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Research Article

Modelling of Sheet Metal Process using Finite Element Analysis 2D-CAD Model to Find the Optimum Sheet Thickness

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Abstract

Deep drawing is popular sheet metal forming process. Complex axisymmetric geometries, and certain non-axisymmetric geometries, can be produced in a few operations in small cycle time. Skill requirement of operator is relatively less. The basic theories governing the deep drawing are based on application of theory of plasticity to the deep drawing process. It is very difficult to apply these theories and arrive at a general solution which can handle any arbitrary geometry. Some simpler 'mechanics models' are more appropriate for such cases, though these do not incorporate all the aspects governing the process. Therefore, design in sheet metal forming, even after many years of practice, still remains more an art than science due to the large number of parameters involved in deep drawing and their interdependence. Design of tooling for deep drawing (die, blank holder and punch) has been largely based on trial and error resulting in loss of time and money and large development cycles. Using the finite element method one can simulate the process and study the effect of various parameters before finalizing the design. Several simulation tests were carried out to obtain the most appropriate value for some of the parameter. A computational experiment is made to explore the effect of process variables on stress distribution and punch load. An elastic-plastic finite element computational program is developed to simulate successive deep drawing process.

Keywords: *Deep Drawing, Finite Element Analysis, Optimum Sheet Thickness; ANSYS*

1. Introduction

Deep drawing is the most fundamental sheet metal forming process. Deep drawing is the tensile-compressive forming of a sheet blank to a hollow body open on one side or the forming of a pre-drawn hollow shape into another shape with a smaller cross-section without an intentional change in the sheet thickness.

In a deep drawing process, flat sheet of metal, called *blank*, is placed over a die, and with the help of a punch, blank is pressed into the die cavity. Blank holder applies on the blank in the flange region during the deep drawing process. The basic tools of deep drawing process are shown in Fig. 2.

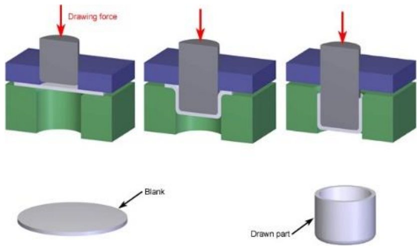

Fig. 1: Conventional deep drawing process

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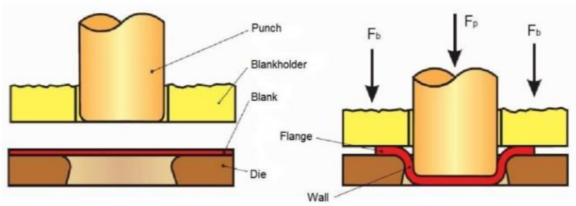

Fig. 2: Basic tools of deep drawing

Fig. 3: Deep drawn parts

Fig. 4: Deep drawn parts

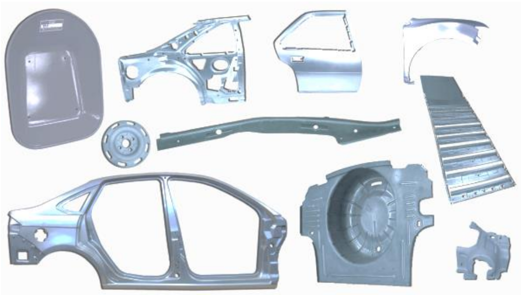

Fig. 5: Deep drawn automobile parts

Deep Drawing is widely used in industry for producing automobile and aircraft body parts, household applications and auxiliary parts in construction field. Deep drawn parts are shown in Fig. 3, Fig. 4, Fig. 5. This manufacturing method is very suitable for producing large amount of simple shaped parts, like cups, cans, vessels, etc

2. Design of deep drawing process and its tools

2.1 Tool geometries

The tool geometry parameters are stated as;

Table 1: Tool geometry parameters

S.No	Geometrical Parameters	
1	Punch Radius	Rp
2	Punch Edge Radius	rp
3	Blank Thickness	t
4	Blank Radius	Rb
5	Die Radius	Rd
6	Die Edge Radius	rd

