DESIGN AND ANALYSIS OF PRESS TOOL

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Abstract: With the advancement in technology, there has been an increasing use of sheet metal components and press tools serve as one of the widely used tool for operations on sheet metals. As the name itself suggests, it is used to produce sheet metal components of different sizes and shapes with a predetermined force. Press tools are used for continuous mass production of components. This leads to the requirement for the use of a tool material that possesses high strength which would be able to withstand repeated heavy loads. Improper selection of tool material and design procedure could incur heavy loss, distorted parts, production risk etc. Prior modeling and analysis of the complete press tool in CAD and CAE software would provide and effective tool to overcome these uncertainties. As far as this project is concerned; a progressive die is designed and modeled using CATIA for manufacturing a handle bracket component. Several operations can be performed in series in a progressive tool as the stock registers at different workstations during each stroke leading to the development of the final component. The corresponding operations to produce a handle bracket include blanking and punching followed by bending operations respectively. In this work, D3 steel is chosen as the punch and the die material for the progressive press tool and finally static analysis is performed using ANSYS software to check the safety of the design.

IndexTerms **- CATIA, ANSYS, blanking, punching, bending, press tool, progressive die.**

I. INTRODUCTION

The machine used for press working operations is called a press tool. A press tool mainly consists of a die and a punch which are specifically designed to get a component of the desired shape. . The component with the desired shape is produce using sheet metals. The sheet metal is placed on the die and the punch is then lowered under a heavy pressure. The metal is thus pressed between the die and the punch so that the component with desired shape is obtained. A progressive tool performs multiple operations in series as the stock registers at different workstations during each stroke leading to the development of the final component. This paper aims at optimum design of a progressive press tool using CATIA and ANSYS. Analysis is carried out in order to prevent practical problems and try-outs. Moreover, it provides an opportunity to incorporate modifications and changes in the design when needed.

II. METHODOLOGY

Initially, a sheet metal component/product (handle bracket) is chosen which is manufactured using a progressive press tool. The operations that are needed to be carried out to obtain the component include punching, blanking followed by bending operations respectively. The bend and unbent lengths of the component are calculated and arranged correspondingly to get the entire strip layout. From the layout, the shape of the blanking and bending punches are obtained. With respect to the layout, the forces required to punch, blank and bend the strip are calculated. After combining all the forces, the total press tonnage capacity of the progressive press tool is determined. Using the total cutting and bending forces obtained, the dimensions of the critical parts of the progressive tool is calculated. From the press tool data handbook, the dimensions of the remaining parts are obtained. Using the dimensions obtained, all the parts of the press tool are modeled in CATIA. With the application of suitable material properties (D3 steel), boundary conditions and loads, the critical parts of the press tool are analyzed in ANSYS. Finally, the results obtained from the analysis are compared with the calculated theoretical results to validate the design of the progressive press tool.

III. DESIGN CALCULATION

3.1Component data:

Material: Aluminium
Thickness- 2.64 mm
Shear strength- 80 N/mm^2
Tensile strength- 120 N/mm^2
Supply condition: Strips

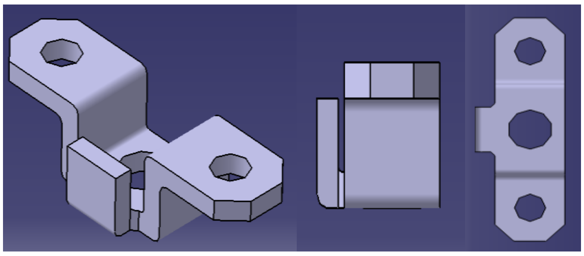


Fig. 1**:** Handle bracket

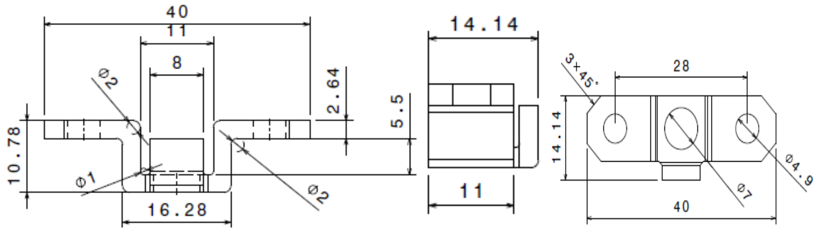


Fig. 2: Dimensions of handle bracket (all dimensions in mm)

3.2 Strip layout:

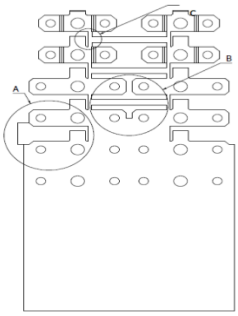


Fig. 3.1: Strip layout

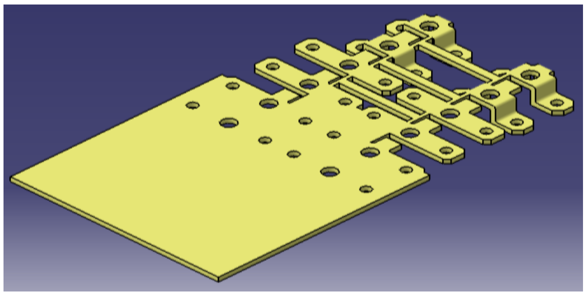


Fig. 3.2: Strip layout

Material utilization:

