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Optimization of Sheet Metal Thickness and Die Clearance of Progressive Press Tool Using Finite Element Analysis and Artificial Neural Network Technique

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Abstract: A ***progressive die performs a series of fundamental sheet-metal operations at two or more stations during each press stroke in order to develop a work piece as the strip stock moves through the die. Progressive die components are modeled in SOLID WORKS with selected dimensions for selected tool component. The main advantage of computer-aided progressive die design and machining is ability to build precision tooling in less time and at a lower cost. In this project main steps are Design and FEA analysis. This design is the optimal design. By using this design we can produce accurate components. This project basically focus on optimization of thickness and die clearance for a given range of cutting forces in order to minimize the stresses produced in die plate block which will lead to lesser deformation on the plate which will further lead to accurate sheet metal components produced by the progressive press tool. The optimized design parameters will be validated using remodeled components in ANSYS Software and further also compared with theoretically calculated design parameters.***

Keywords: Press Tool, Sheet Metal Thickness, Die Clearance, Artificial Neural Network.

1. Introduction

Progressive tool performs two or more operations at different stages in each stroke. The stock strip is advanced through a series of stations that form one or more distinct press working operations on the strip to get the component [1].A progressive or follow on die has a series of operations. At section of the metal in which a hole had been pierced at a previous station. Thus after the first stroke, when only a hole will be punched, each stroke of the press produces a finished washer [4].

1.1 Die Plate of Progressive Press Tool

A die block is defined as the block or plate from which the die profile is cut. It is usually lower member of the tool. It provides cutting edge. The die opening has different designs and the design is selected after looking in the requirements and facilities available [1].

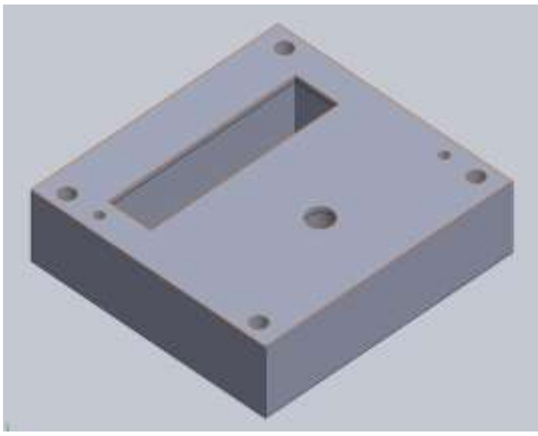

Figure 1: Die Plate of progressive press tool

2. Cutting Clearance

Cutting clearance is the gap between a side of the punch and the corresponding side of the die opening when the punch is entered into the die opening. Cutting clearance should always be expressed as the amount of clearance per side. Proper cutting clearance is necessary for the longer life of the tool. Quality of the piece part also depends on proper cutting clearance. A visual examination of the punched components will indicate the amount of clearance and whether the punch and die have optimum cutting clearance or excessive clearance or misalignment.

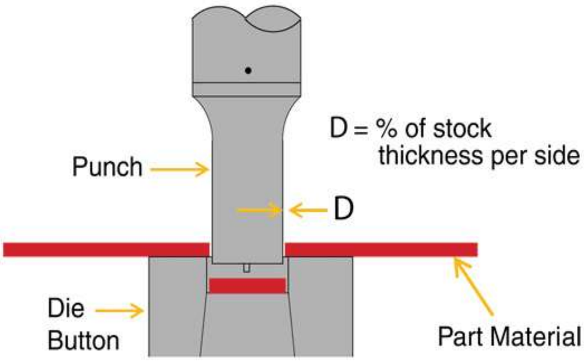

Figure 2: Cutting Die Clearances

2.1 Clearance Equation

The ideal clearance can be calculated using the following formula

$$\text{Clearance} = C * t * \sqrt{\frac{T_{max}}{10}}$$

Where, C = 0.005 (accurate components)

= 0.01 (normal components)
t = sheet thickness in mm
T max = shear strength of stock material in N/mm2

3. Problems in Progressive Tool

Based on my research and industrial survey, sheet metal components produced in the press tool in some particular cases are not found to be in perfect shape. Manufacturers as well as consumers often complain about slight amount of bend formation on final component produced.

