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Evaluation of Deep Drawing Force in Sheet Metal Forming

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***Abstract*— Sheet metal forming is widely used in automotive and aerospace sector. This paper shows the analysis of sheet metal forming process mainly deep drawing. Ansys simulation is used to carry out the results of difficult behaviour of the product. Main purpose of this project is to predict the required force use to perform the deep drawing operation. It also shows the required machine capacity to fulfil the production requirement. From theoretical values the dimensions of die and punch are obtained. Using these dimensions the CAD model is generated in CATIA. This assembly is then converted into igs format and imported in Ansys. The force required to develop the part, deformation and defect like tearing, wrinkles etc. can be obtained through simulation. By using this method it is easy to find the required force in minimum steps as compare to conventional trial and error method, which leads to save in time money and wastage of material.**

Keywords*— Ansys simulation, Deep Drawing, Part Development and simulation, Punch Force, Use of force probe in Ansys. Introduction (Heading 1)

I. INTRODUCTION

Deep drawing is a process of forming sheet metal component through dies and punching action. This is zero forming process which provide the component closer to required tolerance dimensions, good surface finishing, also it provide good strain hardening, higher strength. On the basis of geometry, volume and the material, sheet metal forming operation can be divided into categories like stamping, deep drawing, and super plastic forming. Among these stamping and deep drawing are frequently used operations. If the depth of forming cup is more than the diameter then this forming process is knows as deep drawing. Products like automotive components, aircraft parts, cans, cylinder cup, and submarine hulls are manufactured using deep drawing procedure. [3] The important variable in deep drawing is property of sheet material, surface finishing of punch and die, lubrication, BHF, clearance between punch and die, stages of drawing, coefficient of friction between blank and rigid parts etc. Punch force play an important role to draw blank into desired shape. It is very difficult to obtain exact required force on the punch to draw blank into desired depth. The sheet metal industry faces a number of challenges during development of the Die Punch and other parameters of required part manufacturing. These operations are complicated and calls high competency on the part design, material selection and process factors. If the process parameters are not correct then defects like Wrinkling, Tearing, Fracture, Thinning, Spring Back may be occur. These defects can be minimised by using correct process parameters like punch force, BHF, clearance between die and punch, number of drawing stages etc. This paper shows the FEA method to predict the required force for drawing operation using Ansys simulation. It also shows the significance of joint probe in Ansys and importance in the development process in forming operations.

Shishir Anwekar, [1] discussed the process of development of die and punch. Also they stated that it is complicated process and needs highly skilled workers to produce error free assembly. To overcome the trials and error procedure used the simulation technique. Shambhuraje Jagatap [2] discussed the temperature effect on die, blank, blank holder consider in the process. It stated that as temperature increases contact pressure decreases. Hakim S. Sultan [3] perform the work by using LUSAS simulation software and conclude that The increment of die radius causing decrement in the load needed to deform the same pattern some and at the same time increasing the maximum stress concentration on curve region. Akshay Chaudhari [4] This paper is based on the calculation of different part use in deep drawing process such as blank diameter, draw ratio, draw force, clearance, machine tonnage etc. Mathews Kaonga [5] discussed about the forming processes such as punching, blanking and drawing and also stated the reason behind the variation of calculated and simulated values with significance of constants. S. Schneider [6] provides the use of Ramberg-Osgood equation to find the tangent modulus property of material. In above referred papers feed the basic required data but not shows the actual procedure to find the punch force require to develop defect free component.

II. PROCEDURE FOR PART DEVELOPMENT

Die development for component is very costly process and it takes lot of time as we go for conventional methods. So use the technology like CAE during the designing of actual components to detect the problem areas in forming. This technology saves work, time and cost. During the development of deep drawing component (Emergency cup) first theoretical calculation is carried out for cup height 35mm, cup diameter 125mm,sheet thickness 1.2mm to get the dimensions of parts such and blank diameter, clearance between die and punch, blank holing force, drawing force etc. From this data cad model is generated using 3D cad software like CATIA. From this 3D parts deep drawing process assembly generated. This assembly imported in Ansys software in igs format, by applying material property and boundary conditions values simulation is carried out. As results from simulation finally we get the required punch force by using force probe tool.