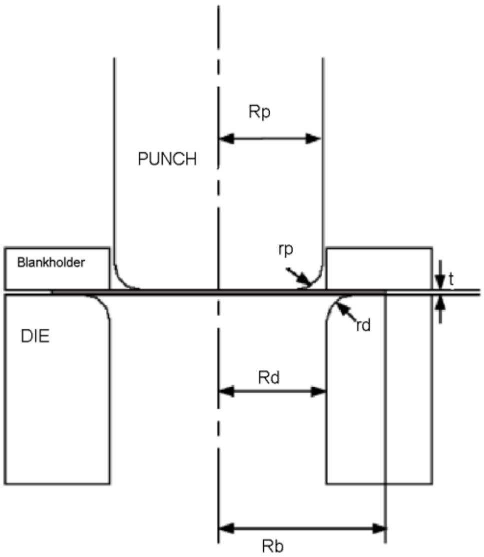

Fig. 6: Geometrical parameters for deep drawing tools

2.2 Stress zones during deep drawing

Deep drawing process is defined as a tensile-compressive forming of the sheet metal. During deep drawing process, due to punch force and blank holder force, different stress zones are formed. These four stress zones are designated as Force application zone, Force transmission zone, bending zone and Forming zone.

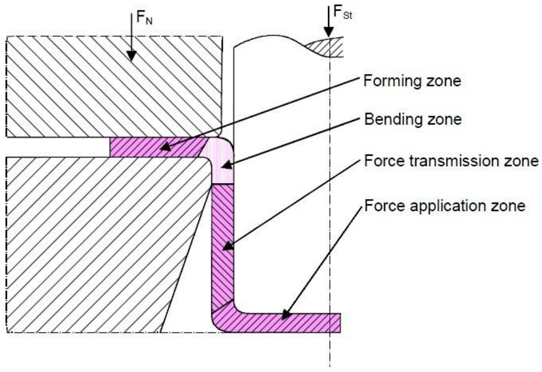

Fig. 7: Four different zones in deepdrawing work piece

The punch force is applied onto the bottom of the drawn part, which is called the Force application zone. Then it is transferred to the flange region. The force is transmitted along the wall of the cup. Bending happens over the die edge radius and forming tales place in the flange region. (*Singh Chandra Pal, Agnihotri Geeta*)

2.3 Deep drawing defects

Deep drawing is affected by many factors, like material properties, tool selection, lubrication etc… Because of these factors, some failures may occur during the process. Tearing, necking, wrinkling, earing and poor surface appearance are the main failure types that can be seen in deep drawing

Tearing and necking are tensile instability caused by strain localization. The strength of the part is reduced and the appearance worsened because of tearing and necking. Another failure is wrinkling, caused by compressive stresses unlike to tearing and necking. Plastic buckling occurs because of the high compressive stress and waves formed on the part. The other one is earing. On the walls of the totally drawn part earing can be seen. The main reason for earing is planar plastic anisotropy. Also, the last defect types which poorly affect the appearance of the sheet metal part are ring prints, traces

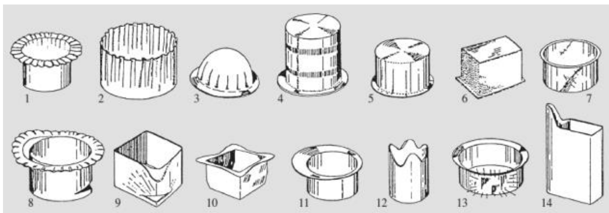

Fig. 8: Various defects of deep drawing

Most of the defects are due to ironing effect. Iron consists principally in reducing the wall thickness of the cup by restricting the clearance between the punch and the die to a value less than the blank thickness. The punch load is of primary importancein ironing because it determines the tension in the cup walls and hence the maximum reduction possible for a given punch load

2.4 Design of deep drawing process using Finite Element Method

The main objective of the present work is to investigate the effects of stress in sheet by changing sheet thickness when exposed to same conditions. There are following objective have been set for this work.

1. Study of deep drawing system for stress reduction in sheet.
2. Prepare the different 2D CAD model of tool, die and sheet.
3. Perform the finite element analysis for all above models with same operating conditions.
4. Compare the results and present the best thickness for the sheet in different models.
5. Avoid the deep drawing defects

3. Finite element simulation methodology of deep drawing process

A time integration method is used in Explicit Dynamics analysis system. It is so named because the method calculates the response at the current time using explicit information. Once the body is meshed properly, the next step is to define initial conditions or boundary conditions. At least one initial condition is required to complete the setup. This is done using software ANSYS 19.The drawing of component is shown in Fig. 10. The flowchart of analysis is given in Fig. 9.

