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MECHANICAL ENGINEERING

DE-39(B)

MECHANICS OF MATERIALS - II

DESIGN PROJECT

DESIGN OF A SINGLE POINT CUTTING TOOL

OBJECTIVE:

To design a Single Point Cutting tool used in lathe machine.

INTRODUCTION:

A lathe is a machine tool that rotates a workpiece about an axis of rotation to perform various operations such as cutting, sanding, knurling, drilling, deformation, facing, and turning, with tools that are applied to the workpiece to create an object with symmetry about that axis. Here we consider Single Point Cutting tool only. The rotating workpiece is brought in contact with the Single Point Cutting tool to create the desired geometry via machining. This rotating workpiece induces stresses in the Cutting tool. These stresses can cause the tool to fail.

OUR APPROACH:

- Make suitable assumptions.
- Choose a suitable material for the Cutting Tool.
- Choose a suitable Failure theory
- Calculate Maximum Moments and Forces produced in the Cutting tool.
- Calculating the respective stresses generated.
- Using the Failure Theory chosen to design the part.

ASSUMPTIONS:

- We assume that the material chosen is Linear Elastic Isotropic Continuous Homogenous.
- Length of the cutting tool does not play an important factor and in designing length, sufficient length is considered so that the tool just comes in contact with the workpart. So the criteria for designing length is merely based on the distance between the toolpost and the workpart. Most lathe machines have cutting tools 120mm long, so we will consider length=120mm. Reference is mentioned at the end.
- The forces are only being applied at the single point of the cutting tool.
- The single cutting point is in the shape of the pyramid with its vertex as the centroid of the cross section of cutting tool so that forces being applied are at the centroid of the cross section of the cutting tool.
- The cross section that will be designed will be square, so the width and height of the cross section are equal.
- Tensile Strength is equal to Compressive Strength.
- We assume that the forces are the same as that shown in the Free Body Diagram (F_x=576 N, F_y= - 3039 N, F_z= - 1482.56 N). Reference is mentioned at the end.

- All the stress concentrations (peak stresses in Ansys) were neglected

MATERIAL SELECTED:

High Speed Tool Steel:

Used in high speed tool and cutting applications promotes toughness and aids cutting properties, but requires more precise hardening conditions and caution about overheating. Quench via oil, air, or salt bath. This material has high Carbon Content so it is **Brittle** in nature

Tensile/Compressive Strength: 2390 MPa

Tool steel, high-speed

High-speed tool steel (M2)

Sample materials data from Granta Design. Additional data and information available through the Granta website.

Granta provides no warranty for the accuracy of the data.

Density	8.16e-06 kg/mm^3

Structural

Isotropic Elasticity

Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	2.26e+05 MPa
Poisson's Ratio	0.29
Bulk Modulus	1.7937e+05 MPa
Shear Modulus	87597 MPa
Isotropic Secant Coefficient of Thermal Expansion	1.02e-05 1/°C
Tensile Ultimate Strength	2390 MPa
Tensile Yield Strength	2170 MPa

