Lap Fillet Weld Calculations and FEA Techniques

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Introduction

The objective of the study is to evaluate the strength of a lap fillet welded joint under an axial load situation, and determine the welded joint capability.

Usually in different structural analysis text books the Lap Joint Weld is analyzed as a joint that is solely subjected to longitudinal shear only. However the demonstration below will show a better method to calculate Lap welded Joint capability.

Definition

Lap welded Joint is a type of weld joint between two overlapping metal parts in parallel planes.

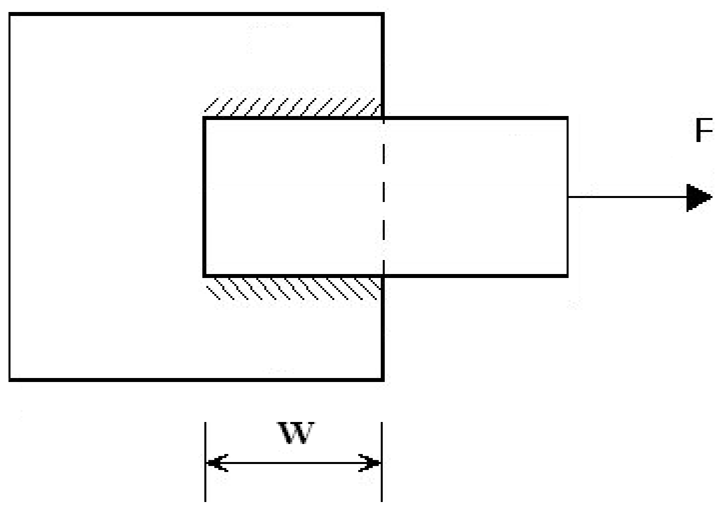

Figure 1 Lap Fillet welded joint

Longitudinal Shear Stress Method

The simple calculation for the shear stress can be given by:

$$\tau_{Simple} = \frac{F}{2a * W}$$

Where:

- F is the force.
- a is the weld's throat thickness

(a= Leg Length * .707)

- W is the length of the weld

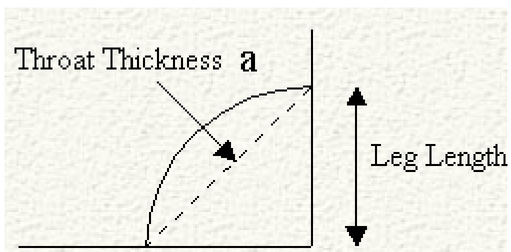

Figure 2 Lap Fillet welded joint cross section view

Tensile Stress Method

The simple calculation for the tensile stress can be given by:

$$\sigma_{Simple} = \frac{2 * F}{a * LegLength}$$

Modified Equation Method

The modified equation will take into account some excremental modifications and both tensile and shear stress in the joint, and could be written as:

$$\sigma_{Modified-Total} = \beta * \sqrt{\sigma_{Simple}{}^{2} + 3*(\tau_{Simple})^{2}}$$

Where:
β is a constant between .7 and 1 based on the strength of material.

* Note: It was assumed that the weld joint will fail before the plates.

Example

The below welded joint model will be analyzed using the following techniques:

a) Hand Calculations.
b) Finite element analysis using shell elements and no fill material.
c) Finite Element method using 2nd order tetrahedral solid elements, with modeling of the fill material.