It can be defined as the ratio of the area of blanks from strip to the area of the strip before blanking. Material utilization can also be defined as the ratio weight of blank strip to the weight of strip before blanking. Its main objective is to reduce the material wastage and scrap rate [9].

$$\text{Material utilization} = \frac{\text{Area of blanks from strip}}{\text{Area of the strip before blanking}} \quad (1)$$

$$\text{Material utilization} = \frac{5177.5-\{(2*335.9)+(2*136.5)+(2*20)+(2*38.485)+(4*18.457)\}}{5177.5}$$

$$=78.06\%$$

3.3Force calculation:

The amount of force required to shear out material from the stock can be calculated using the following formula [9]:

Blanking force:

S_A = Shear area for blank A (mm^2)

S_B = Shear area for blank B (mm^2)

S_C = Shear area for blank C (mm^2)

Perimeter of blank A, C_A= 111.12 mm

Perimeter of blank B, C_B= 92.42 mm

Perimeter of blank C, C_C= 24 mm

Material thickness, T = 2.64 mm

V_A = Cutting force required for blank A (N)

V_B = Cutting force required for blank B (N)

V_C = Cutting force required for blank C (N)

Shear strength of the material (Al) cut from the strip layout, fs = 200 N/mm^2

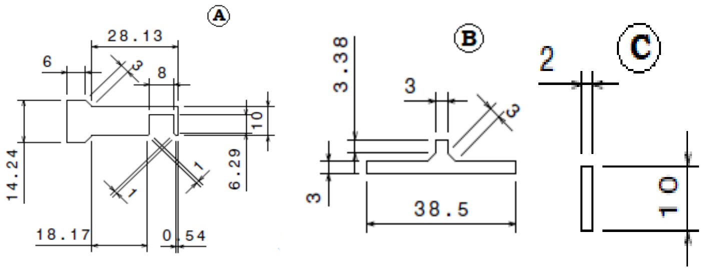


Fig.4: Length of blanks A, B and C (all dimensions in mm)

For blank A:

$$S_A = C_A T \quad (2)$$
$$= 293.356 \text{ mm}^2$$
$$V_A = S_A \times f_s \quad (3)$$
$$= 23468.8 \text{ N}$$

For blank B:

$$S_B = C_B T \quad (4)$$
$$= 243.988 \text{ mm}^2$$
$$V_B = S_B \text{ x } f_s \quad (5)$$
$$= 19519.04 \text{ N}$$

For blank C:

$$S_C = C_C T \quad (6)$$
$$= 63.36 \text{ mm}^2$$
$$V_C = S_C \text{ x } f_s \quad (7)$$
$$= 5068.8 \text{ N}$$

Piercing force (punching):
$S\varphi_7$ = Shear area for φ7 mm punch hole (mm^2)
$S\varphi_{4.9}$ = Shear area for φ4.9 mm punch hole (mm^2)
Material thickness, T = 2.64 mm
$V\varphi_7$ = Cutting force required for φ7 mm punch hole (N)
$V\varphi_{4.9}$ = Cutting force required for φ4.9 mm punch hole (N)
Shear strength of the material (Al) cut from the strip layout, fs = 80 N/mm^2
For hole with diameter 7:

$$S\varphi_7 = CT \quad (8)$$
$$= \pi \text{ x } 7 \text{ x } 2.64$$
$$= 58.056 \text{ mm}^2$$
$$V\varphi_7 = S\varphi \text{ x } f_s \quad (9)$$
$$= 58.056 \text{ x } 80$$
$$= 4644.48 \text{ N}$$

For hole with diameter 4.9:

$$S\varphi_{4.9} = CT \quad (10)$$
$$= \pi \text{ x } 4.9 \text{ x } 2.64$$
$$= 40.639 \text{ mm}^2$$
$$V\varphi_{4.9} = S\varphi_{4.9} \text{ x } f_s \quad (11)$$
$$= 40.639 \text{ x } 80$$
$$= 3251.12 \text{ N}$$

Bending force:

Bending force required to bend a work piece depends upon the thickness of the work piece. Bending force can be calculated from the following formulae [9]:

For bending channels:

$$\text{Bending force, } V_{BEc} = \frac{2.66 \text{ LT}^2 \text{ ft}}{\text{W}} \quad (12)$$

where
L = Transverse length of channel (mm)
T = Material thickness (mm)
ft = Material tensile strength (N/mm^2)
W = Width of channel (mm)

$$V_{BEc} = \frac{2.66 \text{ x } 11 \text{ x } 2.64^2 \text{ x } 120}{16.28}$$
$$= 1503.173 \text{ N}$$

For 'V' bending:

$$\text{Bending force, } V_{Bev} = \frac{1.33 \text{ LT}^2 \text{ ft}}{\text{W}} \quad (13)$$

where
L = Transverse width of blank (mm)
T = Material thickness (mm)
ft = Material tensile strength (N/mm^2)
W = Top width of 'V' (mm)

$$V_{BEv} = \frac{1.33 \text{ x } 11 \text{ x } 2.64^2 \text{ x } 120}{18.153}$$
$$= 674.038 \text{ N}$$

$$\text{Total bending force, } F_{BE} = 2(V_{BEc} + V_{Bev})$$
$$= 2(1503.173+674.038)$$
$$= 4354.422 \text{ N}$$

3.4 Press tonnage:

The capacity of the press is the ability to deliver enough force necessary to perform the metal working operation.

