DESIGN AND ANALYSIS OF PROGRESSIVE TOOL FOR METAL BUCKLE CABLE CLIP

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ABSTRACT

Now-a-days usage of sheet metal components is growing rapidly, hence the production of the sheet metal components by using press tools were increasing day-by-day. So the maintenance of the tool becomes challenging as the matting parts such as punches and dies deforms with the increase in rate of production, and also the rate of deformation depends upon the thickness of the component that is to be produced. As the deformation increases tool should be disassemble and grinded finely, as a result punch length and die thickness decreases and hence tool life decreases. While designing and manufacturing of a press tool selection of die steel alloy is the most important factor. This paper deals in finding the best die steel alloy among M2, SKD11, D2 and HCHCr and deals in development of strip layout, design of die plate, punch holder, thrust plate, stripper plate, top and bottom bolster and calculations for cutting force, press tonnage. Analysis carried out in designing a progressive tool which perform piercing and blanking operation. The former operation is piercing and is followed by blanking. The software's used for CAD designs are AutoCAD 2019, Catia V5r21, and analysis is done in Ansys 17.1.

KEYWORDS: *Progressive die, Die steel, Strip Layout, Press tonnage, Punching force, AutoCAD 2019, Catia V5r21, Ansys 17.1 etc.*

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1. INTRODUCTION

Sheet-metal forming operations produce a wide range of consumer and industrial products, such as metal desks, appliances, aircraft fuselages, beverage cans, car bodies and kitchen utensils. Sheet-metal forming, also called press working, press forming, or stamping, Compared to those made by casting or forging, for example, sheet-metal parts offer the advantages of light weight and shape versatility.

Forming of a sheet metal is generally carried out by tensile forces in the plain of the sheet, as otherwise the application of external compressive force could lead to buckling, folding, and wrinkling of the sheet. The thickness or lateral dimension of workpiece is intentionally changed to produce the part, where as in sheet-forming processes, any change in thickness is typically due to stretching of the sheet under tensile stresses, (Poisson's effect). Thickness decreases in sheet forming should generally be avoided as they can lead to necking and failure, as they occur in tension test.

2. PRINCIPLE IN METAL CUTTING

Hooke'slaw: -

Law of elasticity discovered by the English scientist Robert Hooke in 1660, which states that, for relatively small deformations of an object, the displacement or size of the deformation is directly proportional to the deforming force or load.

The deforming force may be applied to a solid by stretching, compressing, squeezing, bending, or twisting. Thus, a metal wire exhibits elastic behavior according to Hooke's law because the small increase in its length when stretched by an applied force doubles each time the force is doubled.

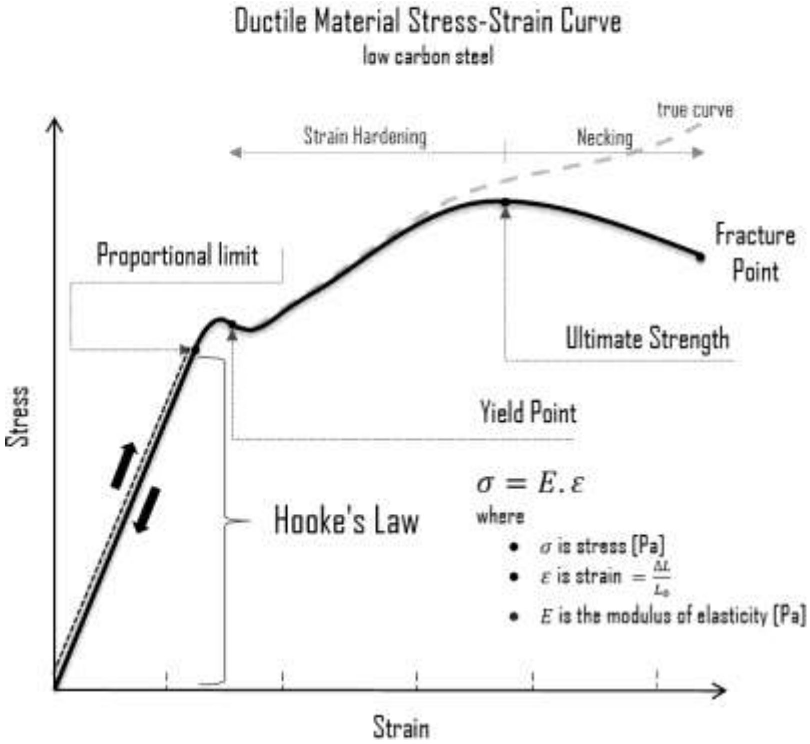

Fig – 1 Demonstration of Hooke's law

3. COMPONENT ANALYSIS

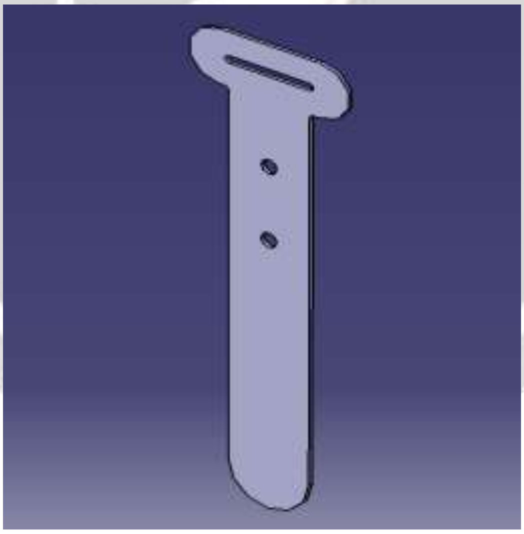

Fig – 2 Wire buckle cable clip

Name	BUCKLE WIRE CABLE CLIP
Thickness	0.5mm
Material	ELECTRO TIN PLATED BRASS BSEN1652-CW508L
Shear Strength	0.27KN/mm^2
Cutting Perimeter	387.08mm
Area of the Component	665.27mm^2
Volume of the Component	332.64mm^3

4. DESIGN OF PRESS TOOLS

a. Determination of force required for the operation

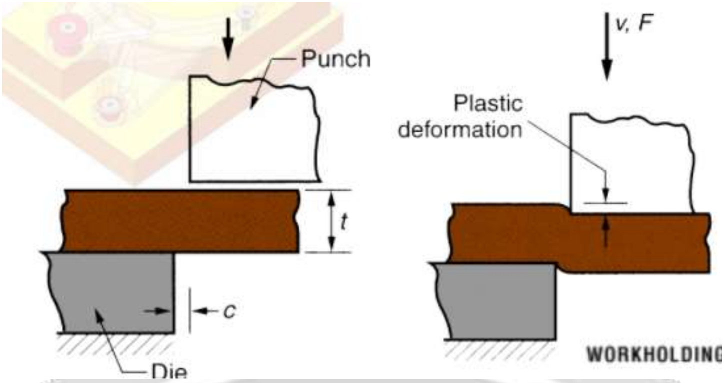

Fig – 3 Demonstration of Deformation of strip

Press tools shear off the required work pieces from the parent strip/sheet. The work material yields and bends before cracking at punch and die edges (Fig. above). The cracks originating at the edges meet to shear the piece from the parent material (fig above). This severance takes place when the punch has penetrated about 40% of worksheet thickness. Further motion of the punch only pushes the fracture piece through the die. The edges of the severed piece are confined within punch and die dimensions. The punched out piece generally appears as shown in fig below.

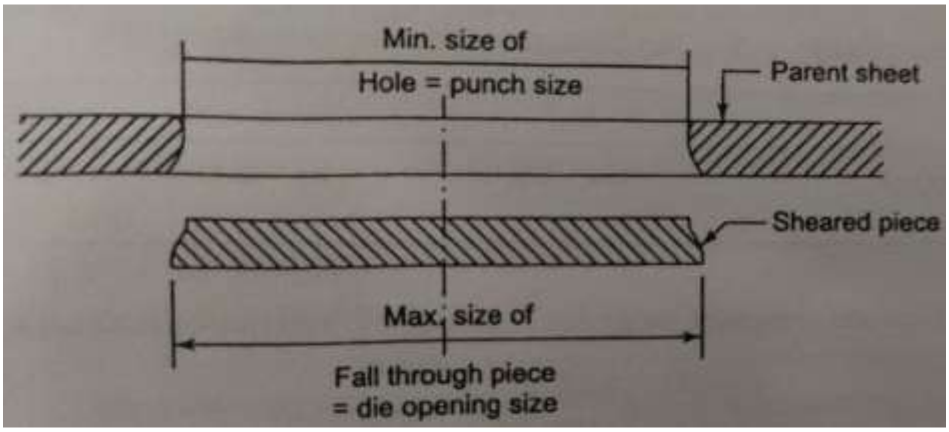

Fig – 4 Edges of shear piece and parent sheet

Force disposition

The forces developed in the shearing operation can be represented by a triangle as depicted in Fig below. The vertical shearing force is represented by V while the horizontal and force is designated H. The resultant force is represented by R.

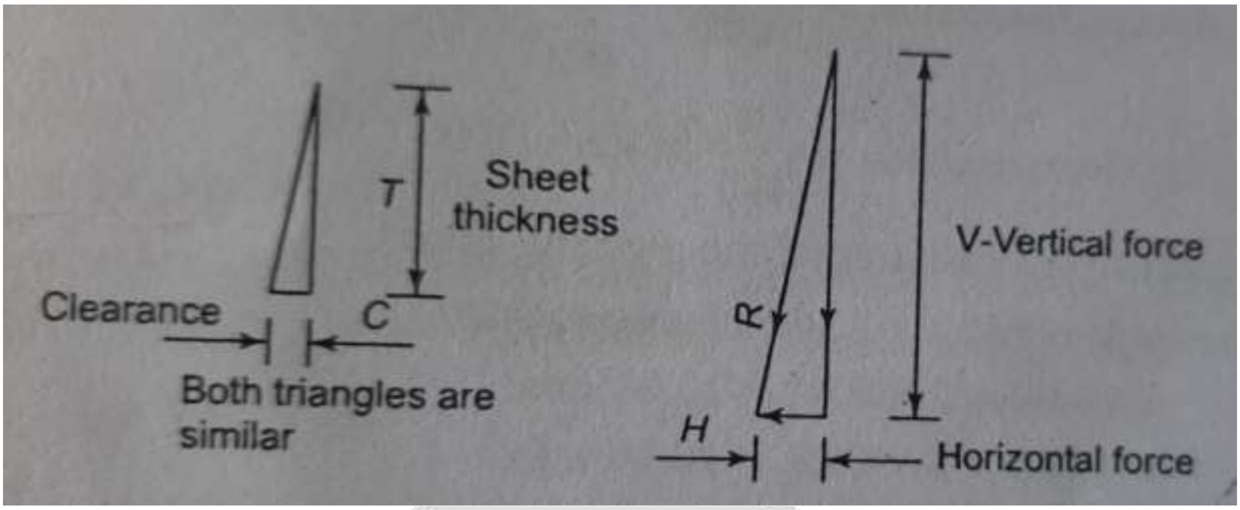

Fig – 5 Forces in shearing

Vertical force

The value of the vertical component V depends upon the shear strength of the material to be cut and the area to be shared. Shear area is the product of the length of the cut and the sheet thickness.

Shear Cut Area, S = Cut Length (C) x Sheet Thickness (T)

Length of cut = 157.84 + 23.14 + 6.28 + 6.28
= 193.54 x 2 = 387.08mm

Sheet Thickness = 0.5 mm

S = 387.08 x 0.5

=193.54 mm^2

$V = S \times f_s$

V = Vertical shearing force (N)

f_s = Shear strength of the material cut (N/mm^2) = 270 N/mm^2

V = 193.54 x 270 = 52255.8 N

=5.32678899 ton ≈ 5.5 tonnes

Horizontal force

The value of the horizontal or lateral force H depends upon the die clearance: the gap between the punch and die cutting edges. The die clearance depends upon the work material and ranges from two to ten per cent of worksheet thickness.

Let us draw a triangle with work-piece thickness as vertical side, clearance as a horizontal, and the third as a diagonal (Fig. above). This triangle is similar to the triangle representing the vertical and horizontal forces in shearing. Consequently, the horizontal force can be stated in terms of vertical force percentage. This percentage is the same as the die clearance percentage per side.