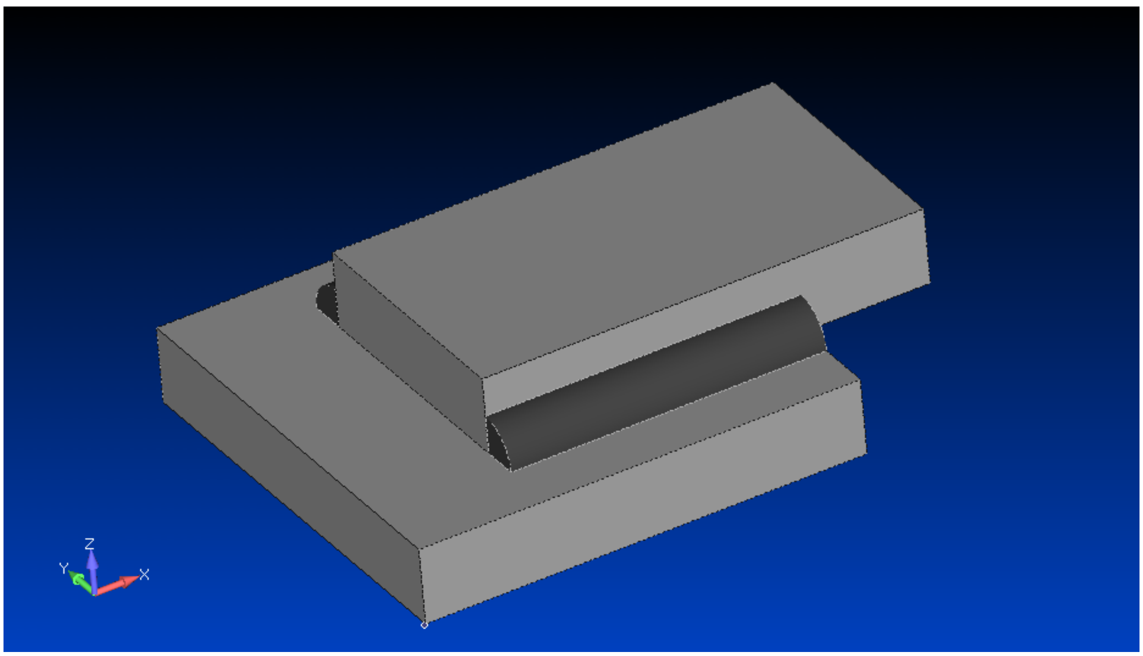

Figure 3 Lap weld joint model

Dimensions:

Large plate dimensions: 12x40X70 mm
Small plate dimensions: 12X70X70 mm
The weld Dimensions: 50X6 mm

Material Properties

For simplification all solids were modeled using the two main isotropic materials, the two main materials are steel 1020 and Weld fill material with tensile strength of 346 Mpa. In Figure 4 the material assignment of the assembly is illustrated.