A. Theoretical Calculation

Important deep drawing process parameters are calculated by using standard formulas as follows

Blank Diameter $D = (d^2 + 4dh)^{0.5}$ -------(1)

Draw Ratio $= h/d_p$ -------(2)

Table I – The relationship between (H/d) ratio & number of draws

If $h/d_p < 0.75$	Then no. of draws = 1
If $0.75 < h/d_p < 1.5$	Then no. of draws = 2
If $1.5 < h/d_p < 3.0$	Then no. of draws = 3
If $3.0 < h/d_p < 4.5$	Then no. of draws = 4

From Equation (2) and table I indicate that drawing process requires only one stage for completion i.e. this is single stage deep drawing process.

Punch and Die Clearance $C= T+ k (10 T)$ -------(3)

Drawing Force empirical relation

$p = \pi * d_p*t*S*((D_0/d_p) – C)$ -------(4)

FOS taken as 1.5,

Blank Holding Force is approx. 20% to 30 % of Draw Force

(B.H.F.) = 30 % of Draw Force -------(5)

Press Tonnage P = p + (B.H.F.) -------(6)

Table II- Design calculation values

Equation No.	Parameters	Values
1	D	182 mm
2	h/d_p	0.3549
3	C	2.04 mm
4	p	26 ton
5	B.H.F.	8 ton
6	P	34 Ton

B. CAD Model And Deep Drawing Assembly

The solid model of Emergency cup is modeled using 3D modeling software CATIA (generative sheet metal design workbench) based on drawing provided by company.

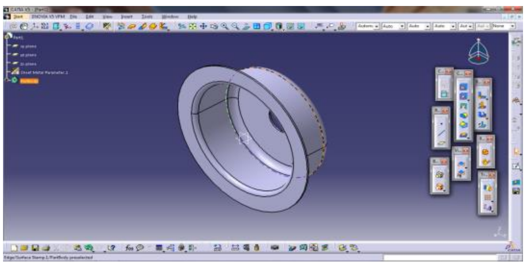

Fig. 1 CAD Model in Catia

This model is then imported in SolidWork. This software has advantage to generate punch and die assembly using user friendly mold tools. Final assembly is export in igs format to carry out simulation.

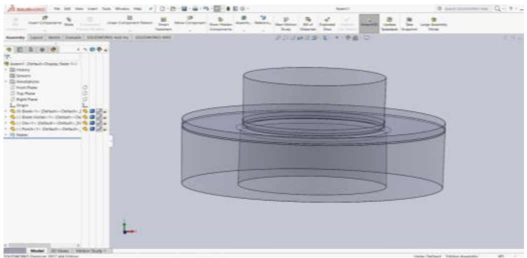

Fig. 2 Die & Punch Assembly in SolidWork

C. Blank Material Property

For deep Drawing process low carbon material is required to minimize the defect generation. Generally for deep drawing process EDD (Extra Deep Draw) material is used. There are some types or grade of materials like CR1, CR2, CR3, CR4, and CR5. As per the company (Priya Autocomponents Pvt. Ltd.) requirements and suggestions CR4 material is used for deep drawing process. CR4 is cold rolled steel with high elongation and lower carbon content. It is good for cold forming process. CR4 material Chemical and Mechanical properties are shown in following tables [7]

Table III – Mechanical properties of material

Quality		Yield Stress R_e Mpa	Tensile Strength R_m Mpa	Elongation Percent A Min		Hardness
Designation	Name	Max		L_o = 80 mm	L_o = 50mm	HR (30T)
CR4	Extra Deep Drawing Aluminum Killed	210	350	36	37	50

The tangent modulus is the slope of the stress strain curve. Below the proportional limit the tangent modulus is equivalent to young's modulus. Above the proportional limit the tangent modulus changes with strain and it is accurately calculate by using actual from test data. The Ramberg–Osgood equation state the relation between young's modulus to the tangent modulus and this is one of the methods for obtaining the tangent modulus. The tangent modulus is playing an important role in describing the behavior of materials that have been stressed beyond the elastic region. When a material is plastically deformed there is no longer a linear relationship between stress and strain as there is for elastic deformations. The tangent modulus determines the "softening" or "hardening" of material that generally occurs when it begins to yield. Tangent modulus is calculated by using constant n is 5, modulus of elasticity 200Gpa for Ramberg–Osgood Equation [6]

$$Et = \frac{E * \sigma ys}{\sigma ys + 0.002 * n * E\left(\frac{\sigma}{\sigma ys}\right)^{n-1}} \quad \text{-----(7)}$$