H = 0.04 x V
H = 2090.232 N

= 0.214 tonnes

b. Selection of press

The press should be capable of delivering about 33% more force than required.
Required force = 5.5 tonnes
Press tonnage = 5.5 + 33% of required force
= 7.315 tonnes ≈ 10 tons (Standard capacity of Press)

The cutting edges of dies and punches get blunt due to usage which increases the vertical force considerably. The press tool size, too, should suit the press. After selecting one of the available presses with suitable tonnage, the following specifications of the selected press should be perused for tool suitability.

c. Computing thickness of all individual parts

Design of Die Plate: - A tool-steel block which is bolted to the bed of a punch press and into which the desired impressions are machined. It constitutes the female half of the two mated tools, which carry the cutting edges. A vertical opening extending through the block determines the size and outline of the blank. The exact opening is provided in the die to obtain a predetermined clearance and vertical land in the die opening is necessary in order to prevent the possibility of a blank or slug jamming in the passage. The overall dimensions should be obtained by having minimum die wall thickness required for strength and the space is needed for mounting screws, dowel pins. The material used in manufacturing is H.C.H.C.R and to be heat treat-treated to 60-62 HRC.

Thickness of the die plate (td) = $(\sqrt[3]{\text{shear force}}) \times 10$
$= (\sqrt[3]{5.5}) \times 10$
$= 17.6517 \text{ mm} \approx 20 \text{ mm}$

Die clearance(c): - 4% of sheet thickness
$= 0.04 \times 0.5$
$= 0.02$ mm/side.

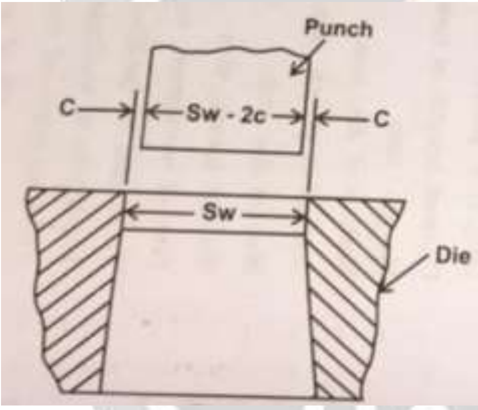

Fig – 6 Clearances for Blanking

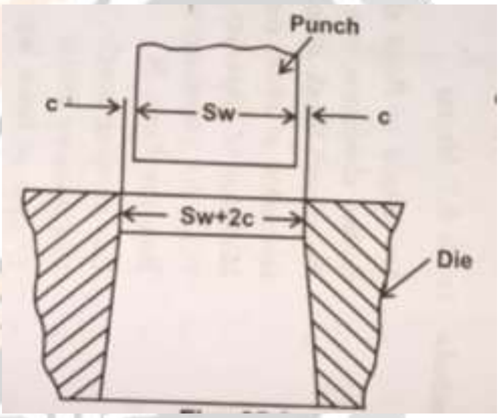

Fig – 7 Clearance for Piercing

Angular clearance: - Angular clearance on die for both blanking and piercing is α = ½ ° to 2 ° on either side.

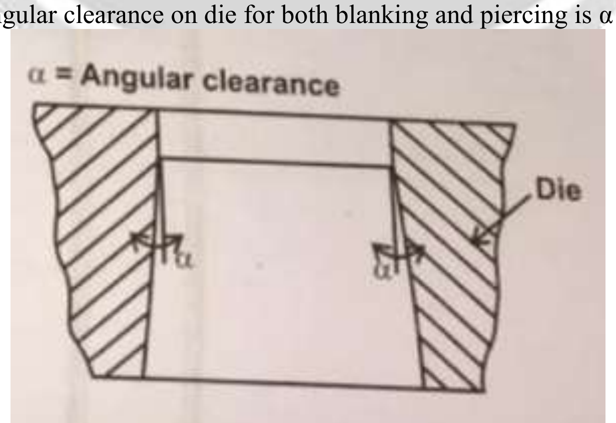

Fig – 8 Angular clearance

Design of Guide Pillars and Guide Bushes: - These elements are responsible for the alignment of the lower and upper part of the tool. Pillars and bushes should withstand deflection during the continuous production.

Design of Punch Holder: -Punch holder holds and support punches. Punch holder dowelled together with the thrust plate and top plate/bolster retains or holds the punches. The center distances are picked up from the die block to eliminate the possibility of misalignment of punches. Holes to receive the body of punches are provided with H7 fit in order to bare a light press fitting. The material used in manufacturing of punch holder is M.S, and heat treatment is not needed.

Thickness of the punch holder = 0.5 x td
= 0.5 x 20 = 10 mm

Design of Stripper Plate: - The major purpose of the stripper is to remove the stock or strip from the punch after blanking or piercing operation. However, the stripper serves two other secondary functions also.
It guides the strip if fixed to the die block surfaces. Secondly, it holds the blank under pressure before the punch descends fully if the stripper is of spring-loaded type. The material used in manufacturing of stripper plate is M.S, and heat treatment is not needed.

Thickness of the stripper plate = 0.75 x td
= 0.75 x 20
= 15 mm

Design of Bottom Plate/Bolster: - The function of the bottom plate primarily as a base for the complete die assembly and in turn is bolted or clamped to the bolster plate over the press bed. Openings are made with respect to the die openings plus allowance, to allow the stamped components to fall freely. The material to be used for manufacturing this part is M.S and heat treatment is not needed.

Thickness of bottom bolster = 1.5 x td
= 1.5 x 20
= 30 mm

Design of Top plate/Bolster: - Top plate holds the upper half component of the die, clamped to the ram by means of the shank being screwed on its top surface where the center of pressure is located. The material to be used for manufacturing this part is M.S and heat treatment is not needed.

Thickness of top bolster = 1.25 x td
= 1.25 x 20
= 25 mm

Design of Thrust plate: -This plate is also called punch back plate. It is used to absorb shock and avoid digging into the soft top plate during cutting operations. Generally, 15 mm to 20 mm thickness thrust plate with En31 material is used, and heat treated up to 56-58HRC.
Thickness of the Thrust plate = 15 mm to 20 mm
= 15mm

d. Drawing strip layout and comparing material utilization

Development of strip layout is the primary task in designing a progressive die and punch holder. It shows the operations that to be carried out at every station.
Strip-layout design is an important step in the planning stage of sheet metal work on progressive die. It is an experience-driven activity and the quality of strip-layout is highly dependent on the knowledge and skill of die designers.

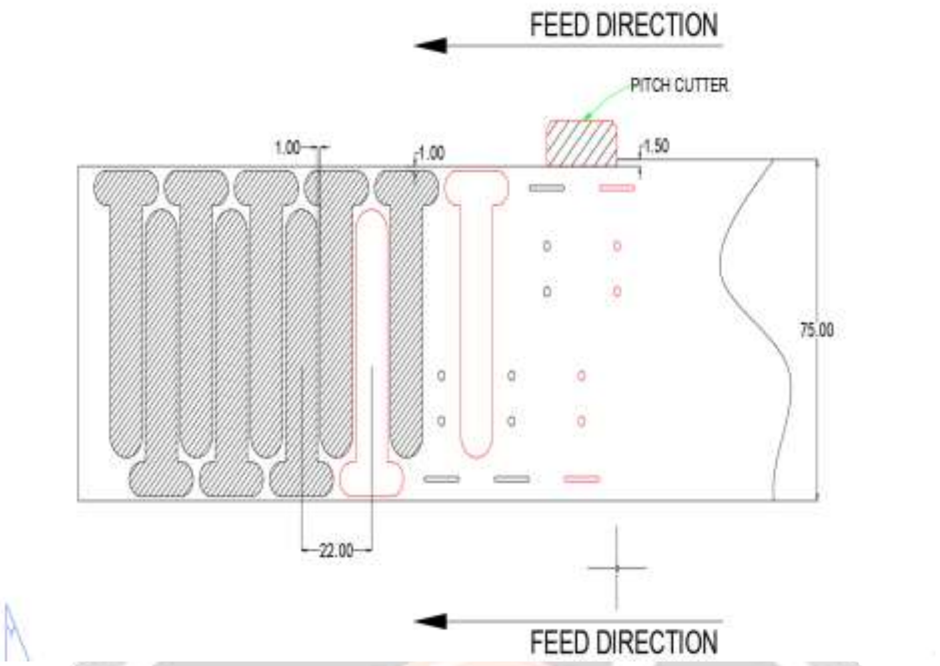

Fig - 9 Strip layout

Strip layout Calculations

A= Front scrap = 2 x t = 2 x 0.5=1mm (t = sheet thickness)
B= Scrap bridge = 2 x t = 2 x 0.5=1mm
Pitch= 22mm
Width of sheet= 75mm

Economy factor or % of Strip utilization
Economy factor= (Area of the component) x (no of rows) x 100 / (Pitch) x (Width of the strip)
Area of the component= 665.27 mm^2
No of rows= 2
Pitch= 22 mm
Width of the strip= 75 mm
Economy factor= (665.27) x 2 x 100 / 22 x 75 = 80.63878% ≈ 80.64%
% of Scrap= 100 - Economy factor = 100 – 80.64 = 19.36%

e. Finding center of pressure

During blanking of irregular shape, the summation of forces at both the side of the ram varies which results in bending moment in the pressing ram. This causes undesirable deflections and misalignment. It is predominant in progressive tool to find a point where the summation of forces is symmetrical. This point is called Centre of Pressure. It is important that the centre of pressure lies on the axis of the ram. This is also known as load centre where the shank is to be fitted.

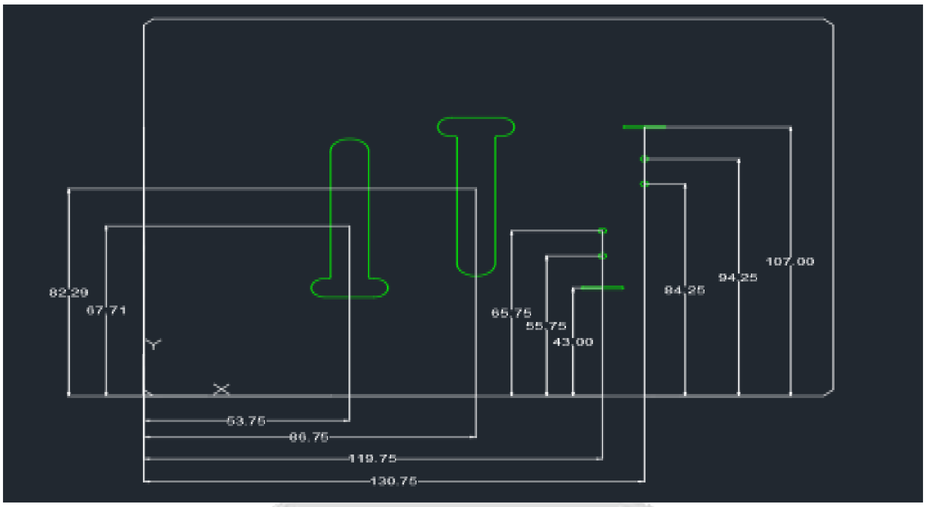

Fig – 10 Co-ordinate dimensions of cutting profile

Serial Number	Load L_i (Tonnes)	Distance from X(mm)	Distance from Y(mm)	X_i x L_i	Y_i x L_i
1	2.2	53.75	67.7	118.25	148.94
2	2.2	86.75	82.3	190.85	181.06
3	0.1	119.75	65.75	11.975	6.575
4	0.1	119.75	55.75	11.975	5.575
5	0.3	119.75	43	35.925	12.9
6	0.3	130.75	107	37.225	32.1
7	0.1	130.75	94.25	13.075	9.425
8	0.1	130.75	84.25	13.075	8.425
Total	5.4			432.35	405

From above table $\sum L_i$, $\sum (X_i \times L_i)$, $\sum (Y_i \times L_i)$ are 5.4, 432.35 and 405 respectively.