For problem identification to some extent it was found that the problem is directly linked to bends observed in the die plate block. The bend in the die plate is caused due to non uniform application of force. The direction of punch travel should always be perpendicular to the direction of die plate face in order to have uniform application of force on the sheet metal.

Stress formation is the primary cause of deformation produced in any component. Due to stress produced in die plate block, deformations are caused which leaves an impression on die plate and creates gap between stripper plates and die plate. Due to which sheet metal strip will misalign. Shearing processes therefore will not produce required contours on component. Also a slight bend is observed on final sheet metal component. The problem identified therefore is stress produced in the die plate which is the main reason behind the production of non accurate components.

4. Aim of Analysis

The rectification of problem as mentioned above in the problem identification part deals with minimizing the stress produced in the die plate component of press tool. Based on the literature review related to the project topic, there are several factors which contribute to minimize the stress produced in the press tool component.

Out of these several factors, die cutting clearance and thickness of sheet metal component is considered for project study. Although other factors also play a very important role in minimizing the stress produced, but aim of study deals with optimization of above mentioned factors in rectifying the problem identified.

5. Cutting Force Calculation

Sheet thickness, t = 1.5 mm
Material, M.S (Component)
Shear Strength, η = 360 N/ mm2
Perimeter of component, P = 215.28 mm
Cutting Force, F = η * P * T
= 116251.2 N
Safety Factor = F * F.O.S
= 116251.2 * 1.2
= 139501.44 N
= (139501.44/9.81) Kg
Weight of Component = 14220.33 Kg
Weight of Component = 14.22 TONNES

5.1 Die Clearance Calculation

Clearance per side = C * t * $\sqrt{(\eta max/10)}$
Where C = constant
C = 0.005 (very accurate component)
C = 0.01 (normal component)
t = sheet thickness = 1.5 mm
Clearance per side = 0.01 * 1.5 * $\sqrt{(360/10)}$
Clearance per side = 0.09 mm per side

5.2 Plate thickness Calculation

Thickness of Die Plate, $t_d = \sqrt[3]{Fs}$
Where Fs = Shear Force in Tones
t_d = 2.422 cm
t_d = 24.22 mm
Thickness of Punch Holder Plate, = 0.5 * t_d
Thickness of Punch Holder Plate = 12.11 mm
Thickness of Stripper Plate, = 0.75 * t_d
= 18.165 mm
Thickness of Bottom Plate, = 2 * t_d
= 48.44 mm
Thickness of Top Plate, = 1.5 * td
= 36.33 mm

5.3 Theoretical Stress Strain and Deformation for Die Plate Block (High Carbon High Chromium Steel)

Die plate is considered as a fixed supported beam and therefore,
DEFLECTION, $\delta = (F L^3) / (192EI)$
Where,
F = 80% of the Cutting Force
F = (Shearing Strength Factor * Cutting Force)
F = 93000.96 N

SHEARING STRENGTH FACTOR = C_s = 0.8
L = Length of the die plate = 110mm (Refer HASCO CATALOG)
E = Young's Modulus of elasticity = 2 * 10^5 N/mm2
I = Moment of Inertia = $(b*h^3)/12$
b = Width of Die plate = 116mm (Refer HASCO CATALOG)
h = t = thickness of Die plate =25mm (Refer HASCO CATALOG)
I = $(bh^3)/12 = (116*50^3)/12$ = 151041.67 mm4
.
Deflection, $\delta = (93000.96 * 110^3) / (192 * 2 * 105 * 151041.67)$
δ = 0.02134 mm
Stress, ζ = F/A = (80% of cutting force) / (cross sectional area of Die set)
ζ = (93000.96) / (110 * 116)
ζ = 7.2884 N / mm2

Strain, ε = deflection / length of Die plate
ε = 0.02032/110
$\varepsilon = 1.94 * 10^{-4}$

6. Cad Modeling

Computer-aided design (CAD) is the use of computer systems to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing.