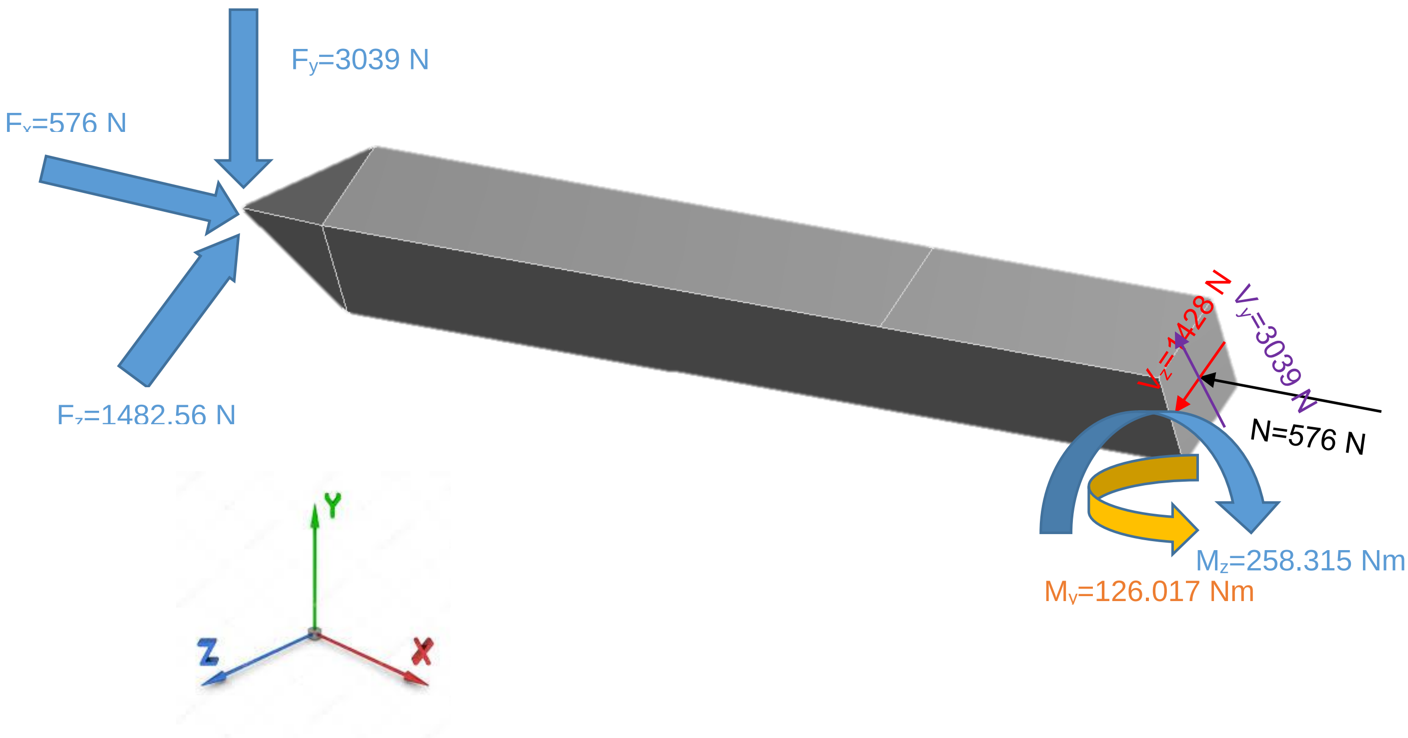
Thermal

Isotropic Thermal Conductivity	0.022 W/mm·°C
Specific Heat Constant Pressure	4.65e+05 mJ/kg·°C

Electric

Isotropic Resistivity	0.000832 ohm·mm

Free Body Diagram:



Calculations:

In the cutting tool a part of the tool is clamped with the toolpost. Thus a certain length of both top and bottom surfaces are fixed. This length is 35 mm. The free body diagram above is shown for the cut body where the body is cut just before the clamping region begins. Why the body is cut from this section will be explained later.

First Calculating reactions;

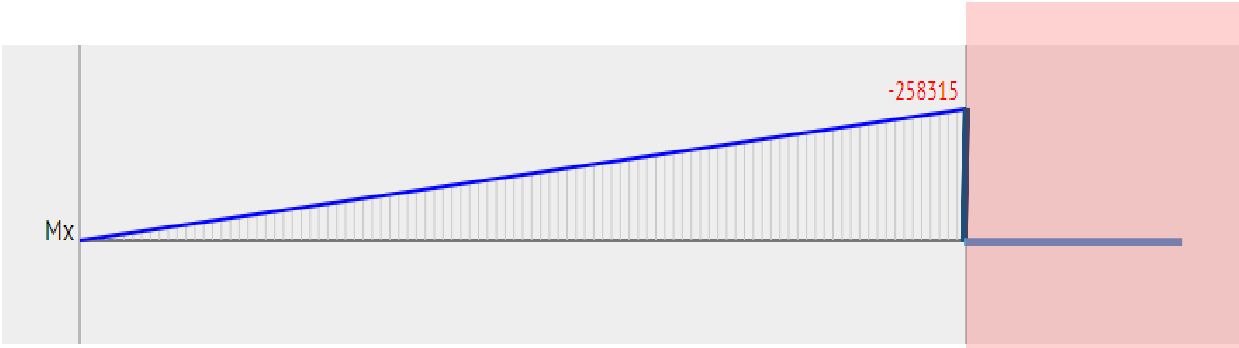
For Failure, we must consider the maximum internal forces and moments. Internal forces have the maximum value no matter where the cutting tool is sectioned along its length so,

$\sum F_x = 0$	576-N=0	N=576 N
$\sum F_y = 0$	-3039+V_y=0	V_y=3039 N
$\sum F_z = 0$	-1482.56+V_z=0	V_z=1482.56N

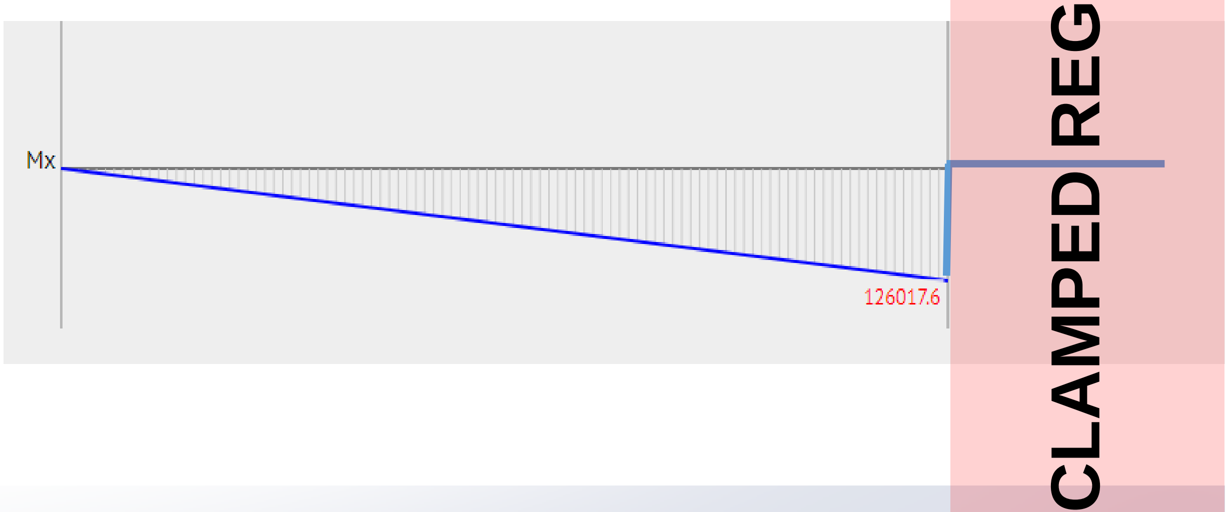
For moments;

