Maryam Hakimzadeh **Due: 04/08/2024**

Part A: FS1 = 0.2204 , FS2 = 0.2239

Part B: FS3 = 0.6515, Maximum Equivalent Plastic Strain = 0.08488 mm/mm

Overall Objective

In this engineering report, the objectives are to determine the safety factors at the notch when subjected to a specified load, considering both linear elastic and nonlinear elastic-plastic material responses. The analysis inherently embodies nonlinear characteristics due to the contact between the pins and the specimen. Additionally, the problem may exhibit geometric nonlinearity if the resulting deformations are considerable.

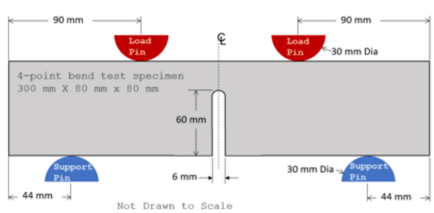
Assumptions

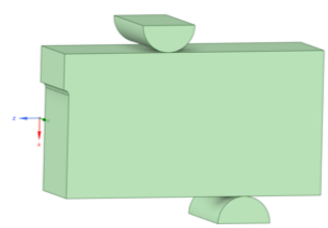
Thermal effects have been ignored.

Linear elasticity has been used for elastic material response analysis (will be justified on the report).

Geometry

The left figure displays the domain's geometry. To use symmetry and enhance efficiency, we bisect the domain along the z-axis and then along the y-axis (referring to CAD file COOS), as shown in the right figure.



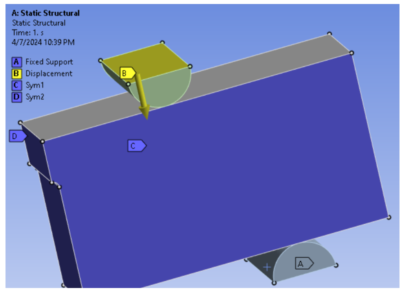


Material Data

The notched specimen is made of a soft aluminum alloy (E = 67 GPa, ν = 0.33, Sy = 220 MPa, Su = 640 MPa), while the support and load pins are of machine steel (E = 205 GPa, ν = 0.29). These material have been created in the engineering material tab (shown in the appendix).

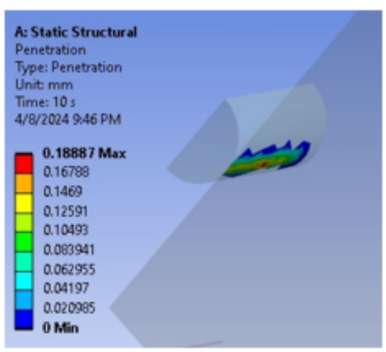
Boundary Conditions

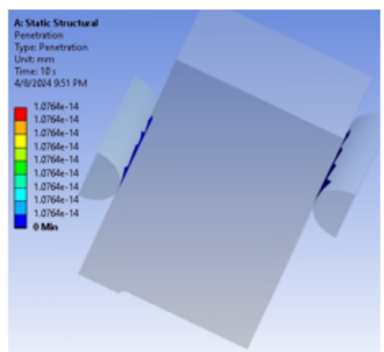
The figure illustrates the applied boundary conditions and the symmetry boundary conditions (BCs) resulting from utilizing ¼ symmetry. A displacement load (delta) of 1mm is applied in the x-direction (referring to CAD file COOS), while displacements in the y and z directions are set to zero.



Penetration Minimization:

We initiated our analysis with the default mesh size, applying a refinement factor of 2 at the notch. Our objective was to assess the penetration results using the Contact Toolbox to ensure that penetration levels were within acceptable limits. The initial findings showed a maximum penetration of 0.212 mm and a maximum specimen deformation of 0.8 mm along the penetration axis, resulting in a penetration to deformation ratio of 26%, which is considered very high. To mitigate this, we first adjusted the Trim Tolerance from 0.48153 mm to 0.05 mm. Despite this adjustment, the penetration reduction was not substantial, prompting us to switch the contact formulation to Normal Lagrange. This change led to a notable improvement, and the convergence in our results. The penetration data before and after applying the Normal Lagrange method are depicted in the respective left and right figures below.