Distance of load from X axis, $X = \sum (X_i \times L_i) \div \sum L_i = 432.35 \div 5.4$

$= 80.06$

Distance of load from Y axis, $Y = \sum (Y_i \times L_i) \div \sum L_i = 405 \div 5.4$

$= 75$

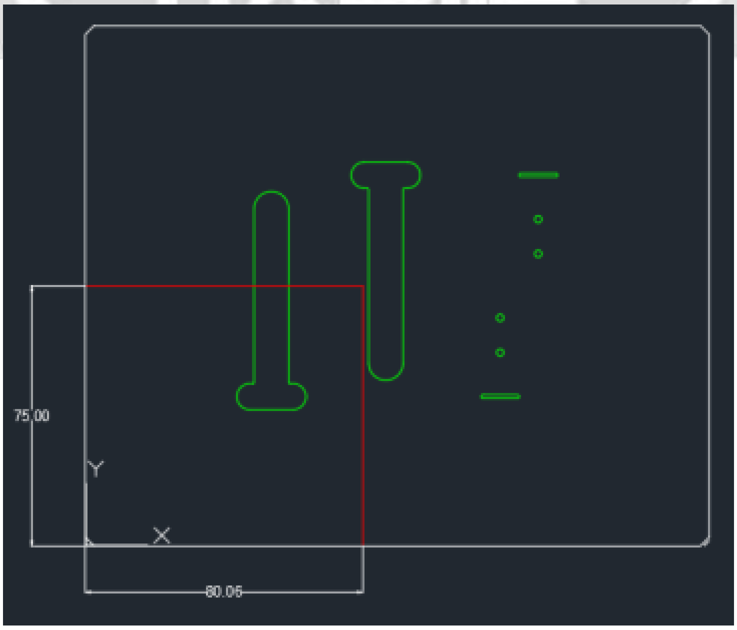

Fig - 11 Center of pressure for Die

f. Drawing details

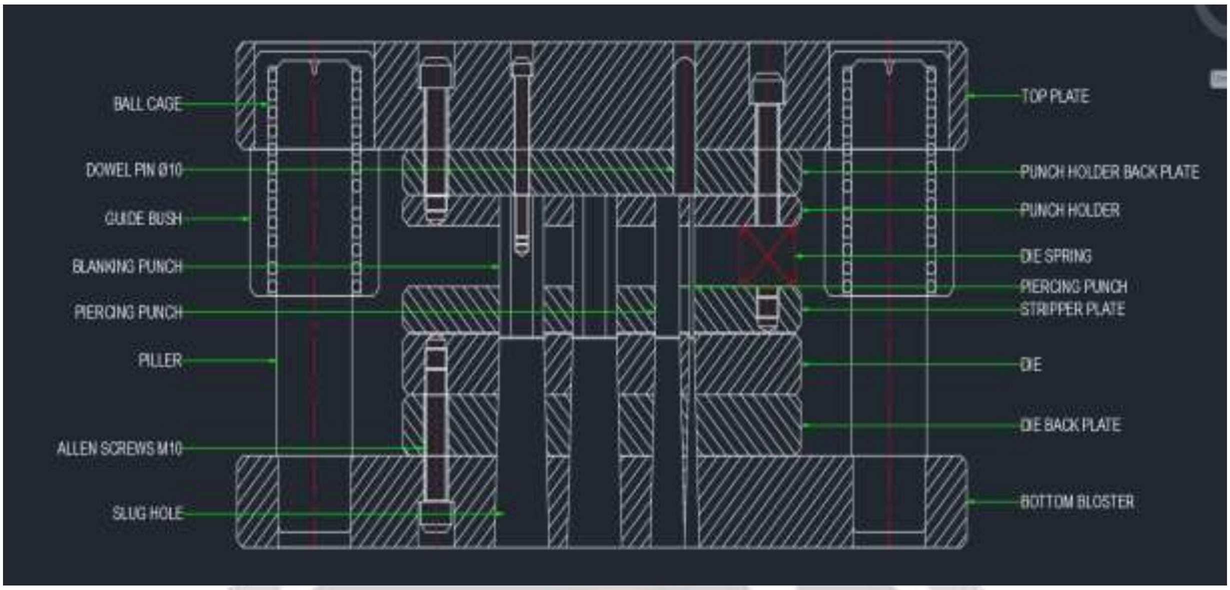

Fig - 12 Cross-section view of progressive tool

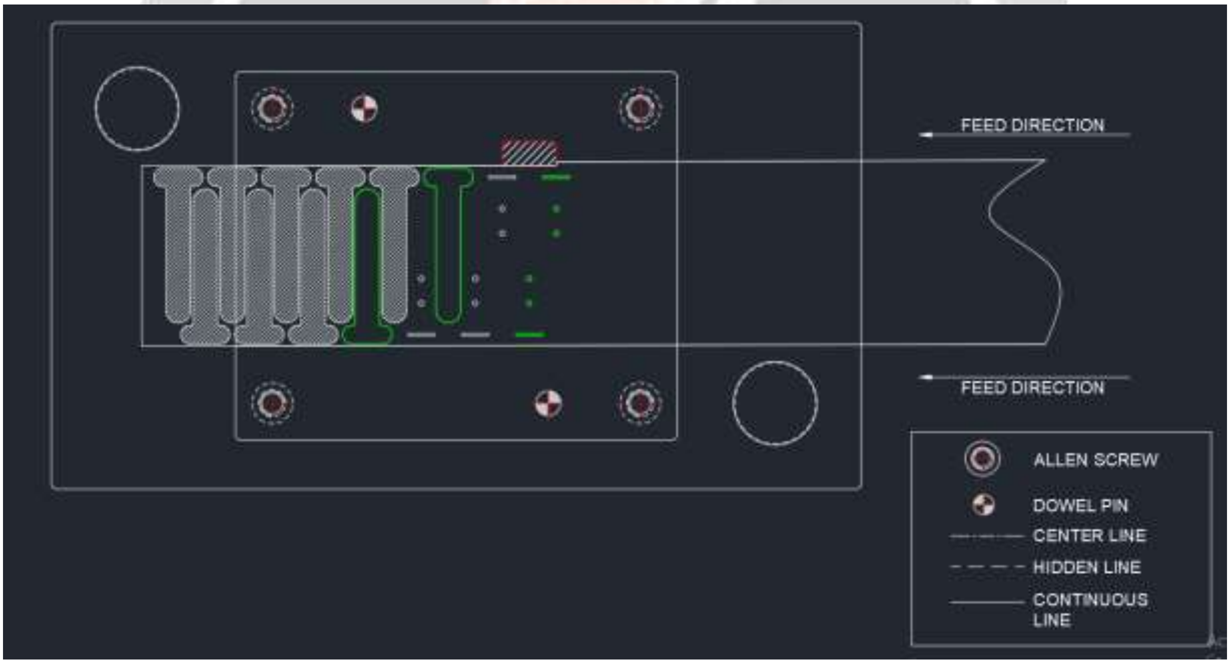

Fig – 13 Top view of Bottom half

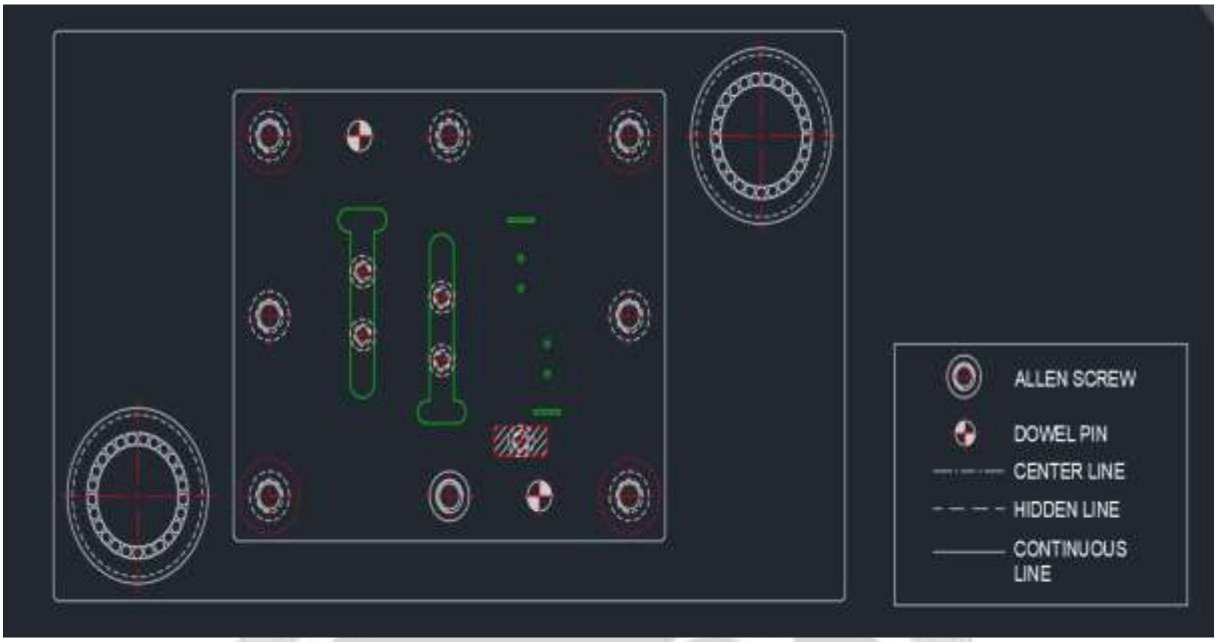

Fig - 14 Inverted top view of top half

5. TYPES OF DIE STEELS

- M2
- D2
- HCHCR
- SKD11

6. FINITE ELEMENT ANALYSIS AND THEORITICAL ANALYIS OF PUNCHES

6.1 FINITE ELEMENT ANALYSIS

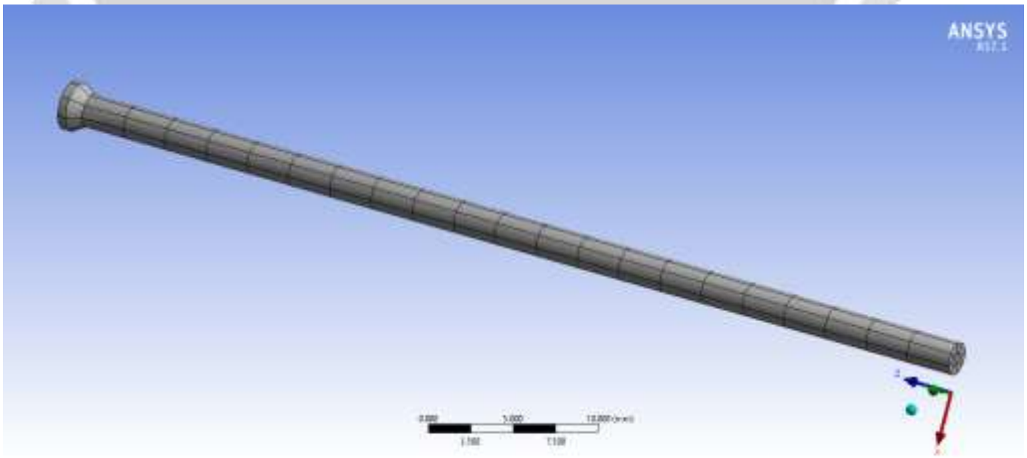

Fig – 15 Meshed model of piercing punch dia 2.0

