Design and Analysis of Four Stage Progressive Tool for House-wiring Wire Clip

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Abstract: **Progressive tool plays a vital role in sheet metal industries. It can perform various individual operations or combination of operations at two or more stations. In progressive tool design, strip layout design plays a key role. The design of strip layout should be in such a fashion that it can utilize more than 70% of total stock material. This paper describes the design of strip layout, actual cutting load required to perform the operations and based on this load calculation of press capacity and design of die element like thickness of die block, bottom bolster, top bolster and punch plate etc. The software used for modeling of die element is Creo 2.0 and for drafting of assembly drawing is AutoCAD 2016. ANSYS 17.2 is used to perform finite element analysis on blanking punch to ensure the working condition of tool within the limit.**

Index Terms: **Strip layout, progressive tool, press capacity**

I. Introduction

The popularity of Metal stamping process is due to its high productivity, ease in manufacturing of intricate shapes and low cost [1].

Progressive die is known for mass production. This tooling set up consists of one or more dies which can perform multiple operations in single stroke of the press machine. The work is carried forward in subsequent stations in the strip layout. Sheet metal products made by progressive tooling set up can be found inevitably in almost all household and/or industrial components and appliances. [2].

The essential prerequisites to execute first class press work are good operation planning, excellent tool design, accurate tool making and knowledgeable press setting [3].

Design of right tool holds the key to costing of the whole tooling set up. A costly tool will increase the cost of the manufactured component. It is important to keep the tooling cost low without sidelining the quality of the tool [4].

Progressive die design is an art rather than a science. The tooling design is decided based on individual designer's skill and knowledge which are acquired through working experience [5].

During the die design, the first step is to generate punch layout which indicates the optimum layout of the punches. This optimum layout is helping to avoid the clashes between punches and die buttons. None of the piercing operations can appear after scrap removal operation. The space between two punches should be enough to give die wall strength [6].

Wire clip has high consumption for demonstration to 1st year students in *'House wiring workshop' at CVR College of Engineering.* So, it produces a four stage progressive tool designed and analysis conducted on die elements like blanking punch. The 3D CAD model of the wire clip is shown in figure 1.

II. Component Details

The progressive die is to be designed for house-wiring wire clip of galvanized sheet. The following details shown in table 1 like area of component, volume of component have obtained from CAD software.

Table I.
Component Details

Material	CPMnS based galvanized steel-Grade 33 [7]
Thickness	0.3 mm
Shear strength (kg/mm2)	35 kg/mm2
Area of the component	367 mm^2
Volume of the component	111 mm^3

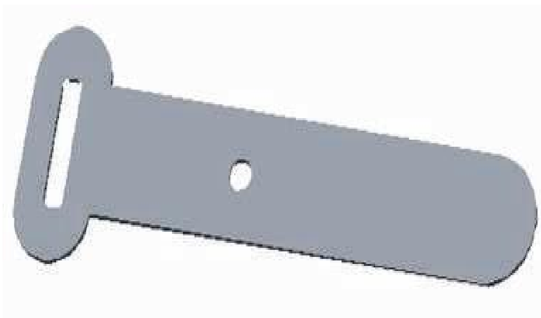

Figure 1. 3D CAD model of the wire clip

III. Strip Layout Development And Shear Force Calculation And Press Capacity

Development of strip layout is the primary task for designing of progressive tool. It represents the operations to be carried out at subsequent stations [8].

A. Strip Layout

A = Back scrap = Front scrap = sheet thickness = 1mm
B = Bridge scrap = 1mm
Width of the stock = 53mm
Pitch = Advance = B + L = 18 mm

Equation 1 shows the percentage utilization of the stock strip. The development of strip layout is shown in figure 2.

B. % Stock strip utilization (n)

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Strip layout has to developed in such a way that stock strip utilization is maximum. It will save appreciable amount of stock material and tooling expenses.

$$n = \frac{Area\ of\ blanks\ X\ no\ of\ rows}{Area\ of\ strip\ per\ pitch} \times 100 \qquad (1)$$

= Area of strip per pitch = Advance x stock width
= 18 x 53 = 954 mm^2
$= \frac{367\ X\ 2}{954} = 76.94\ \%$

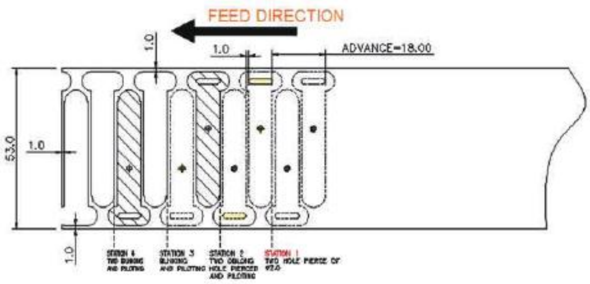

Figure 2. Development of the strip layout

As shown in figure 2, from the right hand side, at station 1 two holes are pierced. At station 2 oblong holes are pierced. Two blanking of two wire clip profiles are blanked at 3 and 4 station to have maximum stock utilization.