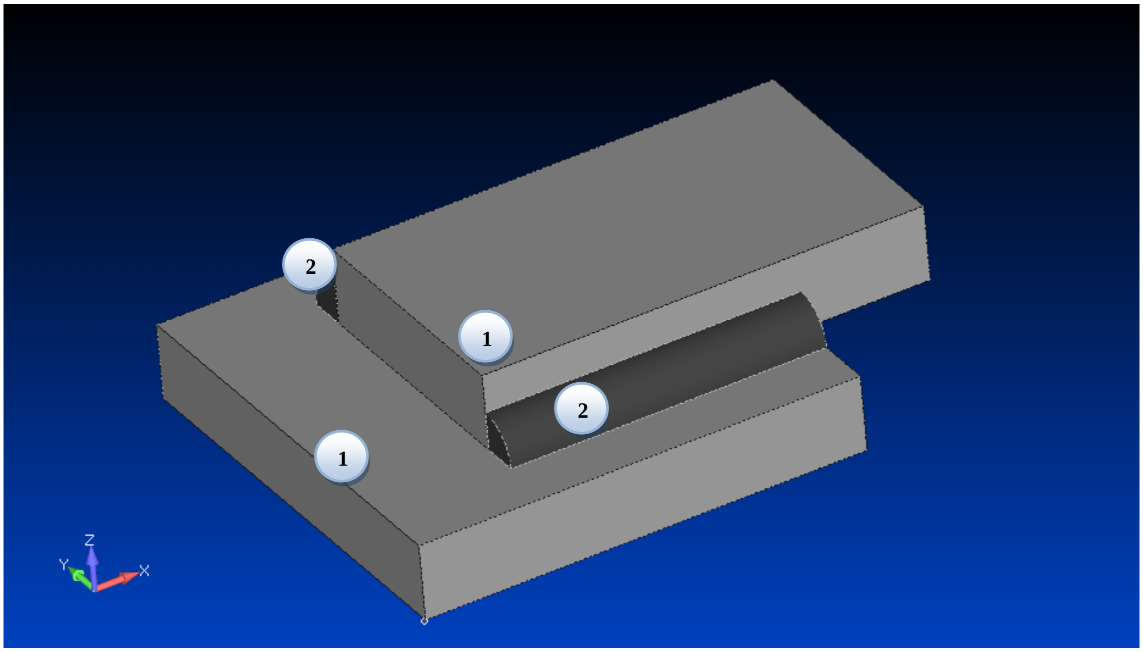

Figure 4 Material assignments of the model

Steel 1020	1
Density:	**7200 kg/m^3**
Elastic Modulus:	**207 GPa**
Poisson's Ratio:	**0.34**
Tensile Strength:	**455 MPa**
Yield Strength:	**350 MPa**
Percent Elongation:	**50%**
Hardness:	**45 (HB)**

Table 1 Steel 1020 mechanical properties

Weld Fill	2
Density:	**7139 kg/m^3**
Elastic Modulus:	**201 GPa**
Poisson's Ratio:	**0.32**
Tensile Strength:	**397 MPa**
Yield Strength:	**346 MPa**

Table 2 Weld fill mechanical properties

Hand Calculations

If we only consider the **shear stress** in our calculations; from the material properties we can write:

A= Throat area = .707*6*50*2 =424 mm^2

S_y=350 MPa.

Shear stress using distortion energy theory could be obtained by:

S_{sy}=.58 S_y =203.0 MPa.

F= S_{sy} *A= 86100 N

Hand calculations using previously introduced equations will give us the following results:

Inputs		
Weld length	50	mm
Number of weld Sides	2	#
Weld leg Length	6	mm
Force	86100	N
β	0.85	#

Outputs		
Shear stress	202.9703	Mpa.
Tensile stress	2391.667	Mpa.
Equivalent Stress	2417.366	Mpa.
Modified Equivalent Stress	2054.761	Mpa.

Since the modified equivalent stresses exceed the yield stress of the material, evaluating the shear stress only is **not** sufficient.

Let's consider that we would like to stay below 250 MPa to satisfy the Factor of Safety of 1.4; then the above calculations could be repeated and we will have the following results:

Inputs		
Weld length	50	mm
Number of weld Sides	2	#
Weld leg Length	6	mm
Force	10250	N
β	0.85	#

Outputs		
Shear stress	24.16313	Mpa.
Tensile stress	284.7222	Mpa.
Equivalent Stress	287.7817	Mpa.
Modifed Equivalent Stress	244.6145	Mpa.

Finite Element Method Analysis

The model could be analyzed using linear static simulations. This problem will be solved by using two types of modeling, first will be shell model, where plane stress theory will be applied, second we will model the problem using 2nd order tetrahedral elements.

Solving the Problem by using Shell (plate) Element Model

Boundary Condition

The boundary condition is fixed, that would mean there are zero degrees of freedom at the shown locations (Curve).