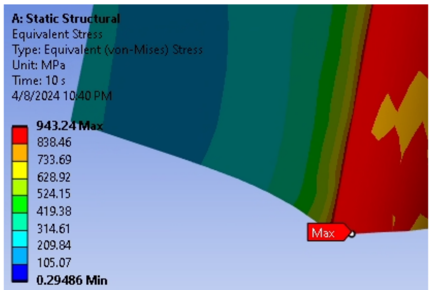


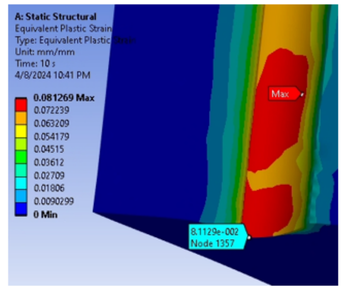


We see that the adjustment to Normal Lagrange formulation has effectively minimized penetration, and the results have converged.

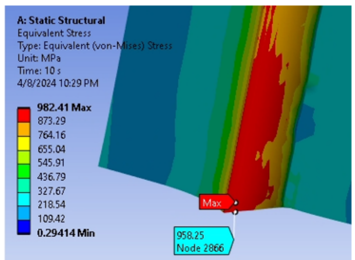
Mesh convergence study:

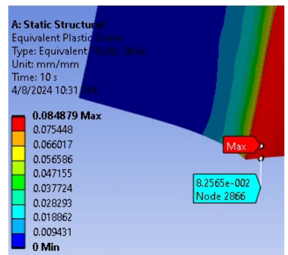
Now that penetration is minimized, it's crucial to conduct a mesh convergence study to ensure reliable results. To verify mesh convergence, we'll use the maximum equivalent stress as the criterion for the elastic part and the equivalent plastic strain for the elasto-plastic part. This approach will help ascertain that the mesh is sufficiently refined for accurate simulation outcomes. First we start with default mesh and refinement 2 on the notch. Results for this simulation is shown below:



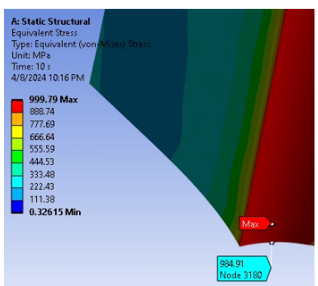


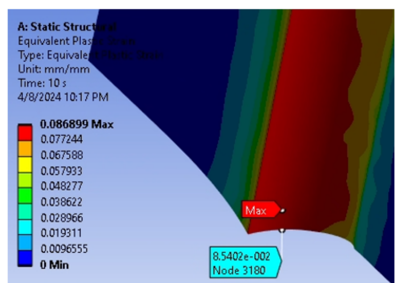
Now, let's increase the refinement on the notch, and use mesh refinement of 3:





Although this maximum point looks like singularity, we will conduct more refinement using "mesh sizing", and will set the mesh size to 5mm for the mesh sizing:





In the mesh convergence study, we disregard the singularity point and focus on the difference in labeled stresses and strains on each plot, which realistically and physically should represent the maximum values. Upon comparing these values, we find that the difference in maximum stress and strain for the last refinement level is less than 2.7%. Given computational constraints, we select the mesh with refinement level 3 at the notch as our converged mesh. The summary of mesh convergence results is presented in the table below:

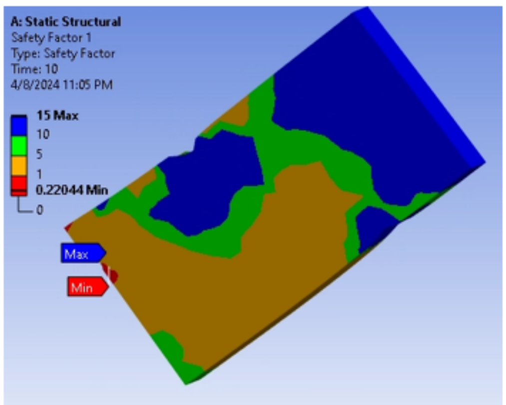
Convergence Criteria	Default mesh with refinement 2	Default mesh with refinement 3	Default mesh with refinement 3 + Face Sizing Refinement
Maximum Value of Equivalent Stress	943.24 MPa	958.25 MPa	984.91 MPa
Maximum Value of Equivalent Plastic Starin	0.081	0.0826	0.0854

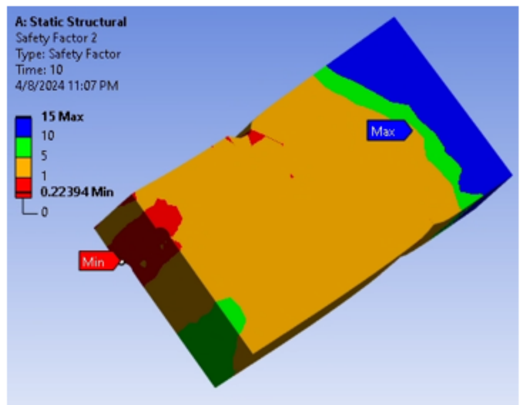
We enabled "large deflections" in the Analysis settings and activated "nonlinear effects" in the geometry settings. The load was applied gradually over 10 steps to enhance the nonlinear solver's convergence.

