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Explicit Dynamic Analysis and Design Optimization of Sheet Metal Forming

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Abstract:- The Sheet Metal forming is technique that is used by various automotive and aerospace industries now a days. The forming process is an old technique of manufacturing operation, in which metal is formed by a punch and die to convert a flat sheet of material to a part required shape and size without any defect. The current research investigated the energy absorption characteristics of copper sheet metal having different sheet thickness using ANSYS Explicit Solver workbench. The CAD modeling and finite element analysis is conducted using ANSYS software (ANSYS design Modeler). Equivalent Stress(Von-misses Stress), Total Deformation, Internal Energy and Shear stress graphs are generated for the material. Also the FEM model is being optimized using Taguchi Response Surface optimization method. The die length and the die angle are taken into account for optimization. The main results reveled to determine the location and magnitude of stress, pattern of internal energy, deformation.

***Keywords**:- ANSYS, Sheet metal Forming, Energy, CAD, FEM*

I. INTRODUCTION

The forming process involves bending sheet metal into desired shape using punch and die as shown in figure 1 below. In some sheet metal forming processes, there is no need for the holder and this is known as air bending such as V-bending and U-drawing as shown in Figure 1.

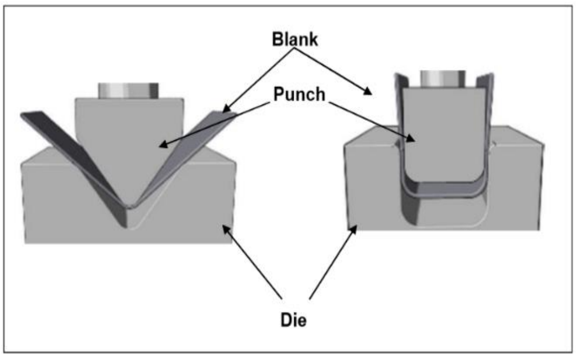

Figure 1 V and U bending sheet metal forming

The automotive industry and aerospace industry has highest requirement of sheet metal forming which contributes to nearly 55% of total parts. Most of the automotive/aerospace components are produced by the process of press bending. Sheet metal forming involves bending, punching, drawing operations. Out of various bending operations, V-die bending is chosen for the sheet metal to be formed.

II. LITERATURE REVIEW

Bahloul R.et al. [1] conducted finite element simulation of sheet metal bending using ABAQUS software. The bending process was evaluated using elastic plastic theory and optimization of process is done using RSM technique. Guo, Y.Q.et. al.[2] has conducted investigation of metal bending subjected to different frictional forces and the optimization process using deep drawing. Karafillis, A.P. and Boyce, M.C. [3] conducted investigation on proper design of tooling from the data obtained by FE analysis. The manufacturing of tooling was done using CNC machine and the tool produced accurate parts. Joshi, Patil and Satao (2014) M.K.N., Patil, B.T. and Satao, M.S. [4] has investigate the optimization of deep drawing process and application of Finite Element Method in determining stresses, deformation during the process. The FE simulation enabled to determine critical areas of high stresses. Chung, K. and Shah, K. [5] conducted FE simulation of sheet metal bending using Barlat's six-component anisotropic yield function. They used “yield function in ABAQUS for modeling hydraulic bulge and cup drawing tests for a 2008-T4 aluminum alloy”[5]. The results obtained from FE analysis for sheet metal bending are in close agreement with experimental results. Jaisinghet. al.[6] has suggested that the blank holder force has the maximum impact on the thinning strain, the coefficient of friction, plastic strain ratio. The strain-hardening exponent depends on BHF. Tommerupet. al.[7] has investigated the effect of blank holder pressure on strain path in the sheet during forming process.

III. OBJECTIVE

The current research investigates the effect of various design parameters i.e. thickness, punch radius using ANSYS explicit dynamics. The equivalent stress, deformation and internal energy absorption is evaluated for different materials i.e. copper and aluminium alloy.