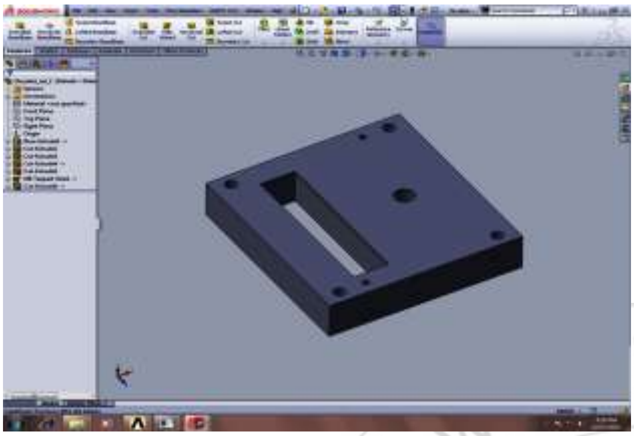

Figure 3: Computer Aided Design of Die Plate

Table 1: Component Data of Die Plate

Material Properties	Die Plate
Material	HcHCr
Modulus of Elasticity, E	2 * 10^5 N/mm^2
Dimensions	110*116 mm
Cutting Force	93000.96 N
Thickness	25 mm
Type of Beam	Fixed Supported Beam

7. Setup and Result Generation through Meshed Model

Free meshed model of various components of press tool helped predicting various results such as stress, strain and deformation. These results can be used for validation in accordance with the theoretically calculated values of stress, strain and deformation. The basic procedure involves setting the directory or specifying the file name where the component (mesh file) will be saved.

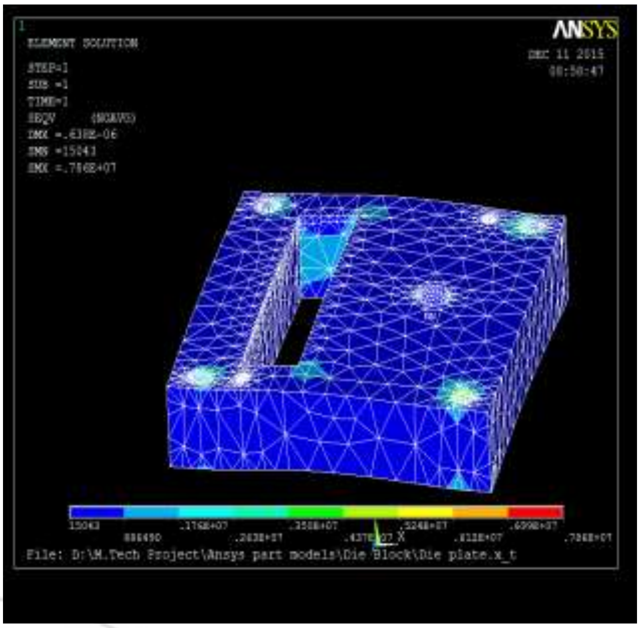

Figure 4: Meshed Model depicting stress and deformation in Die plate

Material properties taken into account for the Die plate block consist of modulus of elasticity, Poisson's ratio and density of the material.

Table 2: Material properties of die plate block

Material Properties	Die Plate(HcHCr)
Modulus of elasticity, E	2 * 10^5 MN/m^2
Poisson's Ratio	0.33
Density	7850 Kg/m^3
Element Type	Solid-20 node 95
Pressure	93000.96 N/mm2

Table 3: Design Parameters

SET	*Cutting Force (Tones)*	*Stress (N/mm2)*	*Strain*	*Deformation (mm)*
SET-1	14.22	7.86	0.000541	0.006381
SET-1	15.22	8.41	0.000579	0.00683
SET-1	16.22	8.92	0.000614	0.00715
SET-2	14.22	5.59	0.00039	0.00625
SET-2	15.22	5.598	0.000417	0.00669
SET-2	16.22	6.37	0.000444	0.00714
SET-3	14.22	6.04	0.000418	0.00604
SET-3	15.22	6.46	0.000448	0.00679
SET-3	16.22	6.89	0.000477	0.00723
SET-4	14.22	5.98	0.000414	0.00634
SET-4	15.22	6.4	0.000443	0.0064
SET-4	16.22	6.82	0.000472	0.00723

To optimize the performance of a press tool design, different ranges of design parameters is proposed in Table 4 to optimize the performance of progressive press tool.

