"Structural Analysis of Sheet Metal Curling Tool"

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Abstract: Out of all traditional process like casting, cutting, forging, forming etc. sheet metal forming is special case of deformation process in which sheet metal work is formed. Curling is a process of converting flat sheet metal into required curved radius surface with applying pre-determined force on press tool, having curl die. Generally, sheet metal formed in press tool with required curl profile die arrangements. The main aim of this project work is design and finite element analysis of curling tool. The curl tool is designed for curling sheet metal of thickness 1.5mm, 2mm and 2.5mm. Based on material properties of sheet metal, radius of curl required and press ton efficiency, Design of curl tool has been done analytically. With these design calculations, 3D modeling of curling tool is done. The finite element analysis carried out by applying appropriate boundary conditions. Then results ofequivalent (Von-Mises) stress and total deformation are evaluated and verified. The software packages used are Solid Edge ST7 for modeling of Curling tool and ANSYS Workbench 14.5 (Structural) for Preprocessing, Solving and Post processing of curling tool.

***Index Terms* - Curling Tool, Equivalent (Von-Mises) stress, FEA, Ansys, and Sheet Metal.**

I. INTRODUCTION

Press Tools used to produce sheet metal components in large volume by applying an external force with the help of Press Machine or Press Tool. Some operation like Blanking, Piercing, Bending, and Forming Etc. this basic operation carried out in Press Tool. [1].Sheet metal is simply metal formed into thin and flat pieces it can also bend and cut into a verity desired shape without removal of chips. Sheet metal operations are economical and producing accurate, strong and durable metal stamping in huge quantity, so it is used in automobile and aircraft firm depend on largely on Press Tools. [1] The Press Tool produces in high productivity, low cost per part, minimum scrap and minimum energy consumption. [2]
Selection of proper material for Press Tool components has become one of the important aspects listed below [2]

- Hardness of sheet metal.
- Type of operation to be performed on Press Tool.
- Geometrical complexity of parts to be produced.
- Die design and die size.

1.1 TYPES OF PRESS TOOL

1. Blanking Tool
2. Piercing Tool
3. Cut off Tool
4. Parting off Tool
5. Trimming Tool
6. Shaving Tool
7. Bending Tool
8. Forming Tool
9. Drawing Tool
10. Progressive Tool

1.2 CONSTRUCTION OF GENERAL PRESS TOOL

Bottom Plate: Bottom plate is the base of the tool. The die and guide pillars are fitted to this plate. It provides cushioning effect to the die. It employs an opening at bottom to collect the output blanked part.
Die Plate: Die is one of important cutting tool in the blanking tool. The size or contour of the die opening will be same as the dimension of the desired output component.
Stripper Plate: After blanking operation when punch is withdrawn back, the blanked part adheres (Stick on) to punch surface. To facilitate removal of part from punch, stripper used. Also it used for guiding punch and to hold the strip flat during punching operation
Punch Holder: It is a plate used to hold the punch in position without any transition. Punch holder provides a rigid support to the punch during punching.

Blanking Punch: Punch is the other important cutting tool in the blanking tool. A force is exerted on the punch by the press to punch the strip placed on the die. The size of the punch will besmaller than dimension of the desired component. It will penetrate into die for minimum of 3 to 5mm.

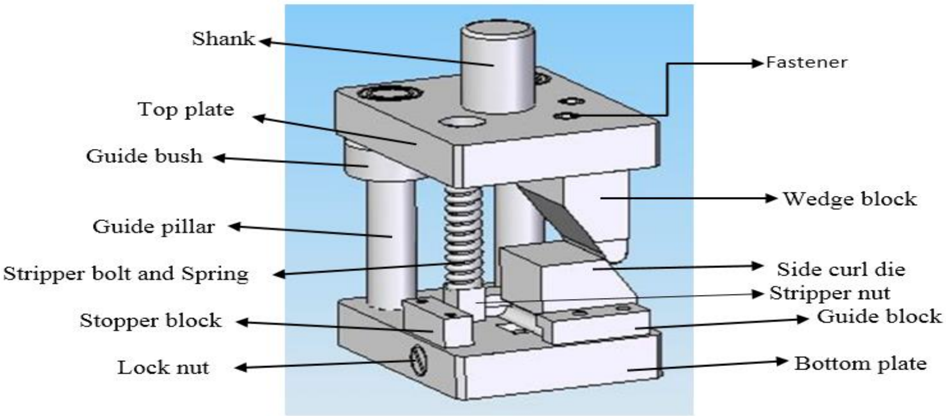


Fig 1: Parts of Press Tool

Thrust Plate: While punching the strip, the punch exerts an upward thrust. To prevent that thrust being transmitted to top plate, a thrust or back plate is provided behind the punch. Otherwise it will damage the top plate.

Top Plate: The punch assembly consisting of punch, punch holder and thrust plate is mounted on the top plate with screws and dowels. Shank also screwed to top plate.

Guide Pillar and Guide Pillar: Guide pillar and bushes are used to align the top and bottom plate. They keep the complete alignment of tool during entire operation.

Shank: Shank is a connector between tool and the press ram. It is screwed to the top plate firmly.