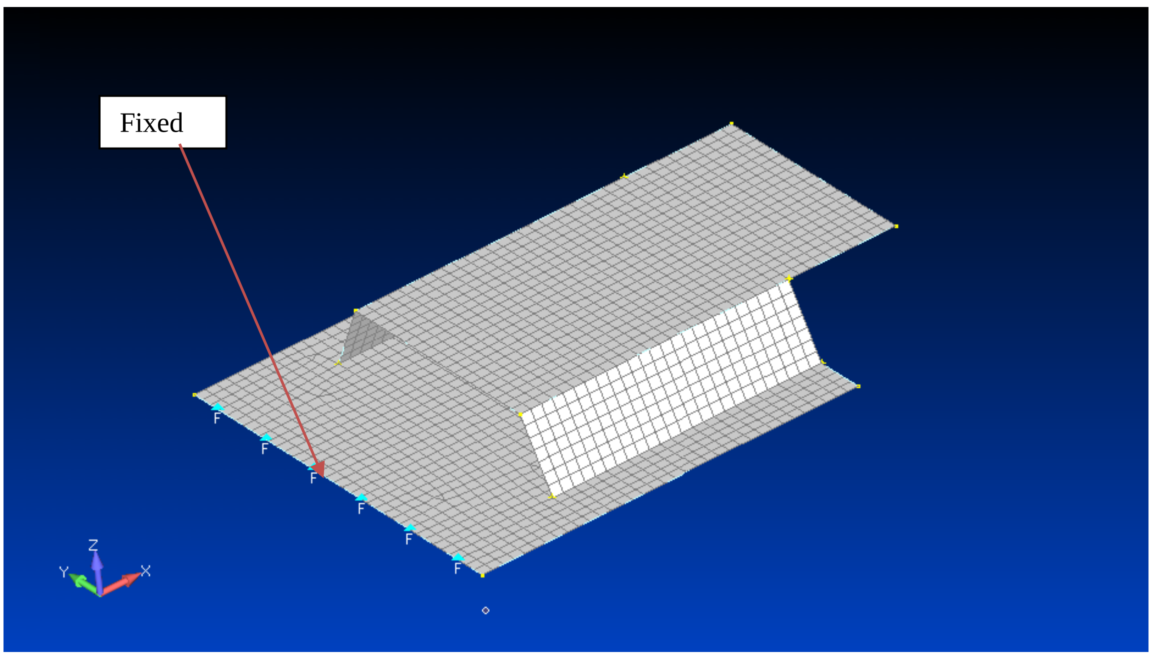

Figure 5 The constraints on the shell model

This will apply that the nodes at the curve will have:

$dx = 0$	(Translation along x-axis)
$dy = 0$	(Translation along y-axis)
$dz = \mathbf{0}$	(Translation along z-axis)
$dr_x = \mathbf{0}$	(Rotation about x-axis)
$dr_y = \mathbf{0}$	(Rotation about y-axis)
$dr_z = \mathbf{0}$	(Rotation about z-axis)

Load

The load will be a distributed force along the curve as shown below:

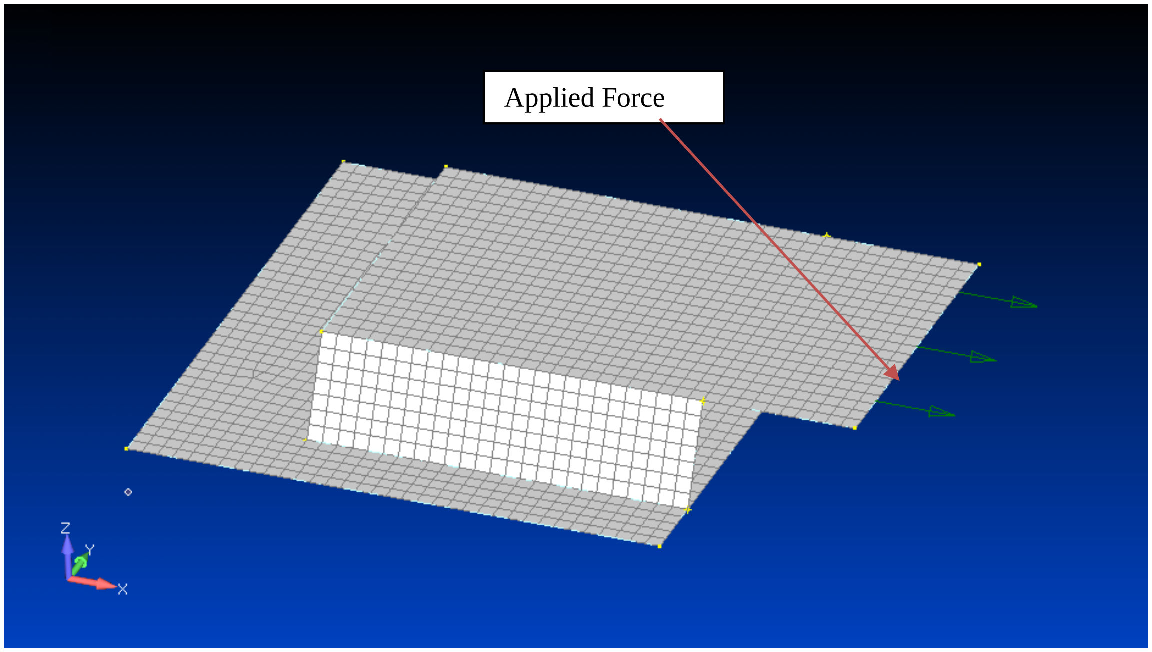

Figure 6 Applied load on the shell model

Stress Results

When applied force is equal to 86100 N, we will have the following stress results:

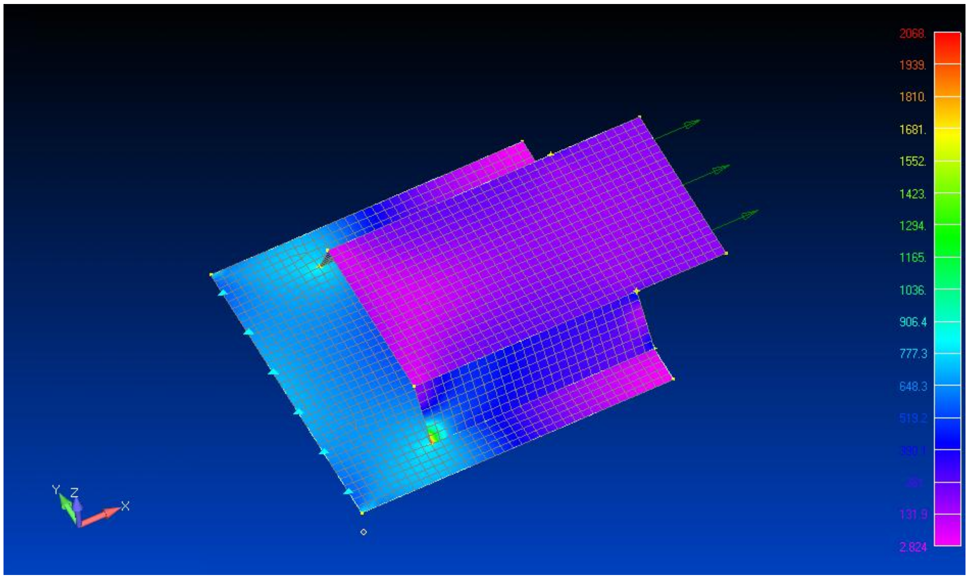

Figure 7 Von Mises stresses in the shell model

When applied force is equal to 10250 N, we will have the following stress results:

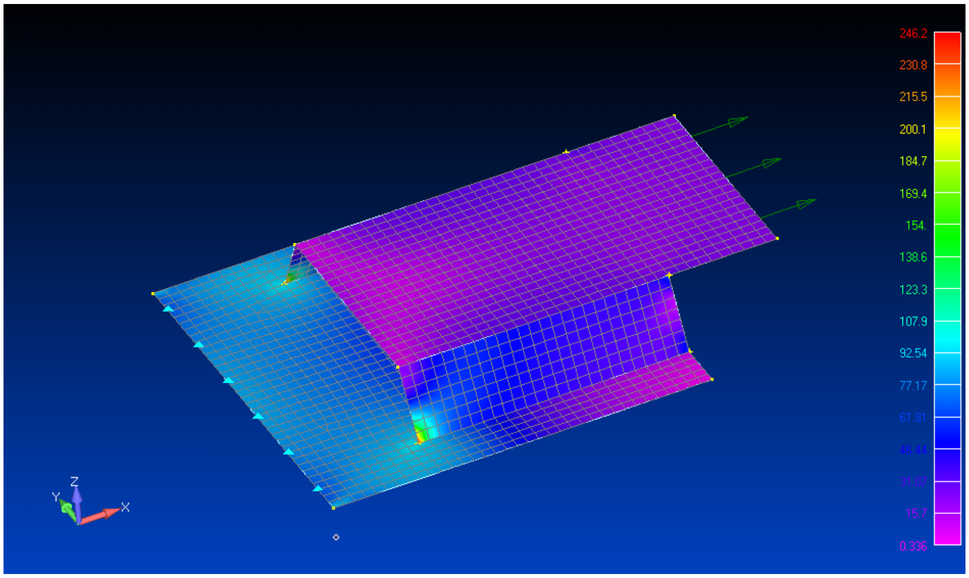

Figure 8 Von Mises stresses in the shell model

Solving the Problem by using 2nd Order Tetrahedral Solid Elements Model

Boundary Condition

The boundary condition is fixed, that would mean there are zero degrees of freedom at the shown locations (Surface).