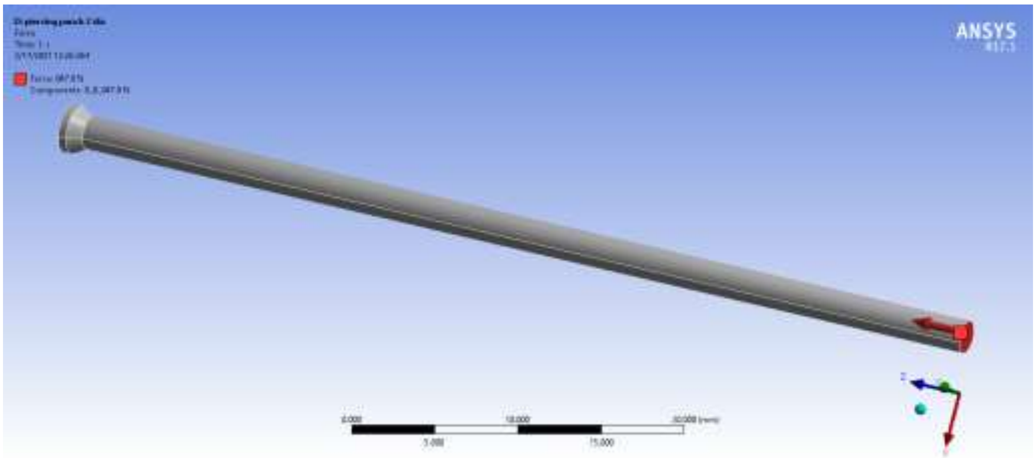

Fig – 16 Boundary condition for force on piercing punch dia 2.0

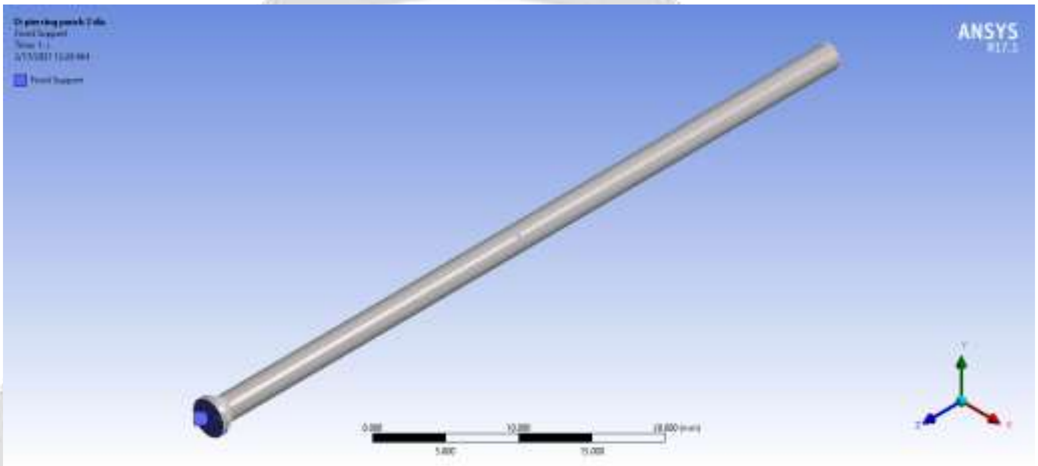

Fig – 17 Boundary condition of fixed support on piercing punch dia 2.0

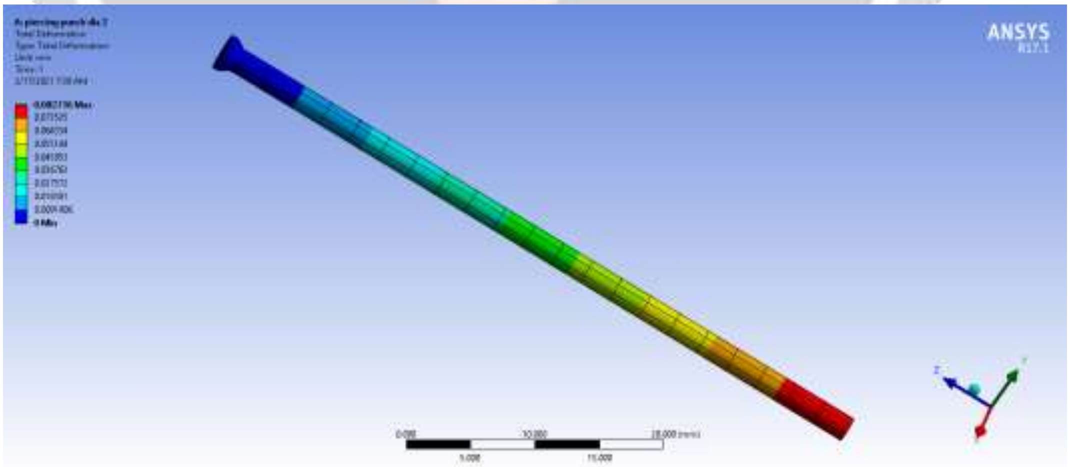

Fig – 18 Deformation of piercing punch dia 2.0 for material D2

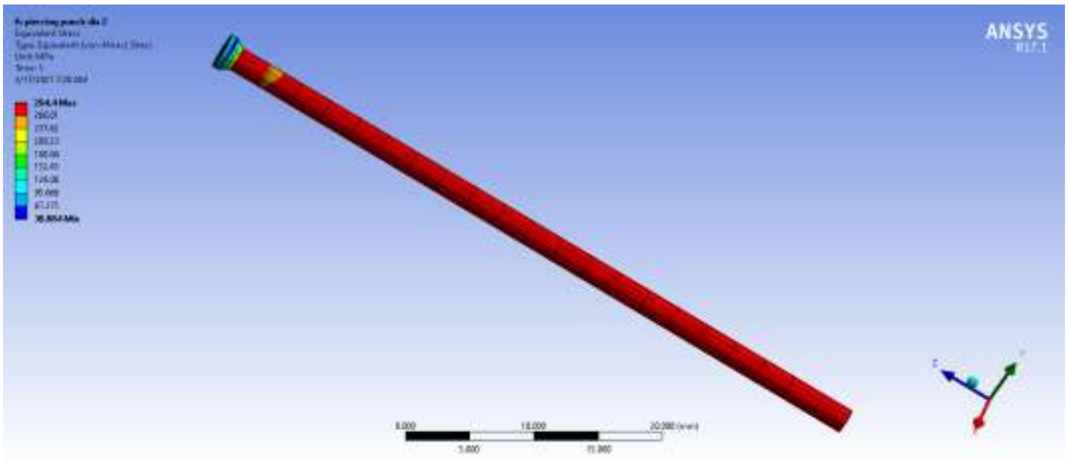

Fig – 19 Equivalent stress (von-Mises) piercing punch dia 2.0 for material D2

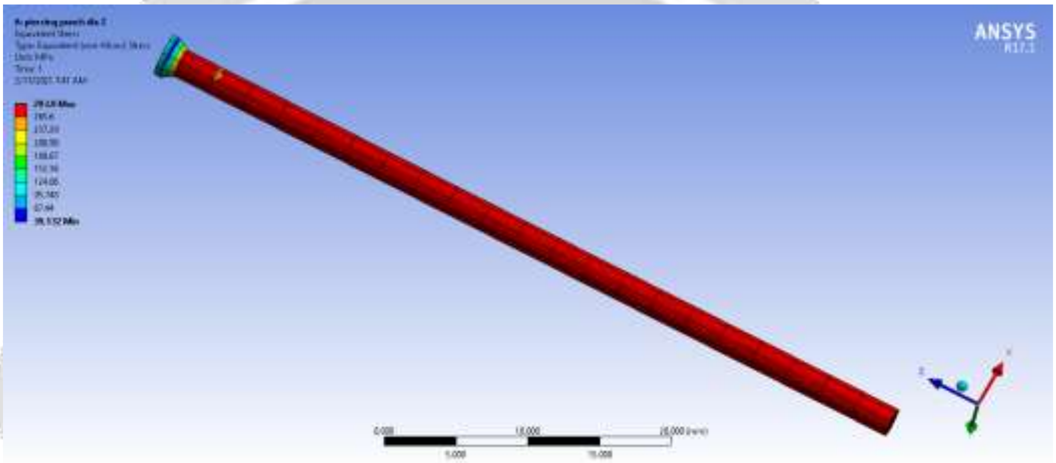

Fig – 20 Equivalent stress (von-Mises) piercing punch dia 2.0 for material M2

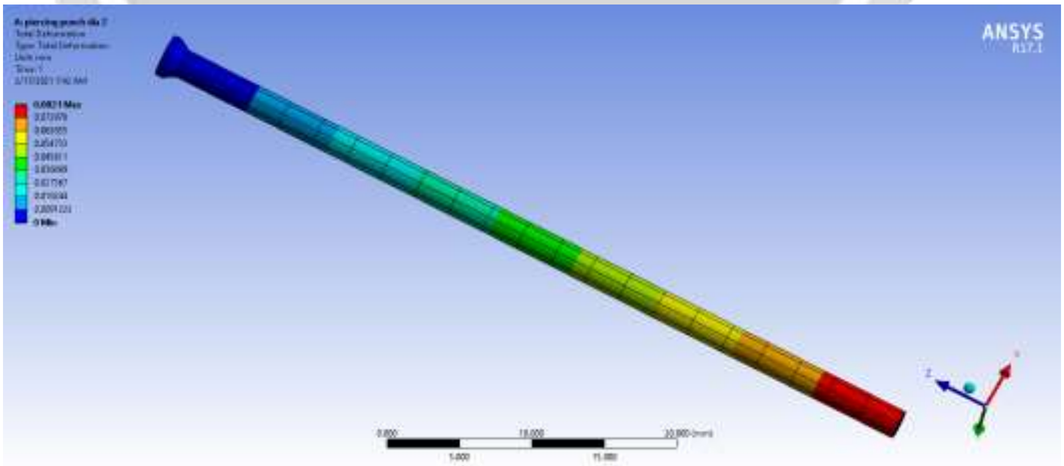

Fig – 21 Deformation on piercing punch dia 2.0 for material M2

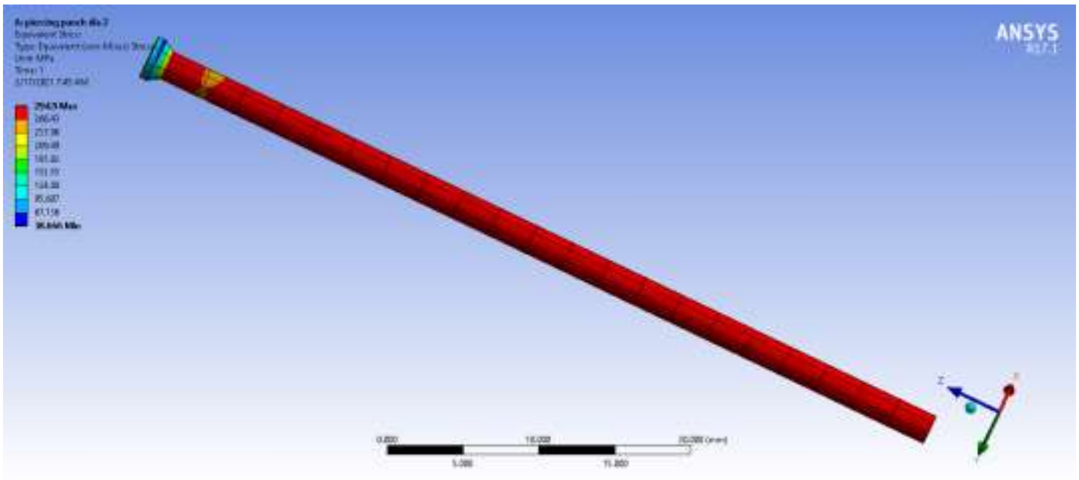

Fig – 22 Equivalent stress (von-Mises) piercing punch dia 2.0 for material SKD11