C. Shear Force calculation in Tons (T)

Equation 2 shows the shear force for cutting in tons (T) [8].

Shear force, $F_{sh} = \frac{K \times L \times t \times S_{sh}}{1000}$ T (2)

S_{sh}= Shear strength of the stock material = 35 kg/mm^2
Stock Thickness, t = 0.3mm
K= Factor of safety = 1.4
L = Total cutting perimeter in mm

A. Perimeters of the contours at each stage:

1) At station 1

The perimeter of the two piercing hole of diameter 2 mm is given by

Perimeter, P_1= 12.6 mm

2) At station 2

The perimeter of the two oblong hole is given by

Perimeter, P_2 = 31.6 mm

3) At station 3

The perimeter of the contour to be blanked is given by

Perimeter, P_3 = 98 mm

4) At station 4

The perimeter of the second contour to be blanked is given by

Perimeter, P_4 = 98 mm

Total cutting perimeter, $L = P_1 + P_2 + P_3 + P_4$
= (12.6 + 31.6 + 98 + 98)
= 240.2 mm

$F_{sh} = \frac{1.4 \times 240.2 \times 0.3 \times 35}{1000} = 3.54$ T

D. Press Capacity (Pc):

Equation (3) is for Calculating the press capacity which will be in Tons (T).

The Total press capacity is 25% more than the total tonnage calculated

Pc = Total Tonnage x 1.25 (3)
= 3.45 x 1.25 = 4.3 T

Since 4.3 T press not available in market, so 10 T press can be use for production of wire clip.

E. Ejection force (F_{ej})

After shearing, the sheet metal get stuck in the land provided in the die hole. The stuck material is called slug which has to be ejected by applying ejection force. Equation 4 shows the calculation for ejection force [9].

Ejection force, $F_{ej} = 0.1 \times F_{sh}$ (4)
= 0.1 × 3.54 = 0.36 T

IV. Development Of The Progressive Tool

A. Clearance (C)

Equation 5 shows the calculation for clearance to be given between die and the punch for shearing [8].

$C = 0.005 \times t \times \sqrt{F_{sh}}$ (5)
$= 0.005 \times 0.3 \times \sqrt{3.6}$
= 0.003 mm per side

B. Die Block Design

Equation 6 shows the thickness of the die which is also known as the female member of the tool [8].

a) Thickness of the die (T_D)in mm

$T_D = \sqrt[3]{F_{sh}} \times 10$ (6)
$= \sqrt[3]{3.6} \times 10$
= 15.33 ≈ 18.5 mm

b) Land and draft

The straight portion of die opening is known land and the intentional amount of tapper in die opening immediate after the land in downward direction is known draft. If draft is not given, internal stress in the punch will cause crack in the die block. The standard value of land is
3 mm or three times of sheet thickness, when sheet thickness is less than 1mm then land is 3mm, while three times of sheet thickness is used when sheet thickness more than 1mm and draft angle is 1/2°.

c) Thickness of Bottom and Top Bolster

Equation 7 and equation 8 show the calculation for calculating the thickness of the bottom bolster and top bolster of the die set respectively [9].

Thickness of bottom bolster, $T_{BB}= 1.75\times T_D$ (7)
$= 1.75\times 15.5 = 27.125 \approx 28$ mm

Thickness of Top bolster, $T_{TB}= 1.25\times T_D$ (8)
$= 1.25\times 15.5 = 19.375 \approx 20$mm

d) Stripper plate design and Punch Plate

Scrap material cling to the punch and during return stroke it try to lift along with punch. Stripper plate is used to strip the scrap material from the punch.

There are two types of stripper plate i.e fixed stripper plate and floating stripper plate. When the stock thickness is less than 1 mm, floating striper is used which is holding the stock against die surface tightly during cutting.

Equation 9 and equation 10 show the calculation of the thickness of the stripper plate and punch plate respectively.

Thickness of the stripper plate, $T_{ST} = 0.5\times T_D$ (9)
$T_{ST} = 0.5\times 15.5 = 7.75 \approx 8$mm

Thickness of the punch plate, $T_{PP} = 0.5\times T_D$ (10)
$T_{PP} = 0.5\times 15.5 = 7.75 \approx 8$mm

V. Centre 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 [9].

Figure 6 is showing all the dimensions for load center of all cutting profile from X-axis and Y-axis. Equation (11) and equation (12) are showing the location of center of pressure from X-axis and Y-axis respectively.