1.3 SHEET METAL PROCESSES

- **SHEARING PROCESS**
  Punching:shearing process using a die and punch where the interior portion of the sheared sheet is to be discarded.
  Blanking: shearing process using a die and punch where the exterior portion of the shearing operation is to be discarded.
  Perforating: punching a number of holes in a sheet
  Parting: shearing the sheet into two or more pieces
  Notching: removing pieces from the edges
  Lancing: leaving a tab without removing any material.

- **FORMING PROCESS [3]**
  Bending: forming process causes the sheet metal to undergo the desired shape change by bending without failure. **Stretching:** forming process causes the sheet metal to undergo the desired shape change by stretching without failure. **Drawing:** forming process causes the sheet metal to undergo the desired shape change by drawing without failure.
  Roll forming: Roll forming is a process by which a metal strip is progressively bent as it passes through a series of forming rolls.
  Curling: It is an operation of rolling the edges of a sheet metal into Curlor roll.

1.3.1 ABOUT SHEET METAL CURLING PROCESS

It is also one type of forming process in which shaping the sheet metal straight profile to cured profile. This is done by using shape and profile of the punch and die. It is also done to remove sharp edge in the component to improve appearance to facilitate assembly. Curling can also increase moment of inertia near the curl end.

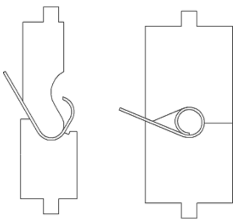


Fig 2: Curling Operation

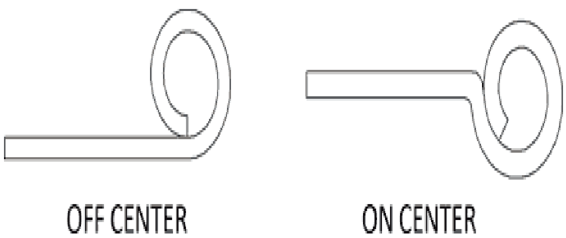


Fig 3: Basic form of Curl

Metal that does not respond to curling may be provided with slight bend in the direction of curling, it is called as Pre-Curling. Curl comes in two basic form those are,

- **Off Centre** - The centre of the roll above the original plane of the sheet metal.
- **On Centre-** The centre of roll in line with the plane of the sheet metal

1.3 FINITE ELEMENT ANALYSIS

To heighten the understanding the behaviour of machine component the analyst at his disposal three standard tools

- Analytical Methods
- Numerical Methods
- Experimental Methods

For small geometries the analytical method is holds good and gives quick close from solution. It captures only idealized structural theory. By the help of experimental techniques the full scale model can be tested, but it is very costly and time consuming. Numerical methods are made little assumptions and solve complex geometries. This is less cost effective compare than experimental techniques. The most versatile numerical method in the engineer are the finite element method (FEM).Finite element analysis is to simulate loading condition. The FEM is also known as computational method.

2.0 METHOLOGY

2.1 DESIGN AND ANALYSIS OF CURLING TOOL

With the help of sheet metal curling tool simulations, we can predict the stress developed in the curling tool which can lead to satisfactory tool design and select proper process parameters. The main step of work is approximate dimension of the individual parts of curling tool as per calculated sheet metal thickness, impact force and shear strength on the tool[9].

2.1.1 Design Calculations of Curling Tool Parts

According to sheet metal curling operation is planed the initial step to analyze the type forces are produced on curl tool. Calculate the force required to curl the sheet metal according to perimeter of curl, thickness of sheet metal and shear stress

2.1.1 (a) Design of Fastener (Screw)

The transverse force acting on the die block which is used to holed the die parts together by means of screws. Therefore the transverse force acting on the die block is usually 20-30% of total shear force for the tool.

Transverse force = 20 - 30%of total F_s

$$\frac{30}{100} \times 11036.25 = 3310.87N$$

Let the minimum number of screws required = 4 no's

Transverse Force = Area × Number of screws × F_s

$$3310.87 = \frac{\pi}{4} \times D^2 \times 4 \times 25$$

$$\frac{4\times 3310.87}{\pi\times 4\times 25} = D^2$$

D^2 =42.41mm:

D = 6.4mm ≈ 6 mm

Therefore, M6 screw is selected.

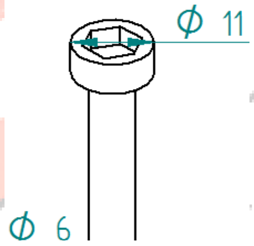


Fig4: Fastener

(b) Thickness of Wedge block and Die block

Thickness of Wedge Block = $T_w = \sqrt[3]{F_s}$

$$T_w = \sqrt[3]{14}$$

= 25 mm

Thickness of Die Block = $T_D = \sqrt[3]{Press\ capacity}$

$$T_D = \sqrt[3]{14} = 25\text{mm}$$

(c) Thickness of Bottom Plate

$$T_b = 1.5\ T_d\ OR\ 1.5\ T_w$$

= 1.5 × 2 = T_b = 33 ≈ 30 mm

(d) Thickness of Top Plate T_t = 1.25T_d = 1.25 ×22 = 27.5 ≈25 mm

(e) Length of Top Plate & Bottom Plate

$$L = \left(\frac{1}{8} \times D\right) + L_D + \left(\frac{1}{8} \times D\right)$$

$$= \left(\frac{28}{8}\right) + 79 + \left(\frac{28}{8}\right)$$

L=105mm (raw material length)