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IV. MODELLING OF FINITE ELEMENT ANALYSIS

Finite Element Formulation

The stiffness matrix is formulated using minimum total potential energy formulation. For the current problem a liner spring of k stiffness is considered and an external force (F) is applied at the right. The spring deformation is given by Δ.

The work done by the single force is

$$W = \Delta.\ F = \Delta_x * F_x = u\ F$$

$$U = \frac{1}{2} K \Delta_x^2$$

Therefore, the total potential energy (Π) for the loaded spring is

$$\Pi = \frac{1}{2} K \Delta_x^2 - \Delta_x * F_x$$

Equation of equilibrium is obtained by minimizing this total potential energy with respect to the unknown displacement, Δ. That is,

$$\frac{\partial \Pi}{\partial \Delta x} = 0 = \frac{2}{2} K \Delta_x - F_x$$

This gets simplified to below given equation which is well known equilibrium equation for leaf spring

$$K \Delta_x = F$$

Finite Element Modeling

The CAD model of die and sheet metal is developed using ANSYS design modeler with the dimensions specified in literature [6].

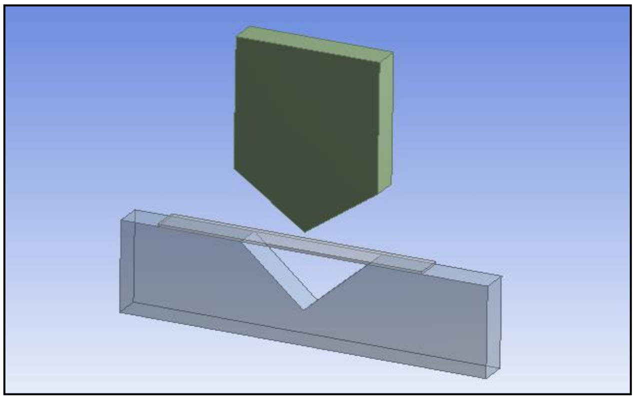
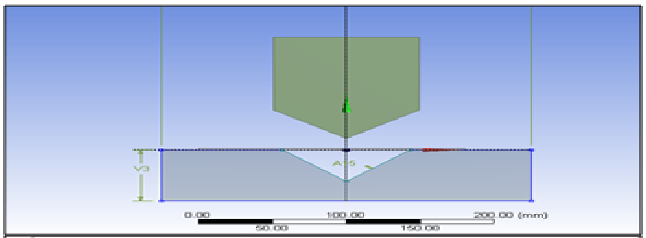
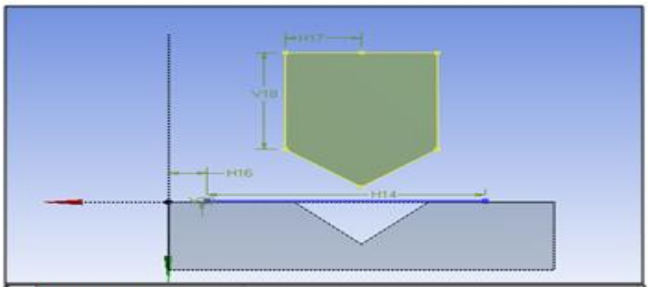


Figure 2: CAD modelling of punch, die and sheet metal in ANSYS design modeler



Dimensions: 4	
D A15	90 °
D H1	125 mm
H2	125 mm
V3	70 mm

Figure 3: Dimensions of die



Dimensions: 2	
H17	49 mm
V18	100 mm

Figure 4: Dimensions of punch

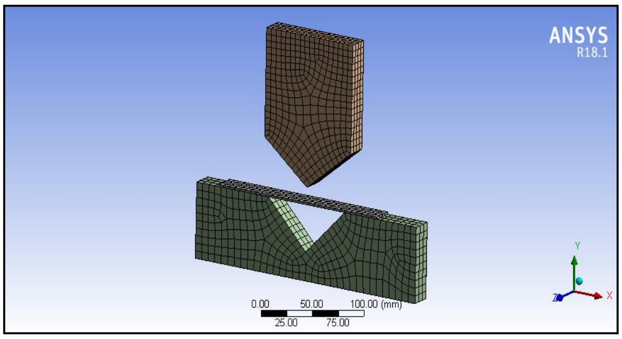


Figure 5: Meshed model of punch, die and sheet metal

The model is meshed using medium relevance and with hexahedral elements as shown in figure above. The transition is set to smooth. The number of elements generated is 2147 and number of nodes generated is 3259.