Calculation of distance X in mm of the center of pressure from the axis Y-Y by the formula
X = (L1×X1+L2×X2+L3×X3+ …..) / (L1+L2+L3+…..)

$$X = \frac{\sum Li \times Xi}{\sum Li} \quad (11)$$

Calculation of distance Y in mm of the center of pressure from the axis X-X by the formula
Y= (L1×Y1+L2×Y2+L3×Y3+ …..)/(L1+ L2+ L3+…..)

$$Y = \frac{\sum Li \times Yi}{\sum Li} \quad (12)$$

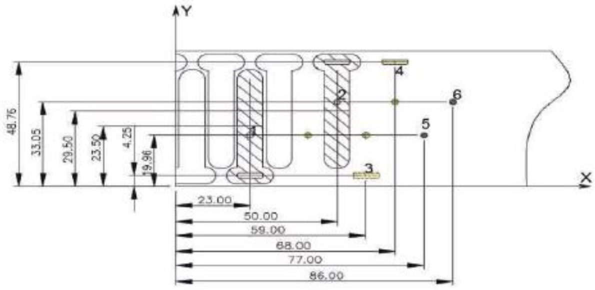

Figure 3. Co-ordinate dimension of cutting profile

Following equations (13), (14) and (15) are the load calculation according to serial number of figure (3) at different stations.

At 1 Load L1= $\frac{L\times t\times S_{sh}}{1000}$ Tons = $\frac{98\times 0.3\times 35}{1000}$ = 1.1T (13)
Load at 2 is similar to L1, both have same profile.
At 3 Load L3 = $\frac{L\times t\times S_{sh}}{1000}$ Tons = $\frac{15.8\times 0.3\times 35}{1000}$ = 0.2T (14)
Load at 4 is similar to L3, both have same profile.
At 5 Load L5 = $\frac{L\times t\times S_{sh}}{1000}$ Tons = $\frac{6.3\times 0.3\times 35}{1000}$ = 0.1T (15)
Load at 6 is similar to L5, both have same profile.

Table II.
Calculation Of Center Of Pressure

Serial Number	Load, L T	Distance, X(mm)	Distance, Y(mm)	X_i x L_i	Y_i x L_i
1	1.1	23	23.50	25.3	25.85
2	1.1	50	29.50	55.0	32.45
3	0.2	59	4.25	11.8	0.85
4	0.2	68	48.76	13.6	9.752
5	0.1	77	19.96	7.7	1.996
6	0.1	86	33.05	8.6	3.305
Total	∑Li			∑(Xi x Li)	∑(Yi x Li)

From table 1, ∑Li, ∑ (Xi x Li), ∑ (Yi x Li) are 2.8, 122 and 74.203 respectively.

Distance of load from X axis, $X = \frac{\sum(Xi \times Li)}{\sum Li} = \frac{122}{2.8}$
= 43.6 mm

Distance of load from Y axis, $Y = \frac{\sum(Yi \times Li)}{\sum Li} = \frac{74.203}{2.8}$
= 26.5 mm

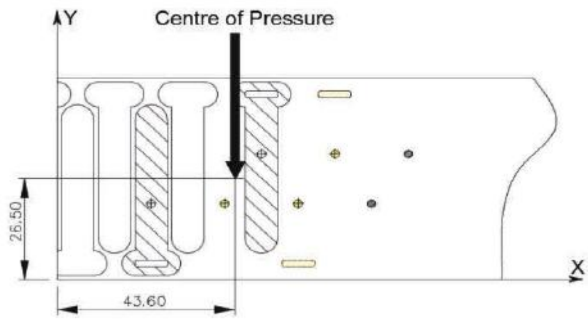

Figure 4. Location of center of pressure

Figure 4 represents the location of center of pressure for shank mounting.

VI. Finite Element Analysis Of The Punches

A. Results for Blanking punch

The stress, strain and total deformation of the blanking punch which is developed due to cutting force has found by the use of Finite element analysis (FEA). The type of element chosen is tetrahedron (10 nodes) and element size is 5mm shown in figure 5.

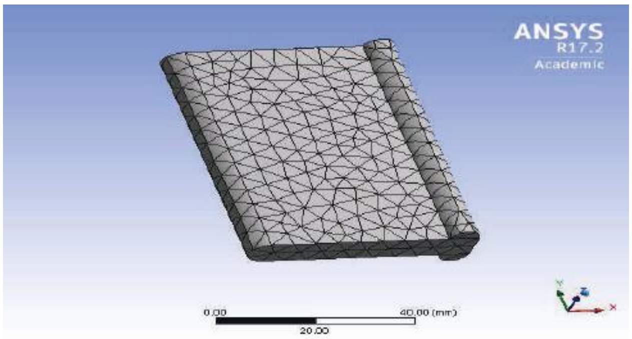

Figure 5. Meshing of the blanking punch (Tetrahedron 10-nodes)

The boundary condition and load application on blanking punch is shown in figure 6 and figure 7 respectively.