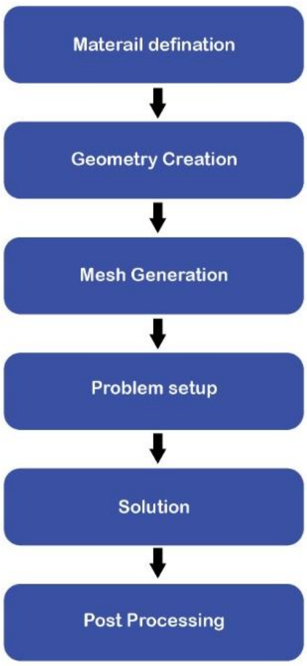

Fig. 9: Flowchart for the analysis of the forming process

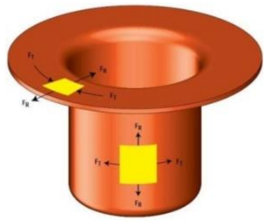

Fig. 10: Drawing of component (Not to scale)

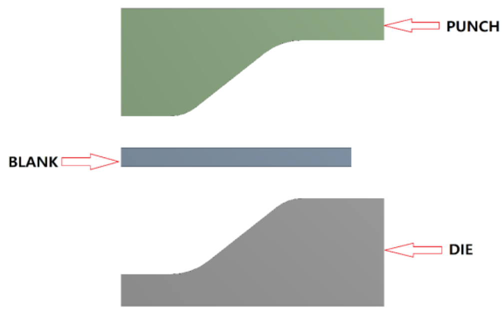

Fig. 11: Details of tool set up (Axisymmetric analysis)

The tool set up details is given in Fig. 11. This problem can be formulated using two different types of approach viz. Plane Strain method or Axisymmetri**c** analysis. The *Axisymmetric* option allows analyzing a 3-dimensional excavation which is rotationally symmetric about an axis. The input is 2-dimensional, but because of the rotational symmetry a symmetric 3-dimensional problem can be suitably analyzed. In this project Axisymmetri**c** analysis is used (*Hakim S. Sultan Aljibori*)

Two types of isotropic material are involved in this simulation model viz. linear elastic-plastic (for sheet metal) and linear elastic (for the punch and die). The basic material properties required for this simulation model are given in Table2 and Table 3.

Table 2: Work piece material properties (*Hakim S. Sultan Aljibori*)

Material	**Sheet Metal (Aluminium)**	
Behaviour	**Linear Elastic-Plastic**	
Property	**Symbol**	**Value**
Young's Modulus	E	78 GPa
Uniaxial Yield Strength	σ_y	550 MPa
Poisson's Ratio	ν	0.3
Mass Density	ρ	2700 Kg/m³

Table 3: Die and Punch material properties (*Hakim S. Sultan Aljibori*)

Material	**Die steel**	
Behaviour	**Linear Elastic**	
Property	**Symbol**	**Value**
Young's Modulus	E	400GPa
Uniaxial Yield Strength	σ_y	4000 MPa
Poisson's Ratio	ν	0.3
Density	ρ	7800 Kg/m³

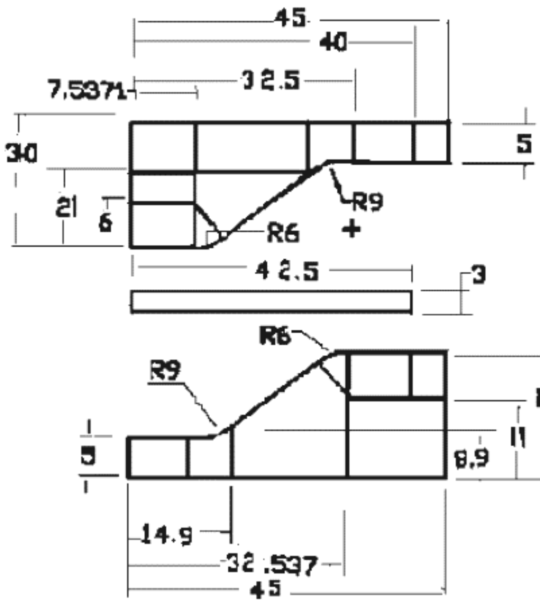

Fig. 12: Schematics diagram and dimensions of the model (Axisymmetric analysis (*Hakim S. Sultan Aljibori*)

