the max von Mises stress found and $\sigma_{nominal}$ is calculated as follows:

$$\sigma_{nominal} = \frac{P}{(W-D)*t} \text{ (eq. 2)}$$

Where P = applied force, W = width of plate, D = Diameter of hole.

$$\sigma_{nominal} = \frac{(100{,}000\ N)}{(100 - 40\ mm)\ *5\ mm}$$

$$\sigma_{nominal} = 333.333\ MPa$$

Study	Element size (mm)	Number of Elements	Number of nodes	# of DOF	Max. resultant displacement (mm)	Max. von Mises stress (MPa)	SCF
tensile load 01	9.08734	1506	3164	9285	2.36E-01	713.5309	2.141
tensile load 02	5.11163	7372	13220	39291	0.236159	744.0529	2.232

tensile load 03	2.27183	62277	99042	295773	0.236224	752.2323	2.257
prescribed disp	5.11163	7372	13220	39168	0.236255	751.3702	2.254

Table 1: Data chart tabulating the results of different mesh settings for tensile loads, and prescribed displacement load.

Difference in SCF value in FEA vs theoretical:

$$\% \, difference = \, abs\left(\frac{K_f - K_t}{K_t}\right) * 100\% \text{ (eq. 3)}$$

Tensile load 10 (course mesh): 4.42 %
Tensile load 02 (medium course mesh): 0.357 %
Tensile load 03 (fine mesh): 0.759 %
Prescribed length (0.236 mm displacement): 0.625%

Material	Max. resultant displacement (mm)	Max. von Mises stress (MPa)	SCF
AISI 1010 Steel, hot rolled bar	0.247899	744.247	2.232741
1060 Alloy	0.717667	745.0446	2.235134
Brass	0.49519	745.0446	2.235134
ABS	24.6997	746.4189	2.239257

Table 2: Chart tabulating results of the Max von Mises stress, max resultant displacement and calculated SCF for different materials

Difference in SCF values from FEA vs theoretical:
AISI 1010 Steel, hot rolled bar: 0.324 %
1060 Alloy: 4.971 %
Brass: 4.971 %
ABS: 0.0317 %

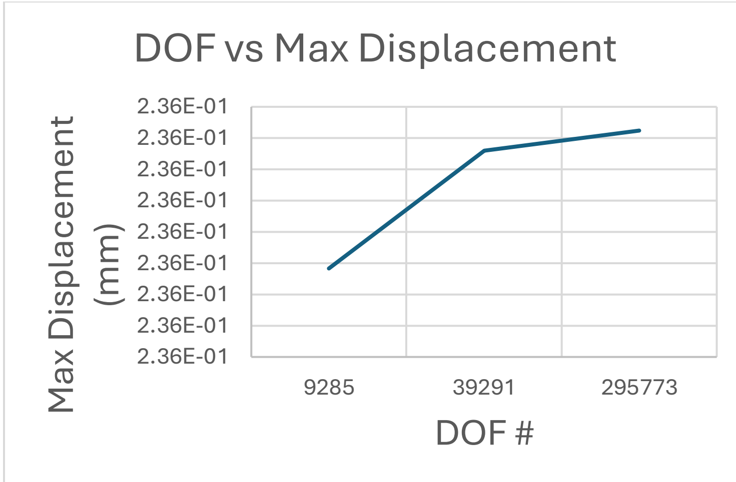

Table 3: Number of degree of freedoms change to Max displacements. Chart is a plot of the tabulated data from (Table 1), using alloy steel and tensile load of 100,000 N.

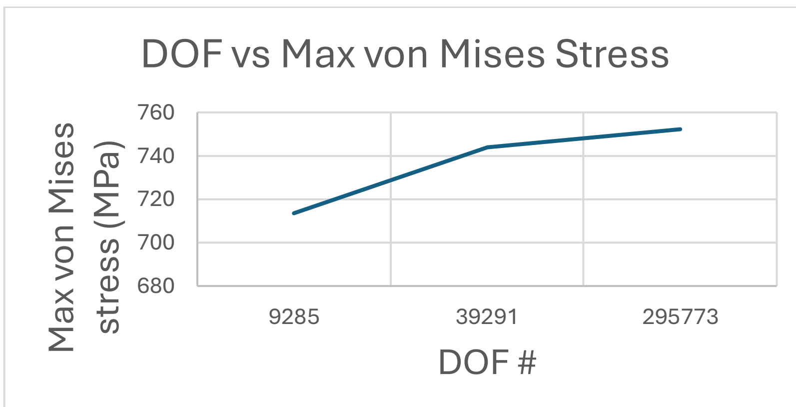

Table 4: DOF effects on the max von Mises Stress. Results from values tabulated in (Table 1), using alloy steel and tensile load of 100,000 N.

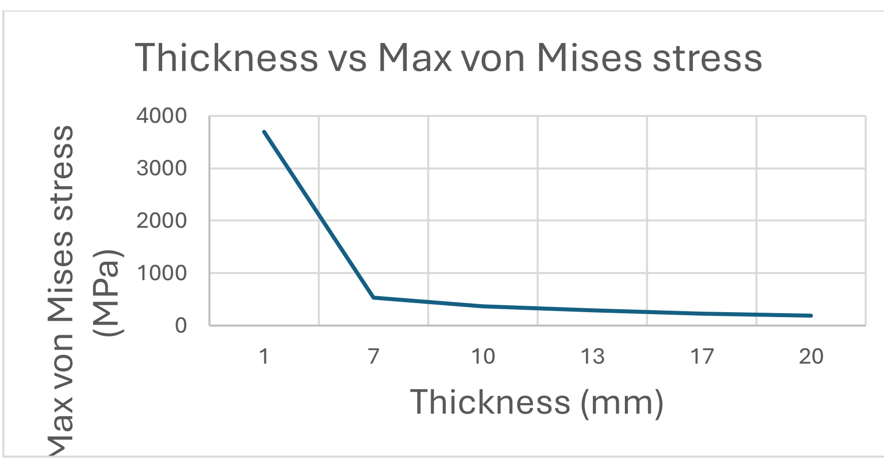

Table 5: thickness of Hollow plate effects on the max von Mises Stress using alloy steel and tensile load of 100,000 N.

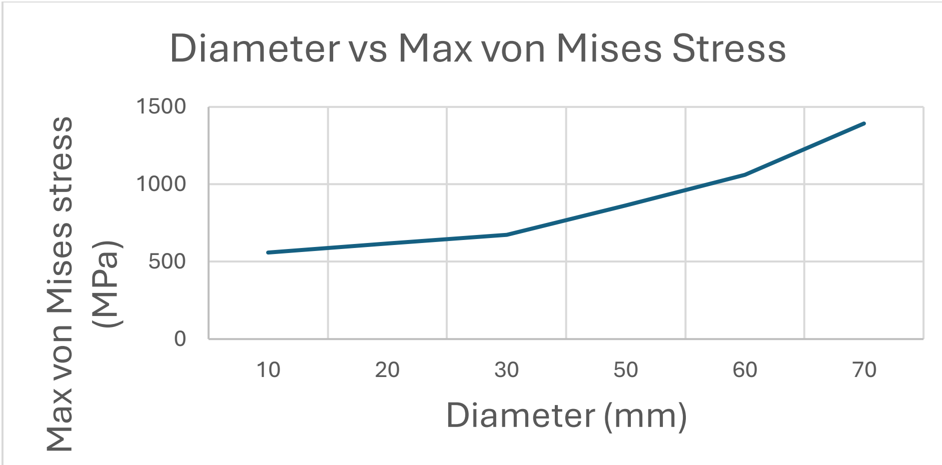

Table 6: Diameter of hole in Hollow plate effects on the max von Mises Stress using alloy steel and tensile load of 100,000 N.

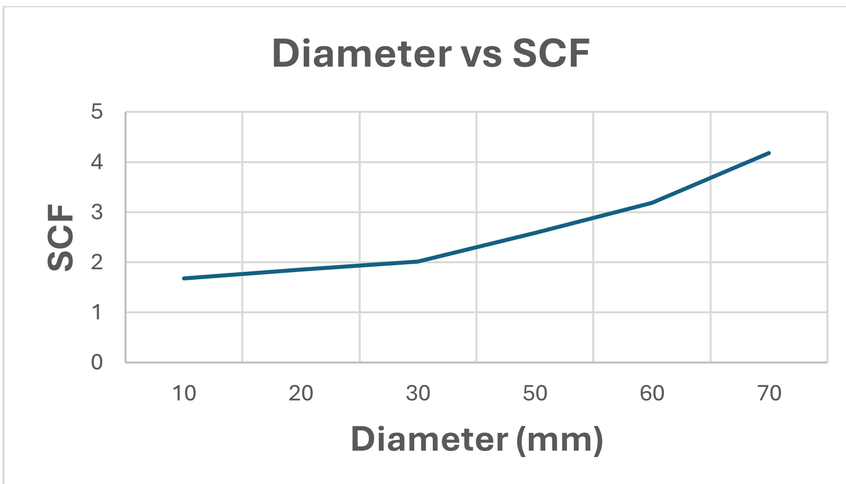

Table 7: Diameter of hole in Hollow plate effects SCF using alloy steel and tensile load of 100,000 N.

Graphical Demonstrations of SolidWorks Results

The first part of the lab looked to utilize different mesh settings to compare the SCF of the settings the SCF calculated theoretically. The plate is fixed on the left face and a 100,000 N force is applied in tension on the right face for all the study shown. Alloy Steel was used for this portion of the lab.

