Investigational Study for the Feasibility of Reverse Deep Drawing Operation without Blank Holder

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Abstract - *Deep drawing is one of the most extensively used sheet metal forming processes. Since the maximum drawing ratio obtained with a single-stage operation is usually about two, the reverse process is typically adopted when larger drawing ratios are necessary. Additionally, the use of blank holder offers an extra cost and an additional force to the drawing system. Therefore, in the current paper, an FE simulation campaign and experimental validation for the ability of reverse- deep drawing without using a blank holder have been examined and implemented respectively. A carbon steel (AISI 1008) blank of 80 mm diameter and 0.5 mm thickness has been used. The speed of drawing has been set to be 200 mm/min for both simulation and experimentation. The setup of the drawing process has been submitted for producing cylindrical cups within two stages: direct or shallow drawing for the first stage and reverse-deep drawing for the second one. DEFORM v10.2 software package has been utilized to accomplish the FE simulation. The FE results indicate that the maximum damage in the cup wall is 33.01% and 46.987% for the shallow and deep cup respectively. Both the FE technique and experimental work have shown that the reverse drawing is possible without adopting a blank holder. The cups modeled by the FE software conform to a large extent those produced experimentally.*

Key Words: Finite element (FE), shallow drawing, reverse-deep drawing, blank holder, etc…

1.INTRODUCTION

Sheet metal forming is the most commonly used manufacturing processes in industry that is used to change the geometry of sheet metal 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 aluminium, 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). 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 [3]. In such operation, the required parts are usually obtained in a single-stage, but in some conditions multi-stage process is required due to geometrical complexity or formability problems. Nevertheless, the minimum number of forming stages necessary to obtain the desired part without failure depends on many process parameters, being its determination, as well the shape of the tools for each stage, an enormous challenge. Since the maximum drawing ratio obtained with a single-stage operation is usually about two, the redrawing process is typically adopted when large drawing ratios are necessary [4]. Generally, the redrawing process is classified in two categories: direct and reverse. The first drawing operation is the same in both types, whereas the difference occurs at the redrawing stage, as shown schematically in Fig. (1).

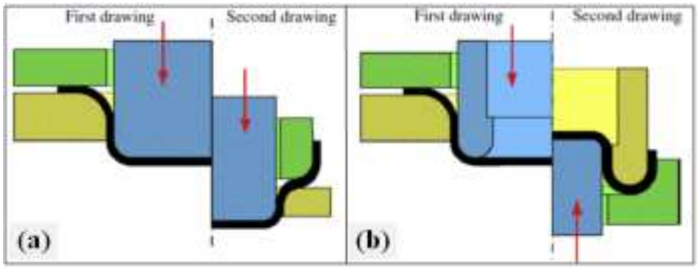

Fig -1: Two-stage deep drawing; (a) direct redrawing, (b) reverse redrawing [4].

In the direct redrawing process (Fig. 1-a) the punch in each stage is always in contact with the same blank side, while in the reverse redrawing (Fig. 1-b) the punch motion during the second stage arises in the opposite direction. Since the number of bending–unbending operations is smaller in the reverse than in the direct redrawing, the required punch force is lower in the reverse redrawing. Moreover, the surface aspect is better in the reverse process since the outside of the part is in contact only once with the die radius [4].

2. Literature Survey

A group of studies related to reverse drawing has been conducted by many researchers in order to improve the formability of the sheet metal. **S. Thuillier et al (2002)** [5] 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. **Z. Keran et al (2006)** [6] have made analyses of deep drawing Cr-Ni stainless steel process. 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. **S.D. Zhao et al (2007)** [7] have developed a novel device of hydro-mechanical reverse deep drawing with axial pushing effect for cylindrical cups. 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)** [8] 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 0° and 45° and it also shows that mathematical model is accurate to simulate this process. **Raman Goud. R et al (2014)** [9] 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. **K. M. Younis et al (2016)** [10] have presented an analysis of the multi-stage deep drawing process considering the three deformation stages namely reverse drawing and reverse redrawing respectively. This work aim 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, 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 first stage will be wall cup in the next stages. In order to increase the maximum drawing ratio higher than this obtained in single-stage drawing, the reverse process has been adopted in this paper. In addition, the use of blank holder offers an extra cost to the drawing system and necessitates an additional force required to overcome the friction generated between the sheet metal and the blank holder, therefore an FE simulation campaign and experimental verification for the ability of reverse deep drawing without using a blank holder have been performed.