(f) Width of Top Plate & Bottom Plate

$$W = \frac{D}{8} + \text{radius of bush} + W_D$$
$$= \frac{28}{8} + 14 + 120$$
$$= 137 \text{ mm} \approx 125\text{mm}$$

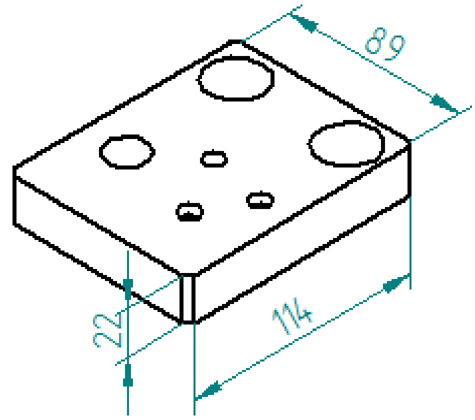


Fig 5: Isometric view of top plate

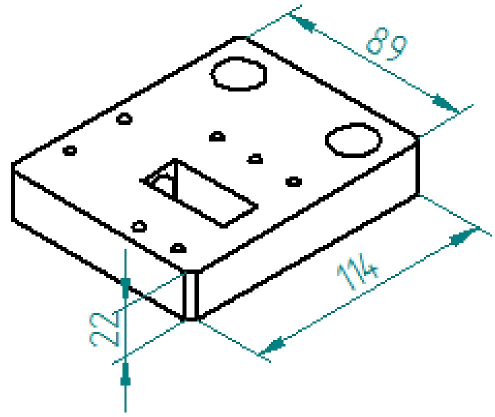


Fig 6: Isometric view of Bottom plate

2.1.2 Design of Shank

Thread diameter should be approximately the 50% of shank diameter

$$= \frac{50}{100} \times 30$$
$$= 15 \text{ mm}$$

Therefore, M12 Thread is selected

(a) Height of Shank above the Top Plate

$$H = \left(1 + \frac{1}{8}\right) \times D$$
$$= \frac{9}{8} \times 30$$
$$H = 33.75\text{mm} \approx 40\text{mm}$$

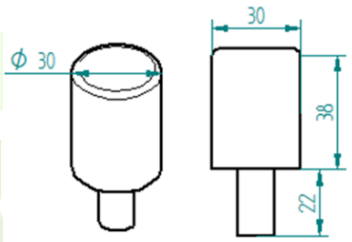
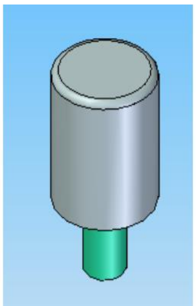


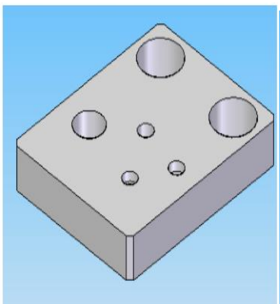
Fig 7: Isometric view of shank

2.2PART MODELLING

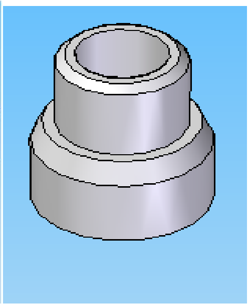
Parts of curling tool are created using CAD Software Solid Edge ST7.For the modelling of each parts are done using solid edge commands like Sketch, Protrusion, revolved Protrusion ,helical Protrusion, cut out, hole, threading on fastener, camper, round corner etc. Parts of curling tool shown in below



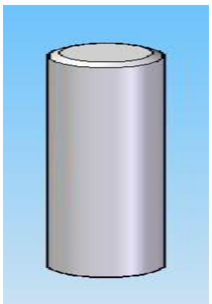
(a) Shank



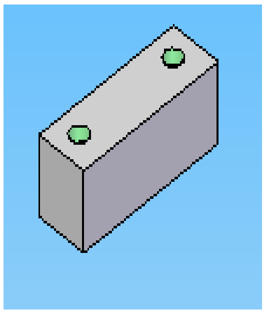
(b) Top plate



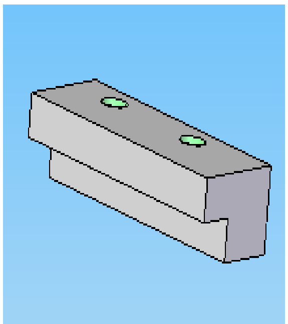
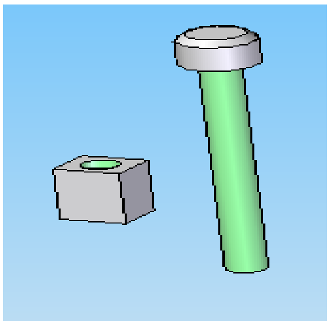
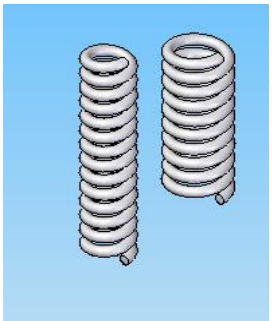
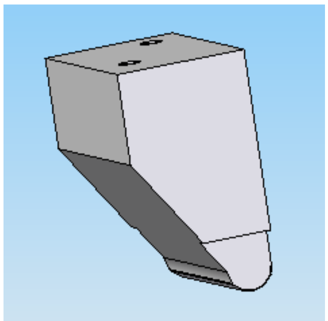
(c) Guide Bush