Tangent modulus for CR4 material is computed by using equation (7) is 2685061000 Pa = 2.68 * 10^9 Mpa

D. Finite Element Analysis

Assembly in igs format, file generated from SolidWork is imported in Ansys software. CR4 material properties such as density, young's modulus, poisons ratio, bulk modulus, shear modulus, tangent modulus, yield strength, ultimate strength are missing in Ansys material library so it is necessary to create custom material properties for CR4 in material library. Following table shows the material property assign to blank.

Table IV – Material property of CR4

Properties of Outline Row 3: CR4

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7861.1	kg m^-3
4	Isotropic Elasticity		
5	Derive from	Young's Modulus an...	
6	Young's Modulus	2.0484E+11	Pa
7	Poisson's Ratio	0.29	
8	Bulk Modulus	1.6257E+11	Pa
9	Shear Modulus	7.9397E+10	Pa
10	Bilinear Isotropic Hardening		
11	Yield Strength	2.1E+08	Pa
12	Tangent Modulus	2.6851E+09	Pa
13	Tensile Yield Strength	2.1E+08	Pa
14	Tensile Ultimate Strength	3.5E+08	Pa

Meshing is done by using Ansys Mechanical APDL with element size for blank and other body parts are 2mm, and 3mm respectively. For this element size node and element counts are 98538 and 21557 respectively. Contact between the punch and blank, blank holder and blank is frictional also die is stationary and punch, blank holder are translational in motion. Punch travels to positive Y axis; displacement is set as 35mm from the contact of blank. The transient simulation is carried out for better convergence of the problem for deflection, stresses, joint probe force.

The results are as follows:

1. Total Deformation is 33.9mm and the thickness of bottom circle is around 9 mm. this shows the total deformation is within acceptable value.

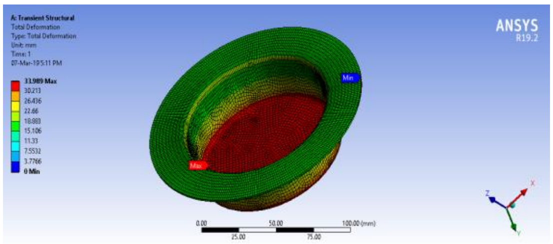

Fig. 3 Total deformation of Cup

2. Equivalent Elastic Strain is 0.009. This value shows the ratio of change in dimension with original dimension. From the results we can say that wall is not too thin.

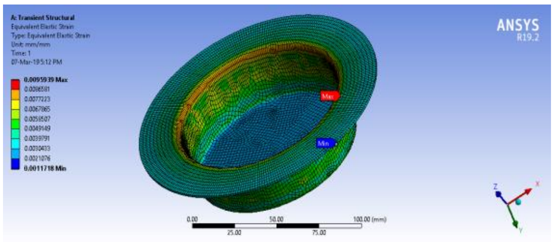

Fig. 4 Equivalent Elastic Stain of Cup

3. Following fig.5 shows the von misses stress generated on component. Maximum stresses occur at the curve or neck of cup. This leads to tearing of component from neck. But in this simulation not single tearing evidence found at neck while checking animated simulation video.

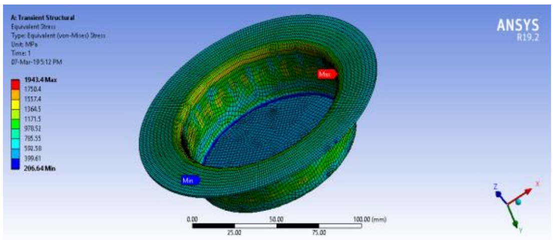

Fig. 5 Equivalent Stress of Cup

4. Shear stress indicates the fracture or failure in material. If shear stress is large then tearing or surface distortion defect generate in product. In this case shear stress is within limit, but on the edge of neck region surface shows the chances of tearing.