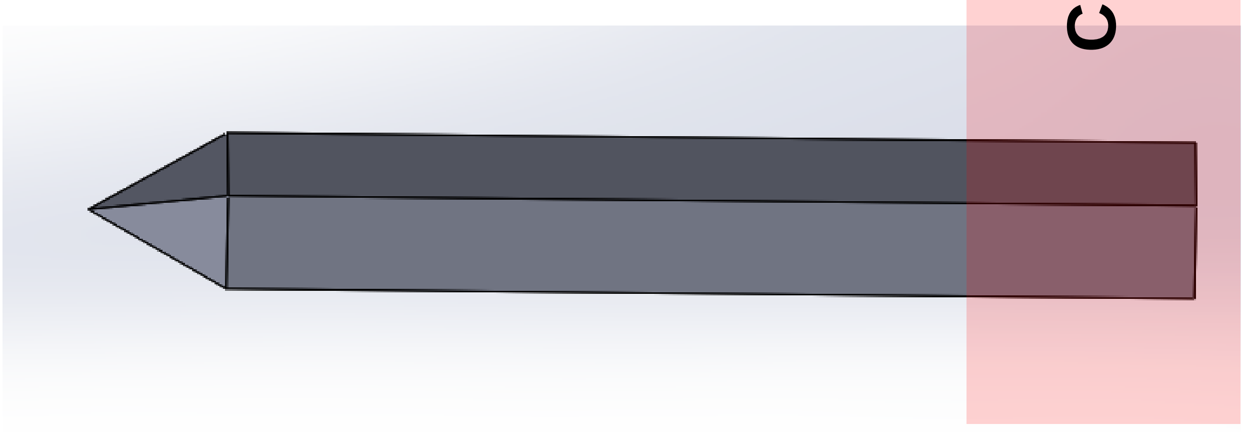
Maximum moment can be seen from the moment diagram:

Viewing from Front plane and Calculating M_z:



Viewing from Top plane and Calculating M_y:





As seen from the moment diagram, maximum moment due to both Fy and Fz occur at 120-35=85 mm distance from the cutting point

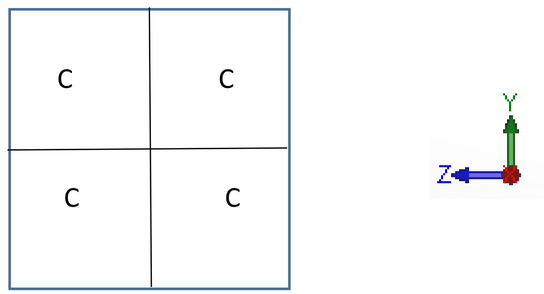
$\sum M_x = 0$ -3039(0.12-0.035) $+M_z=0$ M_z=258.315 Nm

$\sum M_y = 0$ -1482.56(0.12-0.035) $+M_y=0$ M_y=126.017 Nm

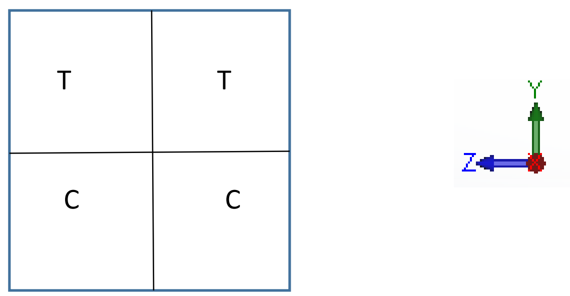
Stresses:

Since the material is brittle we will be using the Maximum Normal Stress theory. For this theory we need the maximum possible normal stress. The directions of stresses due to normal force and moments can be shown as (C=Compressive, T=Tensile)

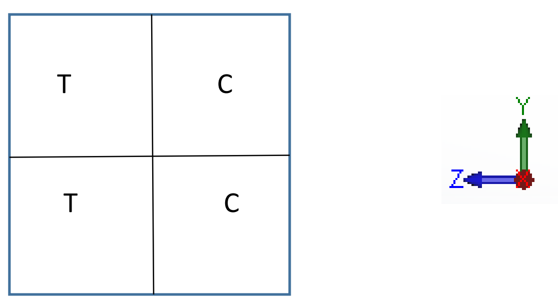
Stresses due to N:



Stresses due to Mz:



Stresses due to My:



Here the box represents the cross section of the cutting tool. From the above three diagrams it is clear that the maximum normal stress is compressive and occurs at the bottom right region of the cross section. Since bending stress is maximum at the edges, the lowest bottom right corner point is chosen.