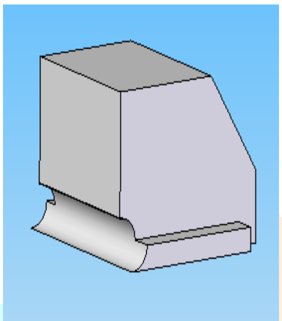
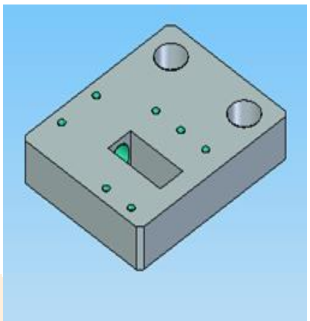
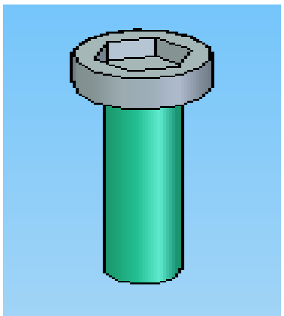
(d) Guide Pillar



(e) Stopper block

(f) Guide block (g) Stripper bolt and nut (h) Springs (i) Wedge block

(j) Side curl die (k) Bottom plate (l) Fasteners

Fig 8: Separate parts of curling tool

2.3ASSEMBLY OF CURLING TOOL

Before assembly of curling tool browse the all parts to the library. By taking top and bottom plate are the reference parts assembling the all parts in correct manner. The fits in the assembly should be clearance fit. The final assembled file should be save in .STEP or .IGES format. The isometric and front view of assembled curling tool shown below Figure 9 and 10 respectively.

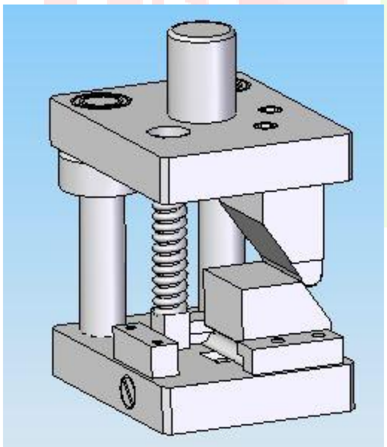


Fig 9: Isometric view

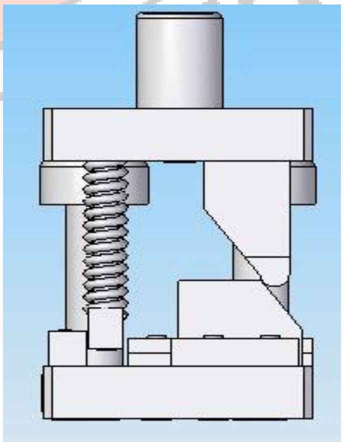


Fig 10: Front view

2.4CAE ANALYSIS OF CURLING TOOL

The software used for FE analysis is ANSYS WORKBENCH 14.5. First step is open the ANSYSIS WORKBENCH14.5 software. Select the suitable problem case (Static Structural) and drag on the work space. After upload below shown data

2.4.1 Engineering Data: The FE model mechanical behavior is decides by the material properties. Here we will used a simple linear-elastic, isotropic material model. In the project schematic, right click on Engineering Data to open a context menu and select Edit and choose the material properties model by dragging the item Isotropic Elasticity from the library and dropping it onto the row with your newly defined material. Isotropic Elasticity requires certain material parameters such as Young'sModulus, Density and Poisson's Ratio. Final step update and return the project. The properties of material shown in below Table 1

Table 1: Material Properties

Materials	Young's Modulus(E) (MPa)	Poisson's (υ) Ratio	Density (ρ) (Kg/m^3)
Mild Steel	210000	0.28	$7.8x10^{-6}$
High Speed Steel	219000	0.26	$8.11 x10^{-6}$
Chromium Vanadium Steel	210000	0.29	$7.8 x10^{-6}$

2.4.2. Geometry: First step is import the file from directory, brows the file extension in .STEP or .IGES files. Open the geometry new design modeller window will open. Now select the measuring units used for task (Millimeter). Now click on generate option, model will be displayed. Save the project and close the design modeller window. The green tick mark will confirm the model is uploaded or not.

2.4.3. Geometry: First step is import the file from directory, brows the file extension in .STEP or .IGES files. Open the geometry new design modeller window will open. Now select the measuring units used for task (Millimetre). Now click on generate option, model will be displayed. Save the project and close the design modeller window. The green tick mark will confirm the model is uploaded or not.