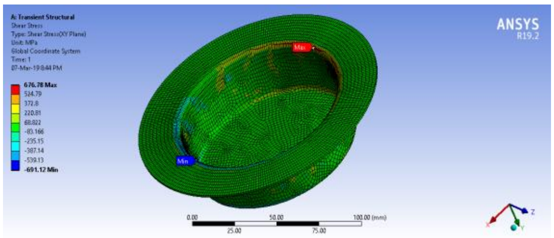

Fig. 6 Shear Stress of Cup

5. Fig 7 shows the load required for the deformation of blank. With respect to the punch targeted elements the load results are calculated by using the reaction values. The load value represented in all axis. The resultant load/force is obtained using mathematical formula.

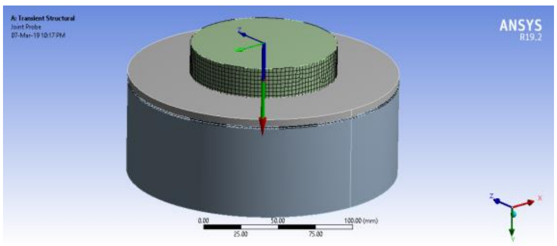

Fig. 7 Local coordinate system of punch probe

Table V shows the reaction force generated on X, Y, Z axis of the punch. Considering this value and mathematical formula resultant is calculated which shows the 30.37 ton force to positive y axis.

Table V – Punch Joint Probe Result

Definition	
Type	Joint Probe
Result Type	Total Force
Results	
X Axis	2.9783e+005 N
Y Axis	-47.583 N
Z Axis	763.65 N
Total	2.9783e+005 N

6. In deep drawing process due to stretching phenomenon of sheet thickness varies from region to region. Thinning parameter mostly depend on the depth of drawing. As depth of drawing increases thinning increases i.e. wall thickness reduces. This results are calculated with the help of altair inspire form software.

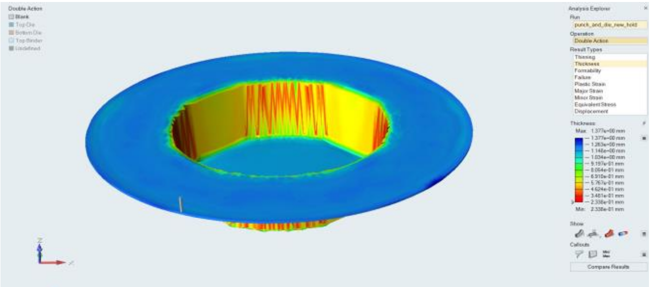

Fig. 8 Thickness of cup at various regions

III. RESULT AND DISCUSSION

Below table shows the strain stress and resultant punch force generated as particular deformation value.

Table VI –Result Table

Total Deformation (mm)	Equivalent Elastic Strain $x10^{-3}$	Equivalent Stress (MPa)	Shear Elastic Strain $x10^{-3}$	Shear Stress (MPa)	Total Force (Ton)
Results					
0.1258	1.52	206.64	1.08	85.852	0.976
12.492	6.49	1328.2	6.8	539.9	19.257
20.310	7.78	1581.6	7.94	636.99	23.942
31.238	9.52	1884.5	8.13	645.51	28.522
33.989	9.59	1943.4	8.52	676.78	31.02
36.270	9.89	2086.2	8.88	704.68	31.437

Below graph shows the increase in von-mises stress and shear stress increases with deformation. This graph increases up to the fracture occur in wall surface. Behaviour of graph is non-linear.

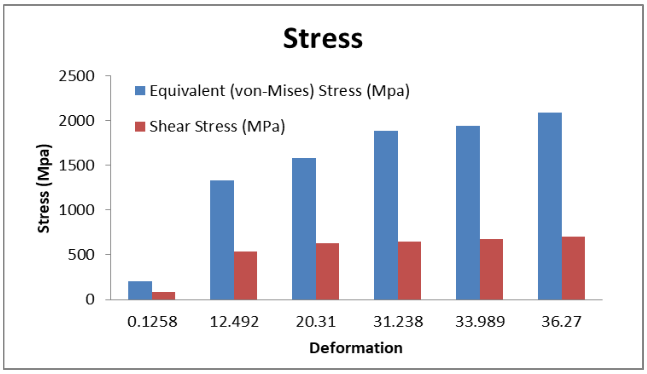

Fig. 9 Stress analysis with change in deformation

This graph shows the relationship with change in deformation with change in strain value. As deformation increases strain also increase. The behaviour of this graph is non- linear.