Total press capacity = Total shearing force+ Total bending force

$= F_{S} + F_{BE}$

= 118402.72+4354.422 N

= 122757.142 N

= 12.517 tons≈12 tons

3.5 Design of press tool elements:

Thickness of a rectangular die can be found from the following formula [9]:

$$T_d = \sqrt{\left(\frac{3V}{f}\left[\frac{\left(\frac{B}{A}\right)^2}{1+\left(\frac{B}{A}\right)^2}\right]\right)} \qquad (14)$$

where

T_d= Thickness of rectangular die (mm)

V= Vertical force (N)

f_t= Permissible tensile stress (N/mm^2) (160 N/mm^2)

B= Width of the slot

A= Length of slot (mm)

$$T_d = \sqrt{\left(\frac{3x118402.72}{160}\left[\frac{\left(\frac{18.153}{50}\right)^2}{1+\left(\frac{18.153}{50}\right)^2}\right]\right)} = 16 \text{ mm}$$

Thickness of bottom plate = 1.9T_d

= 1.9 x 16

= 30.4 ≈ 30 mm

Thickness of top plate = thickness of bottom plate

= 30 mm

Thickness of stripper plate = $\frac{1}{30}$ Width of the strip + 2 Thickness of strip

= $\frac{1}{30}$ x 109+ (2 x 2.64)

= 8.913 ≈ 9 mm

Thickness of punch holder = stripper thickness

= 9 mm

Thickness of back plate = 0.5 stripper thickness

= 4.5 mm

Shut height:

Press shut height is the distance between the table and the ram face in ram down, screw adjustment up position. Or it is the height of the press tool in the closed condition at the end of the downward position.

Shut height = 158 mm

Punch length = Shut height – die thickness – sum of die set bolster thickness- punch thickness +3

= 158 -16 -30-30-9+3

= 70 mm

Assembly:

Finally all the components of the press tool are assembled at the required positions.

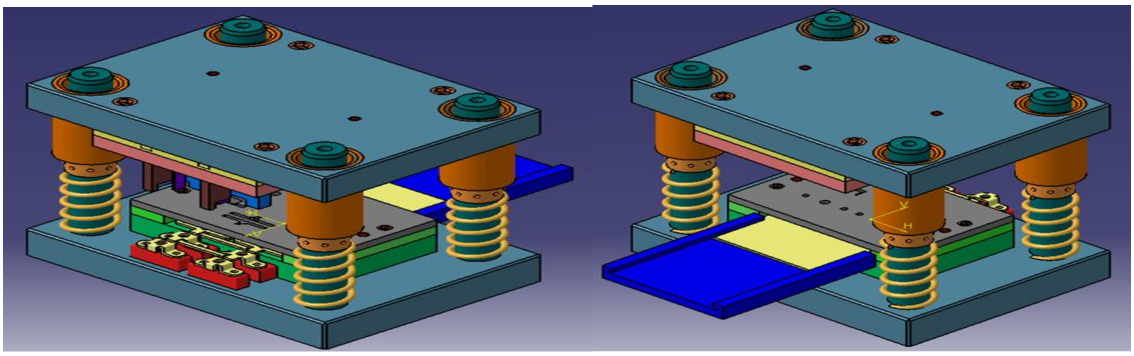


Fig.5: Isometric views of press tool

IV ANALYSIS

4.1 Theoretical deflection and stress calculation:

Die block:

The recommended deflection of the die block should be less than 0.025 mm. Assuming the die block as fixed beam, the deflection can be calculated using fixed supported beam formula [8]:

$$\text{Deflection, } \delta = \frac{FL^3}{192\ EI} \qquad (15)$$

Where F = 80% of cutting force
= 0.8 x 118402.72 = 94722.176 N
L = 170 mm
E = 2.1×10^5 N/mm^2

$$I = \frac{bh^3}{12} \qquad b = 170 \text{ mm}, h = 16 \text{ mm}$$

$$= 58026.66 \text{ mm}^4$$

$$\delta = \frac{94722.176 \times 170^3}{192 \times 2.1 \times 10^5 \times 58026.66} = 0.024 \text{ mm}$$

Stress can be calculated from the following relation:

$$\text{Stress } \sigma = \frac{F}{A} \qquad (16)$$

Where F = Load applied
A = Area of cross section

$$\sigma = \frac{94722.176}{175 \text{x} 111}$$

$$= 4.876 \text{ N/mm}^2$$

Top plate:

Top plate can be considered as simply supported beam loaded at the centre and the deflection can be calculated using the formula as follows:

$$\text{Deflection, } \delta = \frac{5FL^3}{354\ EI} \qquad (17)$$

Where F = 80% of cutting force
= 0.8 x 118402.72
= 94722.176 N
L = 275 mm
E = 2.1×10^5 N/mm^2

$$I = \frac{bh^3}{12} \qquad b = 275 \text{ mm}, h = 30 \text{ mm}$$

$$= 618750 \text{ mm}^4$$

$$\delta = \frac{5 \text{x} 94722.176 \times 275^3}{354 \times 2.1 \times 10^5 \times 618750} = 0.0204 \text{ mm}$$