Table 4: Setting Model Parameters

Set	Thickness (mm)	Die Clearance (mm/side)
SET-1	1.5	0.009
SET-2	1.6	0.096
SET-3	1.7	0.102
SET-4	1.8	0.108

Finally, computational results obtained from two application examples with different design parameters by the use of ANSYS and Cutting force are presented for the further analysis of the mechanical system. This allows for predicting the influence of design parameter changes, in order to minimize stresses, strain, and deformation. Table 5 shows the analytical results for the press tool design.

Table 5: ANSYS Generated Results

SET	Cutting Force (Tones)	Stress (N/mm2)	Strain	Deformation (mm)
SET-1	14.22	7.86	0.000541	0.006381
SET-1	15.22	8.41	0.000579	0.00683
SET-1	16.22	8.92	0.000614	0.00715
SET-2	14.22	5.59	0.000390	0.00625
SET-2	15.22	5.598	0.000417	0.00669
SET-2	16.22	6.37	0.000444	0.00714
SET-3	14.22	6.04	0.000418	0.00604
SET-3	15.22	6.46	0.000448	0.00679
SET-3	16.22	6.89	0.000477	0.00723
SET-4	14.22	5.98	0.000414	0.00634
SET-4	15.22	6.40	0.000443	0.00640
SET-4	16.22	6.82	0.000472	0.00723

8. Design Parameter Optimization

Usually the design process is treated as an optimization problem. To each user specified performance requirement is associated a performance index whose value increases with its level of violation. The stress, strain and deformation are considered as input and the outputs are design parameters and cutting force. The data from Table are used to build the NN- model.

Table 6: Setting simulation model parameters

Input Data			Output Data		
Stress (N/mm2)	Strain	Deformation (mm)	Cutting Force (Tones)	Thickness (mm)	Clearance (mm/side)
7.86	0.000541	*0.006381*	14.22	1.5	0.009
8.41	0.000579	0.00683	15.22	1.5	0.009
8.92	0.000614	0.00715	16.22	1.5	0.009
5.59	0.000390	0.00625	14.22	1.6	0.096
5.598	0.000417	0.00669	15.22	1.6	0.096
6.37	0.000444	0.00714	16.22	1.6	0.096
6.04	0.000418	0.00604	14.22	1.7	0.102
6.46	0.000448	0.00679	15.22	1.7	0.102
6.89	0.000477	0.00723	16.22	1.7	0.102
5.98	0.000414	0.00634	14.22	1.8	0.108
6.40	0.000443	0.00640	15.22	1.8	0.108
6.82	0.000472	0.00723	16.22	1.8	0.108

Figure 6 shows the results of comparative designs parameters and cutting force with those obtained with the ANSYS Model to the NN optimization. The response of the system to the input using the neural network is really good. If it is compared with the output from the ANSYS Model, there are some differences between them, but the two outputs are really near in almost all points and at peak values of the ANSYS results are also optimized in neural networks. So, this shows that is possible to simulate this system with a dynamic neural network, but the results are really dependent from the hidden layers, the number of neurons in each and the number of epochs.

Table 7: ANSYS and Neural network generated stress values

STRESS (N/mm2)	
Ansys	Neural Network
7.86	5.6571
8.41	6.4377
8.92	6.0825
5.59	5.8108
5.598	6.3536
6.37	6.6909
6.04	6.2487
6.46	6.33
6.89	6.99
5.98	6.5627
6.4	6.4123
6.82	6.7413

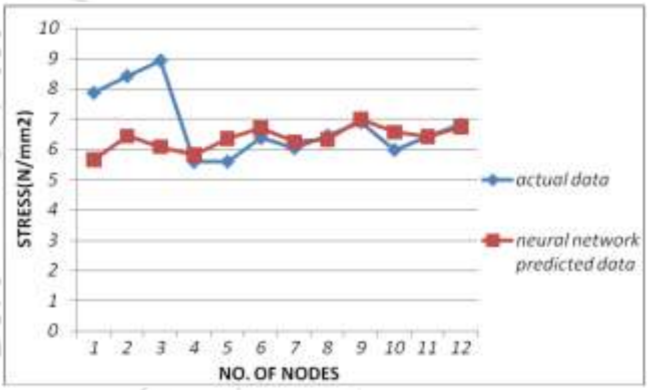

Figure 5: Stress Comparison based on Neural network generated data

Table 8: ANSYS and Neural network generated strain

STRAIN	
ANSYS	NEURAL NETWORK
0.000541	0.00049792
0.000579	0.00057444
0.000614	0.00041891
0.00039	0.00042357
0.000417	0.00041677
0.000444	0.00040344
0.000418	0.00042011
0.000448	0.00039645
0.000477	0.000512
0.000414	0.000509
0.000443	0.0004489
0.000472	0.0004658