Now, calculating stresses, here width and height is unknown, so we will treat it as variable x;

Section Properties:

$$A = x * x = x^2$$

$I_z = \frac{1}{12}bh^3 = \frac{1}{12}x \times x^3 = \frac{1}{12}x^4$

$I_y = \frac{1}{12}bh^3 = \frac{1}{12}x \times x^3 = \frac{1}{12}x^4$

NOW CALCULATING STRESSES:

Normal Stresses:

Due to bending:

Due to Mz:

$$\sigma_{x1} = \frac{M_z z}{I_z}$$

Here, M_z=258.315 Nm, z=Distance from neutral axis to point of interest= (0.5x) m

Putting values

$$\sigma_{x1} = \frac{258.315 \times 0.5x}{\frac{1}{12}x^4}$$

$$\sigma_{x1} = \frac{1549.89}{x^3}$$ **(Compressive)**

Now, Due to My:

$$\sigma_{x2} = \frac{M_y y}{I_z}$$

Here, M_y=126.017 Nm, y=Distance from neutral axis to point of interest= (0.5x) m

Putting values

$$\sigma_{x2} = \frac{126.017 \times 0.5x}{\frac{1}{12}x^4}$$

$$\sigma_{x2} = \frac{756.1056}{x^3}$$ **(Compressive)**

Due to Normal:

$$\sigma_{x3} = \frac{N}{A}$$

Here N=576 N (Compressive) and A=x^2

$$\sigma_{x3} = \frac{576}{x^2}$$ **(Compressive)**

Total normal stress= $\boldsymbol{\sigma_x = \sigma_{x1} + \sigma_{x2} + \sigma_{x3}}$

$$\boldsymbol{\sigma_x} = \frac{1549.89}{x^3} + \frac{756.1056}{x^3} + \frac{576}{x^2}$$

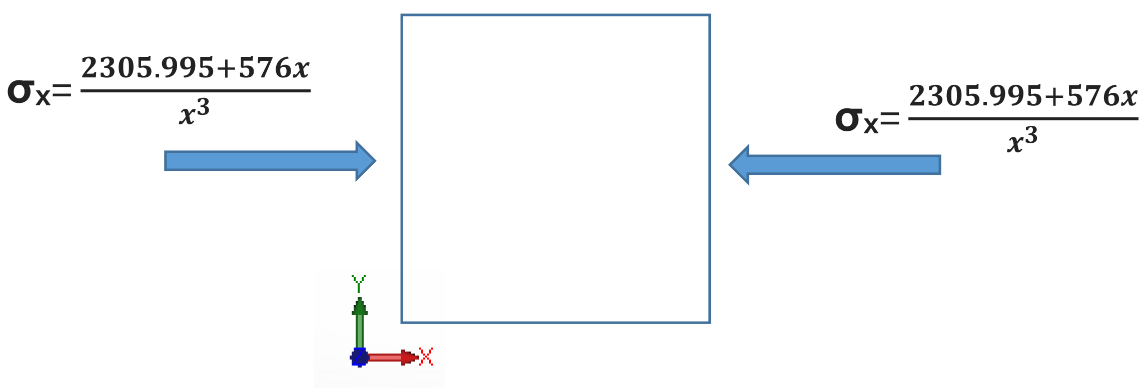
$$\boldsymbol{\sigma_x} = \frac{1549.89}{x^3} + \frac{756.1056}{x^3} + \frac{576x}{x^2}$$

$$\boldsymbol{\sigma_x} = \frac{2305.995+576x}{x^3}$$ **(Compressive)**

Shear Stresses:

At this point, $\mathbf{T}_{xz}$=0 and $\mathbf{T}_{xy}$=0 since the point is at the corner and at a free surface and no external shear is acting here.

Stress Element:



Applying stress Transformation to find maximum normal (principle) stress:

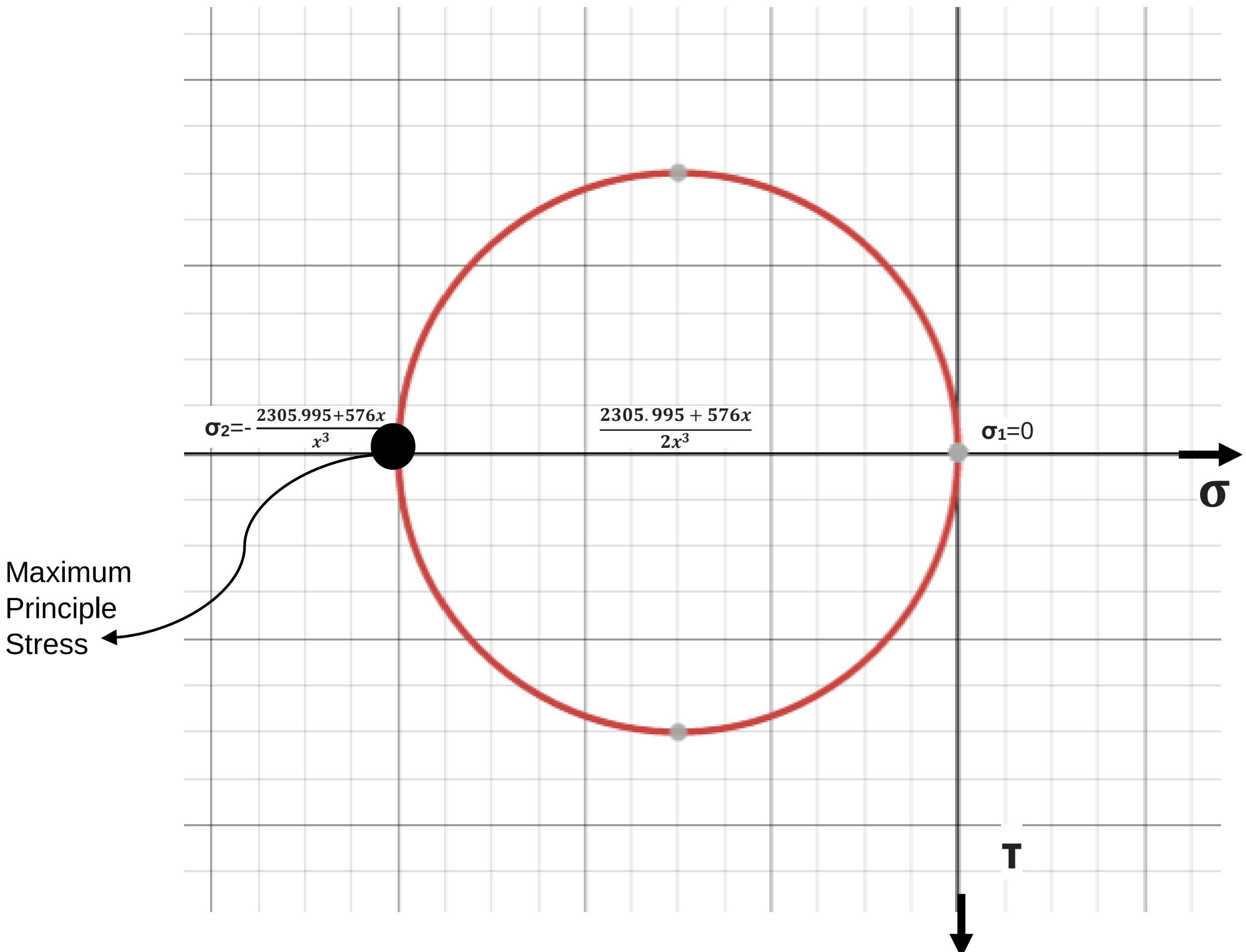
Here, $\boldsymbol{\sigma_y}$=0, $\boldsymbol{\sigma_x} = \frac{2305.995+576x}{x^3}$, T_{xy}=0