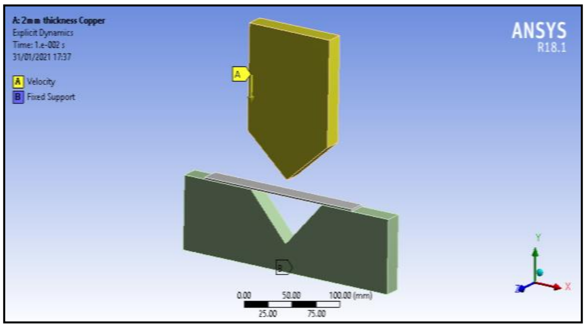


Figure 6: Loads and boundary condition

The initial velocity of 5m/s is applied on punch in downward direction as shown by yellow color and base of die is applied with fixed support. The contact pair between sheet metal and die is defined with frictional of μ=.1.

Material and Material Properties

Copper Alloy-copper sheet is a versatile , durable material that is used for a variety of applications. Copper can be hot or cold formed and it is ductile when heated. However, it is not the best choice if machining or grinding is required. It is often used as a construction material , especially for exterior roofing projects.

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	8300	kg m^-3		
4	Isotropic Elasticity				
5	Derive from	Young'...			
6	Young's Modulus	1.1E+11	Pa		
7	Poisson's Ratio	0.34			
8	Bulk Modulus	1.1458E+11	Pa		
9	Shear Modulus	4.1045E+10	Pa		
10	Specific Heat	385	J kg^-...		

Figure 7: Properties of Material

V. RESULTS AND DISCUSSION

The deformation plot and equivalent stress plot is obtained at different time intervals for 2mm copper thickness metal sheet. The deformation plot of copper sheet metal at .0003 secs is shown in figure below which shows maximum deformation of 1.2737mm.