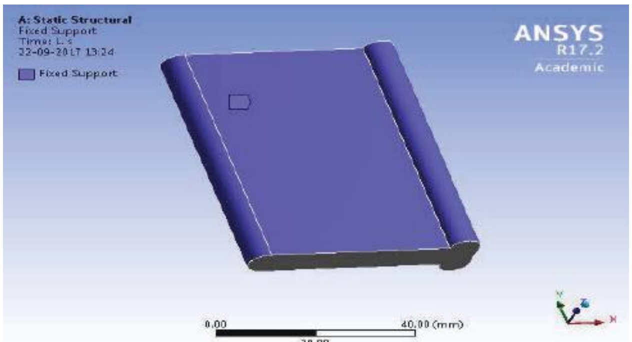

Figure 6. Constraint- fixed support

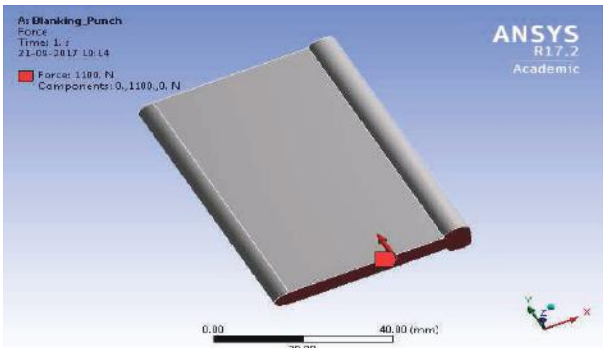

Figure 7. Cutting force applied on cutting face of blanking punch

The results of analysis for blanking punch are shown in figure 8 to figure 10.

Force required for blanking as calculated in equation (13) is 1.1T or 1100N.
Cutting area of the blanking punch = 252.82 mm^2 (Area obtained from CAD software)

The analytical calculation for the stress develop in the blanking punch is as follows

Stress developed (σ_1) in blanking punch in N/mm^2

$$\sigma_1 = \frac{Force\ required\ for\ blanking\ punch}{Cutting\ area\ of\ the\ blnking\ punch} = 4.351\ N/mm^2$$

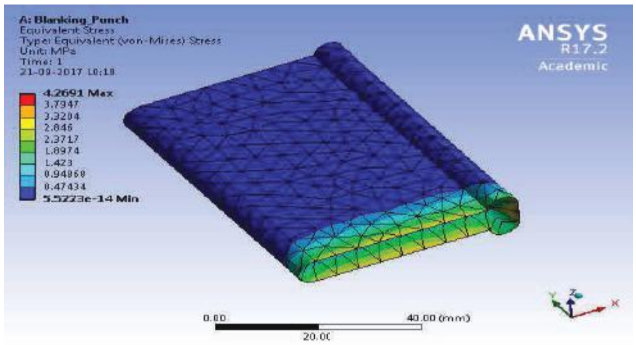

Figure 8. Von-Mises stress developed in the blanking punch

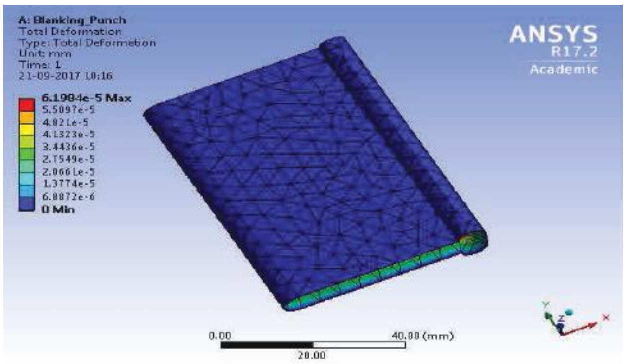

Figure 9. Total deformation occurred in the blanking punch

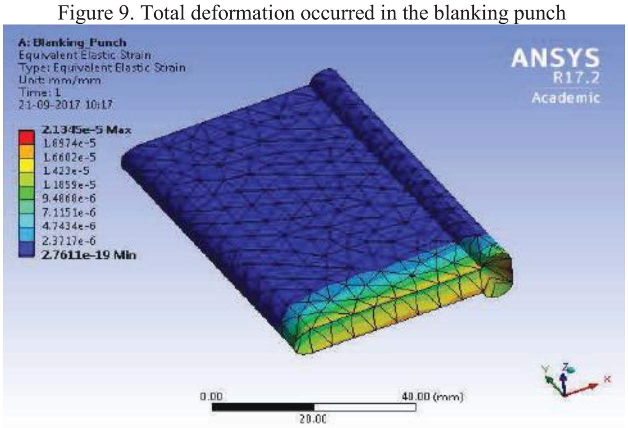

Figure 10. Equivalent Elastic (Von-Mises) strain in blanking punch

B. Results for Piercing punch

The type of element chosen for piercing punch and oblong punch is tetrahedron (10 nodes) and element size is 2.5mm shown in figure 11 and figure 17 respectively.