For Mohr Circle:

$$\text{Centre} = \frac{\sigma x+\sigma y}{2} = \frac{\frac{2305.995+576x}{x^3}+0}{2} = \frac{2305.995+576x}{2x^3}$$

Radius= $\sqrt{\left(\frac{\sigma x-\sigma y}{2}\right)^2 + \tau xy^2} = \sqrt{\left(\frac{\frac{2305.995+576x}{x^3} - 0}{2}\right)^2 + (0)^2} = \frac{2305.995+576x}{2x^3}$

Mohr Circle:



From the circle, it is clear that our chosen stress element is already in its principle position with the maximum compressive stress= σ_2=- $\frac{2305.995+576x}{x^3}$

Theory of Failure:

Here we will use the Maximum Normal Stress Theory because the material we chose was brittle and brittle materials are susceptible to failure due to normal stresses. The maximum-normal-stress theory states that a brittle material will fail when the maximum tensile stress in the material reaches a value that is equal to the ultimate normal stress the material can sustain when it is subjected to simple tension. If the material is subjected to plane stress, we require for failure that

$$|\boldsymbol{\sigma}_1| = \boldsymbol{\sigma}_{UTS} \qquad \text{or} \qquad |\boldsymbol{\sigma}_2| = \boldsymbol{\sigma}_{UTS}$$

Here $\boldsymbol{\sigma}_2$ is greater than $\boldsymbol{\sigma}_1$ so, we will compare $\boldsymbol{\sigma}_2$ with $\boldsymbol{\sigma}_{UTS}$

Factor of Safety:

The factor of safety used is 2, this is also verified by our ansys analysis

Now to avoid failure, $|\boldsymbol{\sigma}_2| < \boldsymbol{\sigma}_{allow}$

$$\boldsymbol{\sigma}_{allow} = \frac{\boldsymbol{\sigma}_{UTS}}{FOS} = \frac{2390}{2} = 1195\ MPa$$

To calculate minimum width/height, we set $|\boldsymbol{\sigma}_2| = \boldsymbol{\sigma}_{allow}$

$$\frac{\mathbf{2305.995 + 576}\boldsymbol{x}}{\boldsymbol{x}^{\mathbf{3}}} = \mathbf{1195 \times 10^{6}}$$

$$\mathbf{2305.995 + 576}\boldsymbol{x} = (\mathbf{1195 \times 10^{6}})\boldsymbol{x}^{\mathbf{3}}$$

$$(\mathbf{1195 \times 10^{6}})\boldsymbol{x}^{\mathbf{3}} - \mathbf{2305.995} - \mathbf{576}\boldsymbol{x} = \mathbf{0}$$