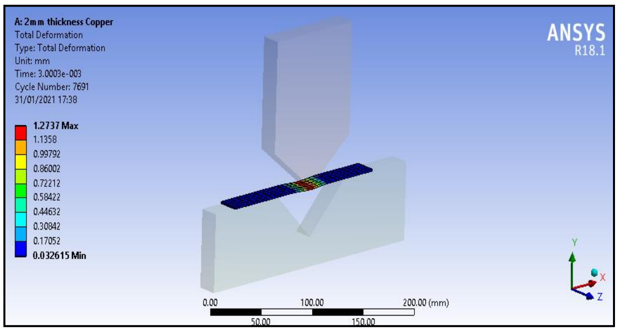


Figure 8: Deformation at .0003 secs

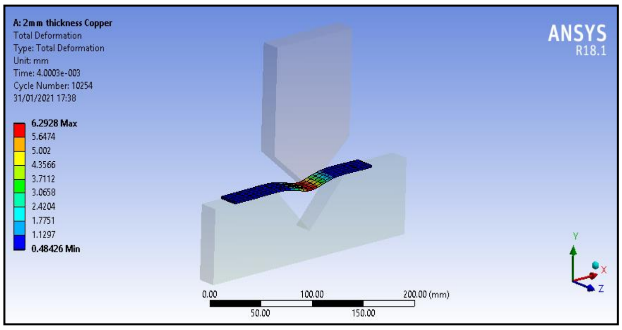


Figure 9: Deformation at .0004 secs

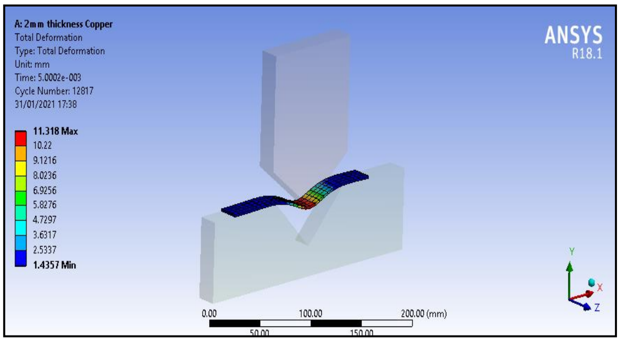


Figure 10: Deformation at .0005 secs

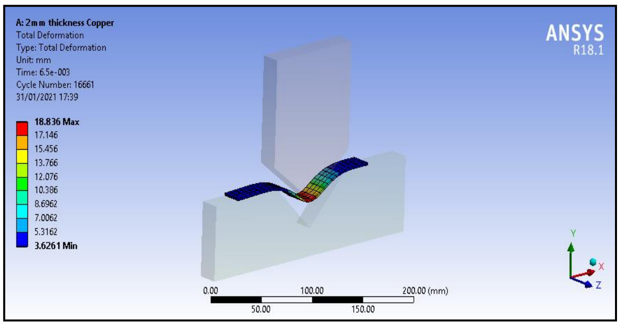


Figure 11: Deformation at .00065 secs

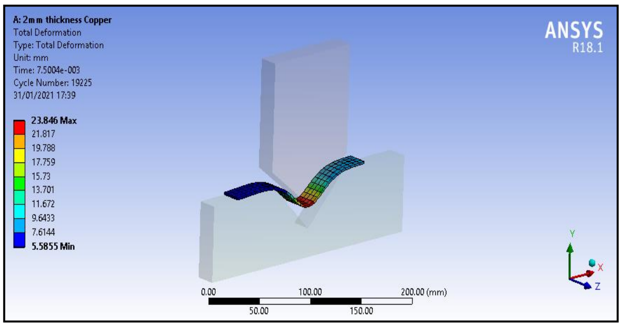


Figure 12: Deformation at .0075 secs

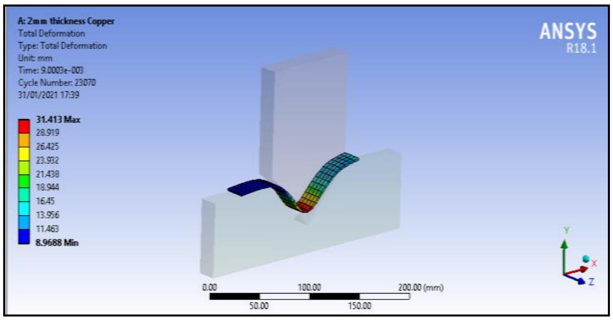


Figure 13: Deformation at .009 secs

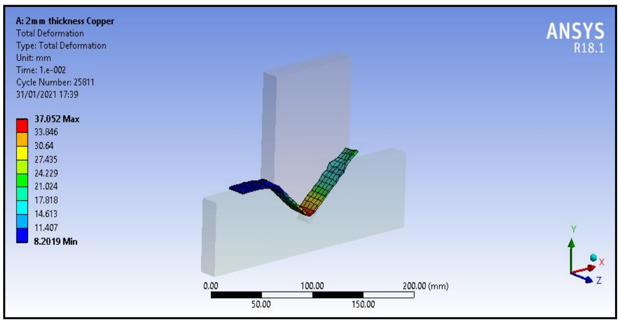


Figure 14: Deformation at .01 secs

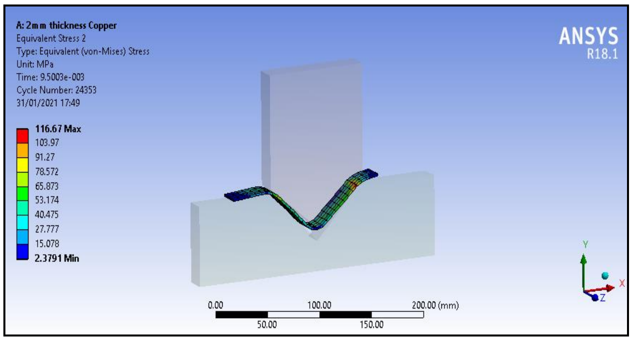


Figure 15: Equivalent stress .00095 secs

The deformation plot of copper sheet metal at .0003 secs is shown in figure below which shows maximum deformation of 1.273mm. The deformation plot of copper sheet metal at .0004 secs is shown in figure below which shows maximum deformation of 6.298mm.The deformation plot of copper sheet metal at .0005 secs is shown in figure below which shows maximum deformation of 11.318mm. The deformation plot of copper sheet metal at .00065 secs is shown in figure 11 below which shows maximum deformation of 18.836mm. The deformation plot of copper sheet metal at .009 secs is shown in figure below which shows maximum deformation of 23.846mm. The