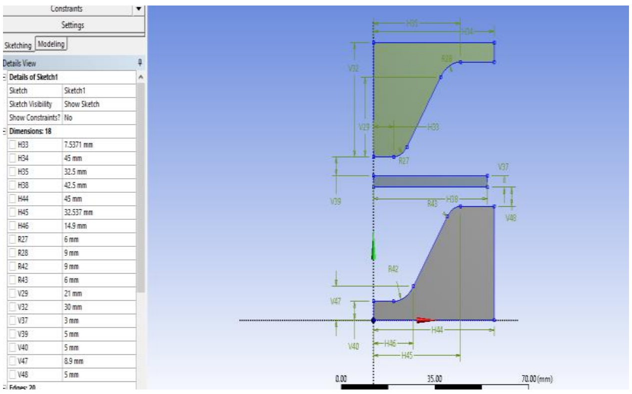

Fig. 13: Modelling of the domain

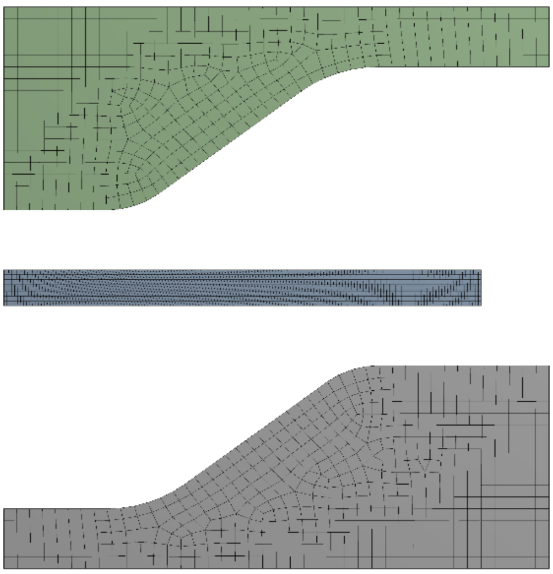

Fig. 14: Drawing of meshing

Details of "Face Meshing" - Mapped Face

Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Suppressed	No
Mapped Mesh	Yes
Method	Quadrilaterals
Constrain Boundary	No
Advanced	
Specified Sides	No Selection
Specified Corners	No Selection
Specified Ends	No Selection

Details of "Face Sizing" - Sizing

Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Suppressed	No
Type	Element Size
Element Size	0.2 mm
Advanced	
Defeature Size	Default (5.e-003 mm)
Behavior	Soft
Growth Rate	Default (1.2)
Capture Curvature	No
Capture Proximity	No

Fig. 15: Details of meshing

The schematic dimension of the die and punch is shown in Fig. 12. After considering the final dimension of the die geometry was produced using Computer Aided Design (CAD) software as shown in Fig. 13. The drawing is in 2D since the analysis is carried out in 2D axisymmetric simulation.

Flexible elements are utilized to model the tools: die, punch and blank. A two-dimensional mesh with quadrilateral elements is utilized to mesh the tools. The mesh is refined around the radii of the punch and die. Four node quadrilateral solid elements are utilized for the modelling of the blank. Meshing details are given in Fig. 14 and Fig. 15.

4. Finite element simulation results

In the present work finite element analysis has been performed for deep drawing process using ANSYS to investigate the nature of material flow during the plastic forming process ofsheet metal. For that three cases of deep drawing setup is created using the design modular software with dimension shown in methodology. All the three cases are enlisted below:

1) Sheet with 3 mm thickness

The Stress contour, Total deformation contour, Plastic strain contour and Reaction force are given in figures Fig.16, Fig.17, Fig.18 and Fig.19 respectively.

2) Sheet with 3.5 mm thickness

The Stress contour, Total deformation contour, Plastic strain contour and Reaction force are given in figures Fig.20, Fig.21, Fig.22 and Fig.23 respectively.

3) Sheet with 4 mm thickness

The Stress contour, Total deformation contour, Plastic strain contour and Reaction force are given in figures Fig.24, Fig.25, Fig.26 and Fig.27 respectively.