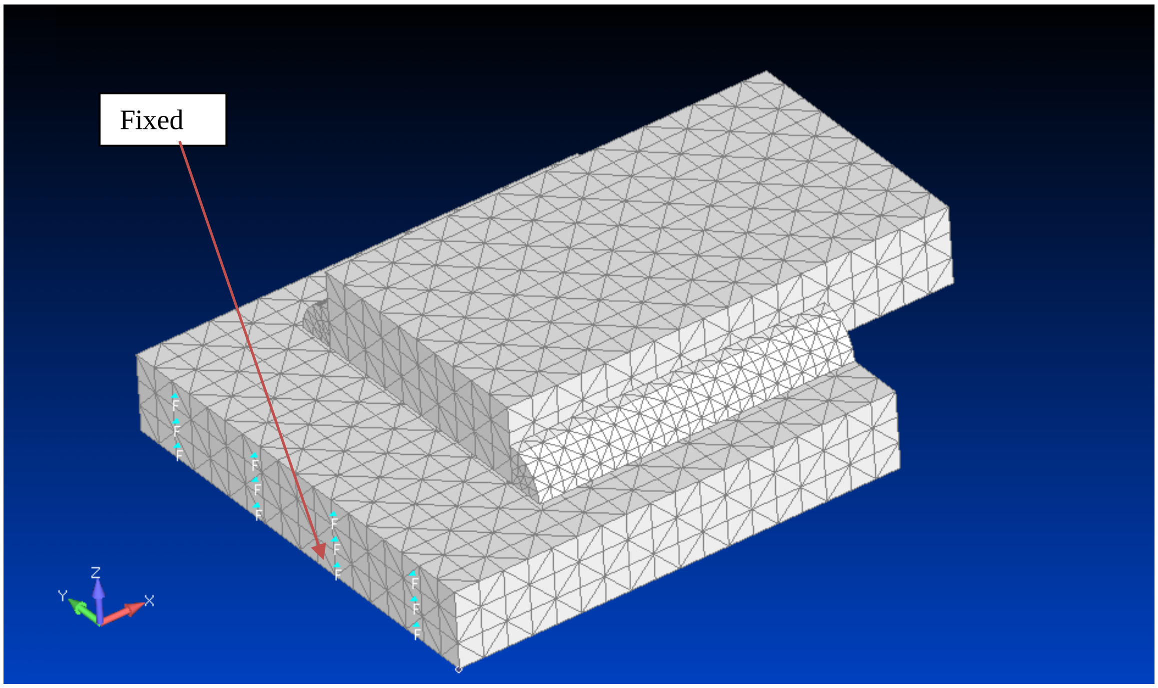

Figure 9 The constraints on the solid model

This will apply that the nodes on the surface will have:

$dx = 0$ (Translation along x-axis)
$dy = 0$ (Translation along y-axis)
$dz = \mathbf{0}$ (Translation along z-axis)
$dr_x = \mathbf{0}$ (Rotation about x-axis)
$dr_y = \mathbf{0}$ (Rotation about y-axis)
$dr_z = \mathbf{0}$ (Rotation about z-axis)

Load

The load will be a distributed force on the surface as shown below:

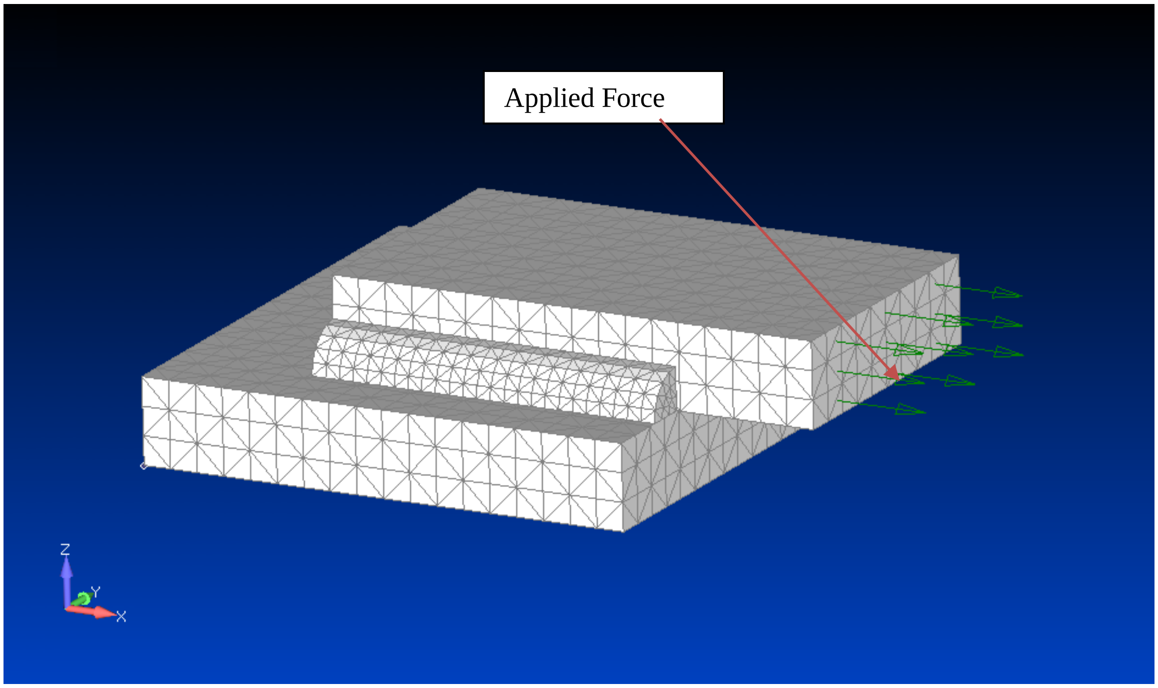

Figure 10 Applied load on the solid model

Stress Results

When applied force is equal to 86100 N, we will have the following stress results:

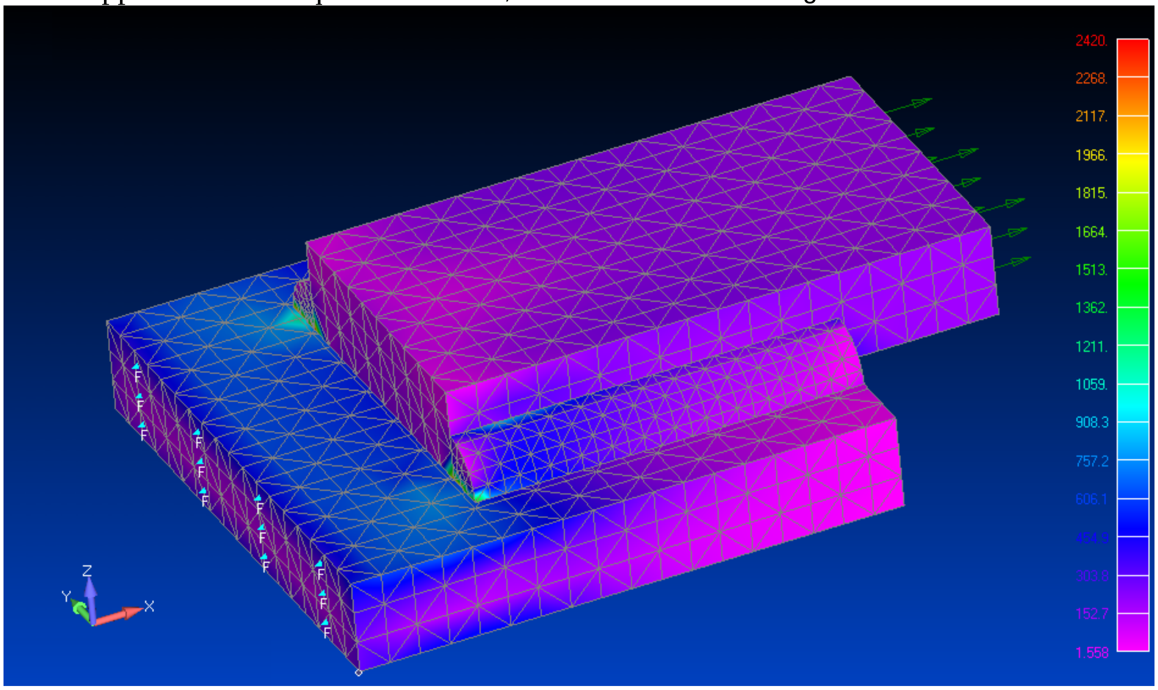

Figure 11 Von Mises stresses in the solid model

When applied force is equal to 10250 N, we will have the following stress results:

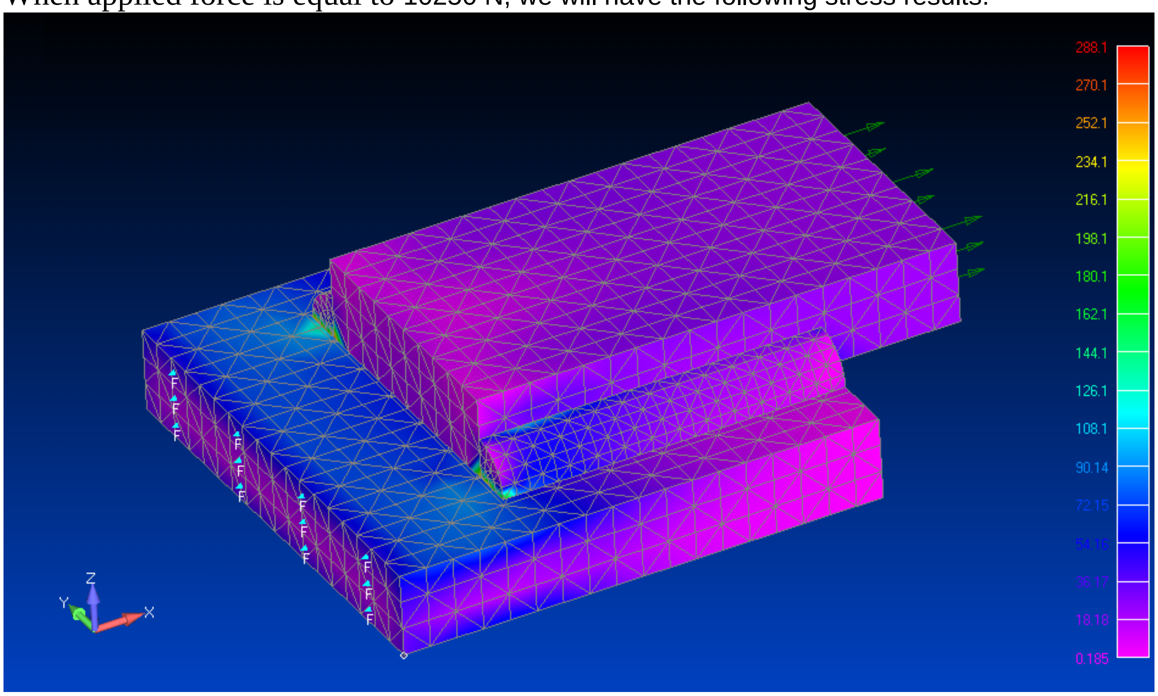

Figure 12 Von Mises stresses in the solid model

Conclusion

Usually, engineers are looking to the shear stress state of the welded joint and most of the effort of the analysis is to determine the shear stress in the weld. Most hand books suggest 33% to 27% max shear stress vs. yield stress as a limiting factor in welded joints.

The reasoning of such approximations could be explained with looking to more advanced failure theories such as Von Mises criterion.

$$\sigma_v = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}{2}}$$

$$= \sqrt{\frac{(\sigma_{11} - \sigma_{22})^2 + (\sigma_{22} - \sigma_{33})^2 + (\sigma_{11} - \sigma_{33})^2 + 6(\sigma_{12}^2 + \sigma_{23}^2 + \sigma_{31}^2)}{2}}$$

As it could be seen in the equation above the shear stress has a larger contribution to the overall Von Mises stress but is not the only contributor. Furthermore, looking to the shear stress only will be misleading if axial stresses are conspicuous in the welded joint.

***The geometry was taken from a standard part library and modified for this study; also all data are assumptions for proof of concept only.**

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