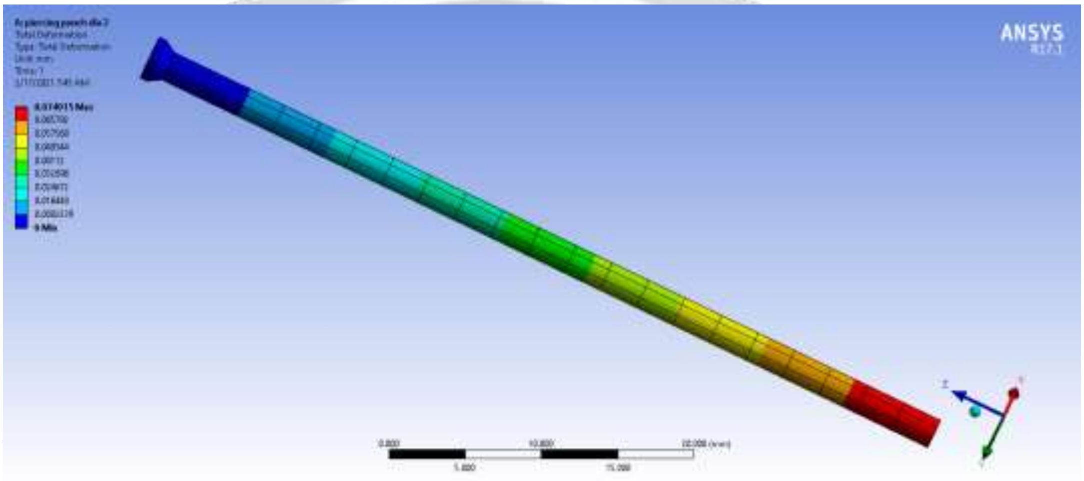

Fig – 23 Deformation on piercing punch dia 2.0 for material SKD11

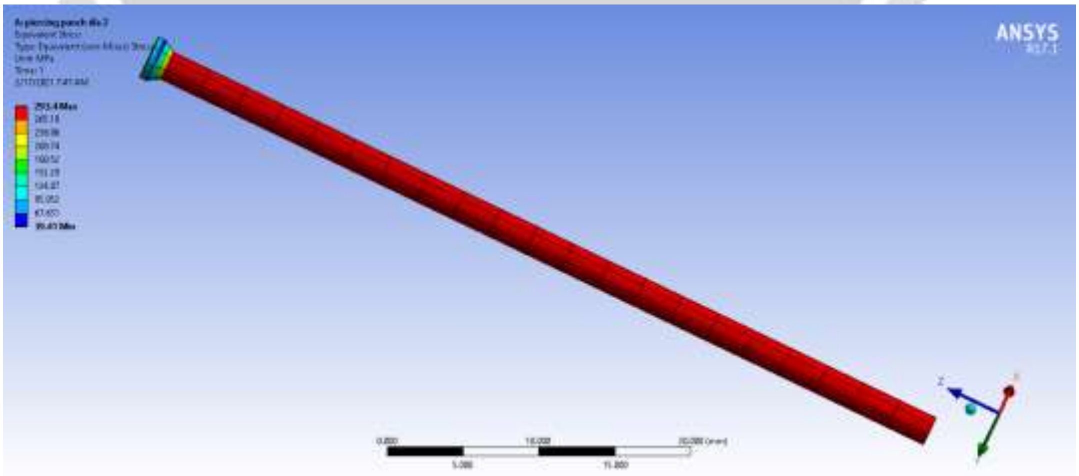

Fig – 24 Equivalent stress (von-Mises) piercing punch dia 2.0 for material HCHCr

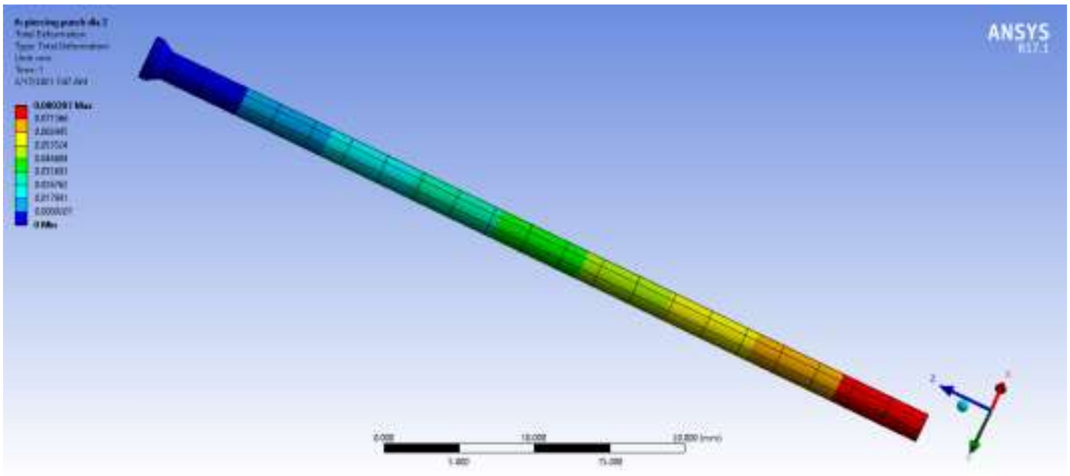

Fig – 25 Deformation on piercing punch dia 2.0 for material HCHCr

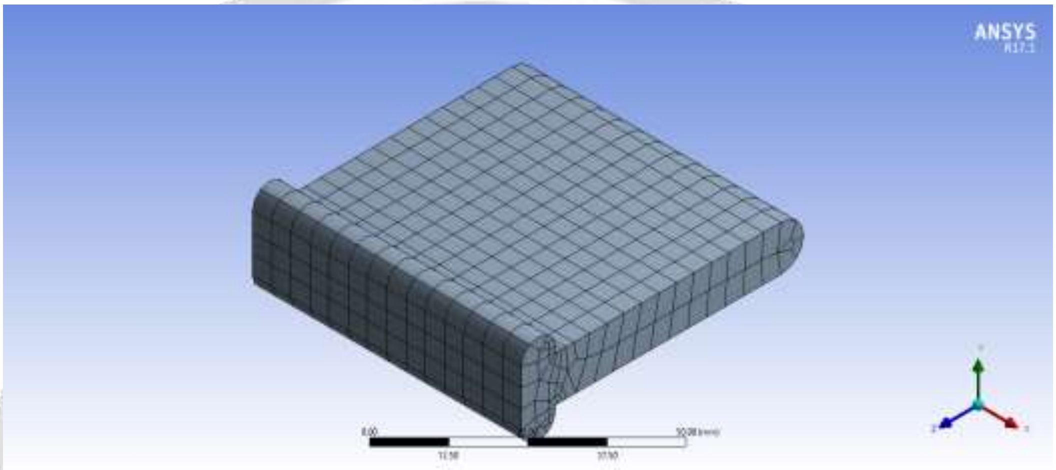

Fig – 26 Meshed model of Blanking punch

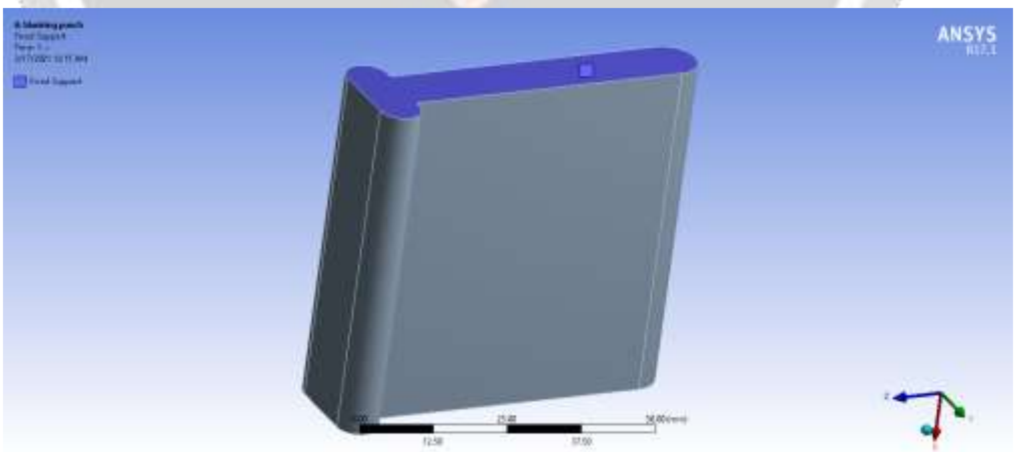

Fig – 27 Boundary conditions of Blanking punch for fixed support

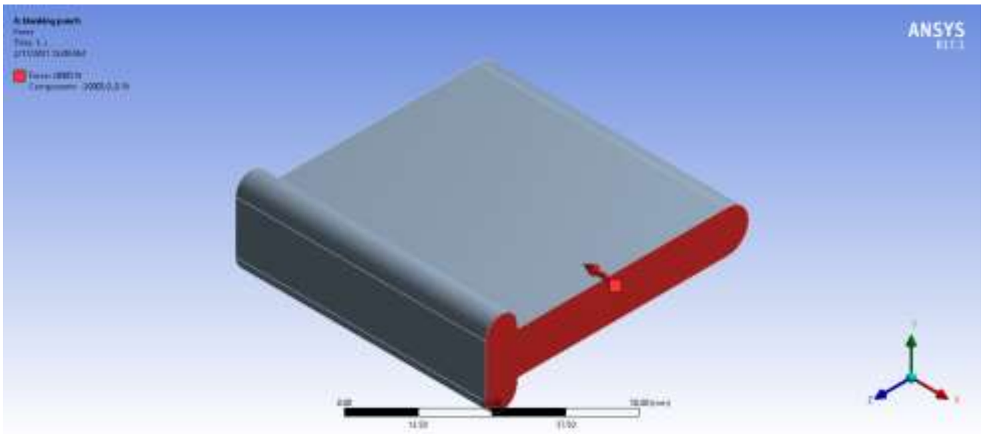

Fig – 28 Boundary conditions of Blanking punch for force

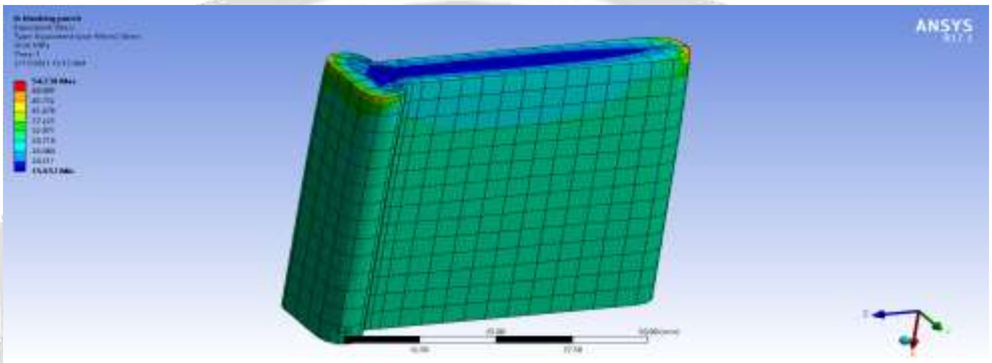

Fig – 29 Equivalent stress (von-misses) for Blanking punch for material D2

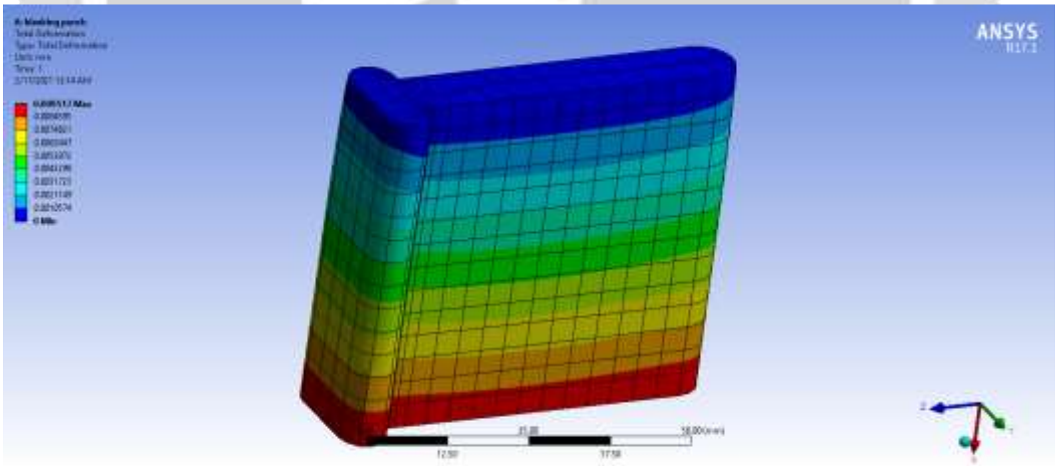