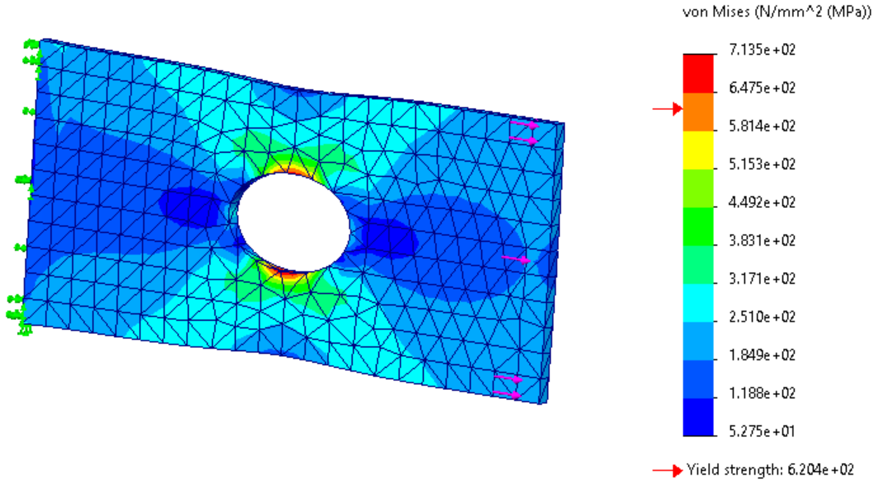

Figure 1A: Stress plots of the Hollow plate with a course mesh setting defined in (Table 1) as tensile load 01.

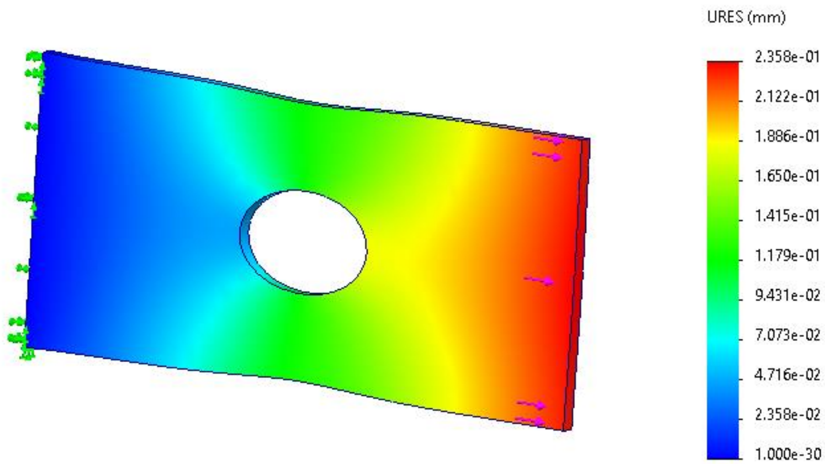

Figure 1B: Displacement plot of the Hollow plate with a course mesh setting defined in (Table 1) as tensile load 01

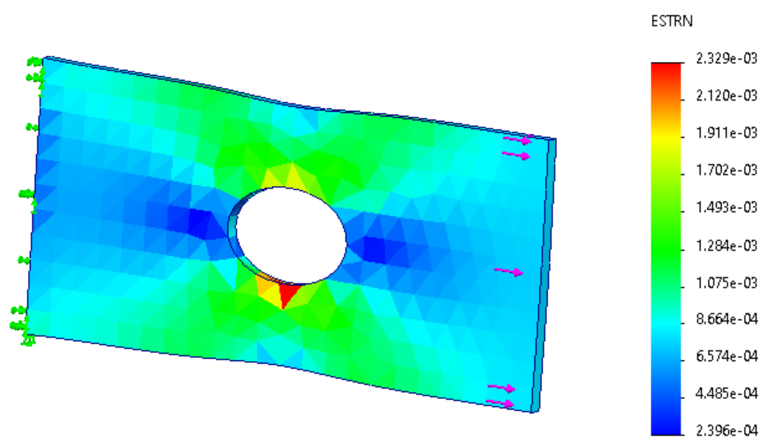

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Figure 1C: Strain plot of the Hollow plate with a course mesh setting defined in (Table 1) as tensile load 01.

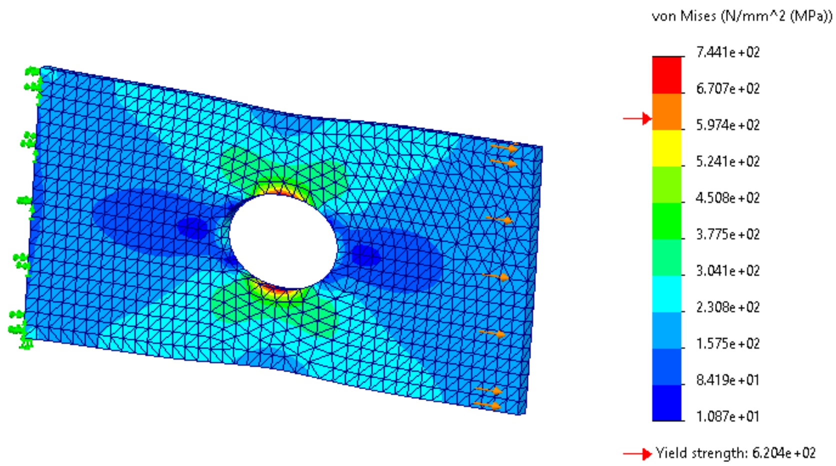

Figure 2A: Stress plots of the Hollow plate with a course mesh setting defined in (Table 1) as tensile load 02.

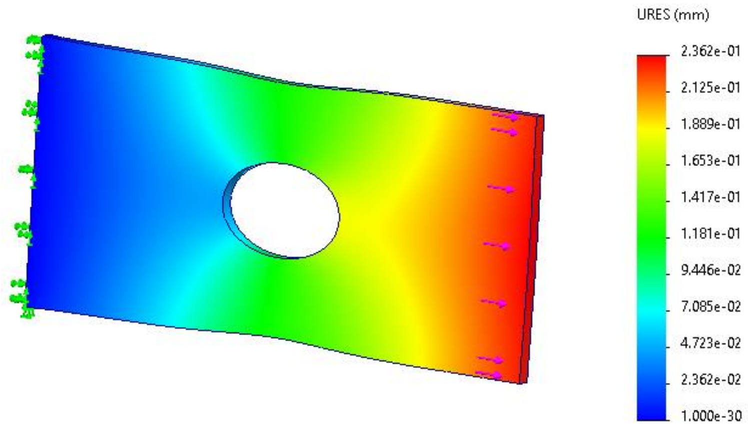

Figure 2B: Displacement plots of the Hollow plate with a course mesh setting defined in (Table 1) as tensile load 02.

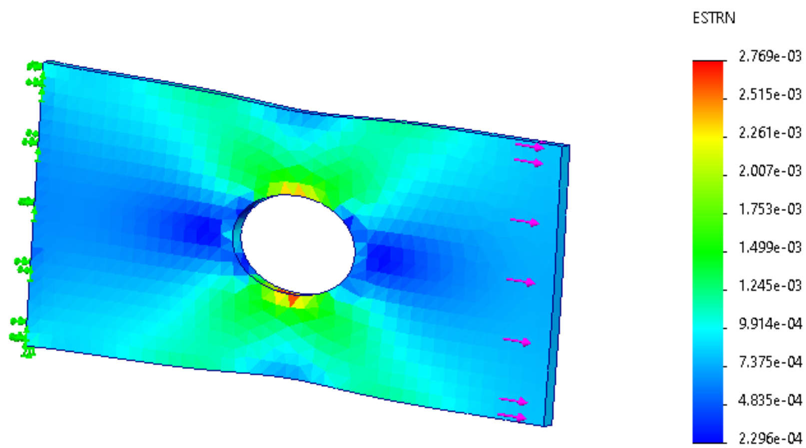

Figure 2C: Strain of the Hollow plate with a course mesh setting defined in (Table 1) as tensile load 02.

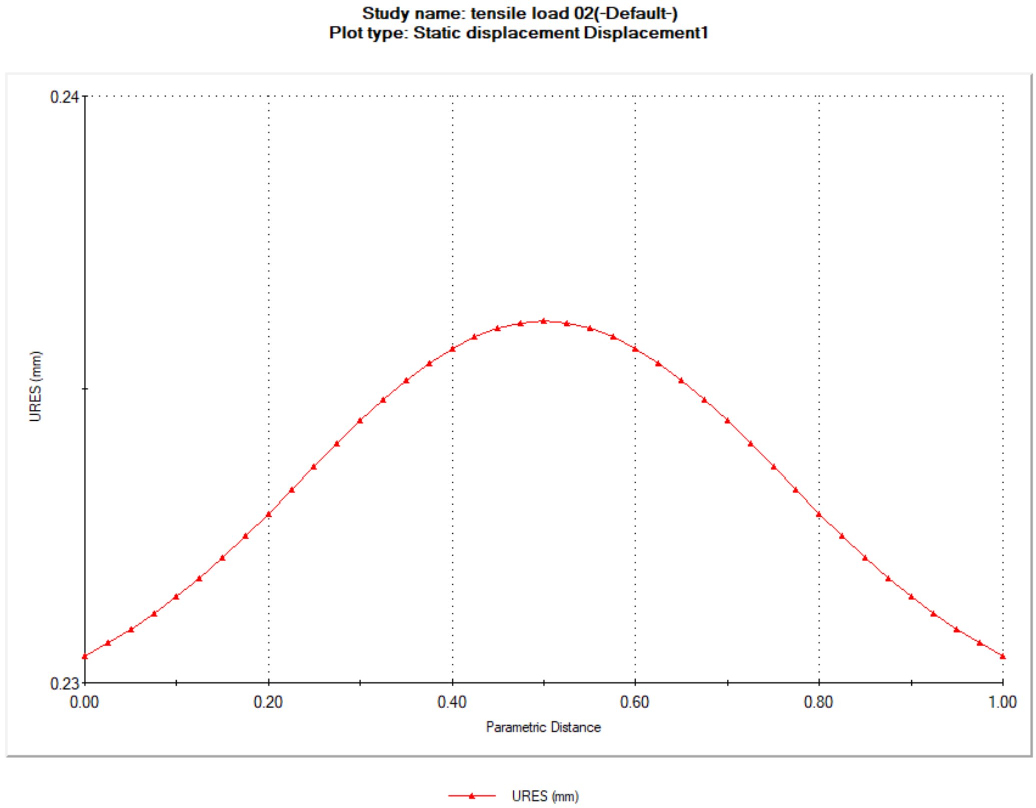

Figure 2D: Parametric Distance vs Displacement of the Hollow plate with a course mesh setting defined in (Table 1) as tensile load 02.

