Numerical Inspection for the Effect of Die Entrance Angle on the Performance of Reverse Redrawing Process

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Abstract - *This study aims to find out the effect of the die entrance angle on the performance in terms of the drawability and load in the reverse redrawing process directly after the first stage by using a single action press during one pass. DEFORM v10.2 software package has been utilized to achieve an FE simulation on low carbon steel sheet blank with dimensions 80 mm in diameter and 0.5 mm in thickness. Four levels of the entrance angle have been included: 30°, 45° and 60° for both the direct drawing (1st stage) and the reverse redrawing (2nd stage) while the fourth level is the fully rounded angle for the die of the reverse redrawing only. This parameter has an important effect on the design and performance of the die in the drawing process. Simulation results that have been obtained, show that the reverse redrawing cannot be completed when adopting a die entrance angle of 30° and 60°. The earing effect has been observed to be less for the reverse redrawing when using a fully rounded angle of the die. In addition, an increase in load has been observed during the reverse redrawing when adopting an entrance angle of 60°. However, no considerable differences in load have been indicated when employing a fully rounded entrance angle compared with that for 60° in the second stage of drawing*.

Key Words: **Reverse redrawing, entrance angle, die, single action press …**

1. INTRODUCTION

Sheet metal forming is the most commonly used manufacturing processes in industry that is used to change the geometry of sheet metal of normally about 6mm thickness without loss of material [1]. Products made by sheet-forming process include a very large variety of different geometrical shapes and sizes, like simple bend to double curvatures even with deep recesses and very complex shapes [2]. The Deep drawing is one of the commonly applied methods in sheet metal forming. Deep drawing operation is based on manufacturing engineering parts with particular shapes through major plastic deformation of completely flat metal sheets [1]. It is most effective with ductile metals, such as aluminum, brass, copper, and mild steel. In deep drawing, a tool pushes downward on the sheet metal, forcing it into a die cavity in the shape of the desired part as depicted in Fig. (1-a). The tensile forces applied to the sheet cause it to plastically deform into a shaped part. Deep drawn parts are characterized by a depth equal to more than half of the diameter of the part. These parts can have a variety of cross sections with straight, tapered, or even curved walls, but cylindrical or rectangular parts are most common. The final quality of parts produced by this operation is based on the final wall thickness and being wrinkle-free and fracture-free [3, 4]. The reverse deep drawing process is proposed to form cylindrical cups with greater drawing depths. In the reverse redrawing (within the second stage), the punch moves in the opposite direction to fit the shape of a hollow die. The process reverses the direction of the material flow. Returning the inside of the cup to the outside, a second cup with new dimensions is then obtained as shown in Fig. (1-b) [5].

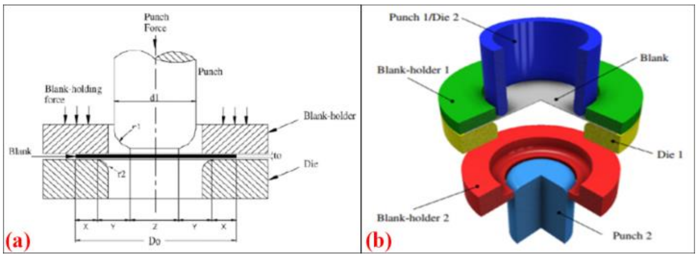

Fig -1: Deep drawing operation; (a) direct drawing, (b) reverse redrawing [4, 5]