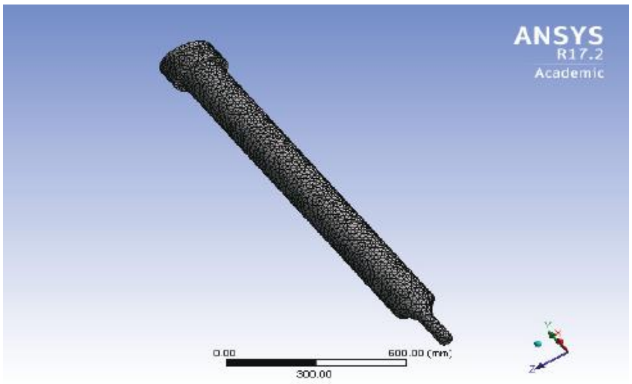

Figure 11. Meshing of the piercing punch (Tetrahedron 10-nodes)

The boundary condition and load application on piercing punch is shown in figure 12 and figure 13 respectively.

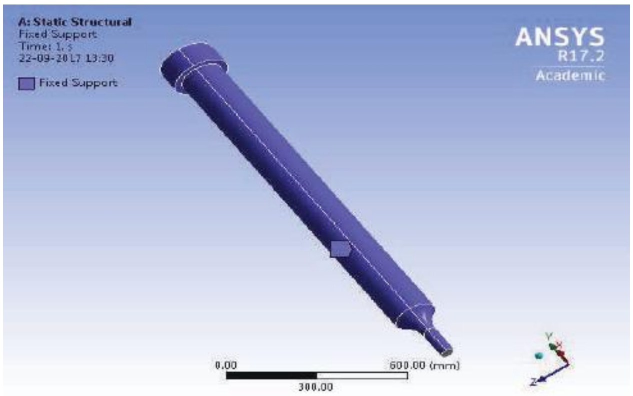

Figure 12. Constraint- fixed support

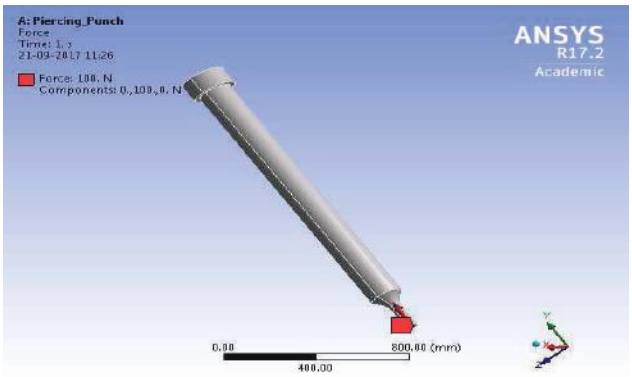

Figure 13. Cutting force applied on cutting face of piercing punch

The results of analysis for piercing punch are shown in figure 14 to figure 16.

Force required for piercing as calculated in equation (14) is 0.1T or 100N.

Cutting area of the piercing punch = 3.142 mm^2 (Area obtained from CAD software)

The analytical calculation for the stress develop in the blanking punch is as follows

Stress developed (σ_1) in blanking punch in N/mm^2

$$\sigma_1 = \frac{Force\ required\ for\ blanking\ punch}{Cutting\ area\ of\ the\ blnking\ punch} = 31.83\ N/mm^2$$