Solving for x,

x=0.01246 m or x= 12.46 mm

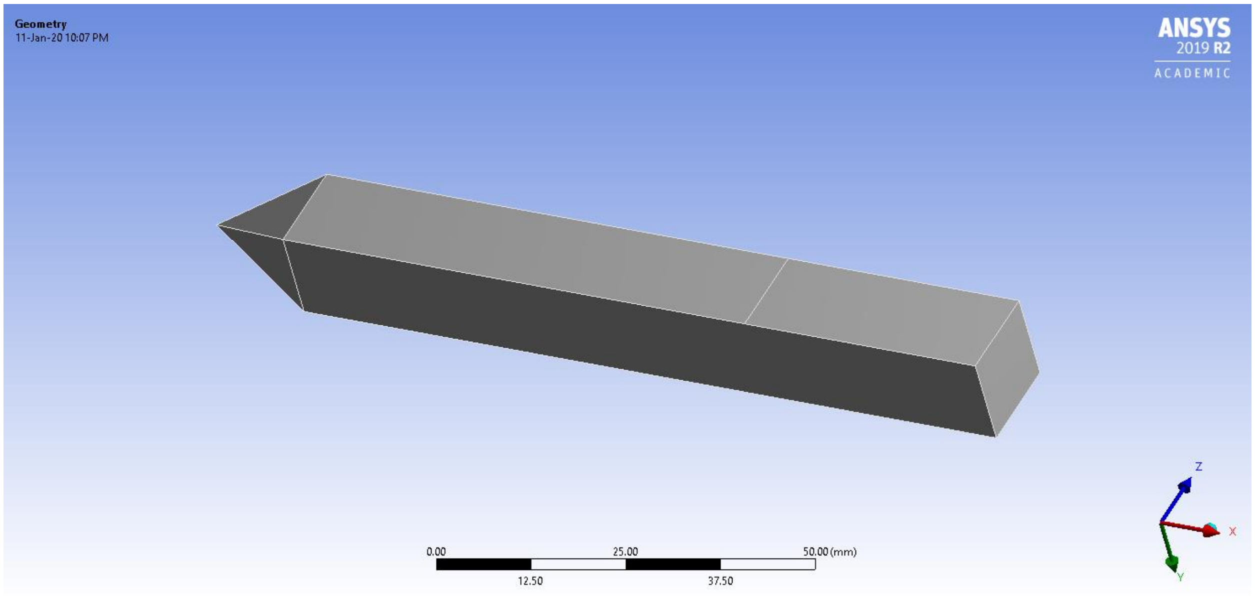
Since 12.46 mm thick material is not easily available, we round it to the nearest greater whole number i.e; 13 mm

Thus the dimensions of the cross section of the Single Point Cutting tool is 13 mm x 13 mm

ANSYS DESIGN ANALYSIS

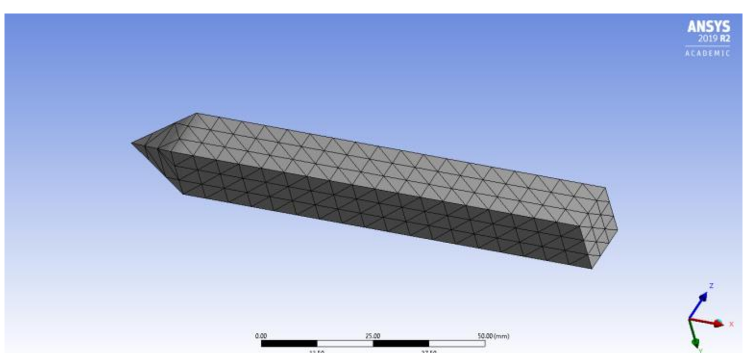
Now our objective is to analyze this designed cutting tool on Ansys. First the part is made on Solidworks using the calculated dimensions, next it is imported to the ansys workbench (Static Structural). After that the material is assigned. Then the forces and the supports are defined on the body, after which the results are obtained.

Geometry:

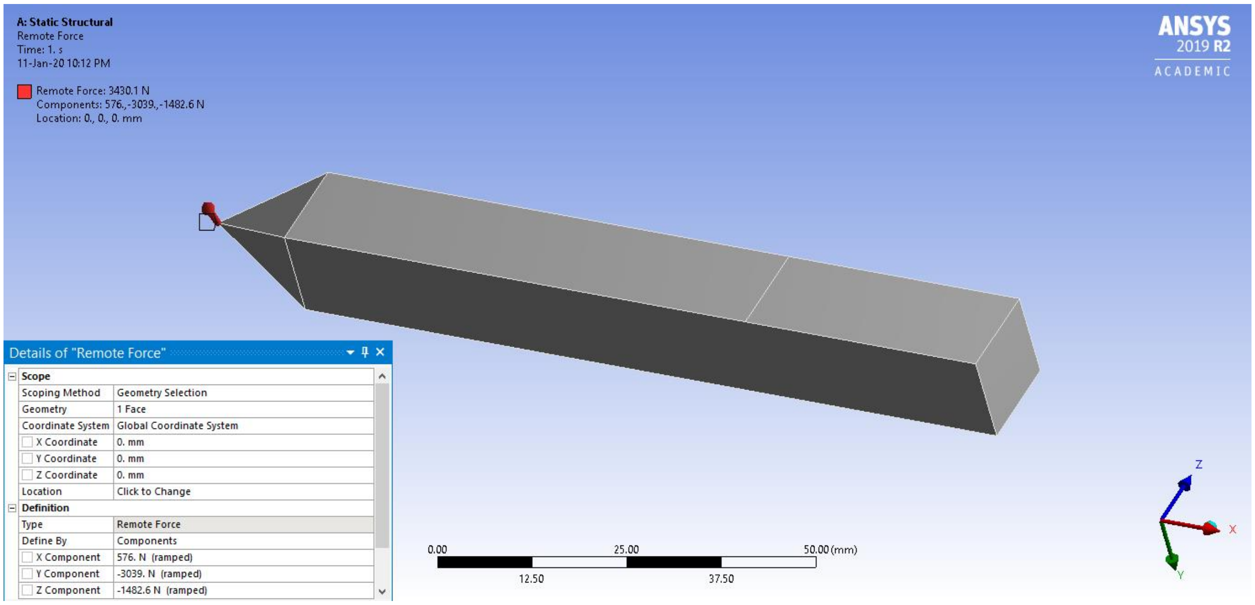


Material	
Assignment	Tool steel, high-speed
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	120. mm
Length Y	13. mm
Length Z	13. mm
Properties	
Volume	18590 mm³
Mass	0.15169 kg
Centroid X	64.943 mm
Centroid Y	-3.872e-012 mm
Centroid Z	3.8721e-012 mm
Moment of Inertia Ip1	4.1954 kg·mm²
Moment of Inertia Ip2	156.01 kg·mm²
Moment of Inertia Ip3	156.01 kg·mm²

