Study of effect of various parameters on Thinning tendency in Deep Drawing using Simulation

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Abstract*—*Deep drawing is one of the versatile process in manufacturing industry. Various cylindrical, cup and square shaped parts can be produced by using this process. It is desirable that parts should be manufactured without any defects. Deep drawing process has defects like wrinkling, tearing and thinning tendency which should be avoided. The finite element method is a powerful tool to predict material thinning deformations before prototypes are made. In this paper, thinning defect has been considered for a rectangular shaped part and simulation has been carried out using ABAQUS/Explicit student version. The CRCA steel blank with 0.5 mm thickness is used for simulation.

Taguchi design of experiments and analysis of variance has been applied to analyze the influencing process parameters on Thinning. Analysis which shows that lubrication is the major contributing factor for thinning tendency.

Index Terms*—*Deep drawing, Thinning, Defects, Simulation, ABAQUS/ Explicit.

I. INTRODUCTION

One of the most common industrial processes in sheet metal forming is deep drawing. It can fabricate a variety of objects with cylindrical cups, rectangular cups even complex shapes. Deep drawing process is defined as a manufacturing process in which a sheet metal work piece is pressed into a die cavity as shown in Fig. 1. In this process metal sheet is subjected to tensile and compressive stresses. The aim of successful deep drawing process is to produce a product with greater final depth as well as with fewer defects. When the length of drawn cup is greater than a half of the drawing punch diameter the product is said to be deep drawn; otherwise the product is classified as a shallow part. In order to prevent the material blank from flowing freely into the die cavity through the process a third forming tool which is named blank holder, is employed to hold down the blank. This technique can be widely applied to manufacture metal products with an aspect ratio larger than unity. Currently, the deep drawing process has an extensive role in aerospace and automobile industries to manufacture structural components. There are many industrial products manufactured by sheet metal like car bodies, airplane wings, roofs, utensils and many more. High safety standards, high reduction of weight that improves fuel consumption, emissions and performance trends, a world class quality at reasonable production costs and schedule timing are changing the development chain in the aerospace and automotive industry.

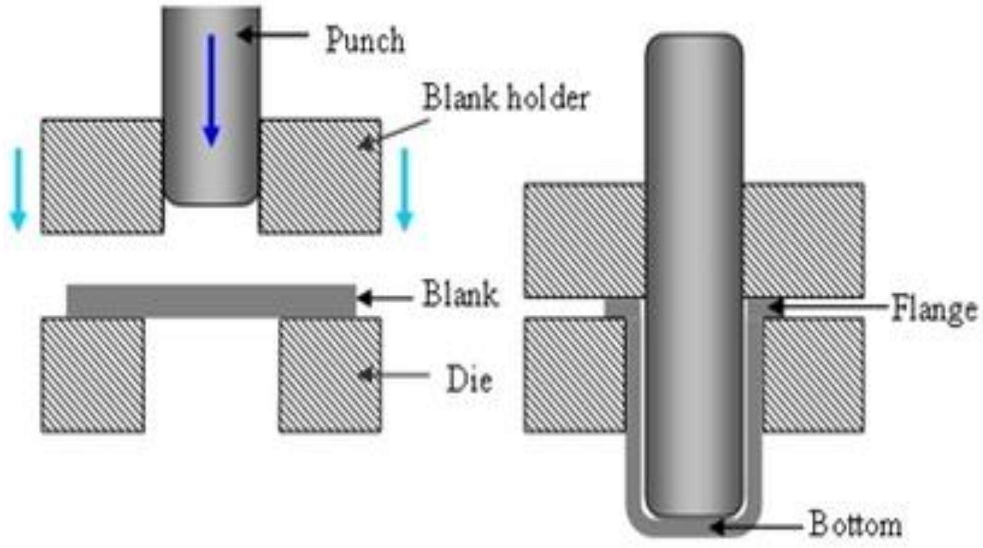


Figure 1. Deep Drawing Process

Kua et al. [1] did finite element analysis for multi-stage deep drawing process for high-precision rectangular cases is carried out especially for an extreme aspect ratio. The results of their analysis show that the irregular contact condition between blank and die affects the occurrence of failure and the difference of aspect ratio in the drawn section leads to non-uniform metal flow which may cause failure. Kim et al. [2] did simulation-based design modification in the multi-stage deep drawing with ironing of a rectangular cup. They provided the initial design criterion and proposed the guideline on the design modification from the finite element analysis result. The analysis was carried using LS-DYNA with continuum elements in the three dimensions. The finite element analysis result with the improved tool design confirms that their proposed design not only reduces the possibility of failure but also improves the quality of a deep-drawn product.