deformation plot of copper sheet metal at .009 secs is shown in figure 13 below which shows maximum deformation of 31.413mm. The deformation plot of copper sheet metal at .01 secs is shown in figure below which shows maximum deformation of 37.052mm.The deformation plot of copper sheet metal at .00095 secs is shown in figure 15 below which shows maximum deformation of 116.67mm. The deformation plot of copper sheet metal at .00095 secs is shown in figure 15 below which shows maximum deformation of 116.67mm.

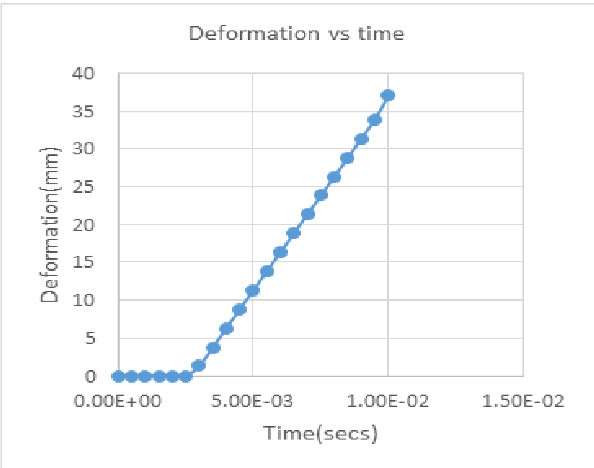


Figure 16: Deformation vs time curve of copper sheet metal

The deformation vs time graph shows linear increase from the time the tool makes 1st contact with copper sheet. The deformation increases linearly and reaches maximum value of 37.052mm by the end of simulation.

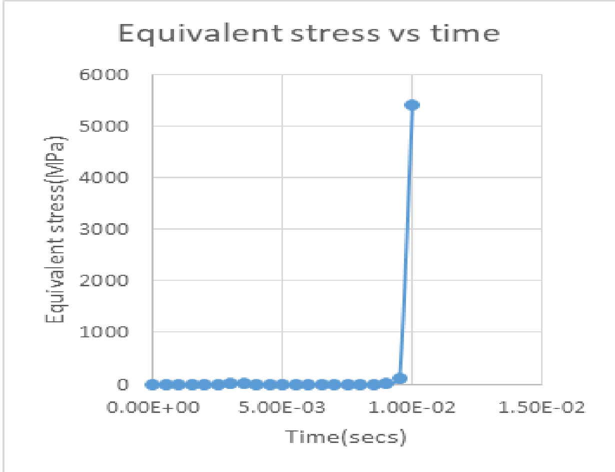


Figure 17: Equivalent stress vs time vs time curve of copper sheet metal

The equivalent stress increase is shown in figure 16 above. The graph shows steep increase in equivalent stress and reaches maximum stress in very short time interval. The equivalent stress behavior is very different from deformation behavior. The maximum equivalent stress reaches to 5399.4MPa at the point of total deformation of copper sheet.