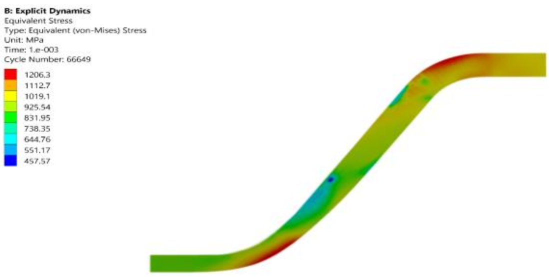

Fig. 16: Stress contour (3mm thickness)

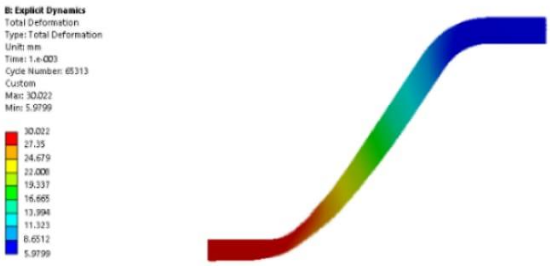

Fig. 17: Total Deformation contour (3mm thickness)

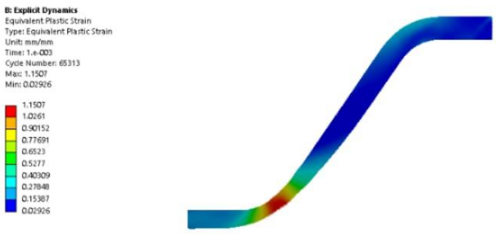

Fig. 18: Plastic strain contour (3mm thickness)

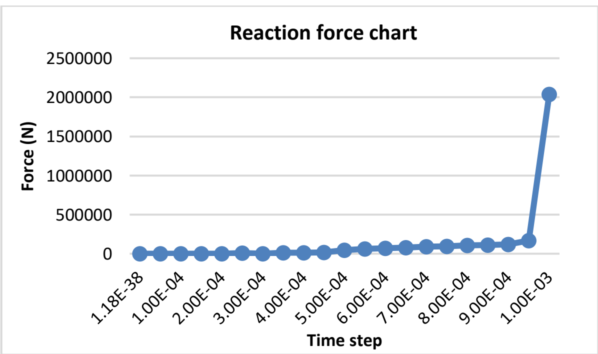

Fig. 19: Reaction force (3mm thickness)

Fig. 20: Stress contour (3.5 mm thickness)

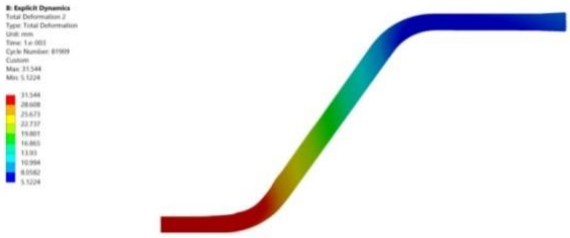

Fig. 21: Total Deformation contour (3.5 mm thickness)

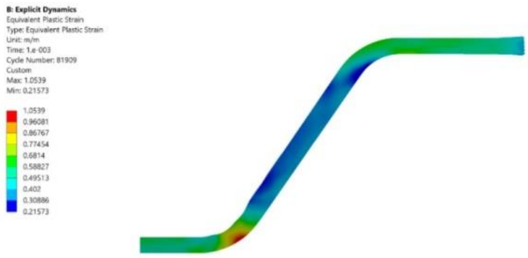

Fig. 22: Plastic strain contour (3.5 mm thickness)

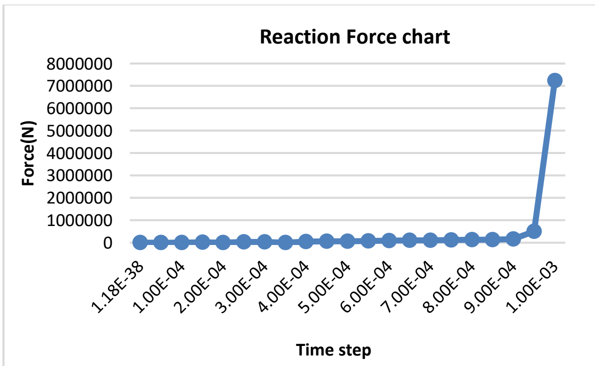

Fig. 23: Reaction force (3.5 mm thickness)