3. Finite Element Simulation

Finite element analysis (FEA) is a simulation technique which computes the behavior of equipments, products and structures for different loading conditions. DFORM v 10.2 software was used to simulate the deep drawing operation. DEFORM is a finite element method based simulation system intended to analyze different forming operations. It minimizes the need for redesign of tooling and processes, improve tool and die design to reduce production and material costs, shorten lead time in bringing a new product to market. A 3D finite element model was imported and suitable material was assigned to the model. Various parameters were applied as in the numerical simulation to get verification of the results. The various stages of this simulation work are summarized sequentially in the following steps:

i. **Preprocessing:** defining the problem; the major steps in preprocessing are given below:

   a. Import geometry of top die/bottom die/workpiece/die holders (Solid Modeling),

   b. Mesh workpiece volumes as required,

   c. Define material/geometric properties.

ii. **Solution:** assigning loads/speed, constraints and solving:

   a. Apply the speed/loads (pressure),

   b. Position Objects (translational and rotational); primary die stroke; simulation control; generate data base,

   c. Switch to simulate; finally solve the problem.

iii. **Post processing:** further processing and viewing of the results, state variables and tools.

3.1 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. (2) 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.

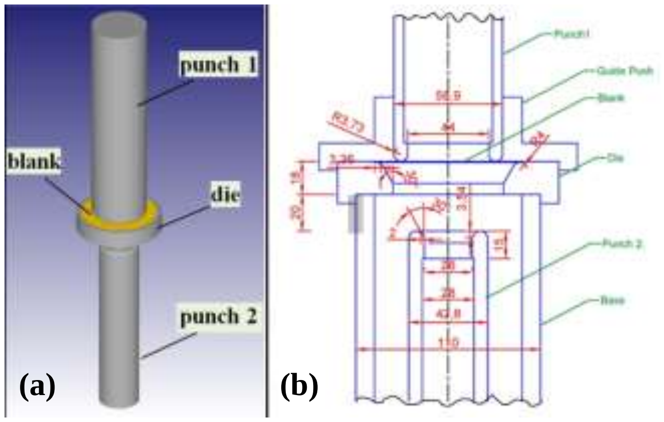

Fig -2: Parts assembly of deep drawing; (a) 3D view, (b) dimensional details.

3.2 Modeling of Parts

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 3-D 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, numbers of element for the blank model is 69812. The process of meshing the sheet is shown in Fig. (3).

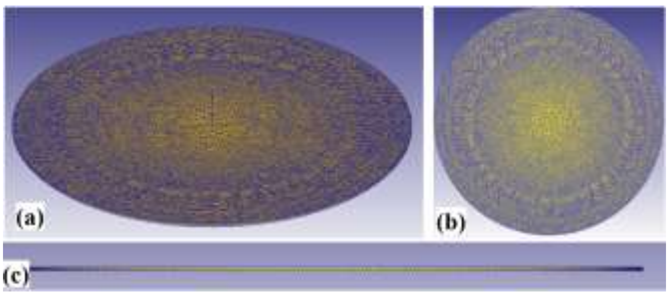

Fig -3: Meshing of the sheet metal; (a) 3D view, (b) Top view, and (c) side view.

3.3 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 1 and Table 2 respectively.