2. Literature Survey

A number of studies related to reverse drawing has been presented by many researchers in order to enhance the formability of the sheet metal. **S. Thuillier et al (2002) [6]** have dealt with the experimental and numerical reverse re-drawing of cylindrical cups. Experimental and simulated results lie within a range of 20%. The agreement is good in the first stage but problems are encountered for the second one: wrinkle formation overestimation of the punch force. Concerning the thickness predictions, they are closer to experiments. Analyses of deep drawing Cr-Ni stainless steel process have been made by **Z. Keran et al (2006) [7]**. The research is related to forces that appear in machine tool during the process. The researchers have concluded that reduction in number of draws is solved by reversed drawing. For the observed Cr-Ni stainless steel minimal reduction coefficient cannot go under 0.55 because the cracking occurs in the second draw. As well, punch force in the second draw is smaller, but by reduction coefficient changing, it also follows its own regression tendency curve. A novel device of hydro-mechanical reverse deep drawing with axial pushing effect for cylindrical cups has been developed by **S.D. Zhao et al (2007) [8].** Then finite element simulations and optimization are conducted and experiments are performed. A cup with a draw ratio of 2.95 is obtained. The study proves that the axial pushing force can improve the deformation extent of blanks considerably, and is one of the key factors for reverse deep drawing. The experimental results were in good agreement with the numerical simulation results. **R. Bortolussi et al (2009) [9]** have done the simulation of deep drawing process and reverse re-drawing of cylindrical cups used in automotive parts industries. The results of this work allow to conclude that in the first step there are no significant differences among simulation and experiments in thickness minimum value and variation while in the second step thickness distribution had a different distribution in the cup wall but minimum values are the same at directions 0o and 45° and it also shows that mathematical model is accurate to simulate this process. **Raman Goud. R et al (2014) [10]** have estimated the drawability of extra deep drawing (EDD) steel in two-stage forward redrawing process. The results show that EDD material blanks with various diameters and temperatures were drawn successfully. That is, direct redrawing has been successfully attempted. The fractures which have occurred are due to increase in blank holding pressure, exceeding the limiting draw ratio. Hence by redrawing process high draw ratios can be achieved in less number of steps and deeper cups can be obtained. An analysis of the multi-stage deep drawing process has been presented by **K. M. Younis et al (2016) [11]** considering the three deformation stages namely reverse drawing and reverse redrawing respectively. This work aims to study the mechanism of deformation during the redrawing process where the second and the third stages were done in reverse redrawing and to study the effect of this mechanism on produced cup wall thickness and strain distribution across the wall of the drawn part. From this work it can be concluded that when considering multi-stage drawing, the task is even more difficult because the strain and thickness distribution resulting from the first stage will influence the subsequent results. In addition, more thinning appears in region under the punch profile radius due to excessive stretch in this region in the first stage. At last, increase in thinning in the wall cup will appear in the second and third stages because this region which suffers from more stretch in the first stage will be the wall cup in the next stages. **K. Ben Othmen et al (2017) [12]** have aimed to study the constitutive models' influence on the reverse deep drawing simulation of cylindrical cups. Several constitutive laws were considered to predict the combined effects of anisotropy as well as the changes in strain path direction of the stainless steel. To this end, a number of models were used, worth mentioning among which are the isotropic with nonlinear kinematic hardening laws, along with the isotropic von Mises and anisotropic Hill'48 yield criteria. For the models' parameters identification, uniaxial tensile and shear tests at several orientations to the rolling direction as well as reversed shear tests were carried out. Then, a subsequent comparison between experimental data and numerical simulations of reverse deep drawing tests were performed, using the finite element code Abaqus/Explicit. On the basis of the major reached results, it has been found that for the first stage, whatever the yield criteria used and for all the hardening models, the numerical punch-force evolution correlates well with the experimental one. For the second stage, the punch-force evolution was found to be remarkably more influenced by the yield criteria than by the kinematic laws. The major strain distribution greatly depends on the yield criteria. Meanwhile, it was slightly linked to the work hardening. This study aims to explore the effect of the die entrance angle on the performance in terms of the drawability and load in the reverse redrawing process (second draw) directly after the first one, by adopting a single action press during one pass. This can be achieved by preparing a simulation on low carbon steel sheet blank.

3. Parameters and conditions

In this work, the main parameter that has been adopted is the entrance angle of die1 and punch1/die2 on single action press during one pass for FE simulation. It is worth to mention that the die1 and punch1/die2 are adopted for the first and second stage respectively. The other conditions such as drawing speed, type of press, material and thickness of the sheet, etc. were kept constant during all FE simulations. The following sections will provide an illustration for the main conditions.

3.1 Entrance Angle

This parameter has an obvious and important effect on the design of the die. Three values of such angle for die1 and punch1/die2 have been used during FE simulation. These values are 30°, 45° and 60° for both dies as illustrated in Fig. (2). As it can be observed that the corners of each die have been rounded with different radii in order to make a smooth sliding of the sheet over the die and to avoid the occurrence of tearing. In addition, a fully rounded entrance angle of punch1/die2 (for the second stage) has been adopted as shown in Fig. (2-c) in order to compare its performance with the other angles. Due to symmetry condition, half-sided dies have been depicted as shown in the subsequent figure.