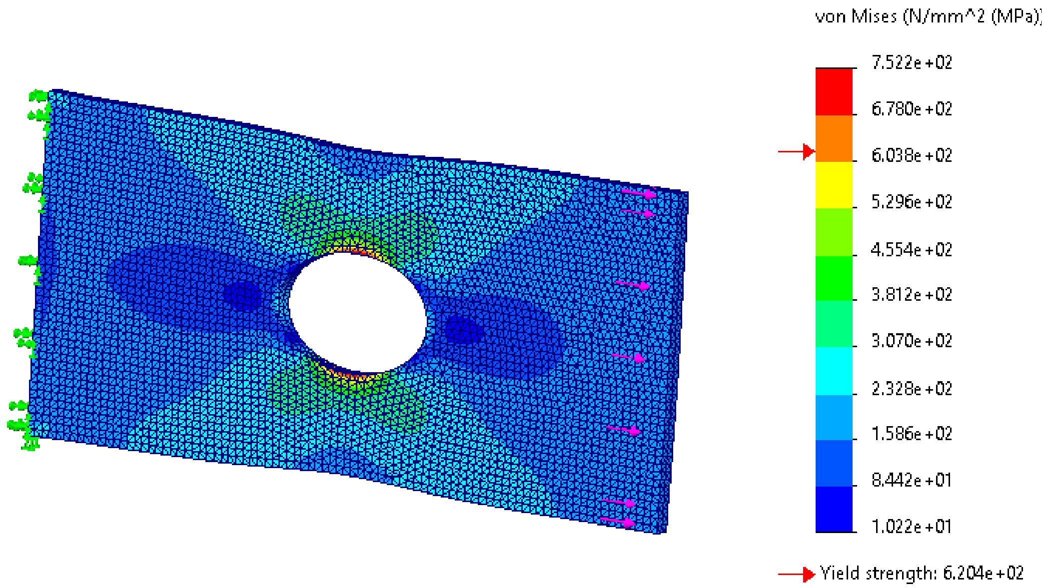

Figure 3A: Stress Plot of the Hollow plate with a course mesh setting defined in (Table 1) as tensile load 03.

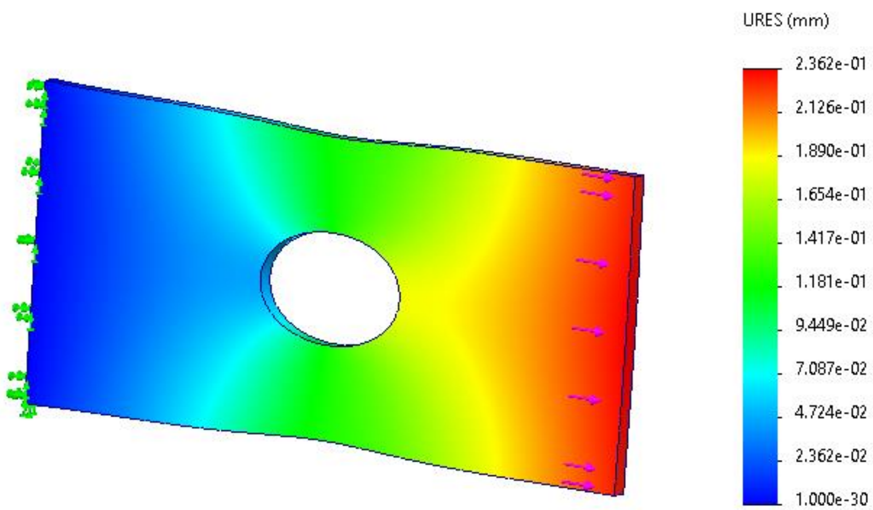

Figure 3B: Displacement Plot of the Hollow plate with a course mesh setting defined in (Table 1) as tensile load 03.

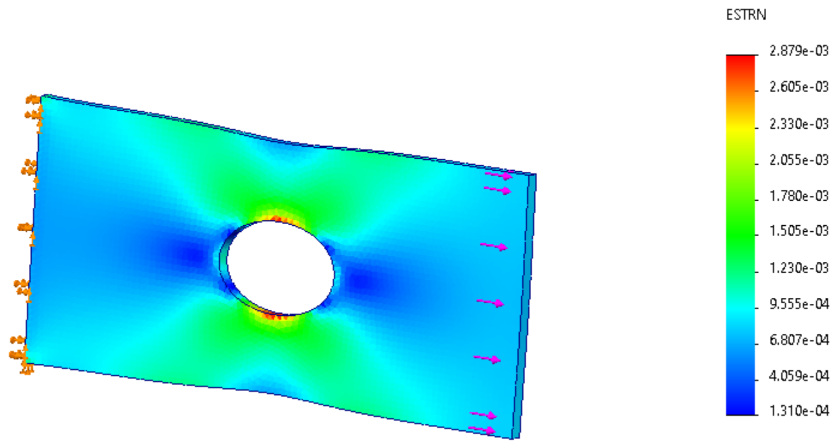

Figure 3C: Strain Plot of the Hollow plate with a course mesh setting defined in (Table 1) as tensile load 03.

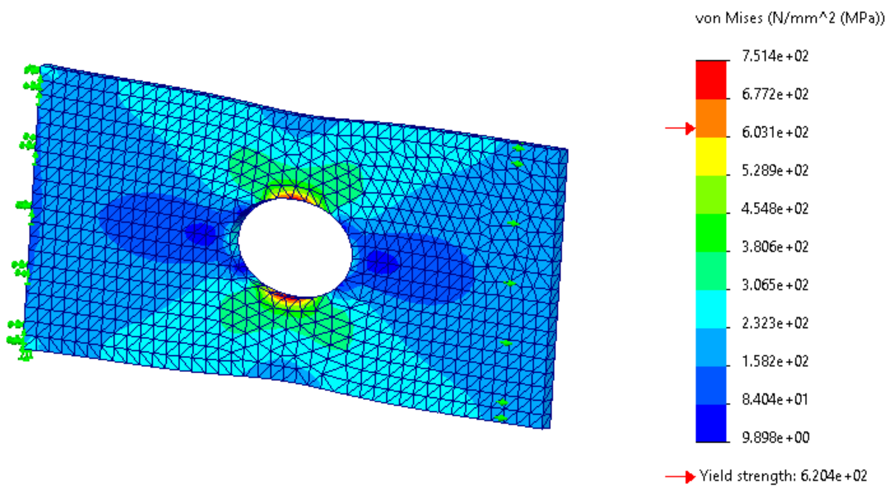

Figure 4A: Stress Plot of the Hollow plate with a course mesh setting defined in (Table 1) as prescribed displ. The prescribed displacement used is 0.236 mm.

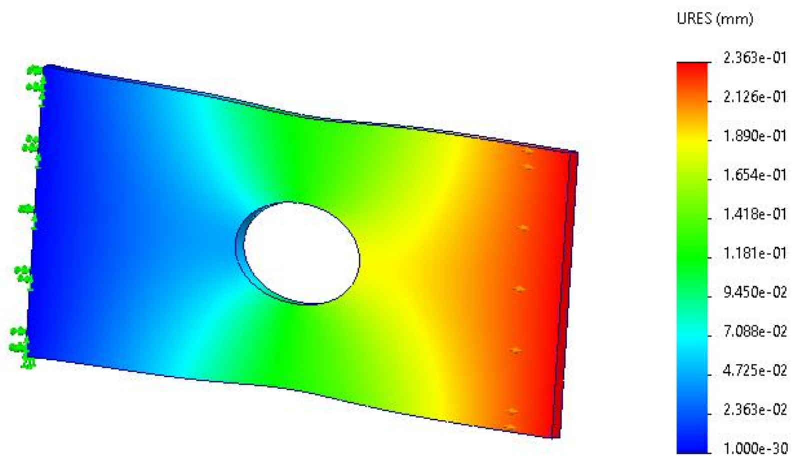

Figure 4B: Displacement Plot of the Hollow plate with a course mesh setting defined in (Table 1) as prescribed displ. The prescribed displacement used is 0.236 mm.

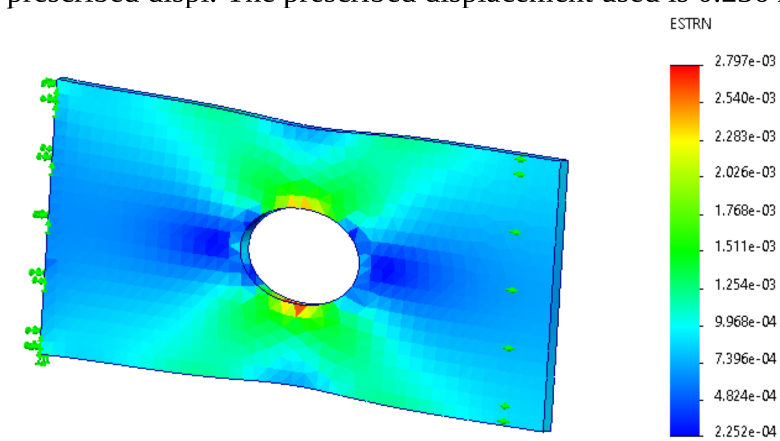

Figure 4C: Strain Plot of the Hollow plate with a course mesh setting defined in (Table 1) as prescribed displ. The prescribed displacement used is 0.236 mm.