Fig – 30 Deformation on Blanking punch for material D2

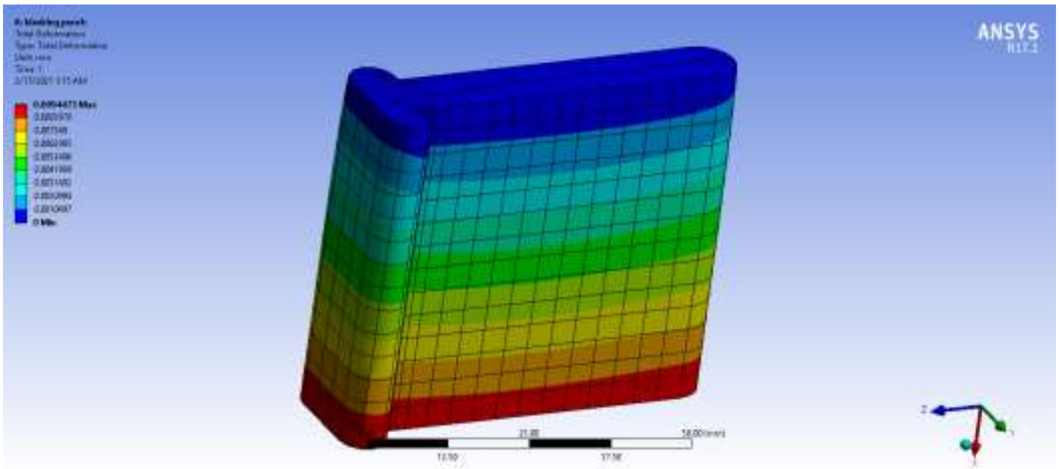

Fig – 31 Deformation on Blanking punch for material M2

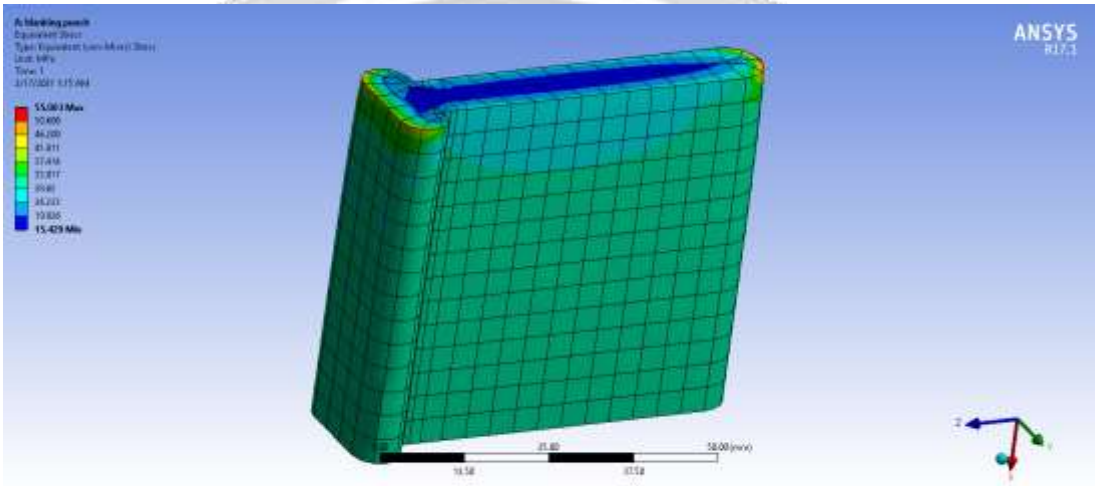

Fig – 32 Equivalent stress (von-misses) for Blanking punch for material M2

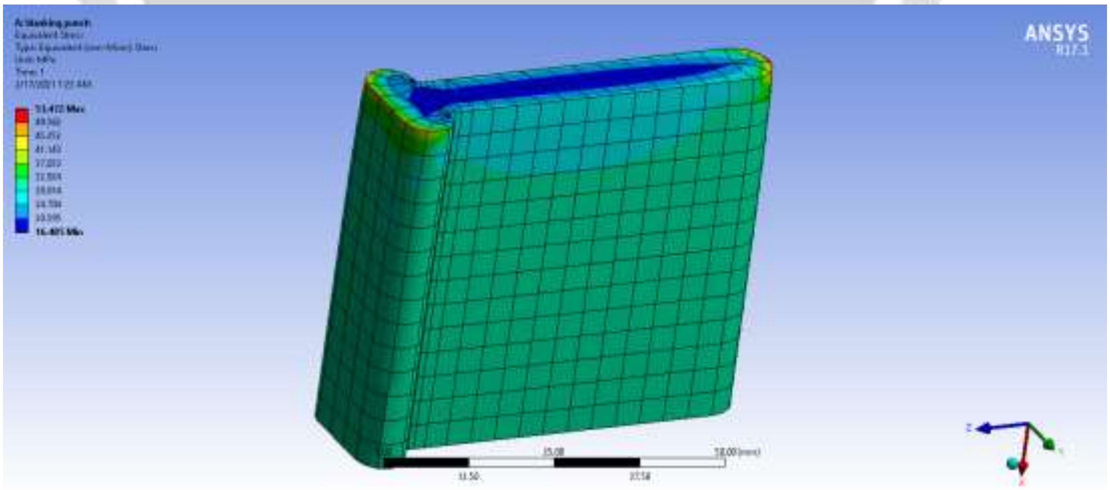

Fig – 33 Equivalent stress (von-misses) for Blanking punch for material SKD11

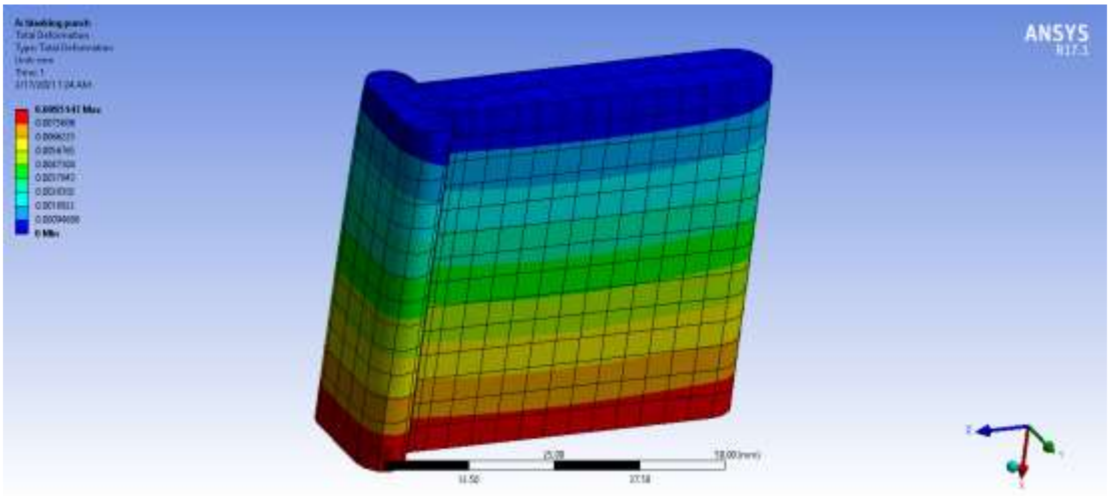

Fig – 34 Deformation on Blanking punch for material SKD11

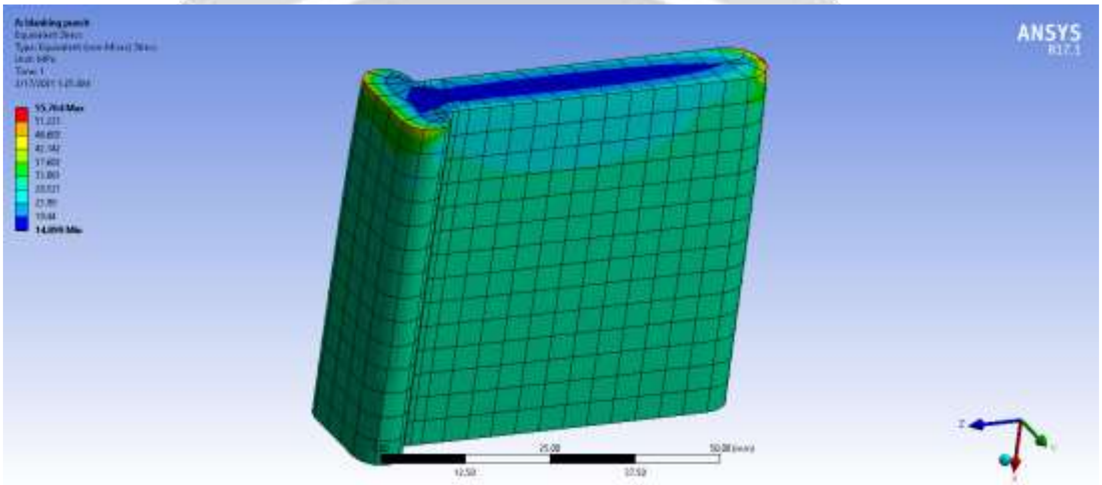

Fig – 35 Equivalent stress (von-misses) for Blanking punch for material HCHCr

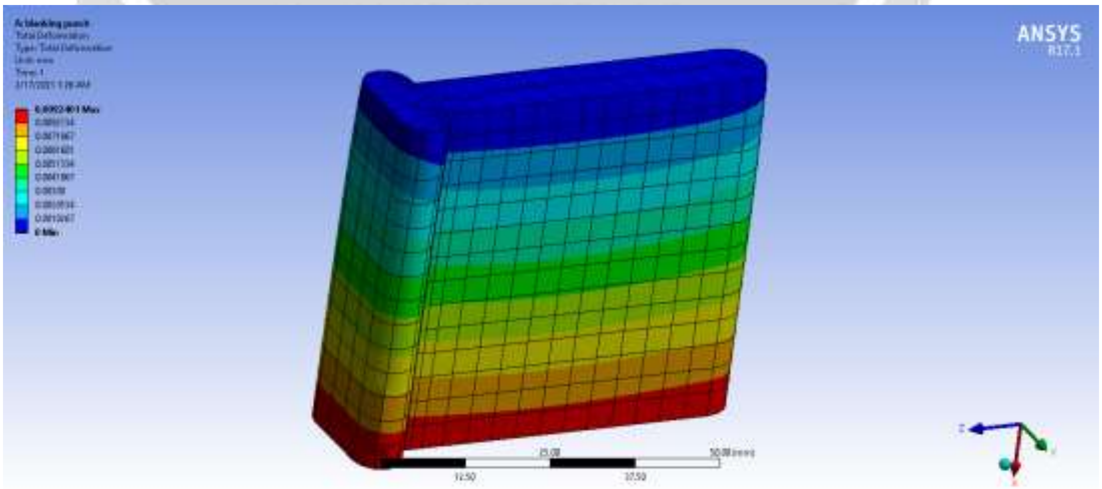

Fig – 36 Deformation on Blanking punch for material HCHCr

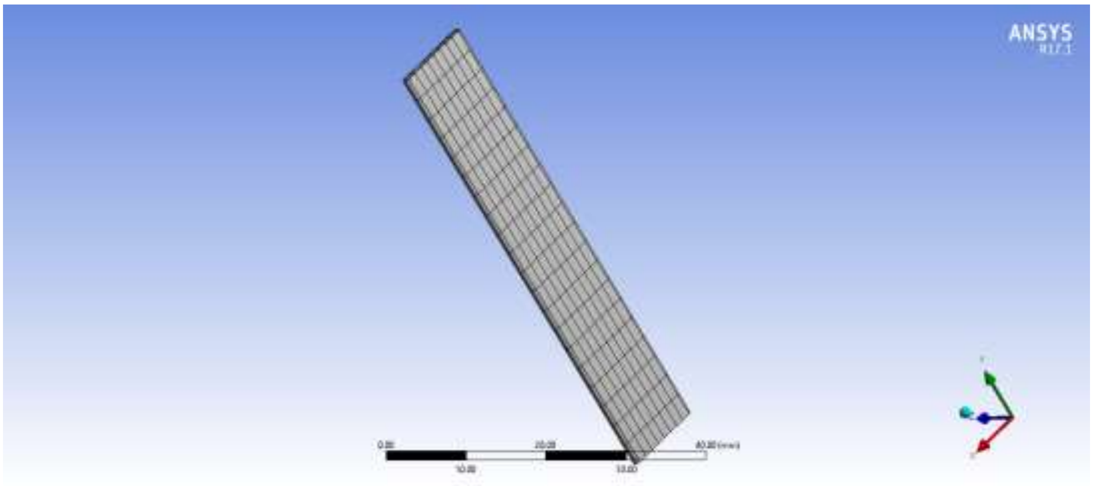

Fig – 37 Meshed model of Oblong piercing punch