2.4.4. Model: The new mechanical (static structural) window will open. Select proper metric units (mm, kg, N, s, mV, mA) Degree, rad/sec, Celsius.

- **Geometry:** Assign the individual parts property in geometry option. For spring material is selected is Chromium Vanadium Steel. For wedge block and side curl die High Speed Steel. Remaining all parts is mild steel.
  The curling tool mass and volume shown in below Table 2

Table 2: Mass and volume of curling tool

Volume	$7.410 X 10^5 mm^4$
Mass	4.94 Kg

- **Coordinate System:** The new global coordinate system if it is required on part or plane for easy to applying boundary condition for analysis. Click on global coordinate then insert new coordinate system by selecting plane on geometry and options principle axis, orientation about principle axis.
- **Mesh:** The dividing complex model into small fine element to make easy calculation. The mesh sizing is less or fine mesh will gives comparatively good and accurate results. The meshing elements used is hexa element and tetrahedral elements For generating mesh on curling tool following steps carried out
  - Select insert option and then click on method option then select the rectangular faces. Then generate hexahedral mesh by selecting option.
  - Click on insert option and then select circular parts in curling tool. Now select the tetrahedral mesh type and generate mesh.
  - Enter the element size 5mm and smoothing is high, now generate mesh
  - Finally check the quality of mesh.
  - Observe the number of nodes and elements shown in Table 3 and also check the quality of mesh.

Table 3: Total numbers of nodes and element

Nodes	95738
Elements	51525

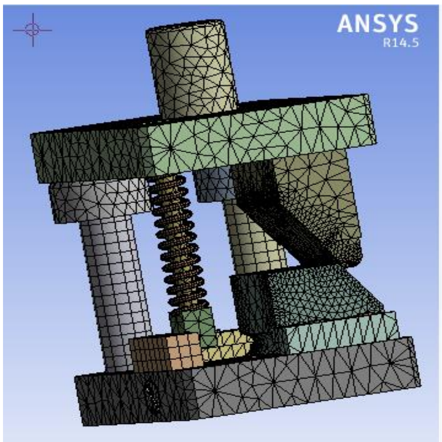


Fig 11: Meshed tool

2.5STATIC STRUCTURAL:

It is main step apply the calculated boundary condition for analysis. The static structural is contains several inertia load, external load and supports.

For analysis of curling tool following boundary conditions applied

- Fixed support is used fix the bottom face of plate.
- Apply vertical force on top face of shank.

Figure 12 and 13 represents fixed support bottom plate and vertical force on shank respectively.

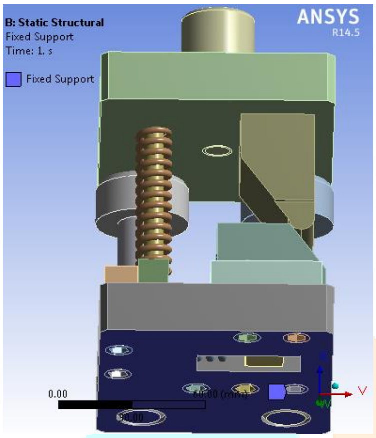


Fig 12: Fixed support at bottom plate

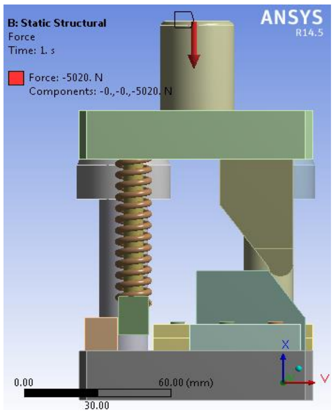


Fig 13: Force applied on shank

2.5.1 Boundary conditions applied: In this work the boundary conditions are, the bottom plate is constrained with fixed support option. The curling tool operation will do by applying vertical load on the shank. The application of vertical load, moment of the side curl die takes place every one stroke therefore the curling of sheet metal will takes place. The amount of load is calculated by using shear force and press capacity formulas. The press selection is mainly depends on the thickness of sheet metal, perimeter of curl, press efficiency and shear stress of sheet metal material[9].In general sheet metal thickness in between 1.5 mm to 4 mm. This curling tool designed for curling sheet metal extreme value 2.5 mm thickness of sheet metal. Here we calculate press capacity for 1.5 mm, 2 mm and 2.5 mm. The press efficiency is 70%.