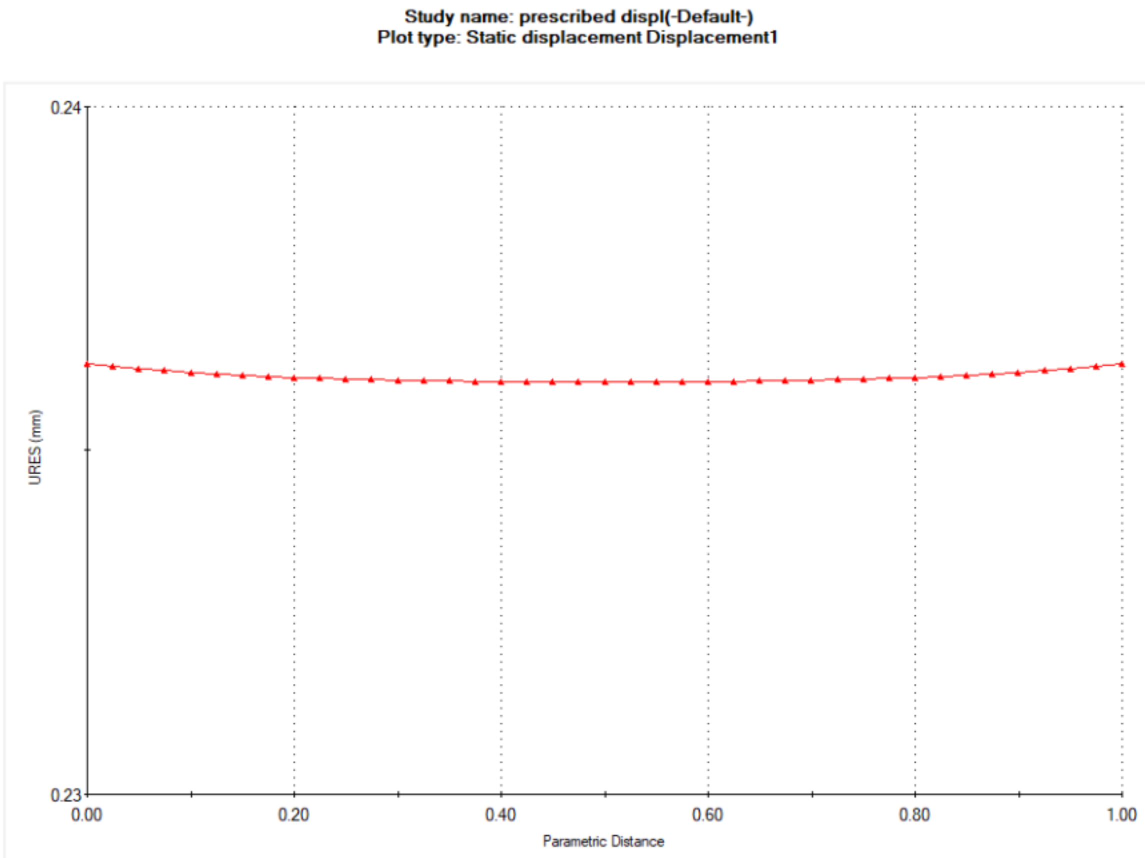

Figure 4D: Parametric Distance vs Displacement of the Hollow plate with medium course mesh setting (Table 1) as prescribed displ. The prescribed displacement used is 0.236 mm.

In the second part of the lab, and comparison of SCF of different materials on the plane as well as their corresponding stress plots over its critical line defined as the line that vertically overlaps the hole of the plate downwards over the height of the plate. **Note:** the critical line determined through this analysis was used by manually choosing nodal points along that edge and only displays a approximate stress plot.

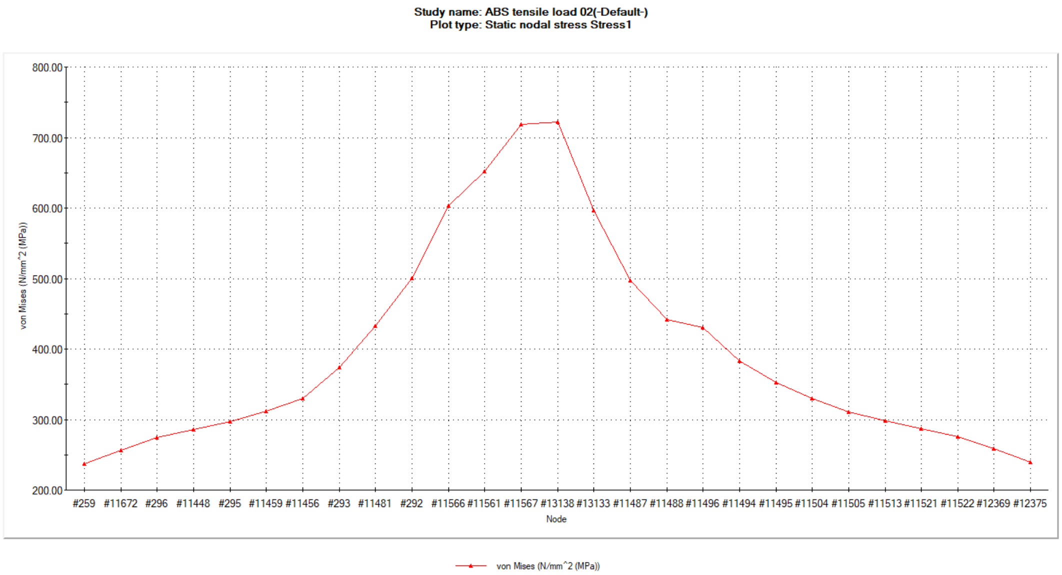

Figure 5A: Stress plot of ABS material over the critical line from the top end to bottom end, through manual nodal selections. Critical line is taken as seen in (Figure 5B).

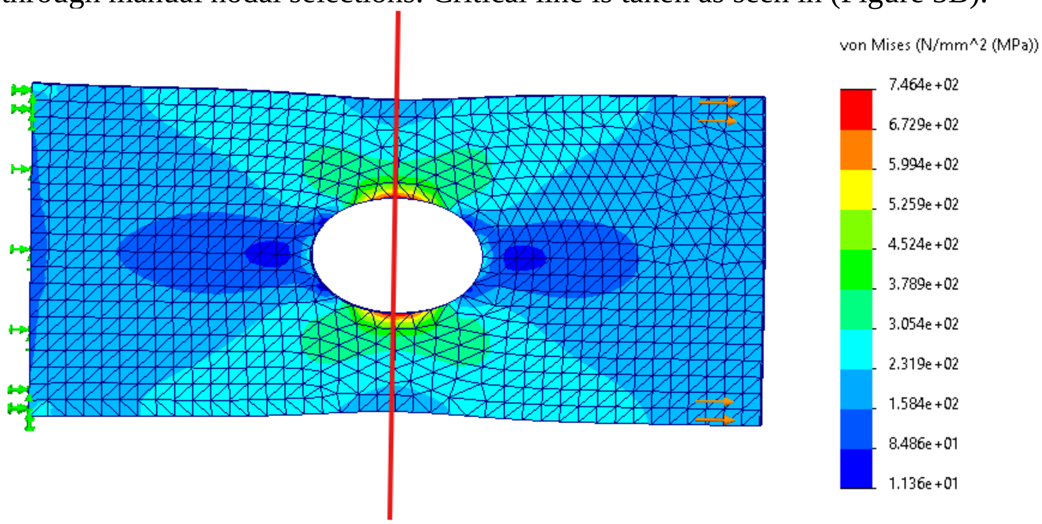

Figure 5B: Stress plot of ABS material under tensile load using mesh settings of tensile load 02 in (Table 1)

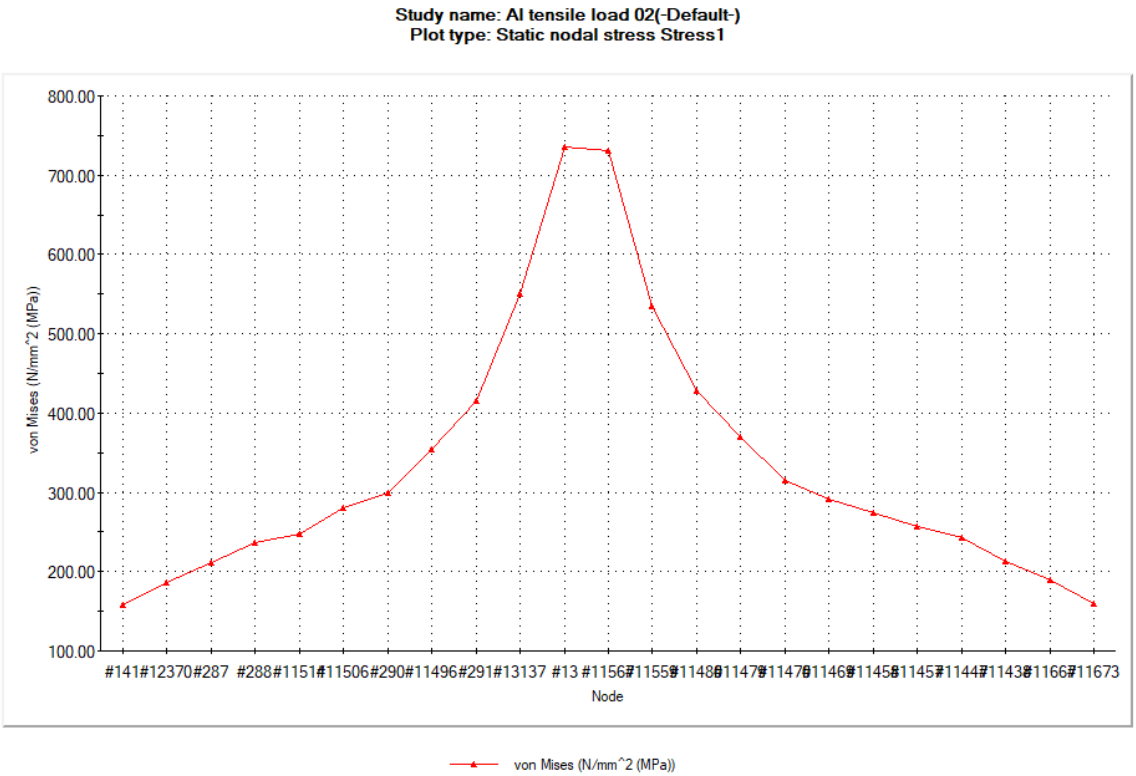

Figure 6A: Stress plot of Aluminum 1060 Alloy over the critical line from the top end to bottom end, through manual nodal selections. Critical line is taken as seen in (Figure 5B).