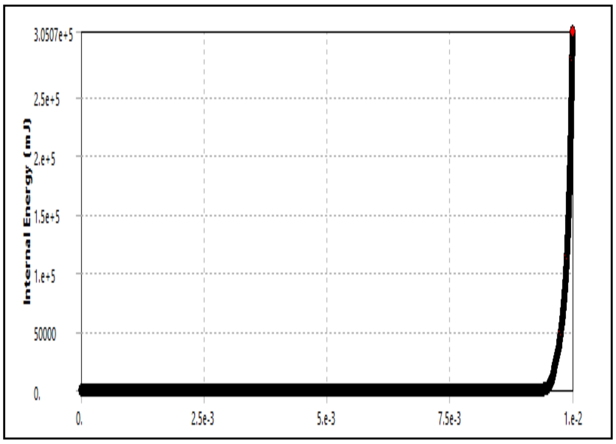


Figure 18: Internal energy vs time vs time curve of copper sheet metal

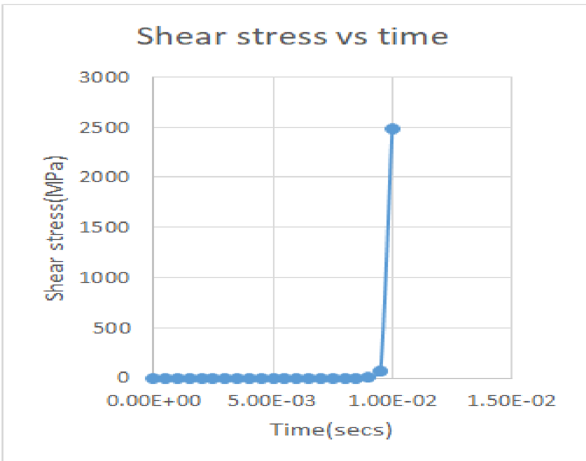


Figure 19: Shear stress vs time vs time curve of copper sheet metal

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The shear stress and internal energy shows similar trend as of equivalent stress. The internal energy increases steeply and the similar trend is observed with shear stress. The maximum shear stress observed by the end of simulation is 2485.7MPa.

Response Surface Optimization

The Taguchi design of experiments is conducted to determine design points and corresponding output parameters i.e. Equivalent stress, Shear Stress, and Total Deformation.

Table of Outline A2: Design Points of Design of Experiments

	A	B	C	D	E	F
1	Name	P1 - dieangle (degree)	P2 - dielength (mm)	P3 - Equivalent Stress 2 Maximum (MPa)	P4 - Shear Stress Maximum (MPa)	P5 - Total Deform... Maximum (mm)
2	1 DP 0	90	125	116.67	2485.7	37.052
3	2	88	125	1608.7	3215.6	36.826
4	3	92	125	86.45	1670.5	36.511
5	4	90	124	117.41	2484.2	37.041
6	5	90	126	124.11	2617.4	36.924
7	6	88	124	1617.1	3046.7	36.814
8	7	92	124	83.651	1485	36.59
9	8	88	126	1592.8	6819.1	37.407
10	9	92	126	87.827	1531.3	36.581

Figure 20 : Design points generated using DOE

Total of 9 different design points are generated. The maximum and minimum values obtained from Taguchi DOE is shown in figure 20. The maximum equivalent stress obtained is 1617.1Mpa and minimum equivalent stress obtained is 83.21Mpa. The maximum deformation is observed for design point number 8 having die angle 88º and die length is 126mm.

	A	B	C
1	Name	Calculated Minimum	Calculated Maximum
2	P3 - Equivalent Stress 2 Maximum (MPa)	83.216	1617.1
3	P4 - Shear Stress Maximum (MPa)	1326.7	6819.1
4	P5 - Total Deformation Maximum (mm)	36.511	37.407

Figure 21: maximum and minimum value of design parameters.