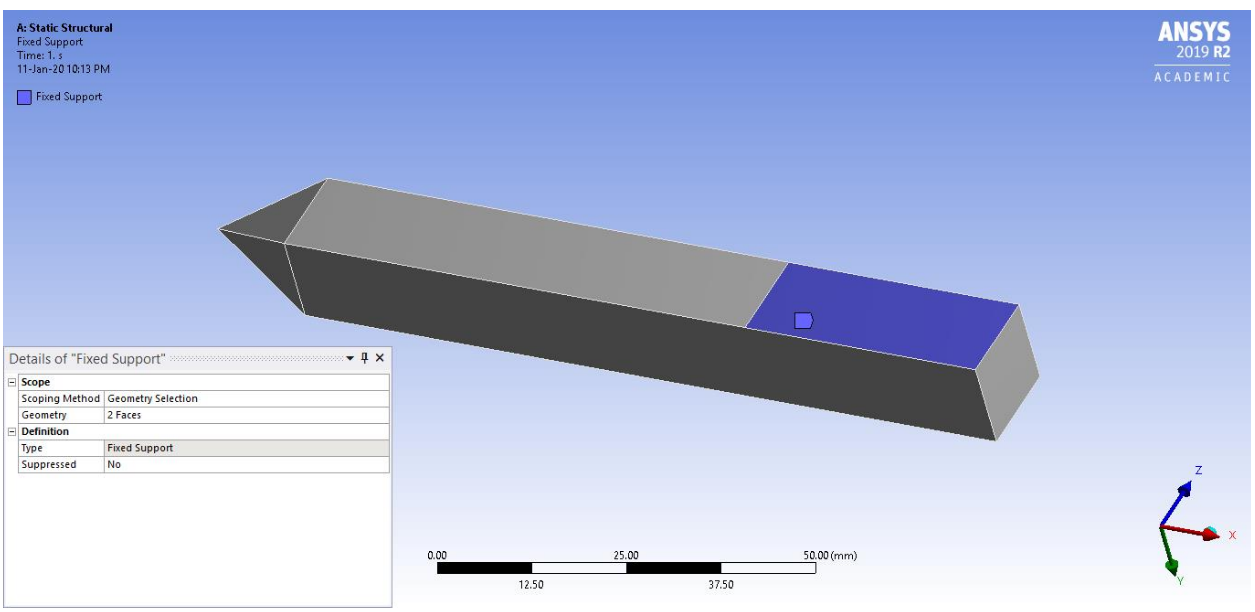
Mesh:



Loads and Fixed Support:



^Loads were applied according to the manual calculations in the same directions



^Fixed Supports were used on top and bottom face for 35 mm length for the clamped region

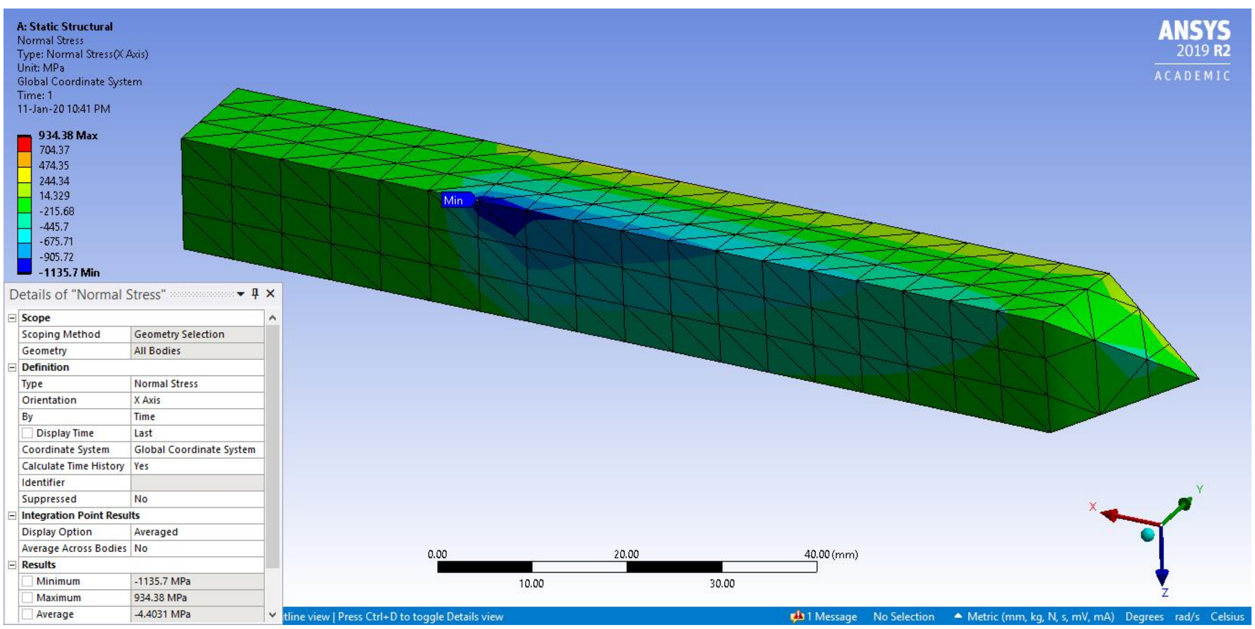
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Remote Force*
State	Fully Defined	
Scope		

Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Coordinate System		Global Coordinate System
X Coordinate		0. mm
Y Coordinate		0. mm
Z Coordinate		0. mm
Location		Defined
Definition		
Type	Fixed Support	Remote Force
Suppressed	No	
Define By		Components
X Component		576. N (ramped)
Y Component		-3039. N (ramped)
Z Component		-1482.6 N (ramped)
Behavior		Deformable
Advanced		
Pinball Region		All

Results:

Normal Stress:



Maximum Normal stress was calculated. Here the maximum compressive stress value exceeds the tensile stress value in magnitude (-1135 MPa), this is a little greater (in magnitude) than the calculated value for 13mm cross section (1058 MPa) due to stress concentrations which ansys calls “peak stresses”.

Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Normal Stress*
State	Solved
Scope	

Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Normal Stress
Orientation	X Axis
By	Time
Display Time	Last
Coordinate System	Global Coordinate System
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged
Average Across Bodies	No
Results	
Minimum	-1135.7 MPa
Maximum	934.38 MPa
Average	-4.4031 MPa

Object Name	*Alert*
State	Solved
Definition	
Fails If	Minimum Below Value
Value	-1195. MPa
Results	
Status	Passed: Minimum Above Value

In addition to the peak stresses, the part is still safe. To check safety, an alert system was used that if the value of Normal stress in any part of the body falls below -1195 (i.e; $\boldsymbol{\sigma_{allow}}$), which was calculated manually as shown earlier, the alert will show that the part failed. In our case the part **passed**.

Maximum Normal Stress Theory:

The theory we used was the maximum Normal Stress theory since the material we chose was brittle.

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Tensile Stress
Stress Limit Type	Tensile Yield Per Material

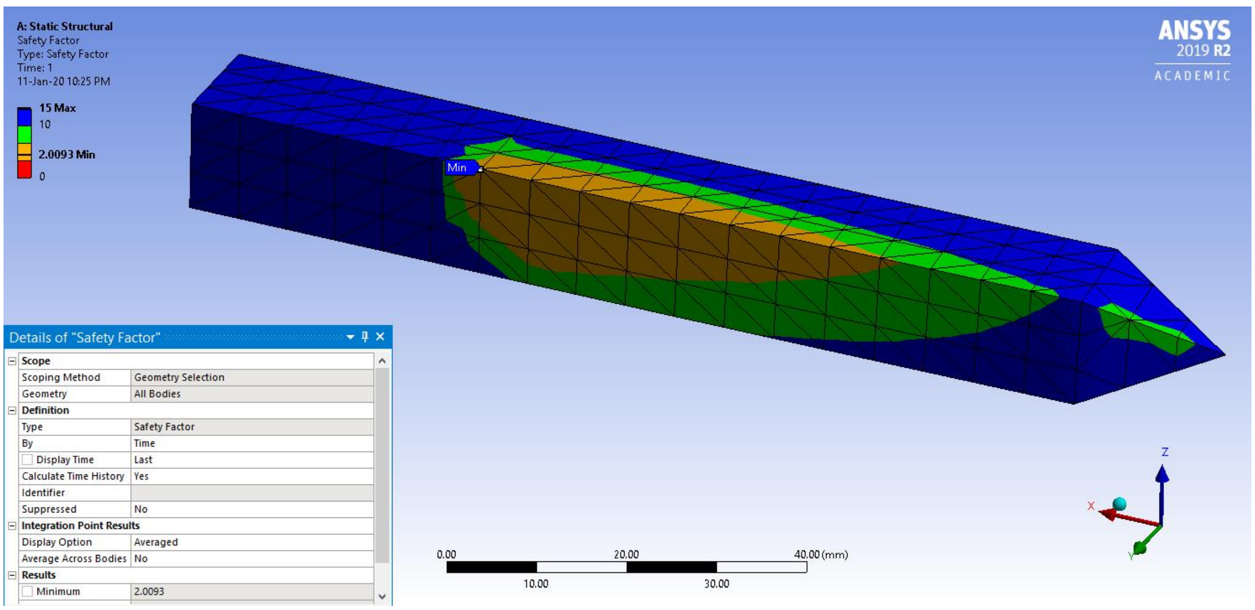
Safety Factor:

Object Name	*Safety Factor*
State	Solved
Scope	

Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
Results	
Minimum	2.0093

Object Name	*Alert*
State	Solved
Definition	
Fails If	Minimum Below Value
Value	2.
Results	
Status	Passed: Minimum Above Value

According to the theory, the material is **SAFE.**



Conclusion:

We have designed our Single Point Cutting tool of Material High Speed Tool Steel with dimensions: Square Cross-Section 13 x 13 mm, and total length 120 mm out of which 35 mm is used for clamping of the cutting tool inside the tool post. After designing, we even analyzed our design on Ansys and found it completely safe with a factor of safety of 2.

REFERENCES

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