Stress can be calculated from the following relation:

$$\text{Stress } \sigma = \frac{F}{A} \qquad (18)$$

Where F = Load applied
A = Area of cross section

$$\sigma = \frac{94722.176}{275 \text{x} 200}$$

$$= 1.722 \text{ N/mm}^2$$

Bottom plate:

Assuming that, the bottom plate is fixed on the parallels, the shoe deflection can be calculated using the formula for supported beams:

$$\text{Deflection, } \delta = \frac{5FL^3}{354\ EI} \qquad (19)$$

Where F = 80% of cutting force
= 0.8 x 118402.72
= 94722.176 N
L = 275 mm
E = 2.1×10^5 N/mm^2

$$I = \frac{bh^3}{12} \qquad b = 275 \text{ mm}, h = 30 \text{ mm}$$

$$= 618750 \text{ mm}^4$$

$$\delta = \frac{5 \times 94722.176 \times 275^3}{354 \times 2.1 \times 10^5 \times 618750} = 0.0204 \text{ mm}$$

Stress can be calculated from the following relation: [19]

$$\text{Stress } \sigma = \frac{F}{A} \qquad (20)$$

Where F = Load applied
A = Area of cross section

$$\sigma = \frac{94722.176}{275x200}$$
$$= 1.722 \text{ N/mm}^2$$

Guide pillar:

Assuming the guide pillar to be cantilever beam with one end fixed and the other free with vertical, deflection of the guide pillar can be calculated using crippling load formula as:

$$P = \frac{\pi^2 EI}{4L^2} \qquad (21)$$

where E = 2.1 x 10^5 N/mm^2

$I = \frac{\pi d^4}{64}$, d=30 mm, L = 260 mm

$$P = 304766.51 \text{ N}$$
$$\text{Deflection, } \delta = \frac{FL}{AE} \qquad \text{where } F = 0.8 \text{ x } \frac{P}{4} = 14200.76 \text{ N}$$
$$= 0.0248 \text{ mm}$$
$$\text{Stress, } \sigma = \frac{F}{A}$$
$$= \frac{14200.76}{\pi \text{ x } 15^2}$$
$$= 5.9016 \text{ N/mm}^2$$

Blank punch 1:

As one end of the punch is fixed compressive load acts on the other end. For punching operation, 80% of the cutting load acts on the punch as compressive nature.

$$F = 80\% \text{ of cutting force}$$
$$= (0.8 \text{ x } 23468.8)/2$$
$$= 9378.52 \text{ N}$$
$$\text{Deflection, } \delta = \frac{FL}{AE} \quad \text{where } L = 70 \text{ mm, } A = 361.428\text{mm}^2$$
$$\delta = \frac{9378.52 \text{ x } 70}{361.428 \text{ x } 2.1 \text{ x } 10^5} = 0.0086\text{mm}$$
$$\text{Stress, } \sigma = \frac{F}{A}$$
$$= \frac{9378.52}{361.428}$$
$$= 25.948 \text{ N/mm}^2$$

Blank punch 2:

Blank punch 2 has one end fixed and assuming compressive load acts on the other end, deflection of the punch can be calculated as:

$$F = 80\% \text{ of cutting force}$$
$$= (0.8 \text{ x } 19519)/2$$
$$= 7807.6 \text{ N}$$
$$\text{Deflection, } \delta = \frac{FL}{AE} \quad \text{where } L = 70 \text{ mm, } A = 136.508 \text{ mm}^2$$
$$\delta = \frac{7807.6 \text{ x } 70}{136.508 \text{ x } 2.1 \text{ x } 10^5}$$
$$= 0.0190 \text{ mm}$$
$$\text{Stress, } \sigma = \frac{F}{A}$$
$$= \frac{7807.6}{136.508}$$
$$= 57.195 \text{ N/mm}^2$$

Blank punch 3:

Blank punch 3 has one end fixed and assuming compressive load acts on the other end, deflection of the punch can be calculated as:

$$F = 80\% \text{ of cutting force}$$
$$= (0.8 \text{ x } 5068.8)/2$$
$$= 1267.2 \text{ N}$$
$$\text{Deflection, } \delta = \frac{FL}{AE} \quad \text{where } L = 70 \text{ mm, } A = 10 \text{ x } 2 = 20 \text{ mm}^2$$
$$\delta = \frac{1267.2 \text{ x } 70}{20\text{x } 2.1 \text{ x } 10^5} = 0.0211 \text{ mm}$$
$$\text{Stress, } \sigma = \frac{F}{A}$$

$$= \frac{1267.2}{20} = 63.36 \text{ N/mm}^2$$

Piercing punch 1:

Piercing punch1 has one end fixed and assuming compressive load acts on the other end, deflection of the punch can be calculated as:

$$F = 80\% \text{ of cutting force}$$
$$= (0.8 \times 3251)/4$$
$$= 650.224 \text{ N}$$
$$\text{Deflection, } \delta = \frac{FL}{AE} \text{ where } L = 70 \text{ mm, } A = \pi \times 2.45^2 = 18.857 \text{mm}^2$$
$$\delta = \frac{650.224 \times 70}{18.857 \times 2.1 \times 10^5} = 0.011 \text{ mm}$$
$$\text{Stress, } \sigma = \frac{F}{A}$$
$$= \frac{650}{18.857}$$
$$= 34.481 \text{N/mm}^2$$

Piercing punch 2:

Piercing punch2 has one end fixed and assuming compressive load acts on the other end, deflection of the punch can be calculated as: deflection of the punch can be calculated as:

$$F = 80\% \text{ of cutting force}$$
$$= (0.8 \times 4644.48)/2$$
$$= 1857.79 \text{ N}$$
$$\text{Deflection, } \delta = \frac{FL}{AE} \text{ where } L = 70 \text{ mm, } A = \pi \times 3.5^2 = 38.484 \text{ mm}^2$$
$$\delta = \frac{1857.79 \times 70}{38.484 \times 2.1 \times 10^5}$$
$$= 0.016 \text{ mm}$$
$$\text{Stress, } \sigma = \frac{F}{A}$$
$$= \frac{1857.79}{38.484}$$
$$= 48.273 \text{N/mm}^2$$

Bending punch 1:

Similarly, for bending punch 1 deflection can be calculated as follows:

$$F = 80\% \text{ of bending force}$$
$$= (0.8 \times 3483.537)/2$$
$$= 1393.414 \text{ N}$$
$$\text{Deflection, } \delta = \frac{FL}{AE} \text{ where } L = 70 \text{ mm, } A = 40 \times 11 = 440 \text{ mm}^2$$
$$\delta = \frac{1393.414 \times 70}{440 \times 2.1 \times 10^5}$$
$$= 0.00105 \text{ mm}$$
$$\text{Stress, } \sigma = \frac{F}{A}$$
$$= \frac{1393.414}{440}$$
$$= 3.16 \text{ N/mm}^2$$

4.2 FEM analysis

In the analysis process the designed and modelled press tool is being analysed. For the analysis, critical parts of the press tool are being considered i.e. punch, die, pillar, top plate and bottom plate. These components are so selected since these are the parts that undergo repeated loading. The analysis is carried out in Computer Aided Engineering software which is ANSYS. It is necessary to carry out analysis in order to prevent practical problems and try-outs. Since, practical try outs are costly; it is advisable to perform the necessary analysis prior to actual manufacturing. Moreover, it provides an opportunity to incorporate modifications and changes in the design when needed.

Material properties

In this analysis D3 steel is used as the tool material for both punch and die. The material properties of the modelled parts are applied. The corresponding properties are:

TABLE 1. Material properties of D3 steel

Properties	Value	Units
Elastic modulus	2.1×10^5	MPa
Density	7.7×10^3	kg/m^3
Poisson's ratio	0.3	

TABLE 2. Chemical composition of D3 steel (Wt. %):

C	Mn	Al	Mo	P	Cr	Si	V	Fe
1.61	0.34	0.028	0.29	0.02	11.55	0.186	0.135	traces amt.

Boundary conditions

During analysis, the functional parts are restricted to move in all degrees of freedom at specified locations i.e. $U_x = U_y = U_z$.

Loads

The loads applied on the blanking and bending dies are taken as 80% of the total cutting forces and bending forces respectively. And for punches like piercing punch, blanking punch and bending punch, loads are applied on Fz positive direction with the magnitude calculated for the particular operation as compressive loads on surface.

4.3 Analysis of components:

Blanking die

The blanking die is analysed in ANSYS R18.1. Initially the die is being modelled and imported to ANSYS. Necessary boundary conditions are being applied along with the application of suitable material properties. The equivalent stress and the deformation on the die are shown in the following figures:

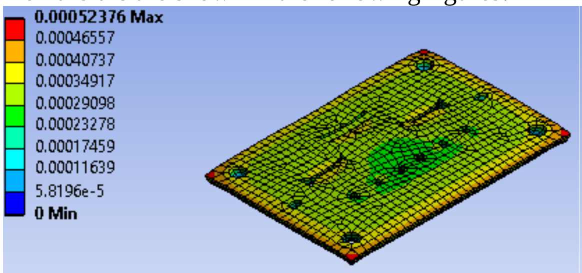


Fig.6.1: Displacement plot of blanking die

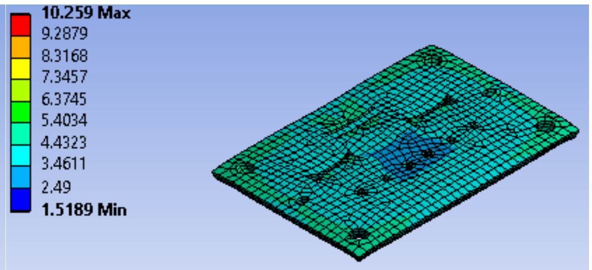


Fig.6.2: Stress plot of blanking die

Bending die:

The equivalent stress and the deformation on the die are shown in the following figures:

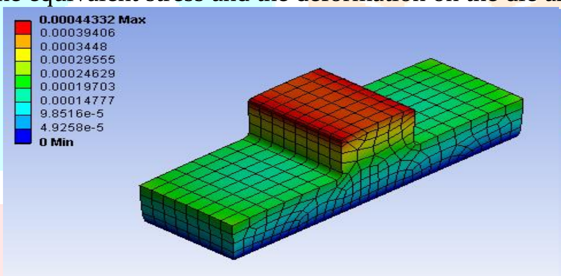


Fig.7.1: Displacement plot of bending die

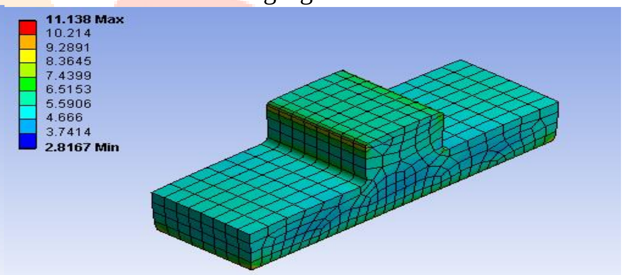


Fig.7.2: Stress plot of bending die

Punches:

The equivalent stress and the deformation on the punches are shown in the following figures:

Blanking punch 1:

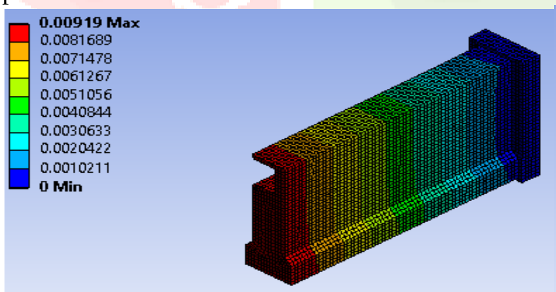


Fig. 8.1**:** Displacement plot of blanking punch

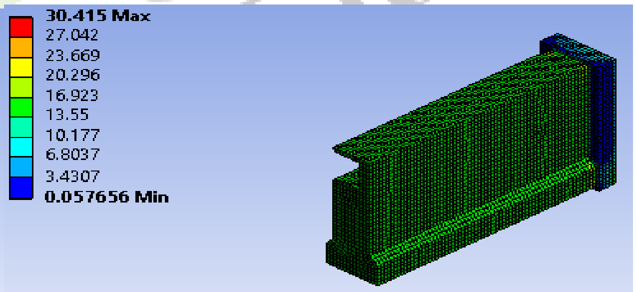


Fig. 8.2: Stress plot of blanking punch 1

Blanking punch

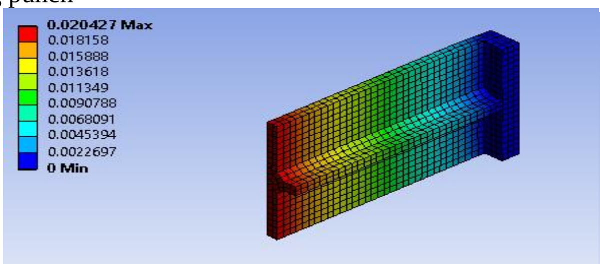


Fig. 9.1: Displacement plot of blanking punch

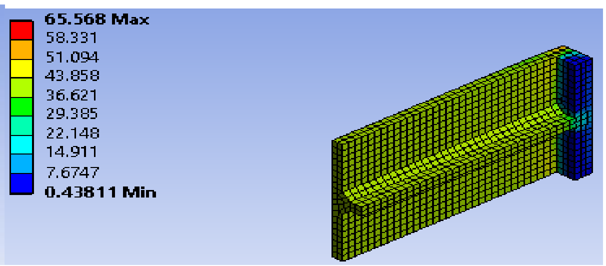
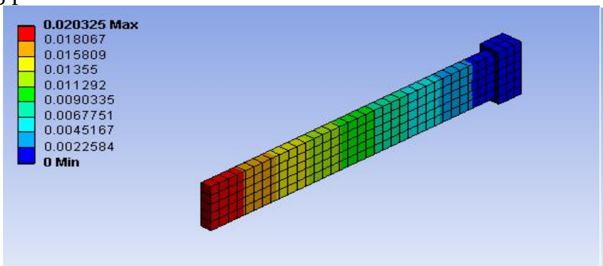


Fig. 9.2: Stress plot of blanking punch 2

Blanking punch 3:



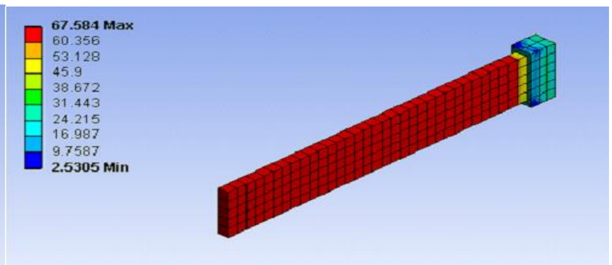
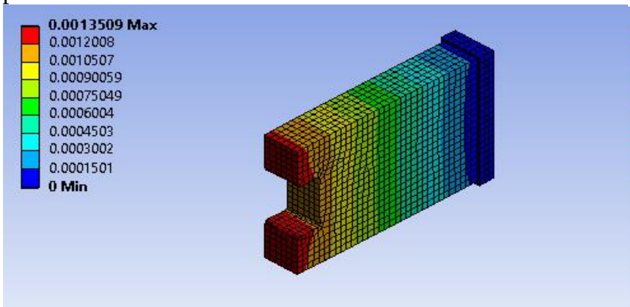