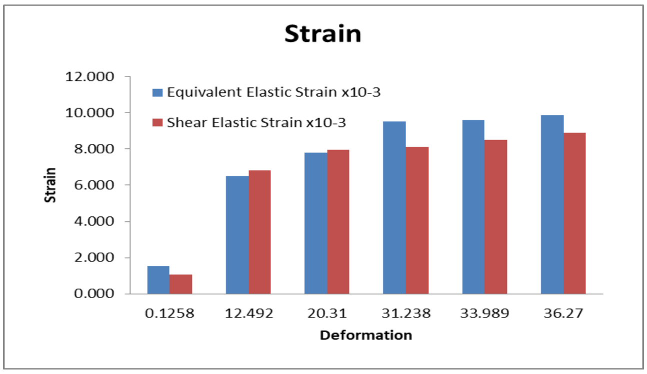

Fig. 10 Strain analysis with change in deformation

The main finding of this paper is to find the punch force required in forming operation like deep drawing which is calculated by using ansys force probe tool. Below graph shows the as increase in deformation punch force also increases. It increases up to the tearing of component wall then it decrease. Next graph shows the force values in tones for specific deformation.

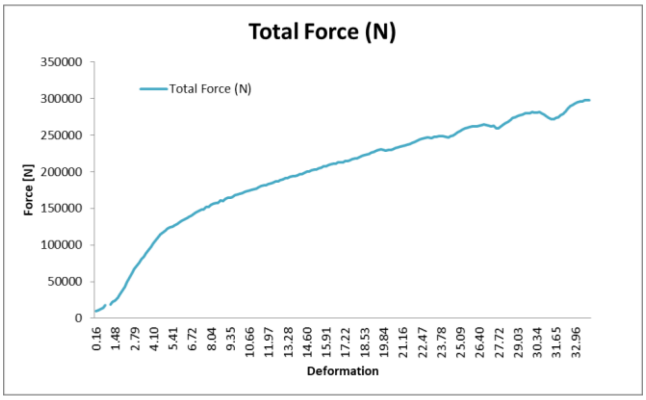

Fig. 11 a) Required force as deformation increases

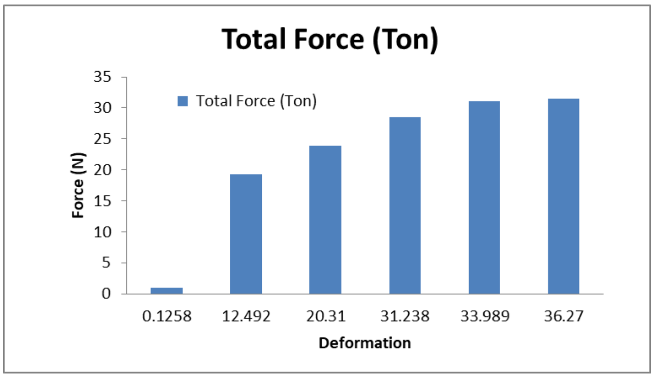

Fig. 11 b) Force values for specific deformation

Joint probe table and chart shows the required force to draw blank into desired shape, i.e. Required Punch Force is $2.978 * 10^5$ Newton which is nothing but 30.37 ton

This punch force is calculated from Ansys transient structural simulation solver. For full body we required punch force 31 ton.