Results:

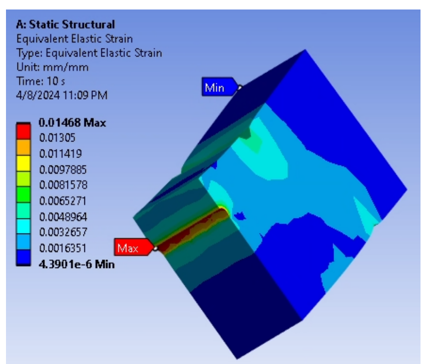
A. Elastic Material Response Analysis:

In this section, we determine the elastic response of the specimen, acknowledging the analysis's nonlinear nature due to contact. We apply the load slowly and meticulously to ensure accurate and converged results. Utilizing the Stress Safety tool, we compute two factors of safety at the notch: FS1, based on the Max Tensile Stress theory using the yield strength as the limiting stress, and FS2, derived from the Equivalent Stress theory with the yield strength as the limiting stress value. FS1 and FS2 are shown below.



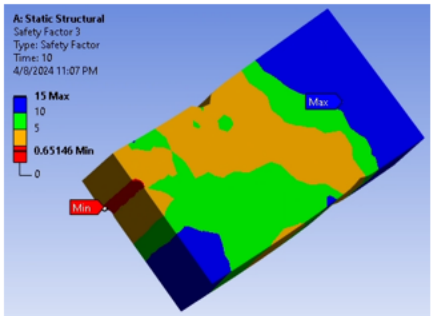


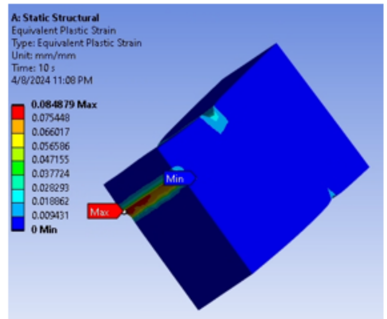
Notes: Since strain is less than 10% (below figure), linear elasticity has been used.



B. Elastic-Plastic Material Response Analysis:

Again, we solve the problem with the same loads and boundary condition, but this time for elastic-plastic response of the specimen. We use Bilinear Kinematic Hardening with a post yield tangent modulus, E_T, equal to 9.0 GPa. This is a nonlinear analysis because of contact and metal plasticity. Slow, careful loading is applied to get correct, converged results. Using the Stress Safety tool, we calculate the factor of safety, FS3, at the notch using the Equivalent Stress theory with the ultimate strength as the limit stress value, as shown below (left figure). Also, maximum equivalent plastic strain is shown below (right figure).





Conclusions:

This engineering analysis achieved its aim of evaluating safety factors under specific loads for a notched aluminum alloy specimen, considering both linear and nonlinear responses. The factors of safety calculated for the elastic (FS1 = 0.2204, FS2 = 0.2239) and elastic-plastic (FS3 = 0.6515) scenarios, alongside a maximum equivalent plastic strain of 0.08488 mm/mm, underscore the specimen's response under simulated conditions. These results, informed by careful load application and mesh convergence studies, provide vital insights for the specimen's design and application considerations.

Appendix:

Properties of Outline Row 5: Soft Aluminium Alloy

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Isotropic Elasticity		
4	Derive from	Young's Modulus and Poisson's Ratio	
5	Young's Modulus	67	GPa
6	Poisson's Ratio	0.33	
7	Bulk Modulus	6.5686E+10	Pa
8	Shear Modulus	2.5188E+10	Pa
9	Bilinear Kinematic Hardening		
10	Active Table	Plastic	
11	Yield Strength	220	MPa
12	Tangent Modulus	9	GPa
13	Tensile Yield Strength	220	MPa
14	Tensile Ultimate Strength	640	MPa

Properties of Outline Row 4: Machine Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Isotropic Elasticity		
4	Derive from	Young's Modulus and Poisson...	
5	Young's Modulus	205	GPa
6	Poisson's Ratio	0.29	
7	Bulk Modulus	1.627E+11	Pa
8	Shear Modulus	7.9457E+10	Pa