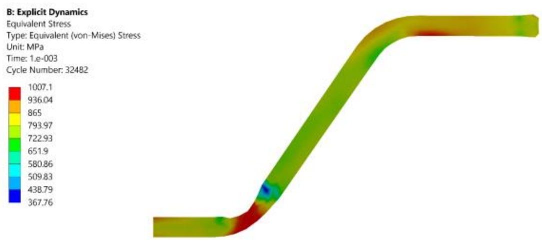

Fig. 24: Stress contour (4 mm thickness)

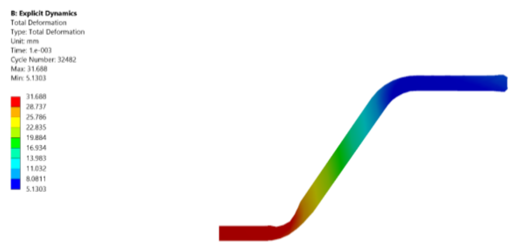

Fig. 25: Total Deformation contour (4 mm thickness)

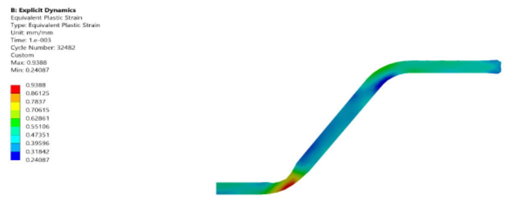

Fig. 26: Plastic strain contour (4 mm thickness)

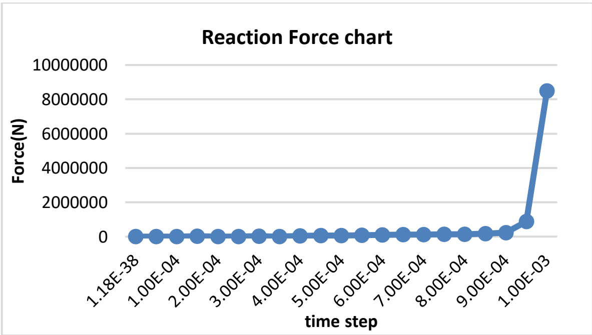

Fig. 27: Reaction force (4 mm thickness)

5. Analysis of data and salient points

5.1 Effect of blank thickness on stress

Table 4: Stress developed in sheet (blank) during drawing process

Thickness mm	Max Stress MPa	Min Stress MPa
3	1206.3	457.57
3.5	1133.1	536.2
4	1007.1	367.76

Here it is found that the stress level decreases as the blank thickness is increased.

5.2 Reaction force

As blank sheet thickness increases, the reaction force also increases, this shows in table 5.

Table 5: Reaction force during drawing process

Thickness mm	Reaction force N	Plastic Strain
3	2.04E+06	1.1507
3.5	7.24E+06	1.0539
4	8.49E+06	0.9388

5.3 Thinning effect

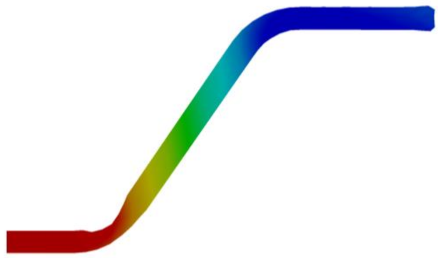

Fig. 28: Thinning effect in 4 mm thickness Sheet (blank)

In deep drawing process because of stretching phenomenon of sheet thickness differs from region to region. Thinning parameter generally rest on the depth of drawing. As depth of drawing increases thinning increases i.e. wall thickness reduces (*H. Zein et al*) This happened where depth of drawing is 35mm in 4 mm sheet thickness. This results are considered by the help of ANSYS software.

Conclusion

Several simulation tests were carrying out to obtain the most appropriate value for some of the parameter. An attempt base on computational experiments is made to explore the effect of process variables on stress distribution and punch load. An elastic-plastic finite element computational program was developed to simulate successive deep drawing process.

Some findings of the project is summarized as follows:

1. In model with 4 mm thickness thinning effect is captured. Because of the percentage of thinning increases with increase of blank thickness.
2. Model with 3.5 mm sheet thickness is getting optimum result where stress level is 1133.1MPa & Reaction force is 7.24E+06 N.

By using a specialized software, one can be save time and other costs on research work. These simulation and analyses, presented here, suggests that, expensive way to find materials behaviour by punch, die and experimental set up can be avoided by using specialized software.

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