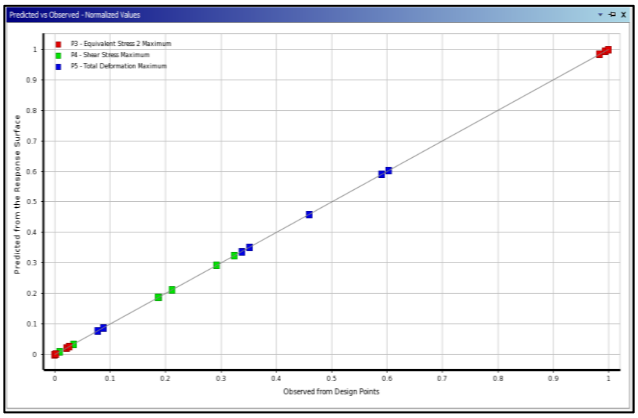

Figure 22 : Goodness of fit curve

The goodness of fit curve is obtained from DOE which shows the accuracy of solution. The expected values are shown by straight curve and observed values are shown by green, red and blue boxes. As it can be observed from figure 22 above, the variation between observed values and expected values is less as the boxes coincide or lie in close proximity of straight curve.

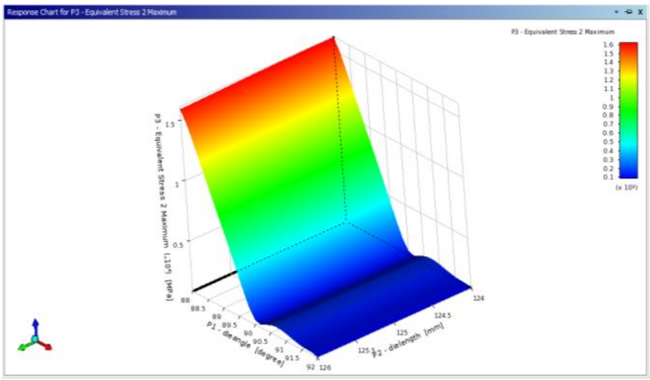

Figure 23 : 3D response surface plot of Equivalent Stress.

The 3D response surface plot generated for equivalent stress shows high values of equivalent stress for die angle ranging from 88º to 88.5º and die length ranging from 124mm to 126mm.The minimum equivalent stress is observed for die angle ranging from 89.5º to 92º and die length ranging from 124mm to 126mm.