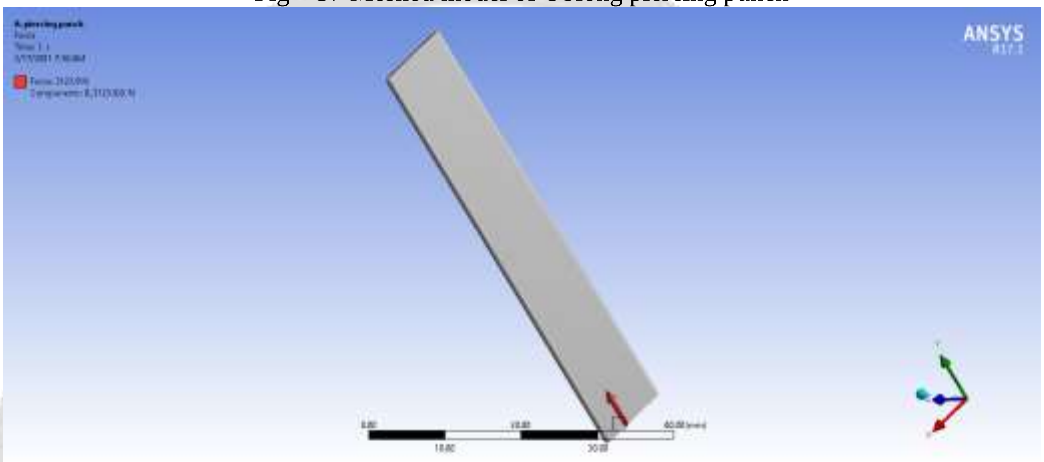

Fig – 38 Boundary conditions of oblong piercing punch for force

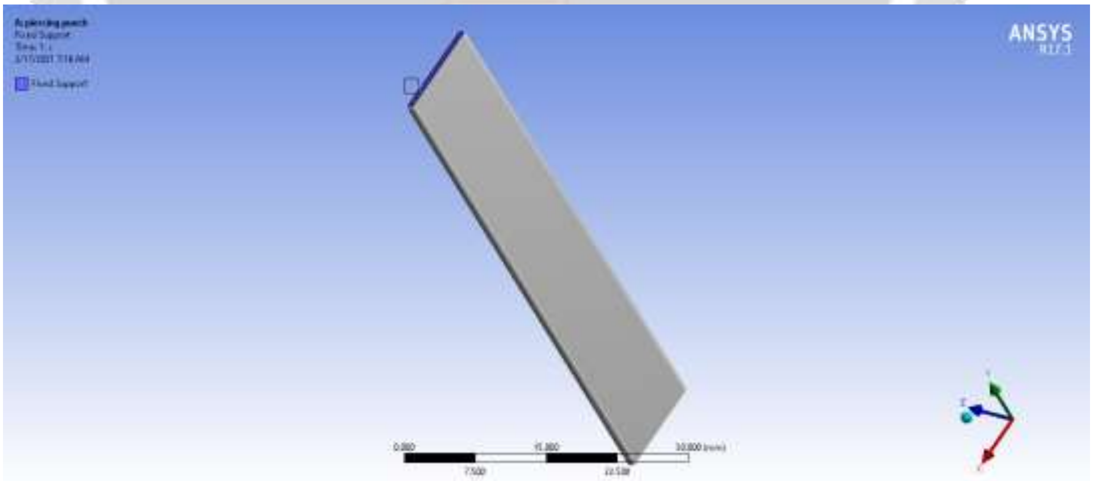

Fig – 39 Boundary conditions of Oblong piercing punch for fixed support

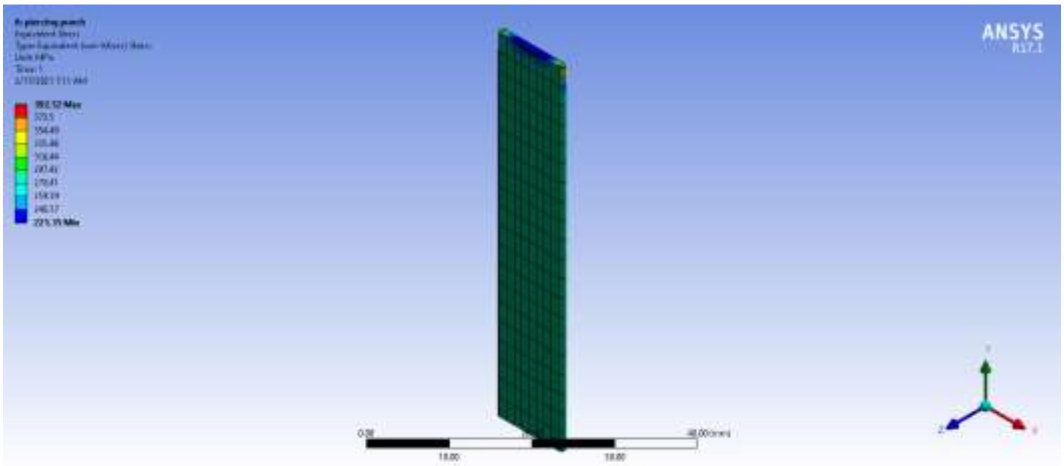

Fig – 40 Equivalent stress (von-misses) on Oblong piercing punch for material D2

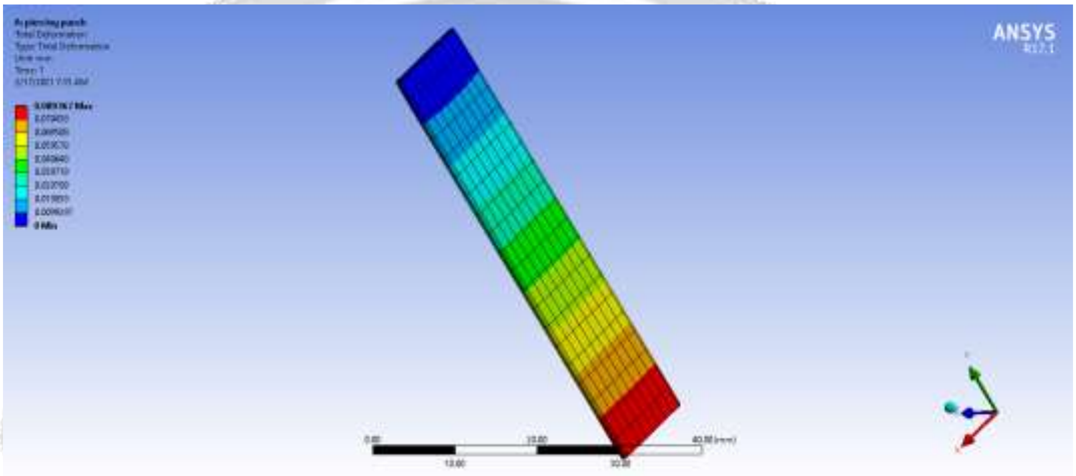

Fig – 41 Deformation on oblong piercing punch for material D2

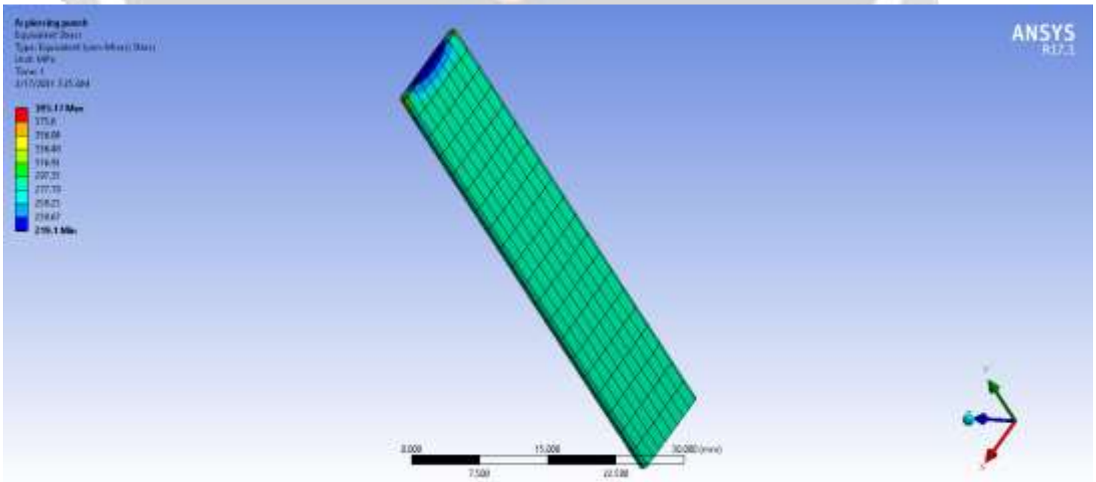

Fig – 42 Equivalent stress (von-misses) on Oblong piercing punch for material M2

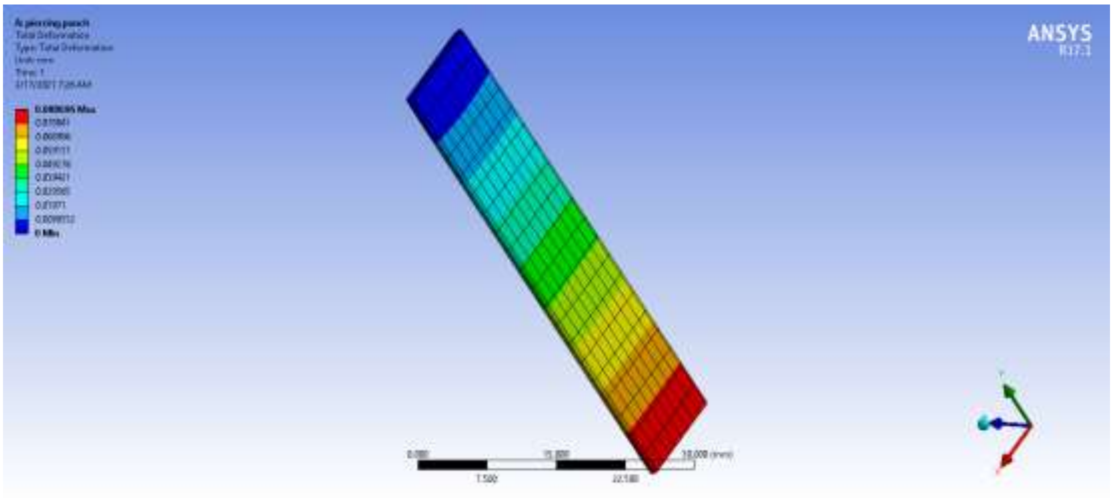

Fig – 43 Deformation on Oblong piercing punch for material M2

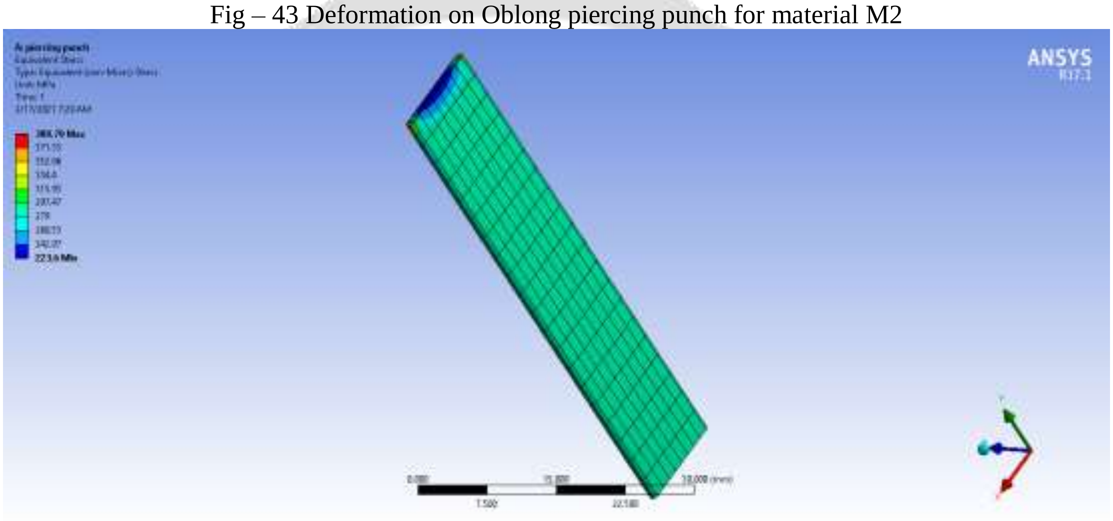

Fig – 44 Equivalent stress (von-misses) on Oblong piercing punch for material SKD11