Figures 5 shows the results of comparative strain with those obtained with the ANSYS Model to the NN optimization.

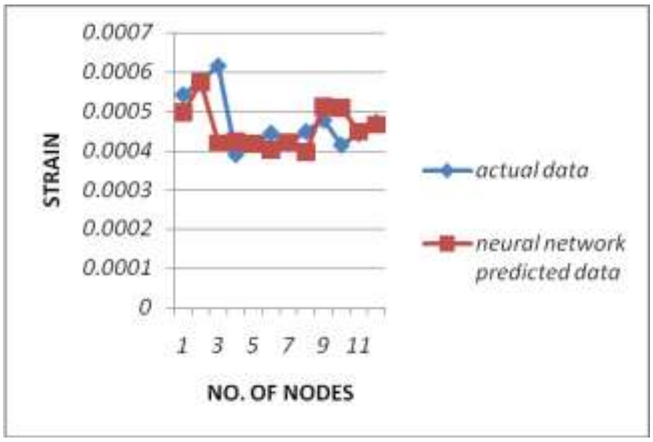

Figure 6: Strain Comparison based on neural network generated data

Table 9: ANSYS and Neural network generated deformation values

DEFORMATION(mm)	
Ansys	Neural Network
0.006381	0.0061706
0.00683	0.006974
0.00715	0.006105
0.00625	0.0060508
0.00669	0.0060679
0.00714	0.0061377
0.00604	0.0060566
0.00679	0.0061743
0.00723	0.006877
0.00634	0.006415
0.0064	0.0065
0.00723	0.007199

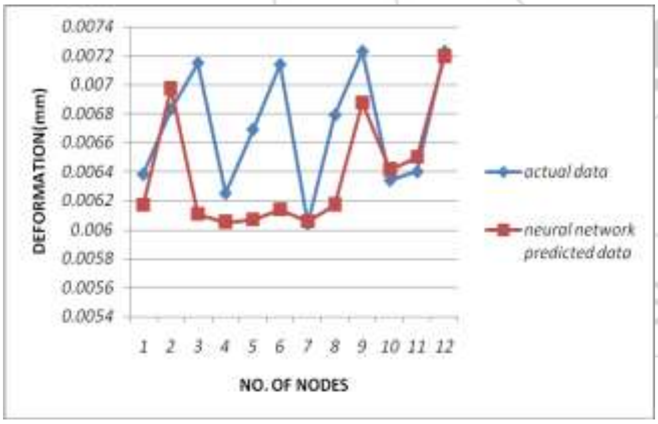

Figure 7: Deformation Comparison based on neural network generated data

Figure 7 shows the results of comparative deformation with those obtained with the ANSYS Model to the NN optimization. Based on the parameters generated by cascade forward backdrop propagation we have generated three different sets of design parameter graph to choose for a certain range of optimized die clearance and sheet metal thickness for a given cutting force

Table 10: ANSYS and Neural network generated clearance values

DIE CLEARANCE (mm/side)	
Ansys	**Neural Network**
0.009	0.095516
0.009	0.088
0.009	0.10704
0.096	0.085105
0.096	0.060232
0.096	0.10359
0.102	0.10653
0.102	0.10218
0.102	0.10315
0.108	0.10523
0.108	0.10599
0.108	0.10788