Sheng and Shivpuri [3] used the process parameters such as temperatures, forming speeds and stroke length while response variables were time and wall thickness were determined by the Finite Element Method (FEM) modelling and simulation. Sensitivity analysis under the constraint of forming limits of Magnesium alloy sheet material and strength of tooling material was also carried out. They used PAMSTAMP software for the analysis. Their developed process improves both formability and forming speed of the magnesium alloy by facilitating the metal flow and reducing the plastic deformation in the forging stage by drawing from well-designed sheet. Hassan et al. [4] studies the deformation characteristics of a newly developed process for increasing the drawability of square cups. Finite element analysis (FEA) was used to study the influences of the geometric parameters on the formability of square cup in order to find out the optimum setup dimensions of the present process. The effects of die fillet radius, die corner radius, die throat length, punch profile radius; punch corner radius, punch shape factor, relative die clearance and blank thickness on the drawability of square cup were mainly investigated.

Kawka et al. [5] find wrinkling of conical cups and simulated using the finite element method (FEM) and verified experimentally. Two different FEM codes static-explicit ITAS3D and dynamic-explicit ABAQUS/Explicit they used in numerical simulations. They found that several parameters could affect results of wrinkling simulation. Most important was the initial shape of the finite element mesh. General difficulties in simulation were reported for both FEM codes, dynamic and static. Stamping of conical cups was conducted using an anisotropic steel sheet to establish a reference frame for the validation of numerical results. Their result showed that the FEM results for both codes appeared to be very sensitive to the blank mesh. Gyadari and Reddy [13] did analysis of optimization of blank holding force developed for cup drawing operation by using explicit finite element package LS DYNA by an iterative procedure the optimum BHF is obtained. In their work die design is done for a cup of 30mm diameter and deep with 1 mm thickness. They found optimum blank holding force by checking the condition of non-formation of wrinkles at different coefficient of friction at (0.045, 0.06, 0.1, 0.13, and 0.15) and at different die radius (2, 3, 4, 5,6mm) and the values of blank holding force has been taken where no wrinkles has been formed for different coefficient of friction and for different die radius. For the same blank holding force is calculated from the empirical formula.

II. FACTORS INFLUENCING THINNING TENDENCY IN DEEP DRAWING PROCESS

The thinning tendency refers to change in original thickness of blank at various sections. In this research thinning is measured by doing the simulation in ABAQUS student version and it is analyzed using ANOVA with the help of MINITAB16 software. Blank holder force, lubrication condition i.e. coefficient of friction, die profile radius and punch nose radius are the major parameters which affect the thinning tendency in deep drawing process.

Blank holding force

For drawing all but simplest of the shape some restraint is required for the controlling the flow of the material. [6] Compressive forces on the metal in the area beyond the edges of the die cause the work metal to buckle. If this buckled or wrinkled metal is pulled into the die during the drawing operation, it increases the strain in the area of the punch nose to the point at which the work metal would fracture soon after the beginning of the draw. The blank holder force is used to prevent this buckling and subsequent failure. The amount of blank holding force required is one third of the drawing. The blank holder force is applied to control the flow of material in the die. Blank holder force has significant contribution on the product quality. Appropriate blank holder force evolved through a process results in controlling the thickness variations in a deep drawn part and thus the quality of the part. An optimal blank holder force eliminates wrinkling as well as tearing, the two major phenomena that cause failure in formed parts.

Lubrication

When two metals are in sliding contact under pressure, as with the dies and the work metal in drawing, galling (pressure welding) the tools and work metal is likely. When extreme galling will occurs, drawing force will increases and becomes unevenly distributed causing fracture of the work piece. Selection of the lubricant is depends on the ability to prevent galling wrinkling, or tearing during the deep drawing. It is also influenced by ease of application and removal, corrosivity, and other factors. Lubrication is normally expressed in terms of coefficient of friction. In deep drawing all areas where sheet and tool slide are relative to each other and plastic deformation occurs with complex state of friction [7]. The friction between die and sheet influences the coefficient which is assumed between 0.05 and 0.15. If friction is too low then it involves a poor control of the sheet flow while too high a friction leads to a risk of crack formation, because the slow movement of sheet can result into tearing and cracking.