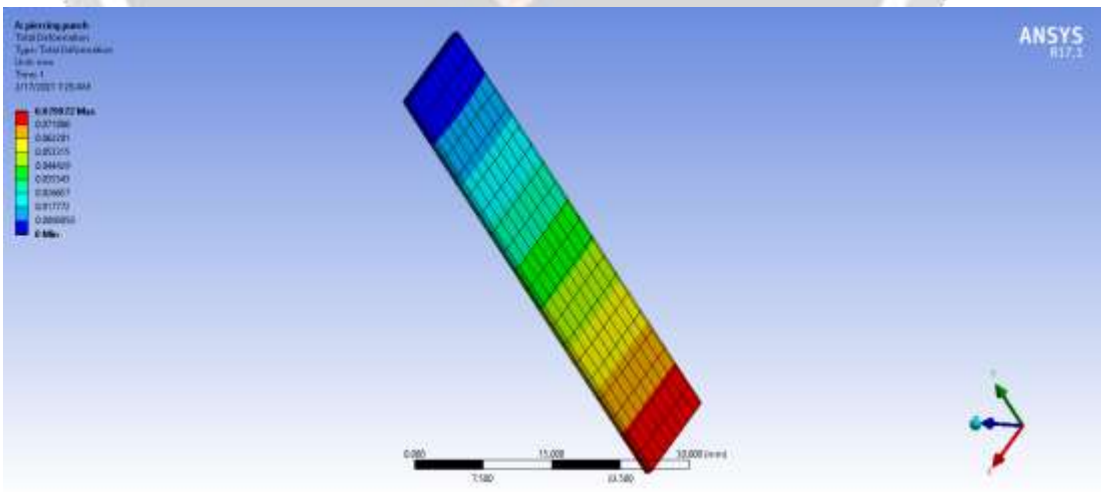

Fig – 45 Deformation on Oblong piercing punch for material SKD11

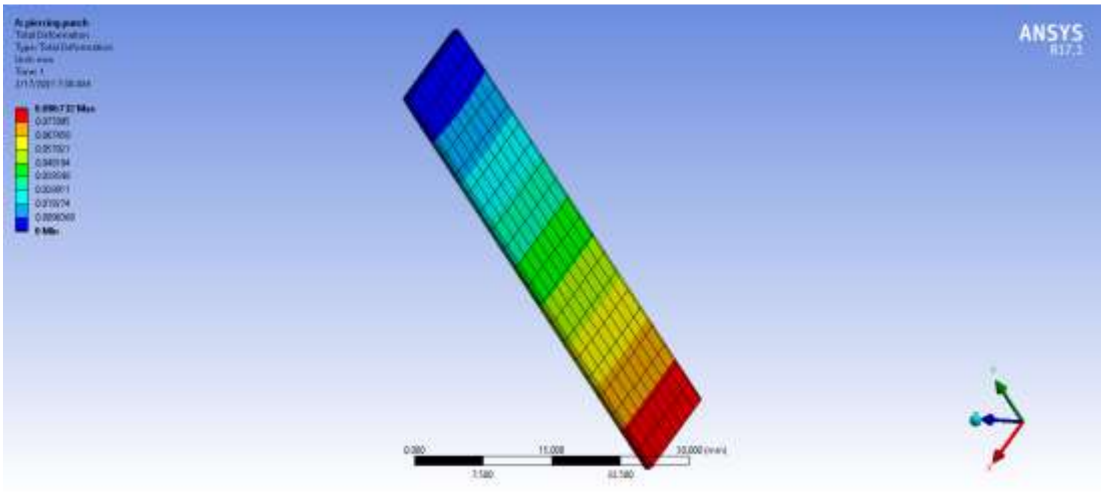

Fig – 50 Deformation on Oblong piercing punch for material HCHCr

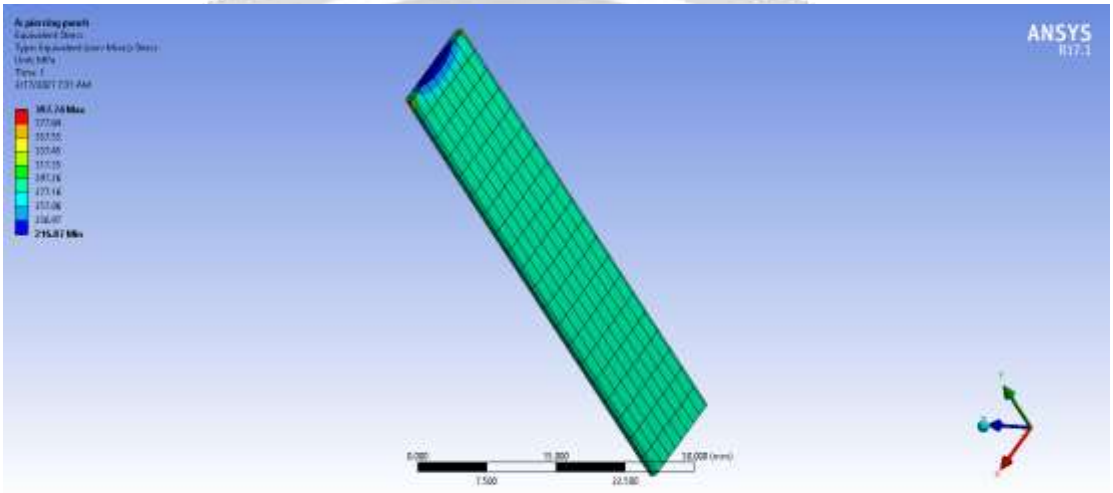

Fig – 51 Equivalent stresses (von-misses) on Oblong piercing punch for material HCHCr

6.2 THEORETICAL ANALYSIS

BLANKING PUNCH

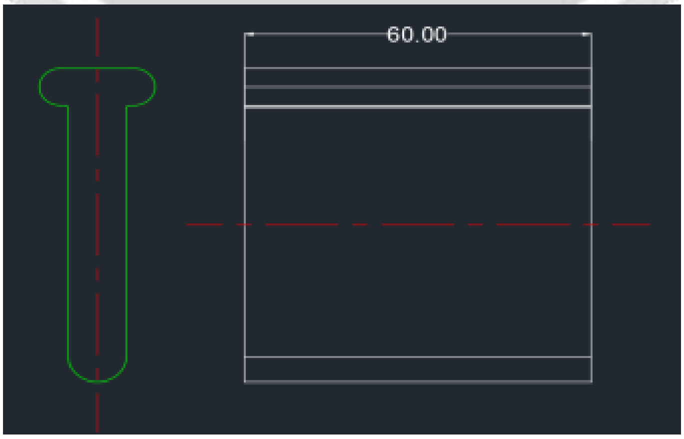

Fig – 52 Sectional view of blanking punch

FOR M_2 MATERIAL

Maximum compressive stress: - Stress (σ) =F/A
F = Compressive force= 20903.4 N
A = Area = 682.31 mm^2
Stress (σ) = 20903.4 N /682.31 mm^2
= 30.636 N/mm^2
Deformation: - dL = (F/E) x (L/A)
dL = Length of deformation
F = Compressive force = 20903.4 N
E = Young's Modulus = 1.956 x 10^5 N/mm^2
L = Length of section = 60 mm
A = Area of section = 30.636 mm^2

dL = (20903.4 N/ 1.956 x 10^5 N/mm^2) x (60 mm/30.636 mm^2)
dL= 9.3976 x 10^{-3} mm

FOR D_2 MATERIAL

Stress (σ) = 20903.4 N /682.31 mm^2
= 30.636 N/mm^2

Deformation: - dL = (F/E) x (L/A)
F = 20903.4 N
E = 1.9416 x 10^5 N/mm^2
L = 60 mm
A = 682.31 mm^2

dL = (20903.4 N/ 1.9416 x 10^5 N/mm^2) x (60 mm/682.31 mm^2)
dL= 9.4673 x 10^{-3} mm

FOR SKD_{11} MATERIAL

Maximum compressive stress: - Stress (σ) =F/A
F = 20903.4 N
A = 682.31 mm^2
Stress (σ) = 20903.4 N /682.31 mm^2
= 30.636 N/mm^2

Deformation: - dL = (F/E) x (L/A)
F = 20903.4 N
E = 217GPa = 217000 N/mm^2
L = 60 mm
A = 682.31 mm^2
dL = (20903.4 N/ 217000 N/mm^2) x (60 mm/682.31 mm^2)
dL= 8.4708 x 10^{-3} mm

FOR HCHCr MATERIAL

Maximum compressive stress: - Stress (σ) =F/A
F = 20903.4 N
A = 682.31 mm^2

Stress (σ) = 20903.4 N /682.31 mm^2
= 30.636 N/mm^2

Deformation: - dL = (F/E) x (L/A)
F = 20903.4 N
E = 2 x 10^5 N/mm^2
L = 60 mm

A = 682.31 mm^2
dL = (20903.4 N/ 2.5 x 10^5 N/mm^2) x (60 mm/682.31 mm^2)
dL= 9.980 x 10^{-3} mm

PIERCING PUNCH

Fig – 53 Sectional view of oblong piercing punch

FOR M_2 MATERIAL
Maximum compressive stress: - Stress (σ) =F/A
F = 3123.9 N
A = 10.79 mm^2

Stress (σ) = 3123.9 N /10.79 mm^2
= 289.51 N/mm^2

Deformation: - dL = (F/E) x (L/A)
F = 3123.9 N
E = 1.956 x 10^5 N/mm^2
L = 60 mm
A = 10.79 mm^2
dL = (3123.9 N/ 1.956 x 10^5 N/mm^2) x (60 mm/10.79 mm^2)
dL= 0.0888 mm

FOR D_2 MATERIAL
Maximum compressive stress: - Stress (σ) =F/A
F = 3123.9 N
A = 10.79 mm^2
Stress (σ) = 3123.9 N /10.79 mm^2
= 289.51 N/mm^2
Deformation: - dL = (F/E) x (L/A)
F = 3123.9 N
E = 1.9416 x 10^5 N/mm^2
L = 60 mm
A = 10.79 mm^2
dL = (3123.9 N/ 1.9416 x 10^5 N/mm^2) x (60 mm/10.79 mm^2)
dL= 0.0894 mm

FOR SKD_{11} MATERIAL
Maximum compressive stress: - Stress (σ) =F/A
F = 3123.9 N
A = 10.79 mm^2

Stress (σ) = 3123.9 N /10.79 mm^2
= 289.51 N/mm^2
Deformation: - dL = (F/E) x (L/A)

F = 3123.9 N
E = 217000 N/mm^2
L = 60 mm
A = 10.79 mm^2
dL = (3123.9 N/ 217000 N/mm^2) x (60 mm/10.79 mm^2)
dL= 0.08005 mm

FOR HCHCr MATERIAL
Maximum compressive stress: - Stress (σ) =F/A
F = 3123.9 N
A = 10.79 mm^2
Stress (σ) = 3123.9 N /10.79 mm^2
= 289.51 N/mm^2
Deformation: - dL = (F/E) x (L/A)
F = 3123.9 N
E = 2 x 10^5 N/mm^2
L = 60 mm
A = 10.79 mm^2
dL = (3123.9 N/ 2 x 10^5 N/mm^2) x (60 mm/10.79 mm^2)
dL= 0.0868 mm

PIERCING PUNCH DIA 2.0

FOR M_2 MATERIAL
Maximum compressive stress: - Stress (σ) =F/A
F = 847.8 N
A = 3.14 mm^2
Stress (σ) = 847.8 N /3.14 mm^2
= 270N/mm^2

Deformation: - dL = (F/E) x (L/A)
F = 847.8 N
E = 1.956 x 10^5 N/mm^2
L = 60 mm
A = 3.14 mm^2
dL = (847.8 N/ 1.956 x 10^5 N/mm^2) x (60 mm/3.14 mm^2)
dL= 0.0828 mm

FOR D_2 MATERIAL
Maximum compressive stress: - Stress (σ) =F/A
F = 847.8 N
A = 3.14 mm^2
Stress (σ) = 847.8 N /3.14 mm^2
= 270 N/mm^2
Deformation: - dL = (F/E) x (L/A)
F = 847.8 N
E = 1.9416 x 10^5 N/mm^2
L = 60 mm
A = 3.14 mm^2
dL = (847.8 N/ 1.9416 x 10^5 N/mm^2) x (60 mm/3.14 mm^2)
dL= 0.0834 mm

FOR SKD_{11} MATERIAL
Maximum compressive stress: - Stress (σ) =F/A
F = 847.8 N
A = 3.14 mm^2
Stress (σ) = 847.8 N /3.14 mm^2
= 270 N/mm^2

Deformation: - dL = (F/E) x (L/A)
F = 847.8 N
E = 217000 N/mm^2
L = 60 mm
A = 3.14 mm^2
dL = (847.8 N/217000 N/mm^2) x (60 mm/3.14 mm^2)
dL= 0.0746 mm

FOR HCHCR MATERIAL
Maximum compressive stress: - Stress (σ) =F/A
F = 847.8 N
A = 3.14 mm^2
Stress (σ) = 847.8 N /3.14 mm^2
= 270 N/mm^2
Deformation: - dL = (F/E) x (L/A)
F = 847.8 N
E = 2 x 10^5 N/mm^2
L = 60 mm
A = 3.14 mm^2
dL = (847.8 N/2x 10^5 N/mm^2) x (60 mm/3.14 mm^2)
dL= 0.081 mm

7. RESULTS

7.1 ANSYS ANALYSIS RESULTS

MATERIAL	STRESS (N/mm^2)		DEFORMATION (mm)
	MIN	MAX	
D2	15.957	54.239	0.009517
M2	15.429	55.003	0.0094475
SKD11	16.485	53.472	0.0085147
HCHCr	14.899	55.764	0.0092401

Tabular column for Blanking punch

MATERIAL	STRESS (N/mm^2)		DEFORMATION (mm)
	MIN	MAX	
D2	221.35	392.52	0.089367
M2	219.1	395.17	0.088696
SKD11	223.6	389.79	0.079972
HCHCr	216.87	297.74	0.086732

Tabular column for Oblong piercing punch

MATERIAL	STRESS (N/mm^2)		DEFORMATION (mm)
	MIN	MAX	
D2	38.88	294.4	0.0821
M2	39.132	293.9	0.0821
SKD11	38.66	294.9	0.074015
HCHCr	39.41	293.4	0.080287

Tabular column for piercing punch dia 2.0

7.2 THEORITICAL ANALYSIS RESULT

	M2			D2			SKD11			HCHCr		
	Blanking	Oblong Piercing	Piercing punch dia 2.0	Blanking	Oblong Piercing	Piercing punch dia 2.0	Blanking	Oblong Piercing	Piercing punch dia 2.0	Blanking	Oblong Piercing	Piercing punch dia 2.0
STRESS (N/mm^2)	30.636	289.51	270	30.636	289.51	270	30.636	289.51	270	30.636	289.51	270
DEFORMATION (mm)	9.3976×10^{-3}	0.0888	0.0828	9.4673×10^{-3}	0.0894	0.0834	8.4708×10^{-3}	0.08005	0.0746	9.980×10^{-3}	0.0868	0.081

8. CONCLUSION

The individual components of progressive tool were modeled in Catia V5r21. Each individual file was imported to Ansys17.1 software through stp format. The following conclusions were made.
1. The results obtained through analysis are approximately nearer to the theoretical values. This demonstrates that the analysis carried out was correct.
2. It is also observed that the design of progressive tool is safe as all the stress values were less than the allowable stress of the material.
3. From the considered die steel alloys (D2, M2, SKD11, HCHCr) SKD11 with density 7.87 g/cm^3, Young's modulus 2.17×10^5, and poison's ratio 0.27 gave the best results among remaining considered die steel.

9. REFERENCE

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