Table -1: 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 -2: Mechanical properties 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

3.4 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 punch 1, bottom blank - top die, bottom blank - top punch 2. In the current work the velocity of the blank sheet has been set 200 mm/min (3.333 mm/s) in Z- direction. Displacement load of the portion of the blank which is initially not in contact with the die is 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 die in FE simulation are considered rigid because they have extreme stiffness when compared to the material of the sheet metal.

3.5 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 max number of steps set as 10000 and a minimum as 1 that represents the step increment in order to accomplish the total punch stroke which is set to be 75 mm for completing the whole drawing process. The resulting drawn cups for the first and second stages simulated by DEFORM software are shown in Figs. (4) and (5) respectively. It is important 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 reverse drawn cup. FEM results demonstrate that there are no any cracks or tearing in all simulated cups.

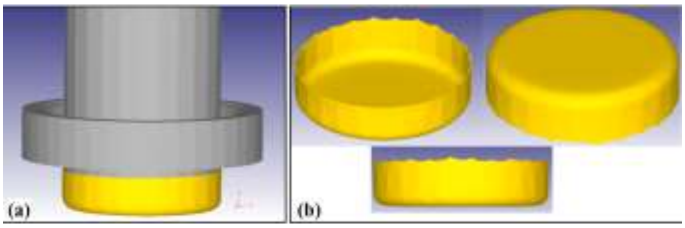

Fig -4: FE simulation of shallow-drawn cup (1st stage); (a) formed cup, (b) different views.

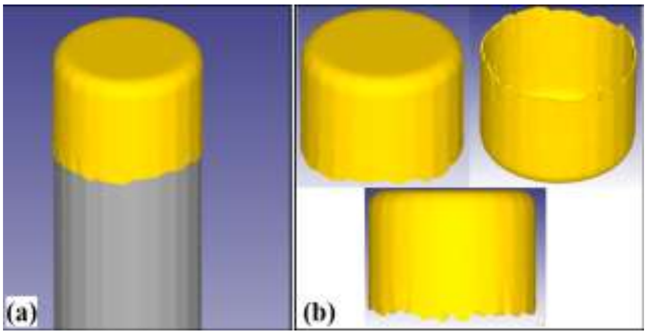

Fig -5: FE simulation of reversely deep-drawn cup (2nd stage); (a) formed cup, (b) different views.

4. Experimental Validation

For selecting the dimensions of the blank there is a paramount importance for the research studies because all the designs and computations will be based on it. The preparation of the blank begins with cutting the required blank size from the sheet. The cutting die for the blank is shown in Fig. (6-a). The deep drawing experiment has been carried out in the Laboratory of Strength of Materials in the Department of Production Engineering and Metallurgy at the University of Technology. Testing machine type (WDW200E) having a capacity of (200 ton) has been used for drawing. The die set was mounted on a hydraulic press as shown in Fig. (6-b). The press is equipped with a computer which reads the punch stroke and the punch load automatically by using load cell as illustrated in Fig. (6-c). Drawing speed equal to (200 mm/min) was selected to draw the material.

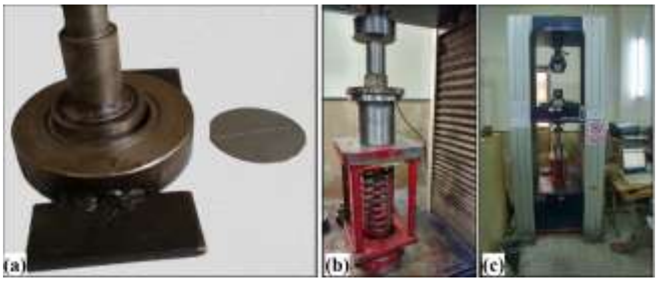

Fig -6: Drawing equipments; (a) cutting die for the blank, (b) tools with hydraulic press, (c) the entire setup.

The produced cups in the first and second stage can been seen in Fig. (7).