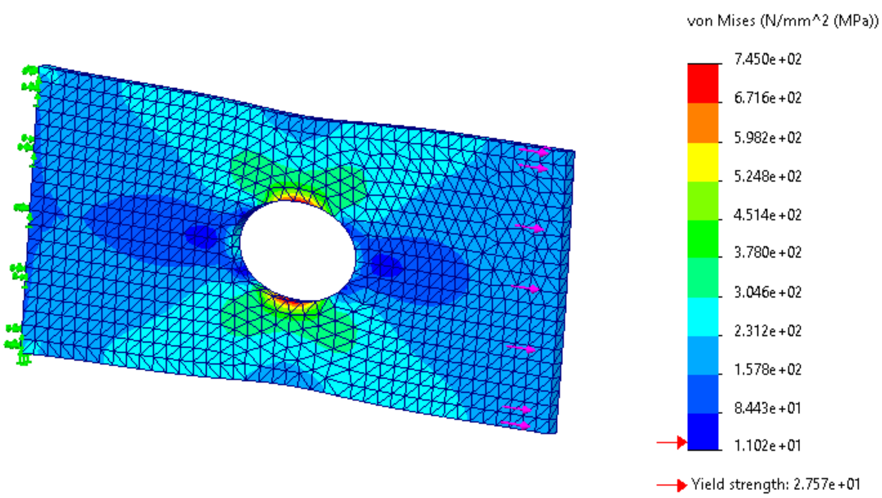

Figure 6B: Stress plot of Aluminum 1060 Alloy under tensile load using mesh settings of tensile load 02 in (Table 1)

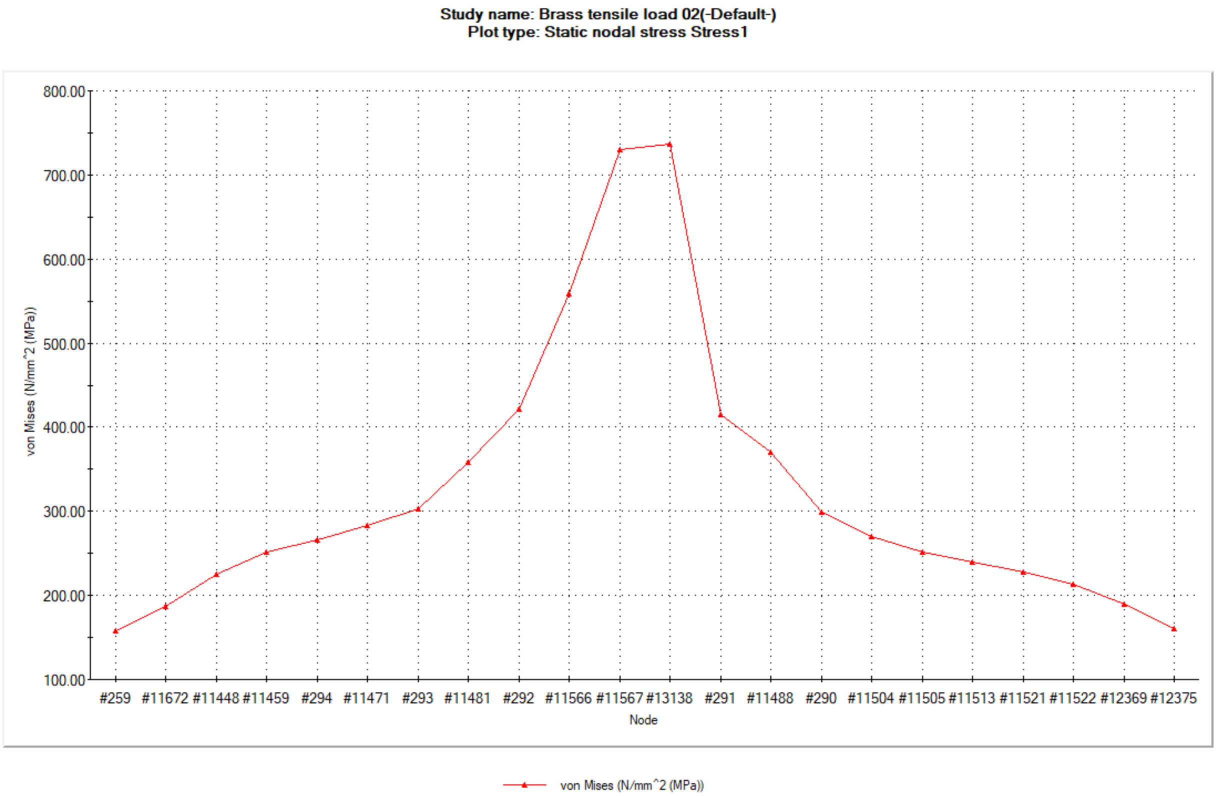

Figure 7A: Stress plot of Brass over the critical line from the top end to bottom end, through manual nodal selections. Critical line is taken as seen in (Figure 5B).

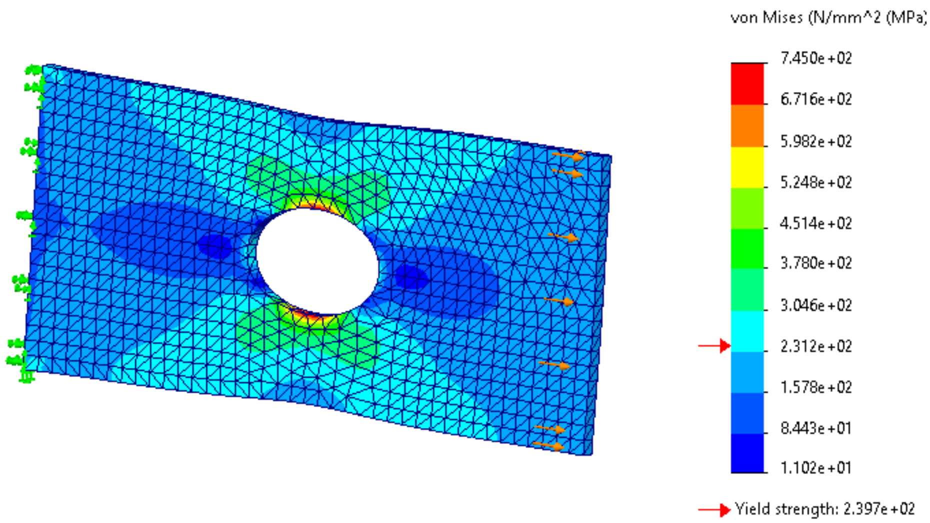

Figure 7B: Stress plot of Brass under tensile load using mesh settings of tensile load 02 in (Table 1)

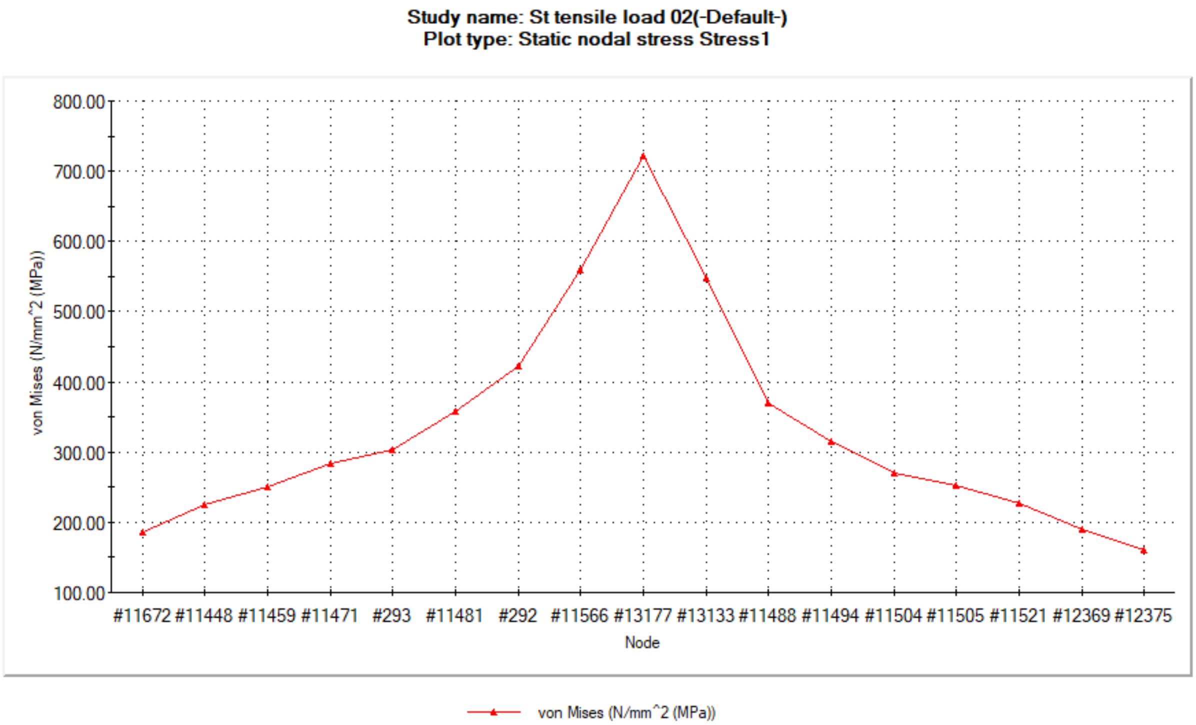

Figure 8A: Stress plot of AISI 1010 Steel, hot rolled bar over the critical line from the top end to bottom end, through manual nodal selections. Critical line is taken as seen in (Figure 5B).