Punch nose radius

The draw punch applies the required force onto the sheet metal blank which causes the material to flow into the die cavity. Too small Punch Nose Radius will try to pierce or cut the blank rather than force the material to bend around the radius [8]. The minimum punch-nose radius depends on material type and thickness. It is equally important to understand that, as the punch-nose radius is increased the blank will tend to stretch on the punch face rather than draw-in the blank edge.

Die profile radius

As the blank is struck by the punch at the start of the drawing, it is wrapped around the punch and die radii; the stress and the strain developed in the work piece are similar to those developed in bending. The force required to draw the shell at intermediate position has a minimum of three components

- The forces required for bending and unbending of the metal flowing from the flange into the side wall.
- The forces required for overcoming the frictional resistance of the metal passing under the blank holder and over the die radius.
- The forces required for circumferential compression and radial stretching of the metal in flange.

So increase in the die radius reduces the work required for the deforming as punch radius has not significant effect on the process but it should be appropriate. On the profile of the die radii flow of the material takes palace [9]. Most of the bending and unbending takes place in that region. Die radii should be optimized for the minimization of the drawing load.

III. SIMULATION

ABAQUS is a suite of powerful engineering simulation programs based on the finite element method, sold by DASSAULT Systems as part of their SIMULIA Product Life-cycle Management (PLM) software tools. ABAQUS contains an extensive library of elements that can model virtually any geometry. For carried out the simulation ABAQUS Student Version was used. A rectangular shaped part has been selected for the simulation purpose. The part size is 315*176*62.5 (L*W*H) with 0.5 mm thickness. The material selected was CRCA steel with some properties as shown in Table 1.

Table 1 Properties of the Material

E (MPa)	K (MPa)	R_0	R_{45}	R_{90}	Density(Kg/m^3)
2.1 E+5	350	1.18	2.46	1.71	7800

Modeling

Blank

Blank dimension: 350mm*480mm.

Blank is made with shell section and 0.5 mm thickness to get required cup drawn thickness and deformable property is defined for it. Each part is meshed separately with S4R quadratic node element (finer mesh) for better results.

Punch

Punch dimensions: 176mm*315mm with total height of 62.5mm.

Punch is made as rigid and inertia mass is applied to it to act as a real time simulation. Punch is also made as a shell element with minimum of 0.1mm thickness.

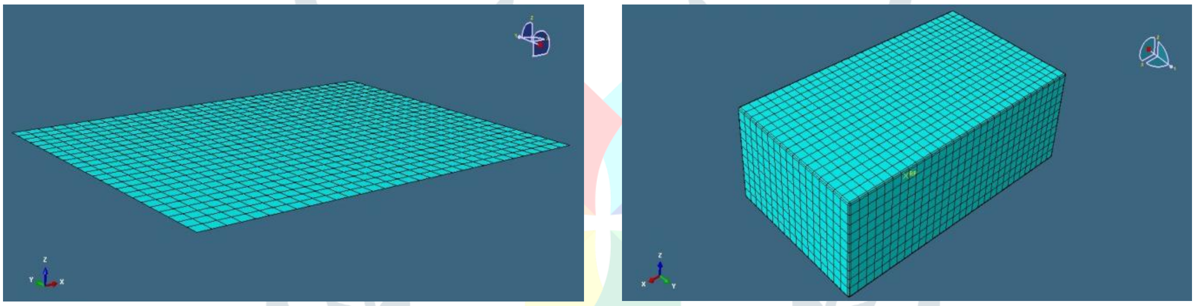
Die

Die Dimensions: Flat surface 350X480mm and draw area of 177.4 * 316.4 mm.