Values are known for this analysis is shown below

Where $l_s = 30\ mm\ ,t\ = 1.5\ mm\ ,2\ mm\ and\ \ 2.5mm$

$$f_s(For\ aluminium) = 25\ kg/mm^2$$

A. Force applied for 1.5 mm Sheet Metal

- Shear force required for press:

Shear force = Shear area * Shear Stress

$$F_s = A_s\ \times f_s$$

Shear Area = (Perimeter of curl) ×(Thikness of sheet metal)

Shear force = $l_s\ \times t\ \times f_s$

$$F_s = (30\ X\ 1.5 \times 25\ X\ 9.81)\ = 11036.25\ N$$

- **Press selection:**

$$\text{Press capacity required} = \frac{Total\ F_s}{70\ to\ 80\%}$$

$$= \frac{11036.25}{0.70} = 15766.07\text{ N} \quad \approx 15800\text{ N}$$

To get experimental press value dividing the theoretical values by π [By fracture mechanics]

Experimental applied force is $= \frac{15800}{\pi} = 5029.30 \approx 5100$ N

B. Force applied for 2 mm Sheet Metal

- Shear force required for press:

$$F_s = l_s\ \times t\ \times f_s$$

$$F_s = (30 \times 2 \times 25\ X\ 9.81)$$

$$F_s\ = 14715\ N$$

Press selection:

$$\text{Press capacity required} = \frac{Total\ F_s}{70\ to\ 80\%}\ = \frac{14715}{0.70} = 21021.4\text{ N} \approx 21100\text{ N}$$

Experimental applied force is $= \frac{21021.4}{\pi}$ =6691.31 ≈ 6700 N

C. Force applied for 2.5 mm Sheet Metal

- Shear force required for press:

$$F_s = l_s \times t \times f_s$$

$$F_s = (30 \times 2.5 \times 25 X 9.81)$$
$$F_s = 18393.75 N$$

- **Press selection:**

Press capacity required $= \frac{Total\ F_s}{70\ to\ 80\%}$

$= \frac{18393.75}{0.70}$

= 26276.7 N ≈ 26300N

Experimental applied force is $= \frac{26276.7}{\pi}$ =8364.1 ≈ 8400 N

Table 4: Experimental force applied for different sheet metal thickness

Sheet metal thickness (mm)	Shear force in sheet metal (N)	Theoretical force on curling tool (N)	Experimental force applied on curling tool (N)
1.5	11036.25	15800	5100
2	14715	21100	6700
3	18393.75	26300	8400

The different boundary conditions applied as follows

Case 1: Force applied for bend 1.5 mm sheet thickness is 5100 N
Case 2: Force applied to curl 2 mm sheet metal thickness is 6700 N
Case 3: Applied Force for bend 2.5 mm sheet metal thickness is 8400 N

2.6 Solution: The final step in analysis in this we get required stress plots, strain plots, deformation plots, table and graphs. To get results click on solve option. The flowing plots we get in solution

- Equivalent (Von-Mises) stress
- Total deformation

The solution information gives the approximate time to solve the problem. It will give some solver output like force convergence, time, max DOF increment and time increment.

The below Figure 14 shows force convergence graph in that the applied force and body forces line are converged or intersect each other, then only we get results. Along the X-axes cumulative increment and Y-axes force.

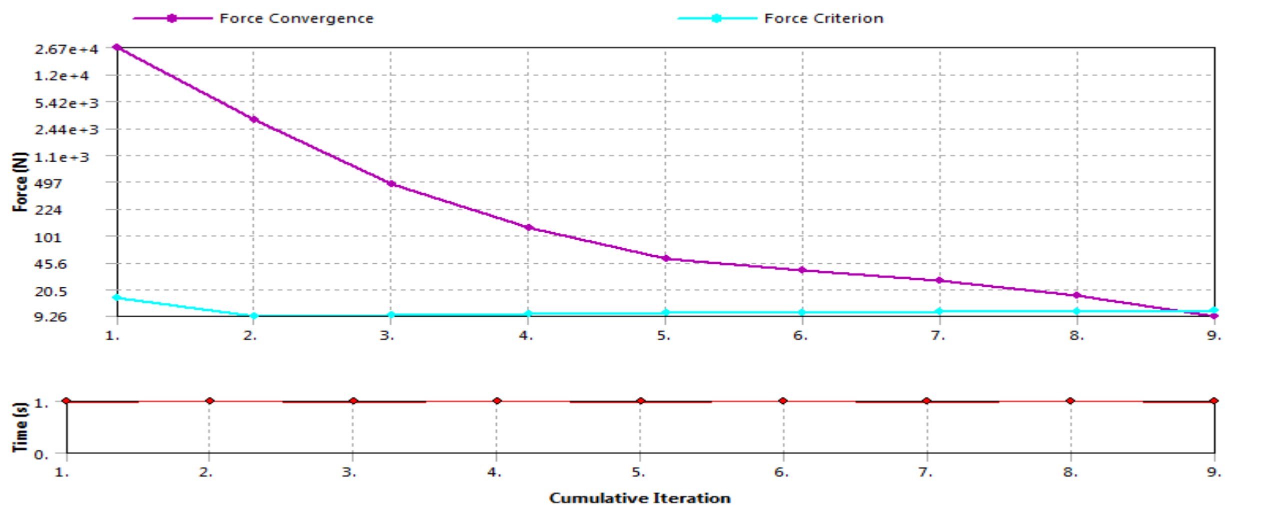


Fig 14: Force convergence graph in that the applied force and body forces

The above plotted graph shows the force convergence of the model. The sky blue colour represents the body force inside the model and pink colour line represents the applied boundary conditions. The number of cycle, time is the increment step by step. At certain point the both lines intersect each other then only solution will completes. That is called force convergence. The graph, tables and counter plots will solve results will come.