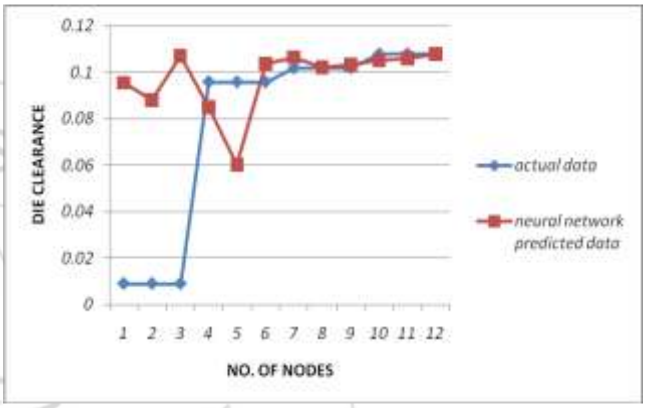

Figure 8: Die Clearance Comparison based on Neural network generated data

Figure 9 shows the results of comparative sheet metal thickness with those obtained with the ANSYS Model to the NN optimization

Table 11: ANSYS and Neural network generated thickness values

Sheet Metal Thickness**(mm)**	
Ansys	*Neural Network*
1.5	1.6353
1.5	1.521
1.5	1.674
1.6	1.7849
1.6	1.7849
1.6	1.6778
1.7	1.7453
1.7	1.6706
1.7	1.7145
1.8	1.7798
1.8	1.8156
1.8	1.8345

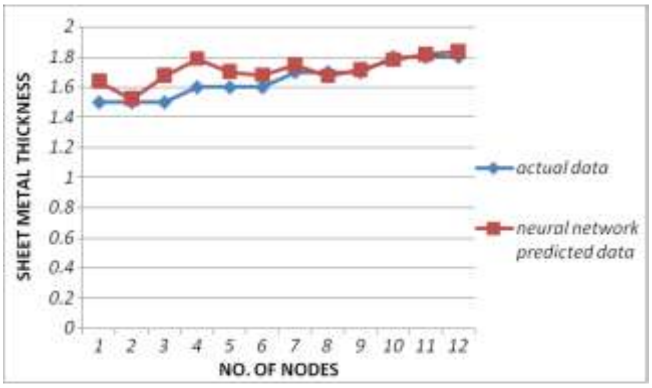

Figure 9: Sheet Metal Thickness Comparison based on Neural network generated data

Figure 10 shows the results of comparative cutting force with those obtained with the ANSYS Model to the NN optimization.

Table 12: ANSYS and Neural network generated force values

Cutting Force (Tones)	
Ansys	*Neural Network*
14.22	14.2273
15.22	16.0204
16.22	14.2522
14.22	14.2371
15.22	14.2233
16.22	16.0992
14.22	14.2274
15.22	16.0757
16.22	14.3533
14.22	14.2221
15.22	16.0861
16.22	16.1001

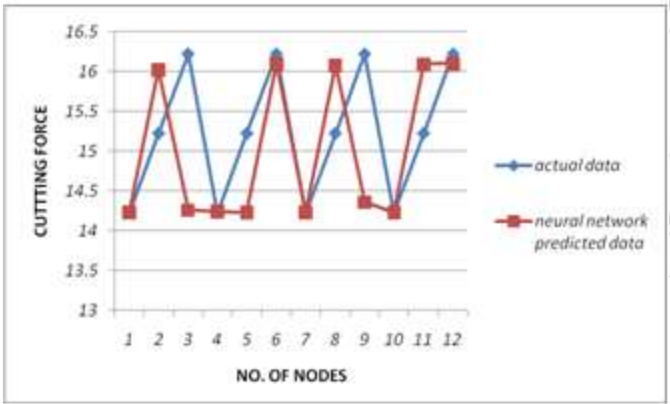

Figure 10: Cutting Force Comparison based on neural network generated data

The values thereby generated helps to choose an appropriate and optimized set of design parameters as well as cutting force input which is being depicted in table given below.

Table 13: Optimized Design Parameters

Cutting Force (Tones)	Die Clearance (mm/side)	Sheet Metal Thickness (mm)
14.2552	0.10704	1.674

In order to validate my optimized design parameters it is essential to collaborate these results with the results generated by ANSYS software. Stress is used as a key factor to validate these results. The stress generated by neural network is compared with the ANSYS generated results. The ANSYS Software was used to remodel the press tool design using the optimized design parameters. After feeding the new optimized design parameters and remodeling the press tool design using SOLIDWORKS we have obtained the following results as depicted in the figure below.