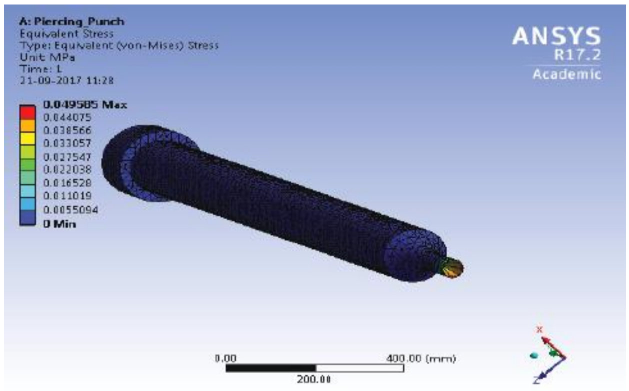

Figure 14. Von-Mises stress developed in the piercing punch

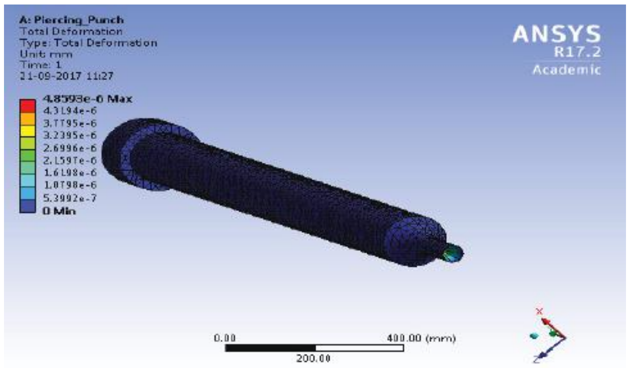

Figure 15. Total deformation occurred in the blanking punch

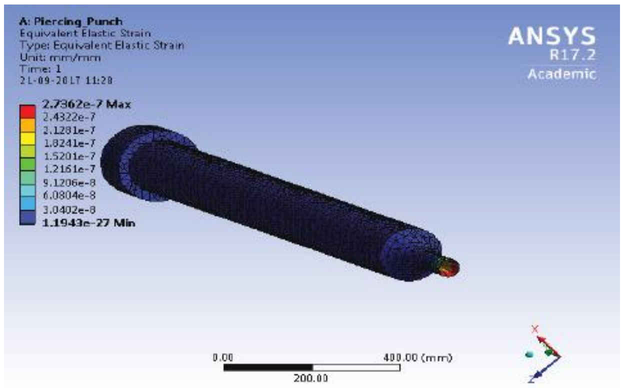

Figure 16. Equivalent Elastic (Von-Mises) strain in piercing punch

C. *Results for Oblong punch*

Figure 17. Meshing of the oblong punch (Tetrahedron 10-nodes)

The boundary condition and load application on piercing punch is shown in figure 18 and figure 19 respectively.

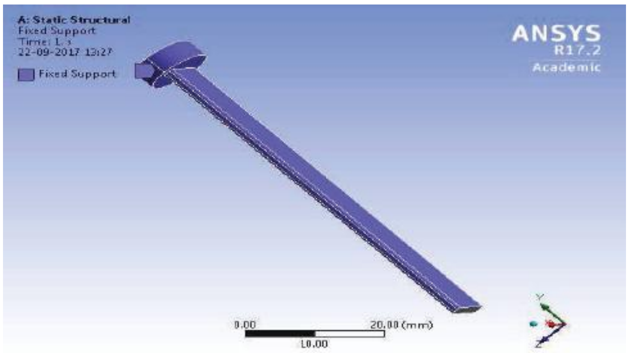

Figure 18. Constraint- fixed support

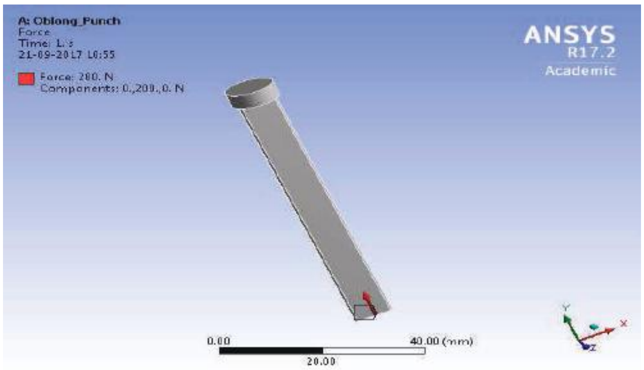

Figure 19. Cutting force applied on cutting face of oblong punch

The results of analysis for piercing punch are shown in figure 20 to figure 22.

Force required for oblong piercing as calculated in equation (15) is 0.2T or 200N.
Cutting area of the oblong punch = 11.89 mm^2

The analytical calculation for the stress develop in the blanking punch is as follows

Stress developed (σ_1) in blanking punch in N/mm^2

$$\sigma_1 = \frac{Force\ required\ for\ blanking\ punch}{Cutting\ area\ of\ the\ blnking\ punch} = 16.821\ \text{N/mm}^2$$