III RESULTS AND DISSCUSIONS

3.1. For curl 1.5 mm sheet metal

Case 1: The contour plot of Von-Mises stress shown in below figure 4.1. Applied load is 5100 N

- **Equivalent (Von-Mises) stress :**

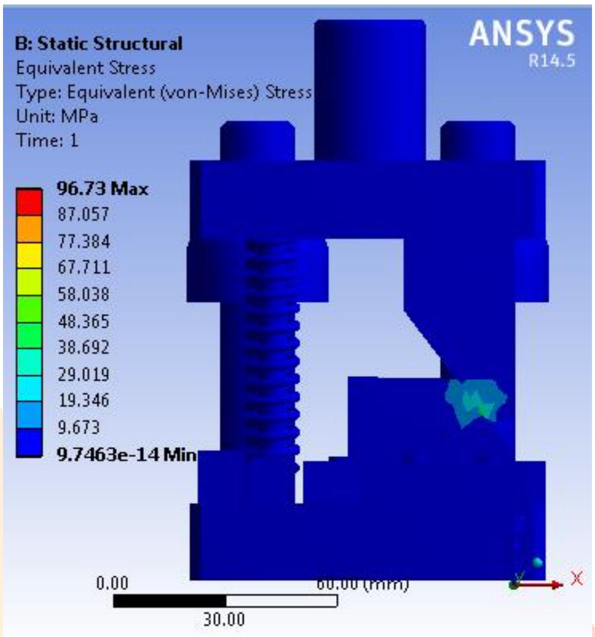


Fig 15: Von-Mises stress distribution of the sheet metal curling tool for applied load is 5100 N

The above Figure 15 shows Von-Mises stress distribution of the sheet metal curling tool. The maximum Von-Mises stress obtained is 96.73 MPa at the wedge block and side curl die interface. The obtained maximum stress is well within the yield stress of the steel (240 MPa). Hence design is safe for curling of 1.5 mm sheet under load of 5100 N.

- **Total deformation :**

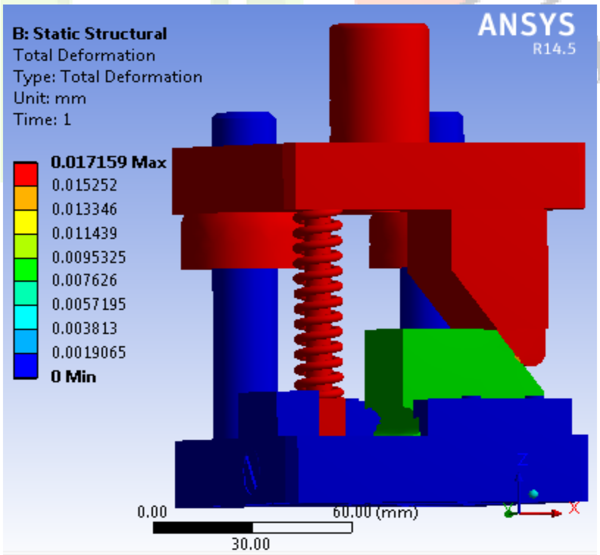


Fig 16: Total deformation of curling tool for applied load is 5100 N

The above Figure 16 shows the total deformation of curling tool. The maximum deflection obtained is 0.017 mm at the tip of a top plate. The less deflection is occurs towards bottom plate.

3.2. For curl 2 mm sheet metal

Case 2: Load applied to curl 2 mm sheet metal thickness is 6700 N.

- **Equivalent (Von-Mises) stress :**

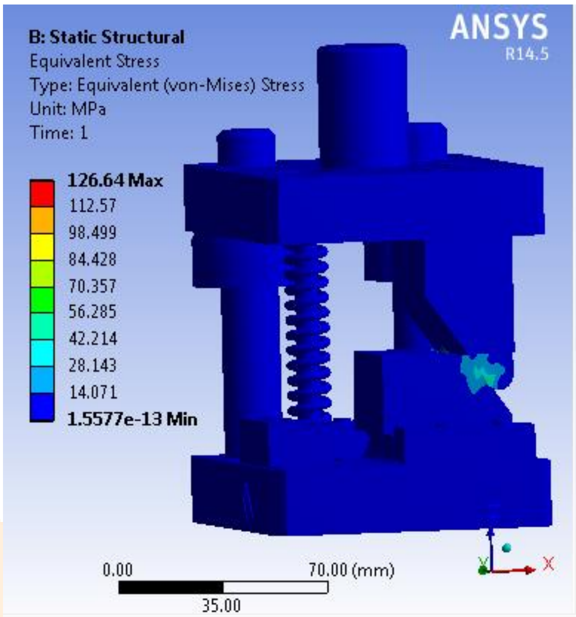


Fig 17: Von-Mises stress contour plots for loading 6700 N

The above Figure 17 shows Von-Mises stress distribution of the sheet metal curling tool. The maximum Von-Mises stress obtained is 126.64 MPa at the wedge block and side curl die interface. The obtained maximum stress is well within the yield stress of the steel (240 MPa). Hence design is safe for curling of 2 mm sheet under load of 6700 N.