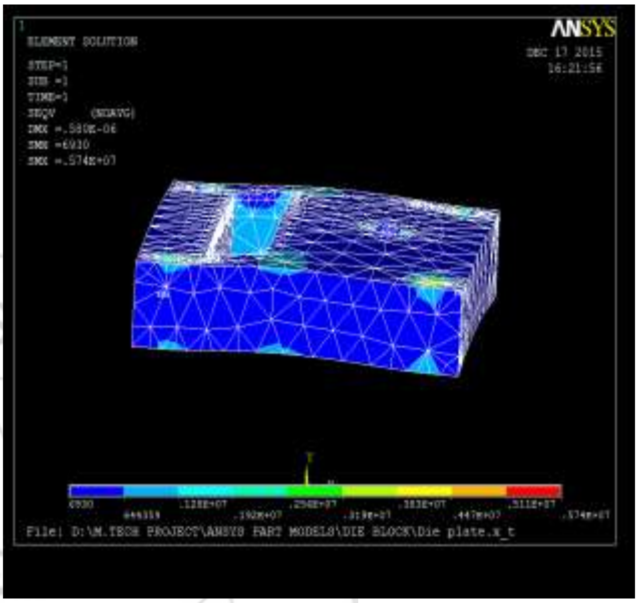

Figure 11: Remodeled & optimized Die plate block

Value of stress is generated based on the finite element meshed model using ANSYS. This value of generated stress is compared with the neural network generated value of stress. This comparison proves that obtained design parameters based on neural network is optimized which concludes the project objective. The final comparison between the stress values generated is being depicted in the table below.

Table 14: Comparison of stress based on optimized design parameters

Optimized Design Parameters		Stress (N/mm2)	
Die Clearance (mm/side)	Sheet Metal Thickness (mm)	Neural Network Based Result	Ansys Based Result
0.10704	1.674	6	5.74

The above result can be further compared to the theoretical value of clearance and stress generated by neural network in order to prove that optimized result is better as compared to the theoretical result to minimize the stress produced in die plate block. The table below present a comparison between theoretical value of clearance and optimized clearance for a given sheet metal thickness.

Table 15: Comparison of theoretical and optimized stress (ANSYS)

	Theoretical	Optimized	Stress (N/mm2)	
Sheet Metal Thickness (mm)	Die Clearance (mm/side)	Die Clearance (mm/side)	Theoretical Result	Ansys Based Result
1.674	0.10044	0.10704	7.306	5.74

9. Conclusion

The influence of the sheet metal thickness and die clearance of a progressive press tool was investigated in this study. This project prescribes a model investigating the effect of potential parameters influencing the piercing and blanking process and their interaction. The die clearance and thickness optimization is carried out by using CAD Modeling (SolidWorks), Finite Element Method (FEM) with ANSYS Package and Neural Network Simulation in order to achieve the intended model objectives. The NN-model was used to replace the computer simulation experiment as a cost-effective mathematical tool for optimizing the system performance. The use of the NN model allowed the prediction of the system's response at other design points with a significantly lower computational time and cost.. In addition to the use of the NN model for the prediction of the response at different design points, the scheme allows for the visualization of the trends of the response surfaces when the design variables are changed. The global results obtained from this study indicate that the model parameters of the mechanical system are quite sensitive to the cutting force. The method presented in this thesis can be utilized for optimizing the performance of mechanical systems with die clearances. By utilizing the NN-model, the computer simulation time can be significantly reduced, while the response of the system can be studied and optimized for a range of input design variables.

Thereby based on analysis by ANSYS software and optimization based on NN technique we have attained optimized result based on sheet metal thickness and die clearance. These results are validated using error found in NN optimization tool, MATLAB. The optimized results of sheet metal thickness and die clearance helps in achieving fewer amounts of deformation and stress produced in die plate. Value of stress is generated based on the finite element meshed model using ANSYS. This value of generated stress is compared with the neural network generated value of stress.

This comparison proves that obtained design parameters based on neural network is optimized which concludes the project objective. The results when further compared to the theoretical value of clearance and stress generated by neural network proves that optimized result is better as compared to the theoretical result to minimize the stress produced in die plate block.

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