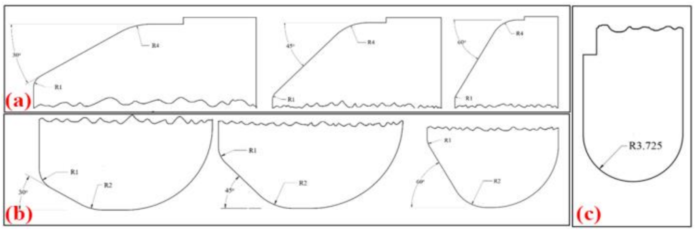

Fig -2: Entrance angles adopted for; (a) die1, (b) punch1/die2, and (c) punch1/die2 at full angle

3.2 Drawing Speed

The drawing speed is the velocity that the punch travels linearly during the drawing process. The value of the punch velocity has been set 200 mm/min for all FE simulation models.

3.3 Type of Press

There are two common mechanisms of pressing used in drawing operations: single action and double action press. In the former mechanism, the punch travels only in one direction to perform drawing as depicted in Fig. (3) while in the later type the punches move in opposite direction relative to each other. In this work, a traditional single action press has been utilized due to its easiness to use and maintain, cheap in price, and it can be used for producing a cup by more drawings. The main parameters and conditions included in this study can be listed in Table 1.

Table -1: Drawing parameters and conditions

Parameter/Condition	First stage			Second stage			
Type of die	Die1			Punch1/die2			
Entrance angle	30°	45°	60°	30°	45°	60°	Full
Drawing speed	200 mm/min						
type of press	Single action						

3.4 FE Simulation Models

The FE models that can be conducted using DEFORM V10.2 software are listed in Table 2 by using the interactions of the entrance angle parameter included in this work.

Table -2: FE Models used in this study

Model No.	Entrance Angle/1st Stage (Die1)	Entrance Angle/2nd Stage (Punch1/die2)
1	30°	30°
2	45°	45°
3	60°	60°
4	60°	Full

4. Finite Element Simulation

Finite element analysis (FEA) is a simulation technique which computes the behavior of equipment, products and structures for different loading conditions. DFORM v 10.2 software has been used to simulate the deep drawing operation. A 3D finite element model has been imported and suitable material was assigned to the model. The various stages of this simulation work are summarized sequentially in the following steps:

i. **Preprocessing:** starts at defining the problem which includes importing geometry of top die, bottom die and workpiece (Solid Modeling), meshing workpiece volumes as required, and defining material with geometric properties.
ii. **Solution:** involves applying the speed/loads, positioning Objects (translational and rotational); setting primary die stroke, simulation control, generating data base, switching to simulate and finally solving the problem.
iii. **Post processing:** includes further processing and viewing of the results with stating variables and tools.

4.1 Modeling of Parts

All parts including punches, dies and blank have been modeled as solids by using AutoCAD 2016 software package and then imported by DEFORM as STL files. Fig. (3) illustrates the modeled parts and their dimensional details. It is worth to mention that the blank has dimensions of 80 mm diameter and 0.5 mm thickness.

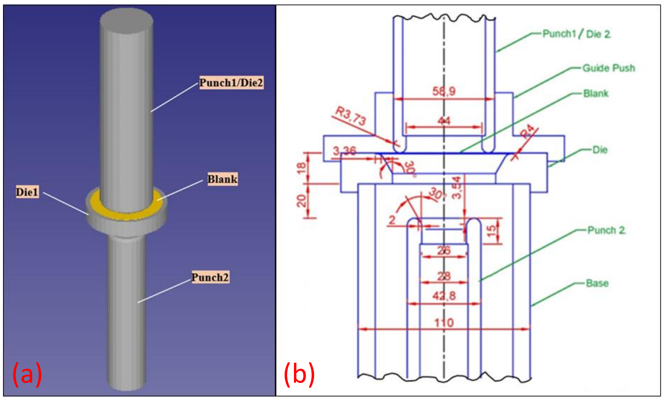

Fig -3: Parts assembly of deep drawing; (a) 3D view, (b) dimensional details

4.2 Elements and Meshing

The type of element to be used in the analysis influences the exactness and accuracy of the results to a great extent. Literature review and examination of peer researchers' works show that tetrahedron 3D elements have been conveniently used in the numerical analysis of anisotropic forming process. This element is capable of representing the large deflection effect with plastic capabilities. The main reason to use this type of element shape is the automatic re-meshing that is started in DFORM 3D for the highly destroyed element shape when simulation is running. Element size plays an important role throughout a simulation. Element sizes influence both the accuracy of the results and computation time. The blank should be meshed finer enough in order to get acceptable results. However, the increase in number of elements results in a drastic increase in computational time. In the presented study, in order to achieve good results, the number of elements for the blank model is set to be 69812. The process of meshing the sheet is shown in Fig. (4).