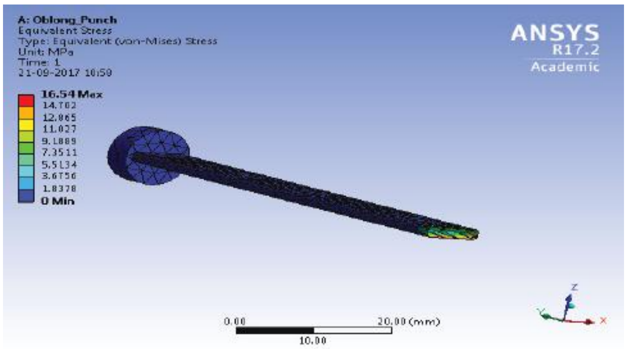

Figure 20. Von-Mises stress developed in the oblong punch

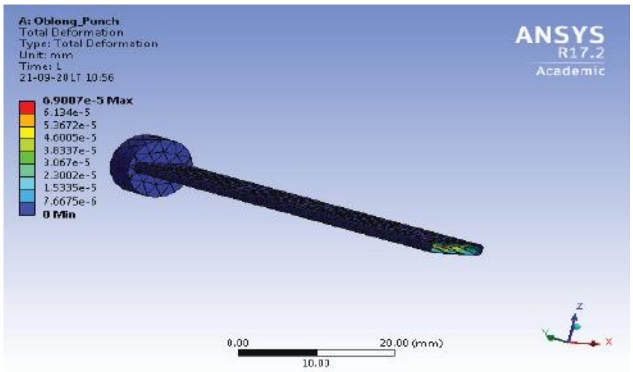

Figure 21. Total deformation occurred in the oblong punch

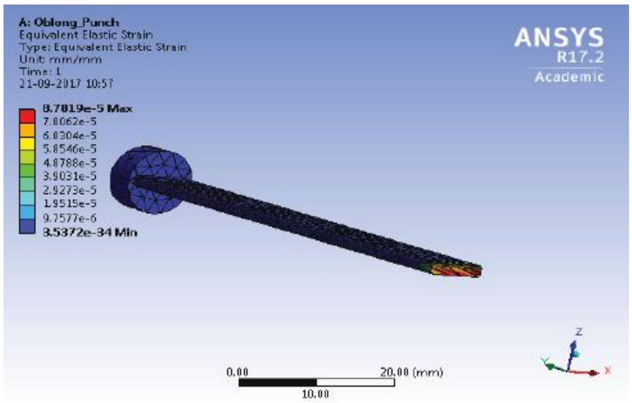

Figure 22. Equivalent Elastic (Von-Mises) strain in oblong punch

VII. Results And Discussions

The results of obtained from finite element analysis and analytical method is tabulated in table II.

TABLE III.
RESULTS AND REMARKS

Serial number	Punches	Maximum Stress developed obtained through ANSYS	Total deformation obtained through ANSYS	Maximum strain developed (mm/mm) obtained through ANSYS
1.	Blanking punch	4.2691 MPa	6.1984x10^{-5} mm	2.1345x10^{-5}
2.	Piercing punch	0.049585 Mpa	4.8593x10^{-6} mm	2.7362x10^{-7}
3.	Oblong punch	16.54 Mpa	6.9007x10^{-5} mm	8.7819x10^{-5}

The material of punches is high carbon high chromium steel (D2 steel). Yield strength of D2 steel is 2200 Mpa [10] and the results obtained from both ANSYS is less than the yield strength of the material. Hence, the material will not fail in the required working condition. The centre of pressure for shank mounting is on X and Y axis 43.6mm and 26.5mm respectively.

This paper has completed most part for the design of a progressive tool. This tool has been designed for in-house manufacturing of tool for wire clip. Students can conduct experiments on same in production technology laboratory. The same components i.e. wire clip can be used by the students for "house wiring" module in workshop practice session.

VIII. Final Assembly

The orientation of punches, pilots and final assembly of the progressive tool is shown in figure 23 and figure 27 respectively.