- **Total deformation :**

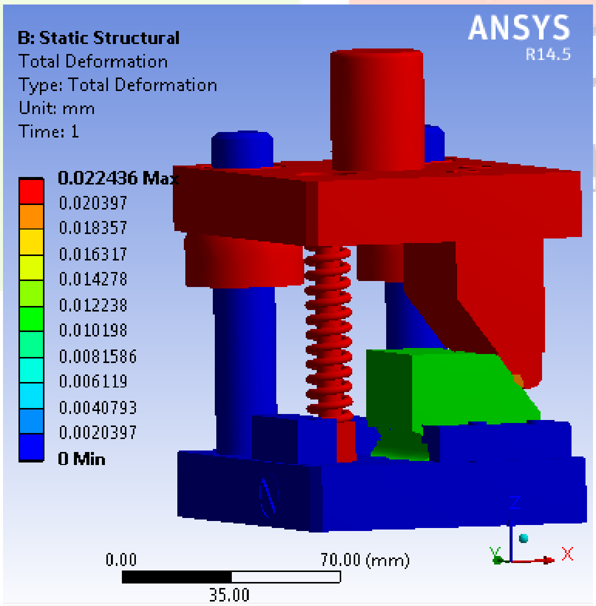


Fig 18: Total deformation tool with loading 6700 N

The above Figure 18 shows the total deformation of curling tool. The maximum deflection obtained is 0.022mm at the tip of a top plate. The less deflection is occurs towards bottom plate.

3.3. For curl 2 mm sheet metal

Case 3: Applied load for bend 2.5 mm sheet metal thickness is 8400 N.

- **Equivalent (Von-Mises) Stress :**

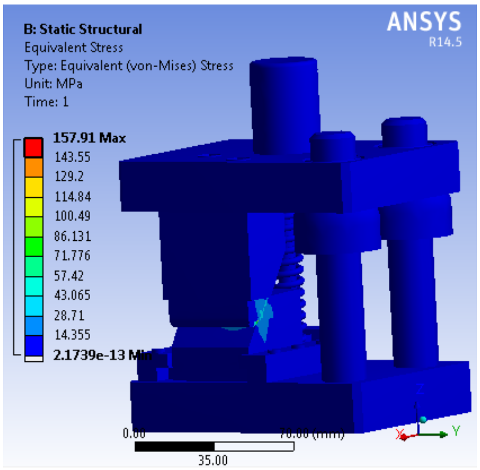


Fig 19: Equivalent stress distribution under load 8400 N

The above Figure 19 shows Von-Mises stress distribution of the sheet metal curling tool. The maximum Von-Mises stress obtained is 157.91 MPa at the wedge block and side curl die interface. The obtained maximum stress is well within the yield stress of the steel (240 MPa). Hence design is safe for curling of 2.5 mm sheet under load of 8400 N

- **Total deformation :**

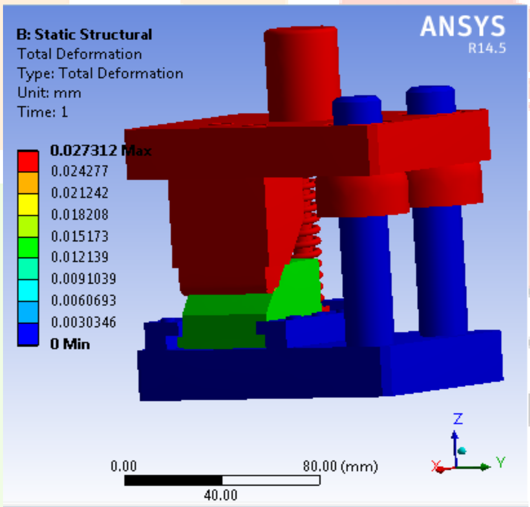


Fig 20: Total deformation of curling tool under load 8400N

The above Figure 20 shows the total deformation of curling tool. The maximum deflection obtained is 0.027 mm at the tip of a top plate. The less deflection is occurs towards bottom plate.

Table 5: Results compression

Sheet metal thickness in (mm)	Force applied On Curling tool (N)	Von-Mises stress of Curling tool (MPa)	Total deformation of Curling tool (mm)
1.5	5100	96.73	0.017
2.0	6700	126.64	0.022
2.5	8400	157.91	0.027

IV CONCLUSION

The present work involves design of curling tool, part modelling and assembly and FE analysis. The structural analysis of sheet metal curling tool has been analyzed to investigate the equivalent (Von-Mises) stress developed in curling tool for different combinations of sheet metal thickness and load applied such as 1.5mm sheet metal thickness with loading of 5100N, 2mm sheet metal thickness with loading of 6700N and 2.5mm sheet metal thickness with loading of 8400N. The maximum equivalent (Von-Mises) stress developed are 96.73 MPa, 126.64 MPa and 157.91 MPa in 1.5mm, 2mm and 2.5mm thick sheet metal respectively. The corresponding deformation in the curling tool sheet metal for these thicknesses are 0.017mm, 0.022mm and 0.027mm respectively.

The obtained stress values are well within the yield stress of the steel (240 MPa) and also the deformation obtained are far less than the prescribed value. Thus the design is safe.

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