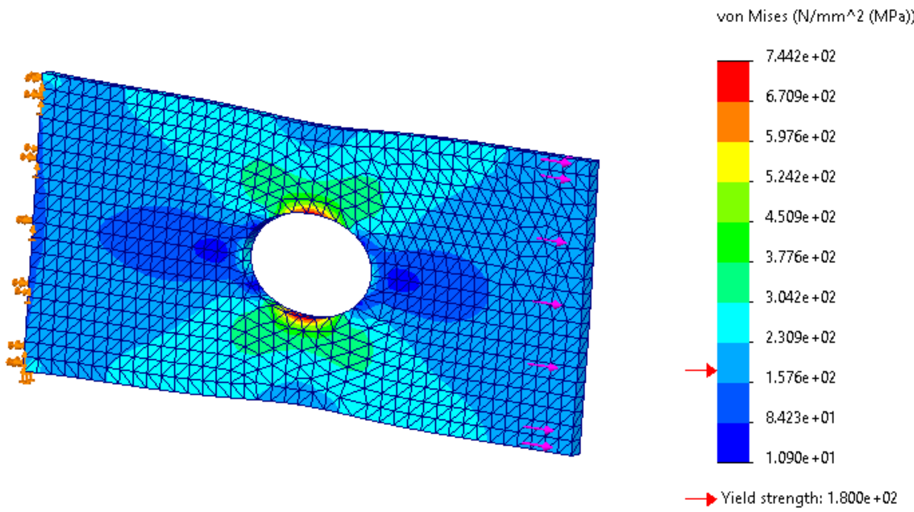

Figure 7B: Stress plot of AISI 1010 Steel, hot rolled bar under tensile load using mesh settings of tensile load 02 in (Table 1)

In the third part of the lab, different plate thicknesses were used to examine the differences in the max von Mises stress. Alloy steel with a load of 100,000 N was used for this part of the study. Mesh setting used are that of tensile load 02 in (Table 1).

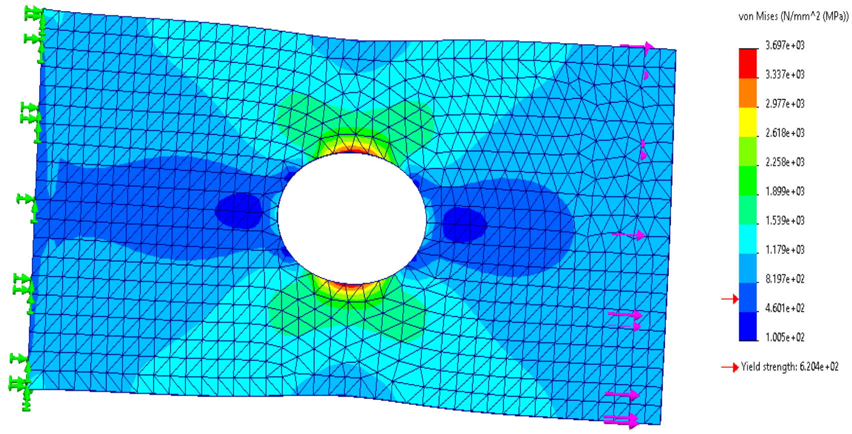

Figure 8A: Stress plot of Alloy steel Hollow Plate of thickness 1 mm.

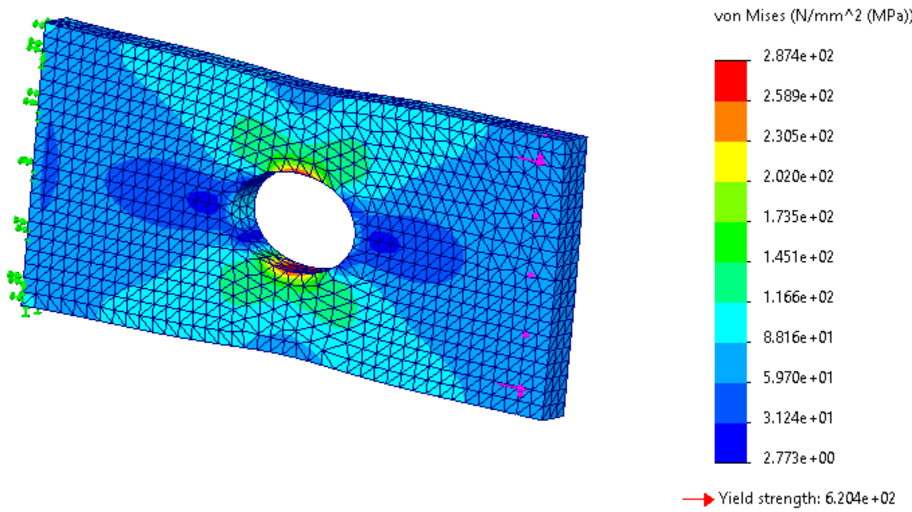

Figure 8B: Stress plot of Alloy steel Hollow Plate of thickness 7 mm.

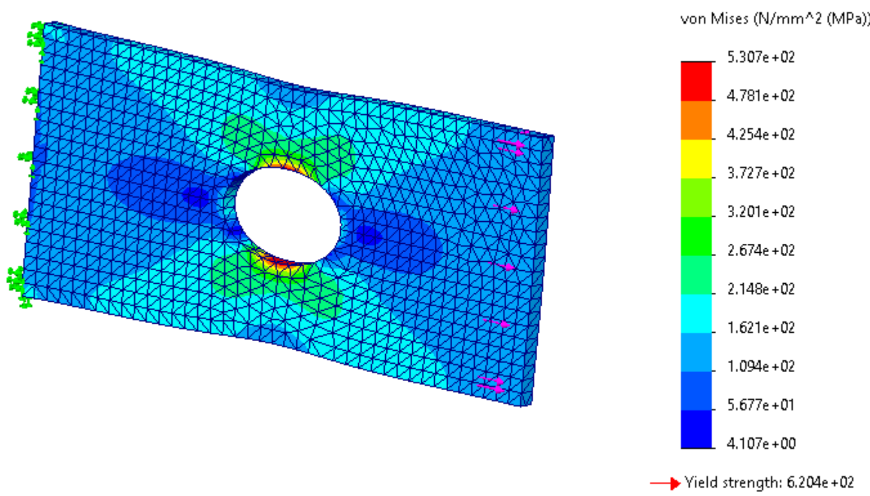

Figure 8C: Stress plot of Alloy steel Hollow Plate of thickness 10 mm.

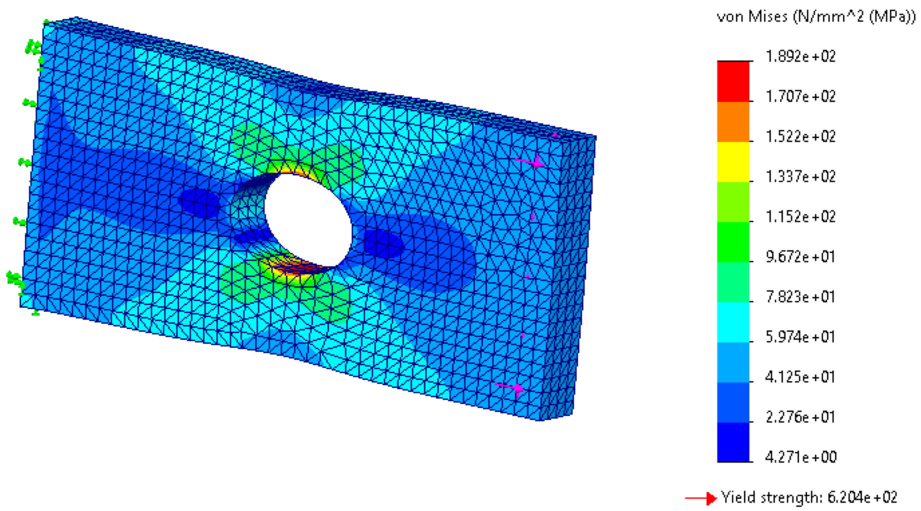

Figure 8D: Stress plot of Alloy steel Hollow Plate of thickness 13 mm.