Factor of safety should be taken 1.5, Therefore, Draw Force (P) = 46 ton

Press Tonnage = Draw Force + (B.H.F.) = 54 ton -----(8)

From the theoretical calculation the required force is 34 ton and from the Ansys simulation we get required force as 54 ton. In actual production the required machine force is in the range of 54 to 55 ton. The maximum forces are however very different in magnitude from the theoretical deep drawing force calculated from the equation is 34 ton. This difference can be attributed to the average value of the constant *C*, used in the equation (4) which is dependent on die angle, friction and lubrication. [5]

The problem areas such as wrinkling, tearing thinning are the biggest challenges in the industry now a days but these problems is minimized and sorted out in the initial stages of the design by using simulation techniques. In this simulation there is no single evidence is found about wrinkle. In case of tearing as shown in fig 6, shear stress is maximum on the neck of cup but it indicates the initial stage of tearing not a proper teardown on neck. Fig 8 shows the thickness of cup which is 1.2mm max i.e. original sheet thickness and 0.7mm minimum thickness. From this value thinning is approximately 41 percentages.

IV. EXPERIMENTAL VALIDATION

Fig. 12 Experimental setup

Die and Punch are mounted on the Digvijay power press 60 ton capacity machine with the help of the guide pin and alignment tool on work bed. Experiment setup is prepared as shown in above fig. Conducting the actual experiment first ensured the machine setting parameter then checks the surface finishing and alignment of punch and die, check the edges and ensure the proper oil application on the surface of component. In actual validation the machine is set to different tones from 40ton to increases with 5ton up to 60 ton. Five components are manufactured for every force set on the punch. Deformation of cup is measured using height gauge, form these five values most repeated deformation value is considered which is mentioned in below table (Table-VII). As force increases we get higher distortion of cup base. At the exact depth of 35mm as per real time experimentation process is required the deformation as shown in table VII are actual value calculated from the experimental work. Wrinkle defect is not observed in any iteration also all parts are safe from tearing problem. From the simulation it shows the signs of tearing at neck region but experimentally not a single part get tear at neck or at bottom region. Maximum thickness of cup is 1.2 mm and minimum thickness is 0.8 at the wall region. Maximum percentage thinning is approximately 33 percentages, which is acceptable.

Table VII – Actual Deformation as Force Increases

Force in ton	Deformation in mm
40	12.58
45	20.26
50	31.15
55	34.31
60	36.80

V. CONCLUSION

The maximum force recorded in the simulation deep drawing processes (Equation 8) is calculated as 54ton, and this force is validate by conducting experimental process at 55ton force (shown in table VI). The experimental and computational value of force obtained matches well with each other. From the results it can also be concluded that the computational method used in this paper is much acceptable for deep drawing.

From the experimental results it is observed that the part manufactured is wrinkle free hence equation (5) provides correct blank holding force to produce defect free production of deep drawing forming parts. Tearing defect is also absent in whole experimentation process. Maximum thinning of cup is 33 percentages i.e. wall thickness is 0.8mm which is acceptable. Therefore press machine up to 60 ton capacity can be used for the required process.

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REFERENCES

[1] Shishir Anwekar1, Abhishek Jain2 ," Finite Element Simulation of Single Stage Deep Drawing Process for Determining Stress Distribution in Drawn Conical Component" , International Journal Of Computational Engineering Research (ijceronline.com) Vol. 2 Issue. 8,December 2012,pp.229-236

[2] Shambhuraje Jagatap 1, Prof. Bharat S. Kodli 2," A Finite Elemental Study of Contact Pressure Distribution in Stamping Operations", International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 10, 2013, pp.311-319.

[3] Hakim S. Sultan Aljibori, "Finite Element Analysis of Sheet Metal Forming Process ",European Journal of Scientific Research, Vol.33 No.1 , 2009, pp.57-69.

[4] Akshay Chaudhari, Suraj Jadhav, Ojas Ahirrao, Rushikesh Deore, Prof.S.R.Jadhav ," Design And Development of Stamping Parts Using CAE Technology", International Education and Research Journal (*IERJ*)
[5] Mathews Kaonga," Simulation And Optimisation Of A Full Deep Drawing Process", The University OF Zambia October 2009
[6] S. Schneider, S. G. Schneider, H. Marques da Silva, C. de Moura Neto," Study of the non-linear stress-strain behavior", Materials research vol.8, no.4, 2005.
[7] Indian Standard Cold Reduced Low Carbon Steel Sheet And Strip (Fifth Revision) Is-513:2018