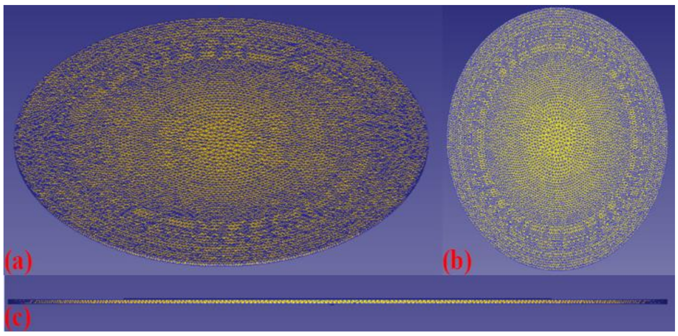

Fig -4: Meshing of the sheet metal; (a) 3D view, (b) Top view (c) side view

4.3 Blank Material

The material of the blank sheet is low carbon steel AISI 1008 grade. It was selected as a plastic type material model in the presented DFORM-3D simulation. Punches and die are assumed as rigid, so there is no need to define material. The chemical composition and the mechanical properties of AISI 1008 material are listed in Table 3 and Table 4 respectively.

Table -3: Chemical composition of AISI 1008

C%	Si%	Mn%	S%	Cr%	Ni%	Mo%	Cu%	Ti%
$* 10^{-2}$								
6	1.5	36	3.3	3	5.9	2.9	5	0.8

Table -3: Chemical composition of AISI 1008

Item No.	Mechanical Property	Value	Item No.	Mechanical Property	Value
1	Young's Modulus	200 GPa	4	Ultimate Tensile Strength	380 MPa
2	Yield Stress	234 MPa	5	Strain Hardening Exponent	0.214
3	Poisson's Ratio	0.3	6	Friction Coefficient	0.08

4.4 Boundary Conditions and Loading

As an important aspect of FE analysis, applying boundary conditions, load/speed consists of defining which parts from geometrical model moves (i.e. defining degree of freedom). Pairs of contact surfaces adopted in the present study are top blank - bottom punch1, bottom blank - top die1, bottom blank - top punch2. In the current work the travel of punch1 has been set in Z- direction. Displacement load of the portion of the blank which is initially not in contact with the die is also given in Z-direction. Movement of the blank which is on the die is unrestricted in both x and y-directions in order to permit the sheet metal to slide through the die cavity. The punches and dies in FE simulation are considered rigid because they have extreme stiffness when compared to the material of the sheet metal.

4.5 Solution and Visualization of Cups

A proper modeling of geometry, meshing and correct applying of boundary conditions and loads have been performed. The punch velocity is applied and problem is executed for material as AISI 1008 grade. After all settings are complete, the simulation has been run. The solution has been carried out with displacement increments, with a maximum number of steps set as 1500 and a minimum as 1 that represents the step increment corresponding to constant punch displacement equivalent to 0.06 mm per step for accomplishing the total punch stroke which is set to be 75 mm for the purpose of completing the whole drawing process. The resulting drawn cups at various die entrance angles simulated by DEFORM software are shown in Fig. (5).

It is worth to mention that the dimensions of the shallow cup are 60 mm diameter and 12 mm depth while 44 mm diameter and 25 mm depth for the reversely redrawn cup.

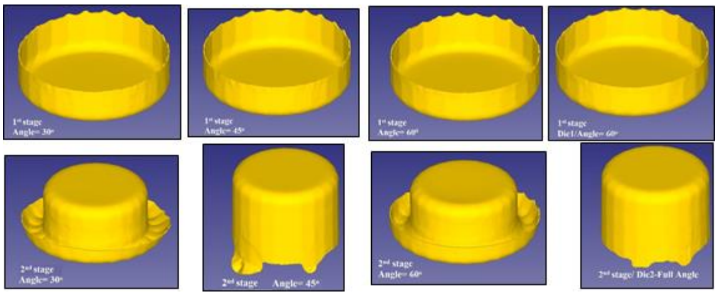

Fig -5: FE simulation models of reverse redrawing for both stages at various entrance angles

5. Results and Discussion

The FEM results prove that the direct drawing of the AISI 1008 sheet (in the first stage) has been successfully achieved for all the four models conducted while for the second stage the reverse redrawing has stopped before accomplishing the whole punch stroke when using an entrance angle of 30° and 60° for punch1/die2 as shown in Fig. (5). In addition, the earing effect has been noticed to be less for the reversely redrawn cup (the second cup) when adopting a fully rounded angle compared with that for 45°. The graphs of the load-stroke of the punch for the four FE models can be seen in Figs. (6) and (7).