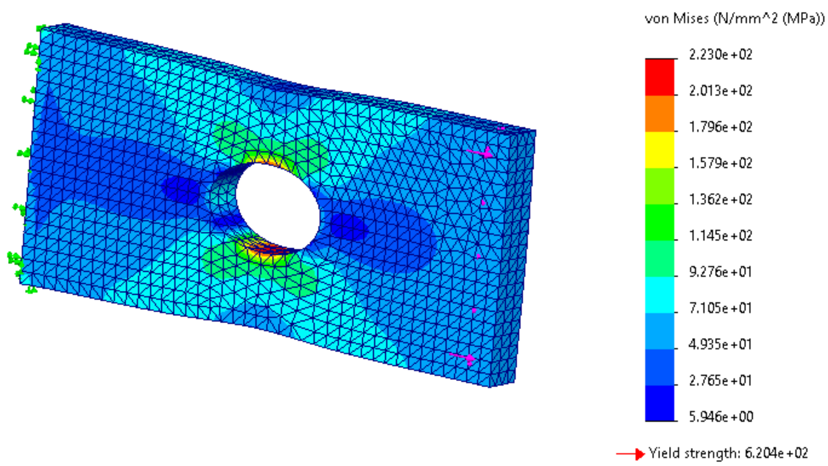

Figure 8E: Stress plot of Alloy steel Hollow Plate of thickness 17 mm.

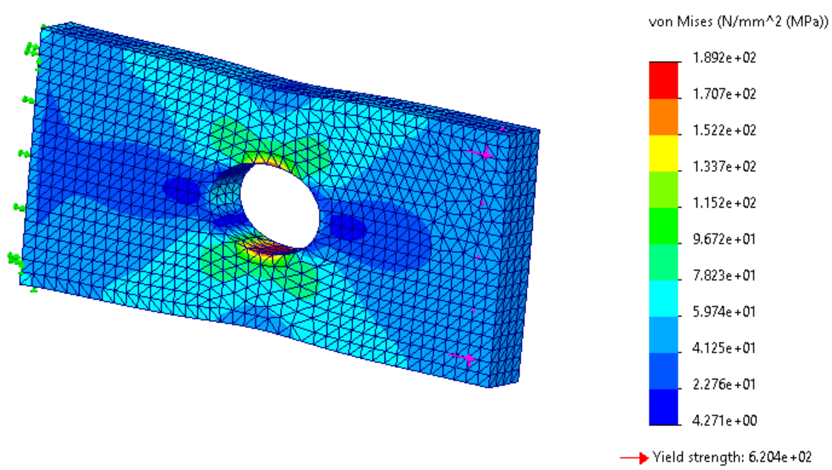

Figure 8F: Stress plot of Alloy steel Hollow Plate of thickness 20 mm.

In the fourth part of the lab, varying diameters in the Hollow plate was examined on its effect of the stresses. A tensile force of 100,000 N was applied on a Alloy Steel plate.

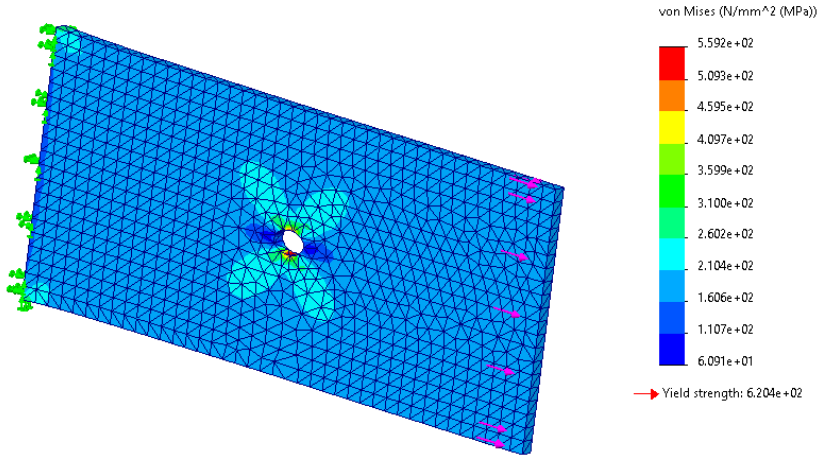

Figure 9A: Stress plot of Alloy steel Hollow Plate with a hole of 10 mm diameter.

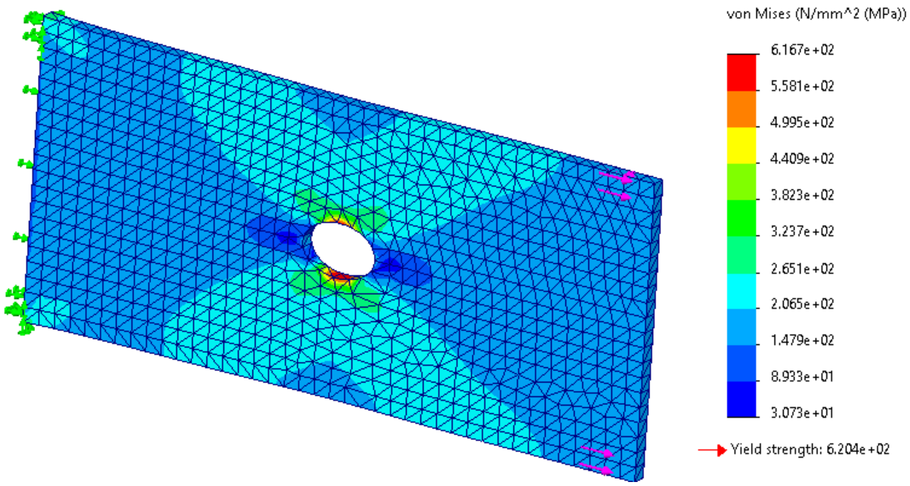

Figure 9B: Stress plot of Alloy steel Hollow Plate with a hole of 20 mm diameter.

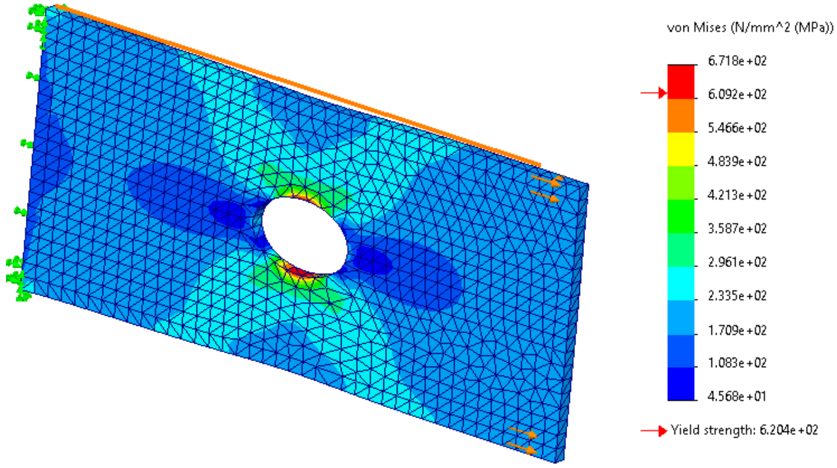

Figure 9C: Stress plot of Alloy steel Hollow Plate with a hole of 30 mm diameter.

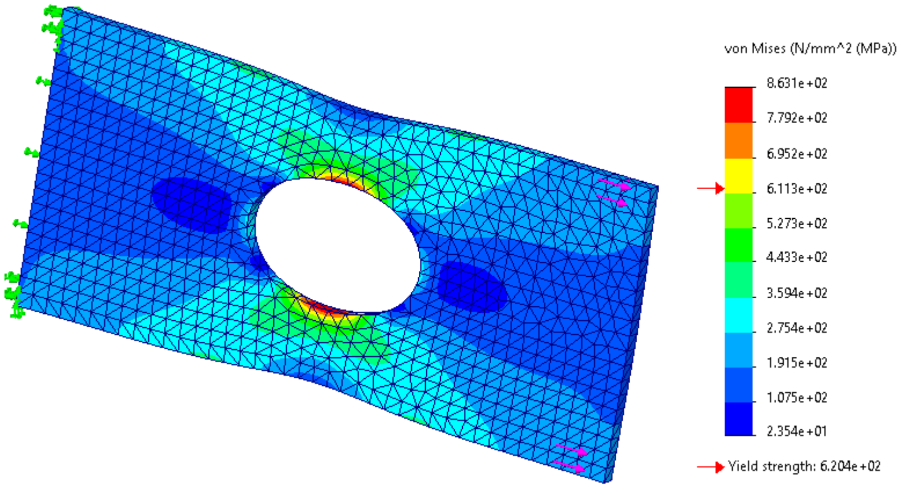

Figure 9D: Stress plot of Alloy steel Hollow Plate with a hole of 50 mm diameter.

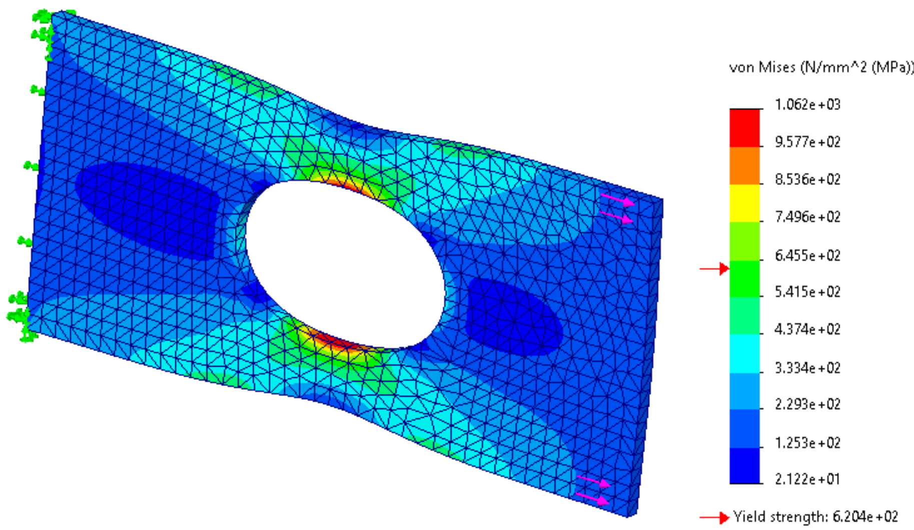

Figure 9E: Stress plot of Alloy steel Hollow Plate with a hole of 60 mm diameter.