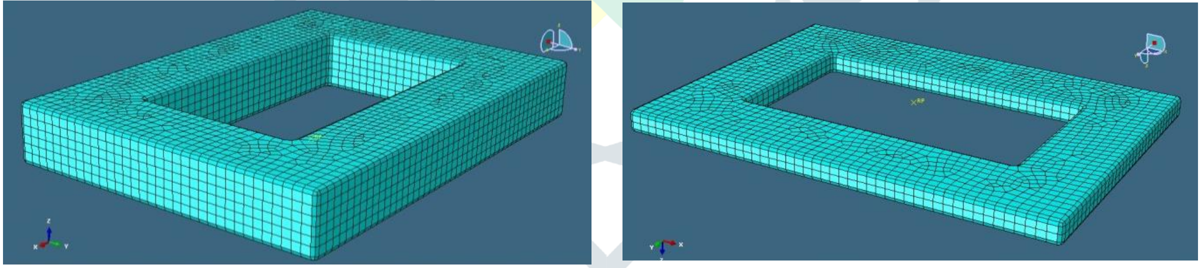
Similar to punch die is also made as rigid with shell element of 0.1mm thickness.

Blank Holder

Blank Holder dimensions: Flat surface 350*480mm and draw area of 177.4 * 316.4 mm with extrude 25mm. Properties of blank holder is same as that of die.



(a) Blank (b) Punch



(c) Die (d) Blank Holder

Figure 2. Meshed Parts

All different modeled and meshed parts are assembled together in Assembly Design. After that loads and boundary conditions are applied. Punch is allowed displacement in only Z direction. Load is applied on blank holder which is later treated as one of input parameter and output request for displacement, stress, thickness, strain and velocity graph is defined.

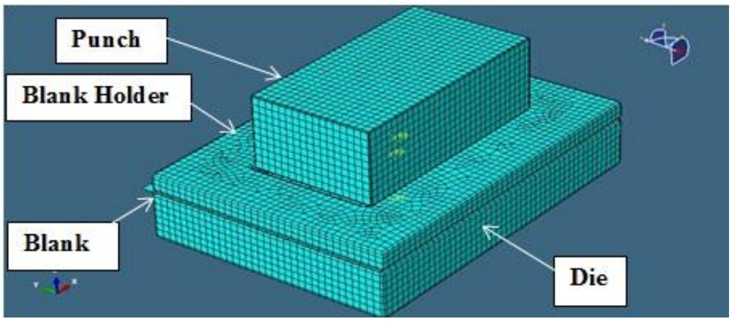


Figure 3. Deep drawing simulation model

Model is symmetric part about Z-X plane so half modeling and simulating will give same results as whole also it has advantage of simulation time reducing to half. Symmetric half model drawn component and STH (Shell Thickness) field plot are as shown in Fig. 4 and 5.

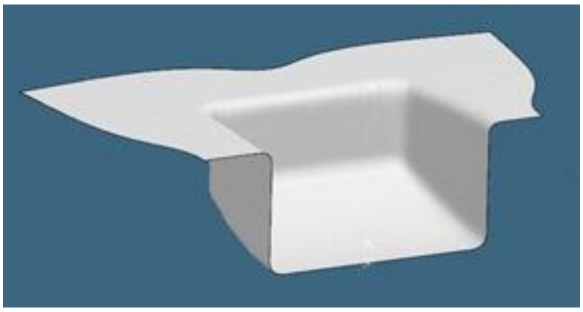


Figure 4. Symmetric half model drawn component

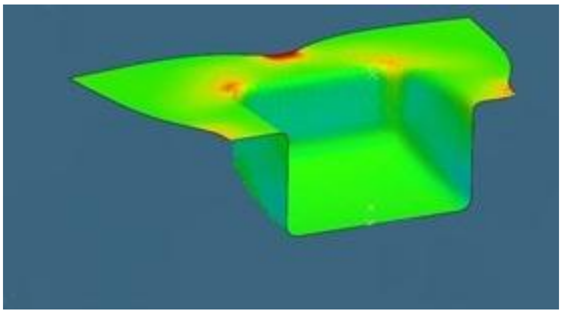


Figure 5. STH (Shell Thickness) field plot

IV. DESIGN OF EXPERIMENTS

Depending upon the trials performed 3 levels of each BHF, Lubrication (μ), Die Radius (R_d) and Punch Radius (R_p) are selected. After selecting these parameters and their levels with the help of Design of Experiments (DoE), L9 orthogonal array was chosen with the help of MINITAB16 software. Process Parameters and their levels are as shown in Table 2.

Table 2 Process Parameters and their levels

Parameters	Level 1	Level 2	Level 3
BHF	100kN	120kN	140kN
Lubrication (μ)	0.05	0.10	0.15
Die Radius (R_d) (mm)	1.5	2	2.5
Punch Radius (R_p) (mm)	6	7	8

The L9 array can be shown as follows in Table 3.