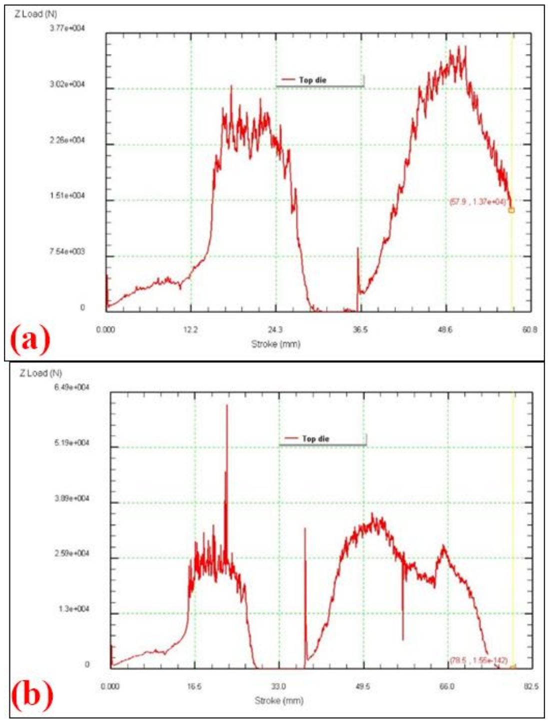

Fig -6: Load-stroke graph of the punch when adopting entrance angle of (a) 60°, (b) 60° for die1 & fully rounded for punch1/die2

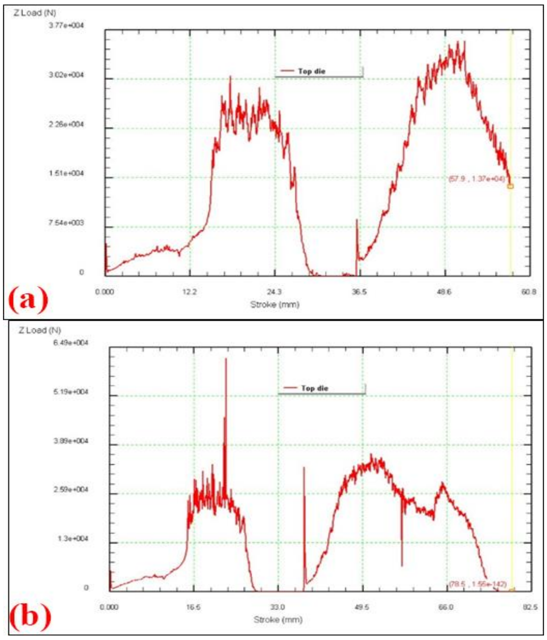

Fig -7: Load-stroke graph of the punch when adopting entrance angle of (a) 30°, (b) 45°

The load-stroke graphs indicate that there is a slight decrease in the punch load required for drawing at both stages when increasing the entrance angle from 30° to 45° but with further increase in such angle to 60°, the load is increased more exactly during the reverse redrawing (second stage). In addition, no significant differences in load have been indicated when using a fully rounded entrance angle of punch1/die2 compared with that for 60° in spite of some undesirable fluctuations in load characteristics.

6. CONCLUSIONS

This work deals with exploring the effects of the die entrance angle on the reverse redrawing of a cylindrical cup from a blank of 80 mm diameter and 0.5 mm thickness using a single action press. The FE investigations that have been performed allow to conclude the following remarks:

1. The reverse redrawing has stopped before achieving the entire punch stroke when adopting a die entrance angle of 30° and 60°.
2. The earing effect has been observed to be less for the reverse redrawing when adopting a fully rounded angle of the die. There is an insignificant decrease in the punch load at both stages when increasing the entrance angle from 30° to 45°.
3. An additional increase in load has been noticed during the reverse redrawing when using a die entrance angle of 60°.
4. No substantial variations in load have been indicated when utilizing a fully rounded entrance angle compared with that for 60° in the second stage of drawing.

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