Fig. 10.1: Displacement plot of blanking punch 3 Fig. 10.2: Stress plot of blanking punch 3

Bending punch 1:



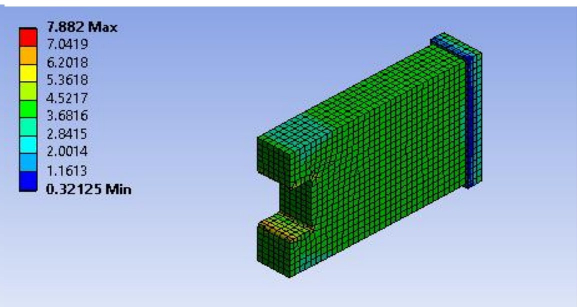
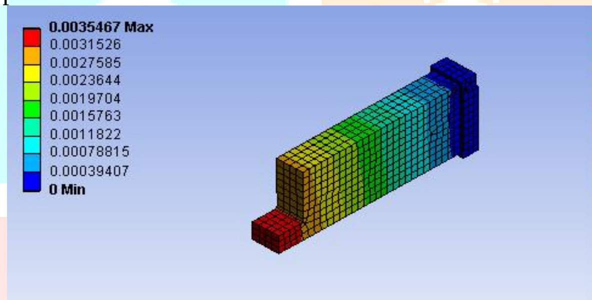


Fig. 11.1: Displacement plot of bending punch 1 Fig. 11.2: Stress plot of bending punch 1

Bending punch 2:



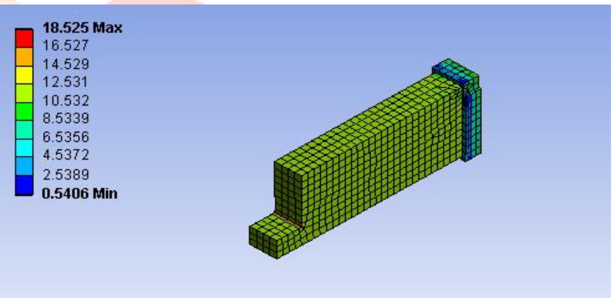
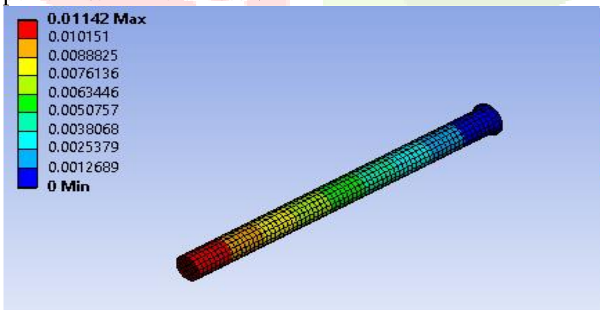


Fig. 12.1: Displacement plot of bending punch 2 Fig.12.2: Stress plot of bending punch 2

Piercing punch 4.9 mm diameter:



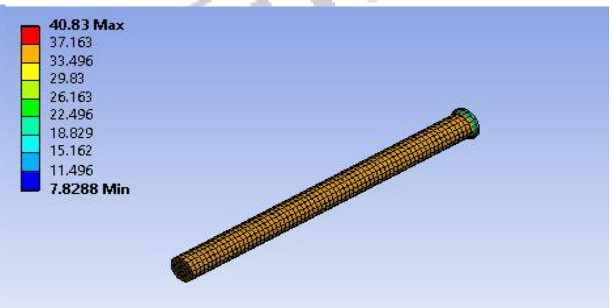
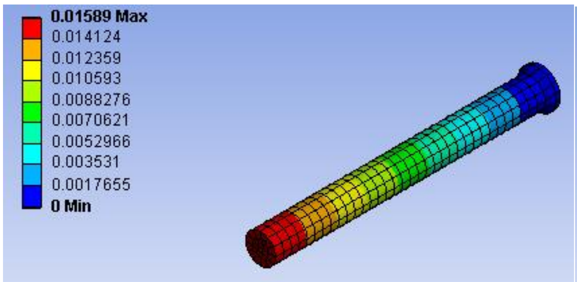


Fig. 13.1: Displacement plot of φ4.9 mm punch Fig. 13.2: Stress plot of φ4.9 mm punch

Piercing punch 7 mm diameter:



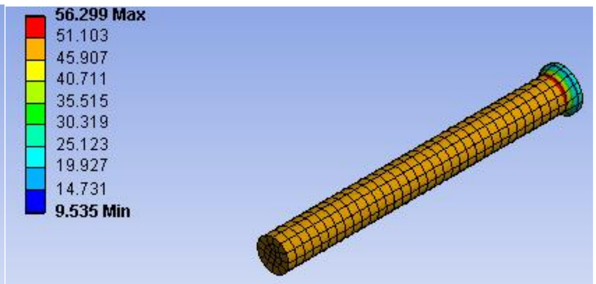


Fig. 14.1**:** Displacement plot of φ7 mm Fig. 14.2: Stress plot of φ7 mm

Pillar:

The equivalent stress and the deformation on the pillar are shown in the following figures:

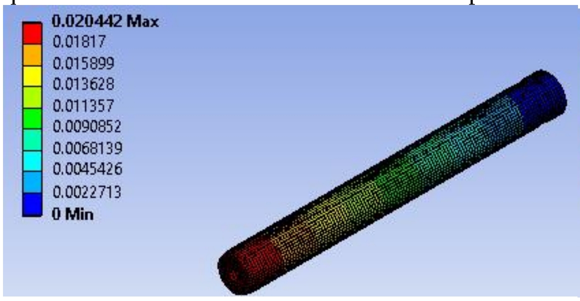


Fig. 15.1: Displacement plot of guide

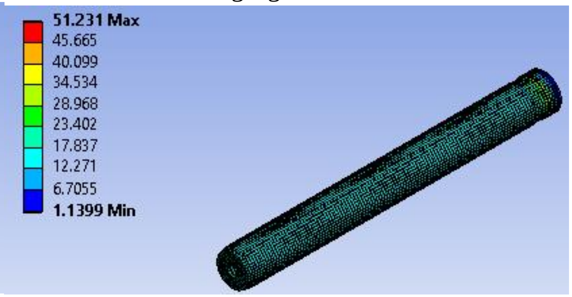


Fig. 15.2: Stress plot of guide

Top plate:

The equivalent stress and the deformation on the top plate are shown in the following figures:

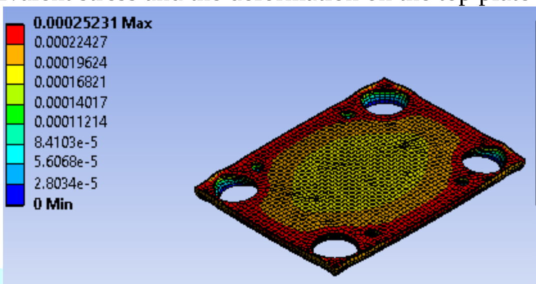


Fig. 16.1: Displacement plot of top

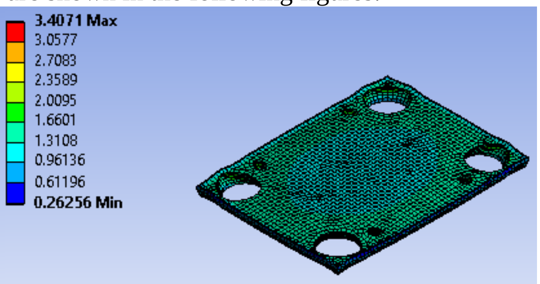


Fig. 16.2: Stress plot of top plate

Bottom plate:

The equivalent stress and the deformation on the bottom plate are shown in the following figures:

Fig. 17.1: Displacement plot of bottom

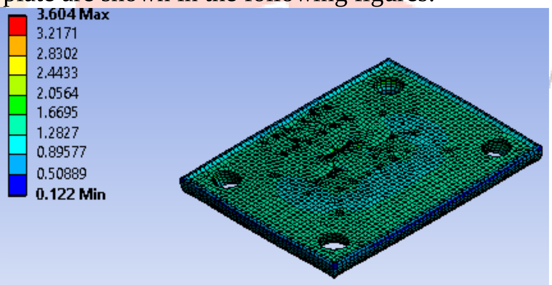


Fig. 17.2: Stress plot of bottom plate

The results obtained from ANSYS and theoretical calculations are tabulated as follows:

TABLE 3. Comparison of ANSYS results and calculated results

Sl. No.	Description	ANSYS results		Calculated results	
		Deflection (mm)	Stress (MPa)	Deflection (mm)	Stress (MPa)
1	Bending die	0.0004	11.138	0.0005	5.062
2	Blanking punch 1	0.0091	30.415	0.0086	25.94
3	Blanking punch 2	0.0204	65.568	0.0198	57.19
4	Blanking punch 3	0.0203	67.584	0.0211	63.36
5	Bending punch 1	0.0013	7.882	0.0010	3.166
6	Bending punch 2	0.0035	18.525	0.0038	11.63
7	Piercing punch1	0.0114	40.83	0.011	34.48
8	Piercing punch2	0.0158	51.103	0.0160	48.27
9	Pillar	0.0204	51.231	0.0207	50.25
10	Blanking die	0.0005	10.259	0.0240	4.87
11	Top plate	0.0002	3.407	0.0204	1.72
12	Bottom plate	0.0002	3.604	0.0204	1.72

V CONCLUSION

All the components of the press tool were modelled in CATIA V5 and each file were imported to ANSYS 18.0 software in igs format. Necessary material properties, boundary conditions and loads were applied before analysis. After analysis the following conclusions were made:

1. It is observed that the stress values for all the components are less than the respective yield stress of the material.
2. It is also observed that the deformation of the components analysed are well within the recommended deformation.
3. The results obtained from ANSYS and the theoretical results are approximately more or less the same.

Hence, it is conluded that the design is safe under the given loading condition.

IV. ACKNOWLEDGMENT

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