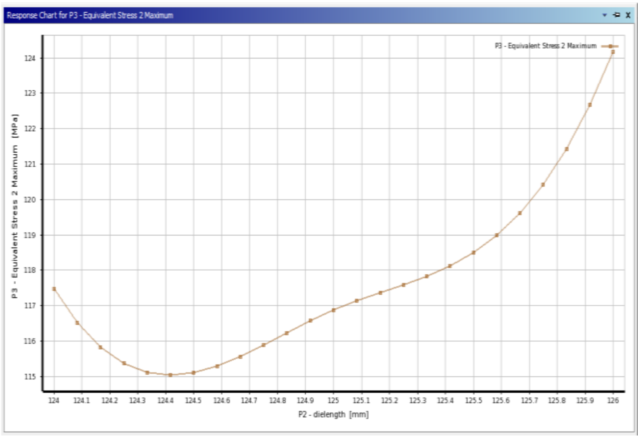

Figure 23 : equivalent stress vs die length

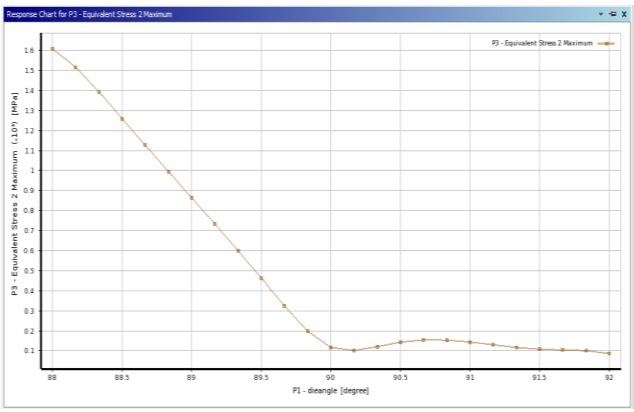

Figure 24 : equivalent stress vs die angle

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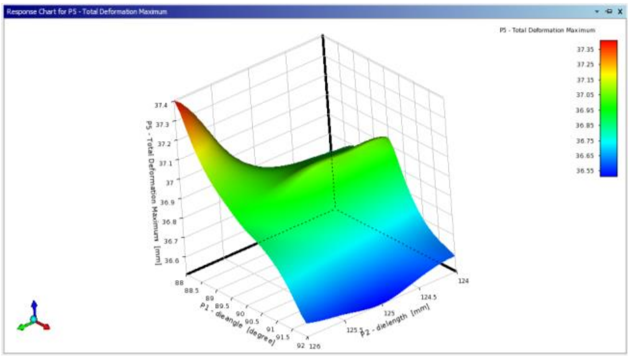

Figure 25 : 3D response Surface plot of total deformation.

The 3D response surface plot generated for total deformation shows high values of deformation for die angle ranging from 88º to 88.5º and die length ranging from 124mm to 126mm. The minimum deformation is observed for die angle ranging from 90.5º to 92º and die length ranging from 124mm to 126mm.

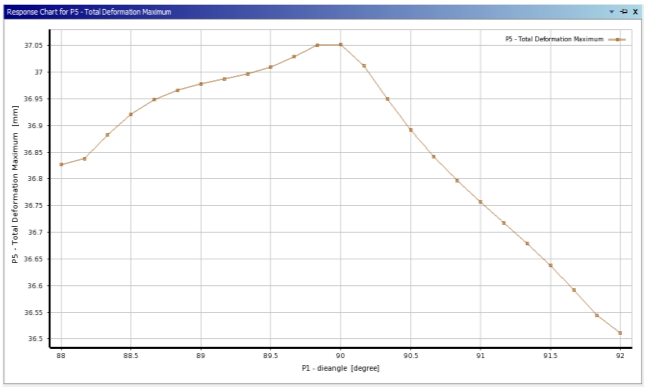

Figure 26 : Total deforation vs die angle

The variation of total deformation with die angle is shown in figure 26 above. The curve shows increase in total deformation upto 90º die angle and decreases thereafter and reaches minimum values at 92º die angle.

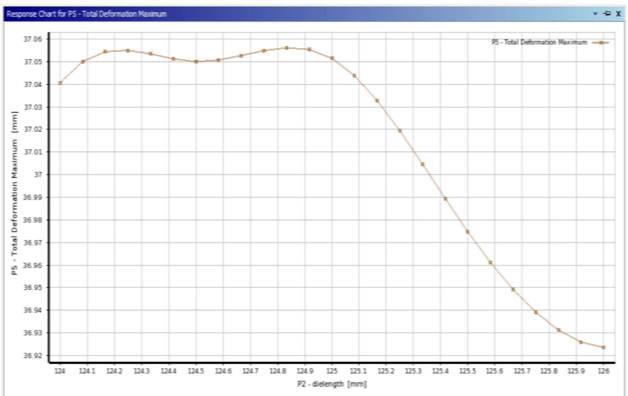

Figure 27 : total deformation vs die length

The variation of total deformation v/s die length is shown in figure 27 above. The plot shows constant deformation for die length up to 124.8mm die length and than decreases linearly and reaches minimum at 126mm die length.

VI. CONCLUSION

In the current analysis the shear stress, equivalent stress, deformation and internal energy evaluated using explicit dynamics at different time intervals. The analysis conducted enable us to determine the location and magnitude of stresses, pattern of internal energy. The shear stress and equivalent stress is lower till deformation occurs and then increases suddenly when deformation is restricted by die. Between die length and die angle, the die angle has much more influence on the equivalent stress, shear stress and total deformation than die length. For further analysis the punch parameters can taken for optimization.

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