Table 3 L9 Array

Exp. No.	BHF (kN)	Lubrication (μ)	Die Radius (R_d)	Punch Radius (R_p)
1	100	0.05	1.5	6
2	100	0.10	2	7
3	100	0.15	2.5	8
4	120	0.05	2	8
5	120	0.10	2.5	6
6	120	0.15	1.5	7
7	140	0.05	2.5	7
8	140	0.10	1.5	8
9	140	0.15	2	6

V. RESULTS OF SIMULATION

The simulations were performed according to L9 orthogonal array in ABAQUS. The part was checked for its thinning tendency. The thickness ratio is found out and the results obtained can be tabulated as shown in Table 4. (All dimensions are in mm.)

Table 4 Results of Simulation

Exp. No.	Avg. Thickness	Thinning Ratio (%)
1	0.42	16
2	0.35	30
3	0.38	24
4	0.45	10
5	0.39	22
6	0.37	26
7	0.42	16
8	0.42	16
9	0.4	20

VI. ANOVA ANALYSIS

ANOVA was performed for analyzing the effect of process parameters on thinning. As it is expected that the thickness difference should be as minimum as possible. So, smaller the better is considered while performing the analysis. MINITAB16 software was used to perform the ANOVA analysis. Analysis of variance (ANOVA) for thinning is given in Table 5. It shows that, lubrication is the major contributing parameter affecting the thinning tendency with 49.92 % contribution. Then Punch Radius with 25.37% contribution followed by BHF with 17.18% and Die Radius with 6.95% contribution. The confidence level obtained is 96.5%. The F-values obtained for BHF, lubrication, Die Radius and Punch Radius are 21, 61, 11.29 and 31 while p-values are 0.045, 0.016, 0.081 and 0.031 respectively.

Table 5 ANOVA for number of wrinkles

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	% Contri.
BHF	2	56	56	28	21	0.045	17.18
μ	2	162.68	162.68	81.34	61	0.016	49.92
R_d	2	22.667	2.667	1.333	11.29	0.081	6.95
R_p	2	82.667	82.667	41.333	31	0.031	25.37
Residual Error	2	1.667	1.667	0.833	-	-	
Total	10	325.81		-	-	-	
S = 1.155 R-Sq. = 99.1% R-Sq.(adj.) = 96.5%							

The response table of S/N ratio for BHF, lubrication, Die Radius and Punch Radius is as shown in Table 6.

Table 6 Response Table of S/N Ratio for thinning

Level	BHF	μ	R_d	R_p
1	-27.08	-22.72	-25.49	-25.65
2	-25.05	-26.82	-25.19	-27.31
3	-24.73	-27.31	-26.18	-23.9
Delta	2.35	4.59	0.99	3.41
Rank	3	1	4	2

Fig. 6 shows Main effects Plots for thinning based on S/N ratios. The graph shows optimum parameters for the process i.e. Higher BHF, Lower Lubrication, Moderate Die Radius and Higher Punch Radius is preferred to minimize thinning tendency.

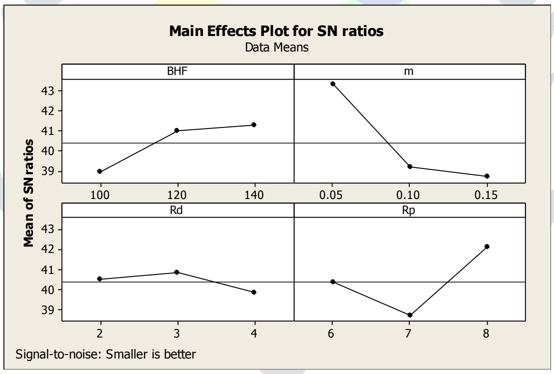


Figure 6. Main effects Plot for thinning

VII CONCLUSION

The simulation model has been developed in ABAQUS and the simulation of deep drawing has been performed according to L9 orthogonal array. The thinning ration has been determined and the ANOVA analysis was performed using MINITAB16. It can be observed from the analysis that Lubrication is the most significant parameter which affect the thinning tendency followed by punch radius, BHF and lastly die radius. Also as per literature, the thinning ratio below 20% is acceptable to avoid thinning tendency. Also ABAUS/Explicit can be used for simulating the deep drawing process effectively.

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