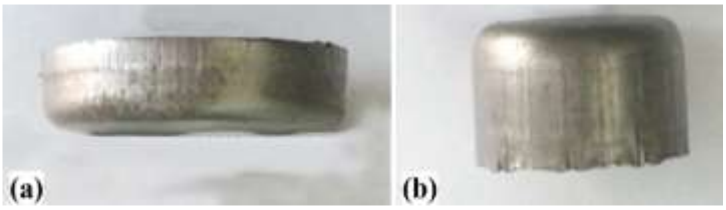

Fig -7: The produced cups; (a) Shallow-drawn cup (1st stage), (b) reversely deep-drawn cup (2nd stage).

It has been observed that the shallow and reverse-deep drawing processes can be performed so that no cracks or tears are present in the produced cups for both first and second stages.

5. Results and Discussion

The results of the FE analysis reached by DEFORM software demonstrate that there are no any cracks or tears observed in the walls of the simulated cups for both shallow and reversely deep-drawn cups. However, slight wrinkling has been noticed in the walls of the modeled cups as a result of the absence of the blank holder as shown in Figs. (4), (5) and (8). In addition, earing phenomenon is obvious at the edges of the cups as a consequence of the inherited anisotropic behavior of the blank material. In order to evaluate the feasibility of reverse drawing without using a blank holder, the damage that occurs in the cup wall has been modeled by DEFORM software as illustrated in Fig. (8).

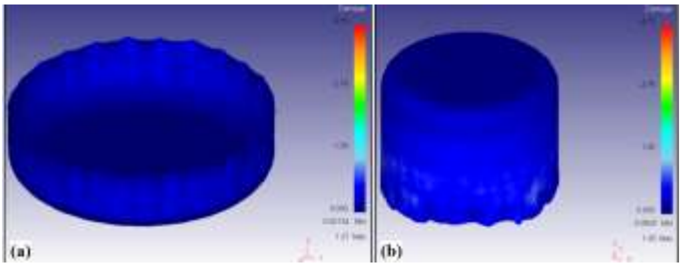

Fig -8: FE simulation of damage distribution for (a) shallow-drawn cup (1st stage), (b) reversely deep-drawn cup (2nd stage).

It can be seen from Fig. (8) that the minimum and maximum magnitude of damage in the wall are 0.00134 (0.032%) and 1.37 (33.01%) respectively for the shallow cup while those values are equal to 0.0509 (1.226%) and 1.95 (46.987%) for the reversely deep-drawn cup. The results also show that the peak damage value which is responsible for tearing and cracking of the cup is 4.15 for both stages. It is clear that the damage within the second stage is larger than that for the first stage because of forcing the material to flow in the reverse direction during the second stage resulting in more damaged region. However, these values of damage ensure there is no possible failure during both shallow and reverse deep drawing processes of the cups to be produced. It can also be observed that the cups modeled by the FE simulation conform to a large extent those produced experimentally. As a result, both the FE technique and experimental work have shown that the reverse drawing is possible without adopting a blank holder.

6. Conclusion

Since the highest drawing ratio reached by a single-stage process is usually about two, the reverse operation is typically taken when higher drawing ratios are required. In addition, the use of blank holder offers an extra cost and an additional force to the drawing system. Therefore, this work deals with investigating the possibility of reverse-deep drawing of a cylindrical cup from a blank of 80 mm diameter and 0.5 mm thickness without using a blank holder. The investigation that is performed allows to conclude the following remarks:

1. Both the FE simulation and experimental investigation have shown that the reverse drawing is possible without adopting a blank holder so that there are no any cracks or tears observed in the walls of the drawn cups for both shallow and reverse-deep drawing.

2. FE results show that the minimum and maximum percentage of damage in the wall are 0.032% and 33.01% respectively for the shallow cup while those values are equal to 1.226% and 46.987% for the reversely deep-drawn cup.

3. The values of wall damage ensure that there is no possible failure during both stages.

4. Slight wrinkling in the wall as well as earing phenomenon at the edges of the cup have been observed by both FE simulation and experimental investigation.

5. The cups modeled by the FE software conform to a large extent those produced experimentally.

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