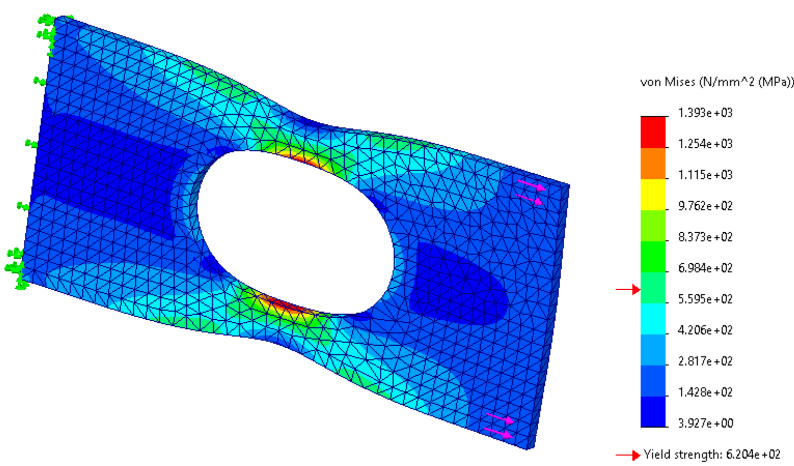

Figure 9F: Stress plot of Alloy steel Hollow Plate with a hole of 70 mm diameter.

In the final portion of the lab, a method to reduce the maximum von Mises stress is proposed without changing the dimensions of the plate. The hole is moved closer to the fixed end, at a distance of 25 mm from the center of the hole to the edge of the fixed end.

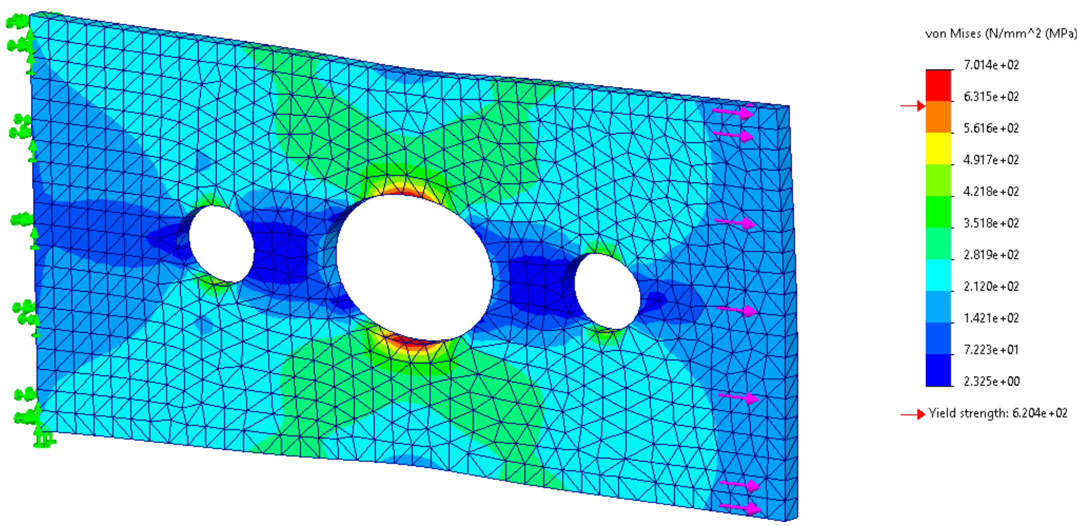

Figure 10: Alloy Steel Hollow plate of thickness 5 mm under 100,000 N tensile load to the right of the plate. Central hole has a diameter of 40 mm and the two additional holes in the same horizontal line has a diameter of 30 mm. Mesh settings are that of tensile load 02 in (Table 1).

Discussion and Interpretation of Results

From the first portion of the lab, varying mesh sizes played a role in the accuracy of the results of the FEA. In the comparison of the FEA values, it can be note that although the percent difference calculated through (eq. 3) of the actual results should converge to it true results the finer the mesh, this lab did not show that. This may be due to the actual stress value differing from the theoretical stress calculated. As seen in Table 4, the value of the stress does seem to converge more so when the number of elements in the mesh increases. The convergence pattern is all=so seen with the max displacement (Table 3). The difference in the theoretical SCF then tells us more so that the actual stress concentration factor is higher than calculate for alloy steel specifically. Mesh setting does not vary the actual values and observed stress distribution of the element under the same conditions but rather an finer mesh allows for a more accurate convergence to the anticipated results. As seen in Figures 1-4, under the different mesh settings, each stress, strain and displacement distribution plots do not vary much in their placement, only a refinement to their values. For the rest of the lab, a medium course mesh is chosen due to the plateauing in accuracy as the mesh setting increases and to save in computational time.

In the second part of the lab, different materials SCF values are compared. The SCF in the ABS was seen to be the highest amongst all the materials tested (Table 2). The other materials are all metals, which indicates that metals can distribute the stress more evenly than that of plastic materials. All the stress observed through the critical line is seen to be highest closest to the hole (Figure 5A, 6A, 7A, 8A), much as expected due to the stress concentration highest the closer to the hole (Figure 5B 6B, 7B, 8B).

In varying the thickness of the hollow plate, the max von Mises stress as seen in Table 5. The highest stress is observed at the plate thickness of 1 mm and declines somewhat exponentially. The decrease in stress can be explained through the formula, an increase in area will decrease the total stress in the plate. Varying thickness is one mode of lowering the max stress under the same load but other factors such as material can play a role on the von Mises stress.

Increasing the diameter of the hole in the plate will also increase the maximum von Mises stress experienced by the plate as seen in Table 6. One contributing factor to this observation is the total area is decreasing and therefore the stress increases. Another observation made from Figures 9(A-F) is that the region of the SCF expands as the hole get bigger. As seen in Table 7, SCF increases with the diameter of the hole. The stress distribution becomes more contrasting with the bigger hole diameters, with the region parallel to the force having less stress. This can be due to the SCF increasing in the critical line of the plate.

In the last part of the lab, an approach to decrease the maximum stress of the plate without changing the dimensions of the plate was to add additional holes into the plate. This decreased the max von Mises stress from 744.0529 MPa to 701.4 MPa. This decrease can be due to a more distributed stress along the plate. As seen in figures 10, the least amount of stress is experienced in the portion of the plate where the additional holes lie parallel to the central hole. The additional holes help to smooth the loading of the applied force over the area of the high stress (along the critical line seen in Figure 5B) [7]. Such reduction in the maximum stress experienced will directly lower the SCF as seen from equation 1.

Conclusions

This lab demonstrated the effects of mesh size, material properties, geometry of the specimen and hole placement on stress distribution and concentration. The theoretical values calculated does not account for the material selection but a convergence to a value seen by the refinement of mesh through FEA is important. ABS, a plastic material, had the highest SCF, showing its vulnerability to stress concentration compared to metals. Thicker plates reduce the max von Mises stress, while a larger hole diameter increased the value. Moving the hole closer to the fixed end effectively lowered the maximum von Mises stress.

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Appendices

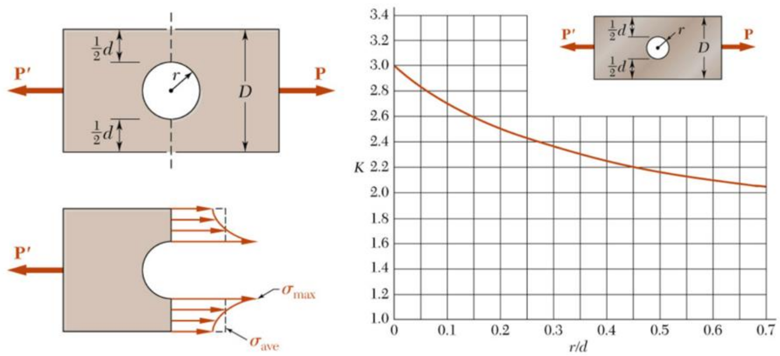

Figure A1: Stress concentration vs ratio of radius/height of hollow rectangular plate [5].

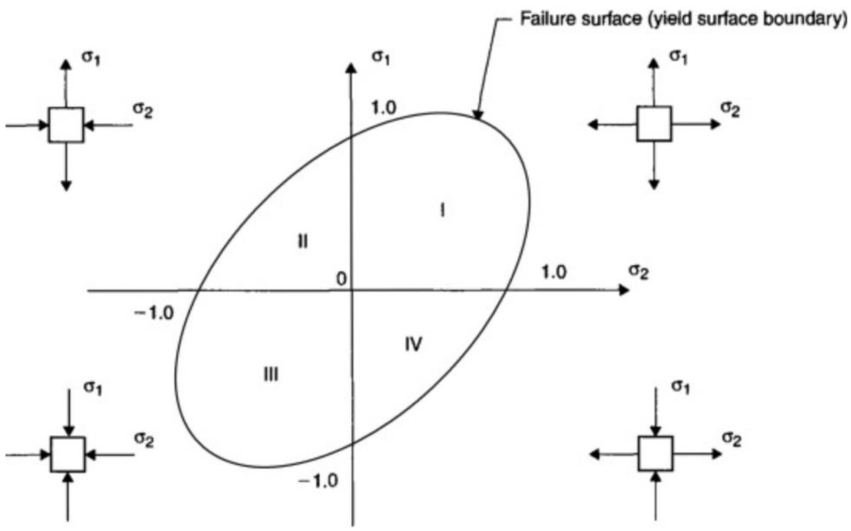

Figure A2: von Mises Stress four states biaxial stress and yield bounds [4].