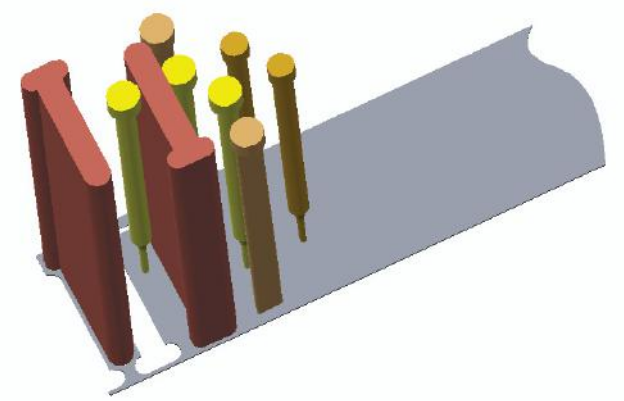

Figure 23. Orientation of punches and pilots for progressive tool

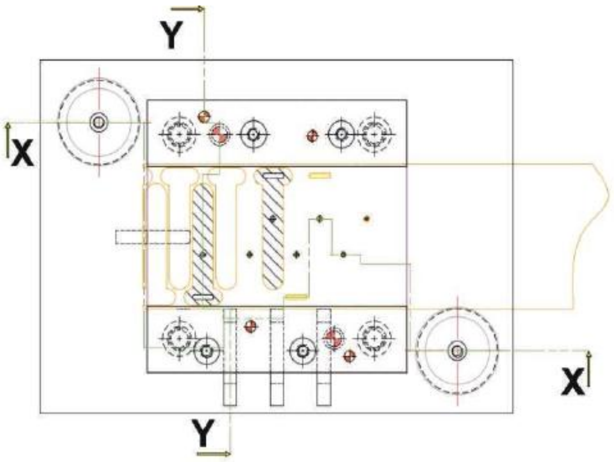

Figure 24. Bottom assembly of the progressive tool

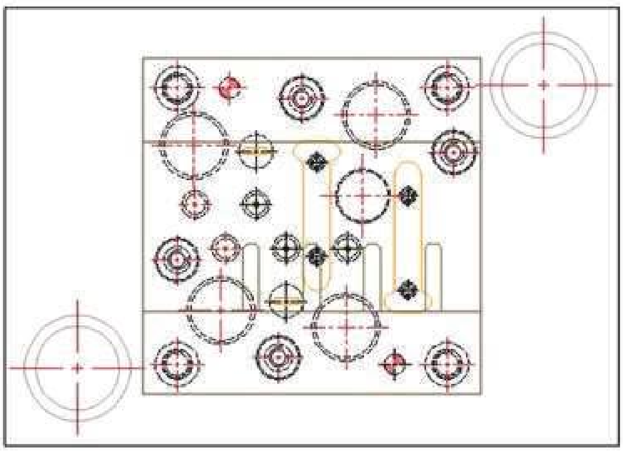

Figure 25. Top half assembly (inverted view) of the progressive tool

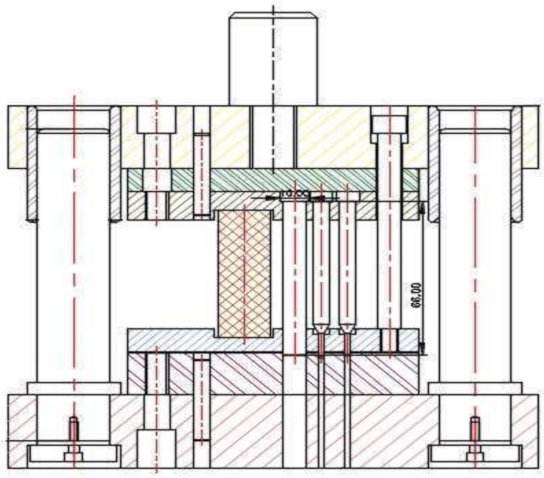

Figure 26. XX-Sectional view of the progressive tool

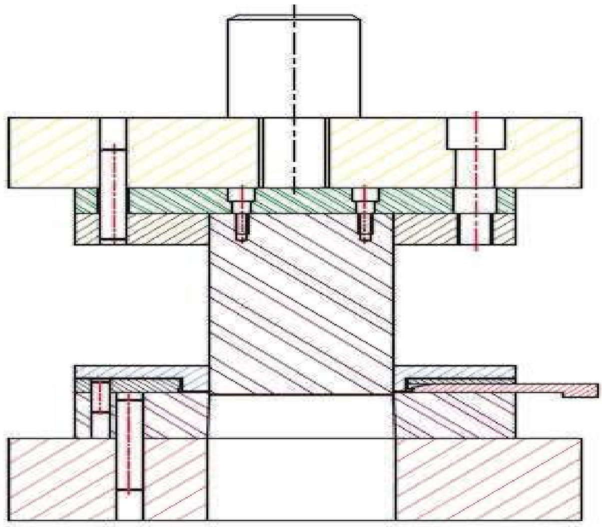

Figure 27. YY-sectional view of the progressive tool

IX. Conclusions

In this paper, a four stage progressive tool wire clip is designed, modeled, analyzed and drafted. Modeling has done in Creo2.0. Analysis has done in ANSYS 15.0 and Drafted in AutoCAD 2016. Strip layout for maximum stock strip utilization is developed. Stock strip utilization achieved is approximately 77 %. Further, finite element analysis for maximum Von-Mises stress and deformation is carried out on the punches using ANSYS 17.2 for validating the design. The results obtained are well within the limit. The press capacity obtained is of 10 T. The moment generation due to cutting force during cutting stroke will be negligible as location of centre of pressure locate the shank, which will fixed onto the ram of press machine in same axis.

Currently, the wire clip component is purchased from commercial stores in the market. By studying the component profile and its method of manufacturing, it is understood that the component is produced by simple single stage tool due which the concentricity in the profile of the component is missing out. To overcome it, progressive tool for its manufacturing is designed so that good profile concentricity can be maintained and finally the cost of component per piece can be reduced as compared from the previous method of manufacturing.

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