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Numerical and Experimental Investigations of Some Parameters Affecting Reverse Redrawing Process in Multi-Stage Deep Drawing during One Stroke

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Abstract: ***This study aims to find out the effect of some parameters on the reverse redrawing process (second draw) directly after the first one, in the multi-redrawing process on single action press during one pass. This can be achieved by preparing an FE simulation and an experimental investigation on low carbon steel sheet blank with dimensions 80 mm in diameter and 0.5 mm in thickness. Parameters that have been emphasized are the speed that was 200 mm/min, and 500 mm/min, and three different distances between punch1/die2 and punch2, where the first was overlapped so that the top of punch2 aligns to the half distance from die1, the second distance has been set so that the upper surface of punch2 will be in touch with the lower surface for die1, and the third distance has been adjusted so that the top surface of punch2 is distant to die1 by the cup depth. These parameters have an obvious and important effect starts from the design of the die and ends in production process. Experimental and simulation results that have been obtained, show that as the speed increases the force will decrease as well as the production of a cup is successful when the distance between die1 and punch2 equals to the depth of the cup produced from the first stage. In addition, the utilization of a traditional single action press is easy to use and maintain, cheap in price, and it can be used for producing a cup by more drawings.***

Keywords: Reverse redrawing, multi-stage deep drawing, single action press, stroke.

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. The drawing direction during the second stage arises in the opposite direction as depicted in Fig. (1-b) [5].

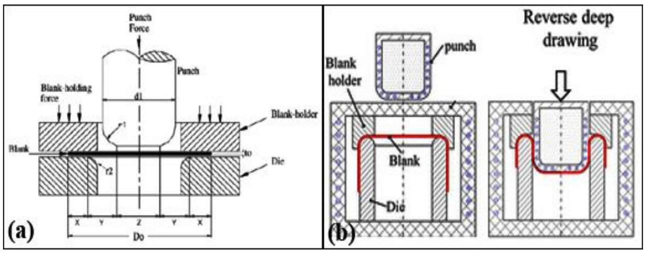

Figure 1: Deep drawing operations; (a) direct drawing, (b) reverse redrawing [4, 5]

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 45o 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 some relevant parameters on the reverse redrawing process (second draw) directly after the first one, in the multi-redrawing process on single action press during one pass. This can be achieved by preparing a simulation and an experimental investigation on low carbon steel sheet blank. The parameters that have been emphasized are the drawing speed and the distance between punch1/die2 and punch2.

3. Reverse Redrawing Parameters

In this work, the parameters that have been adopted are the drawing speed and the distance between punch1/die2 and punch2 on single action press during one pass for both FE simulation and experimental validation. These parameters have an obvious and important effect starts from the design of the die and ends in production process. The following sections will provide an illustration for each parameter.

3.1 Drawing Speed

The drawing speed is the velocity that punch travels during the drawing process. Two values have been utilized: 200 and 500 mm/min for both simulation and experimentation in order to investigate the influence of this parameter on the reverse redrawing operation.

3.2 Punch1/Die2-Punch2 Distance

Three distances between punch1/die2 and punch2 have been adopted for both simulation and experimentation to explore the effect of this factor on the formability of the sheet during reverse redrawing. The first distance (d1) was overlapped so that the top of punch2 aligns to the half distance from die1 (Fig. (2-a)) while the second one (d2) has been set so that the upper surface of punch2 will be in touch with the lower surface for die1 (Fig. (2-b)) besides the third distance (d3) has been adjusted so that the top surface of punch2 is distant to die1 by the cup height to ensure a complete-direct drawing of the cup during the first stage as illustrated in Fig. (2-c).

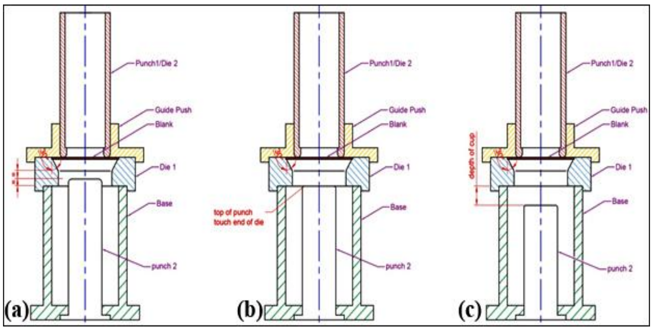

Figure 2: Various sets of punch distances that utilized

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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(s) travel(s) only in one direction to perform drawing as depicted in Fig. (2) 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 parameters included in this study can be summarized in Table 1.

Table 1: Drawing parameters and their levels

Parameter	*Levels*		
Drawing speed	200 ,500 mm/min		
Punch distance	1st distance (d1)	2nd distance (d2)	3rd distance (d3)
Press type	Single action		

4. 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 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:

1) **Preprocessing:** starts at defining the problem which includes importing geometry of top die, bottom die and work-piece (Solid Modeling), meshing work-piece volumes as required, and defining material with geometric properties.
2) **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.
3) **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.

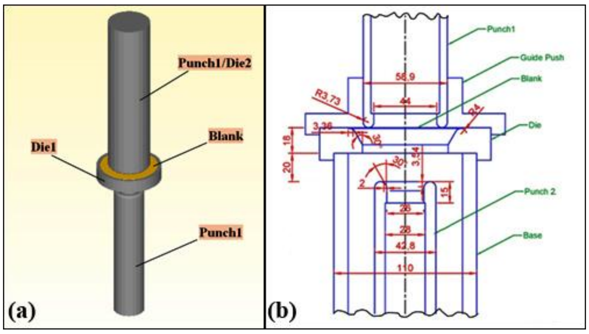


Figure 3: Parts assembly of deep drawing; (a) 3D view, (b) dimensional details

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).

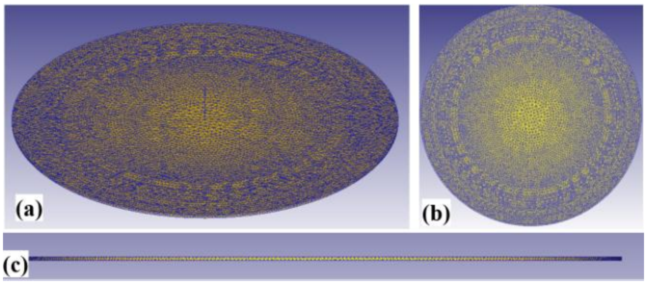


Figure 4: Meshing of the sheet metal; (a) 3D view, (b) Top view (c) side view

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 2 and Table 3 respectively.

Table 2: Drawing parameters and their levels

C%	*Si%*	*Mn%*	S%	Cr%	Ni%
0.06	0.015	0.36	0.033	0.03	0.059
Mo%	Cu%	Ti%			
0.029	0.05	0.008			

Table 3: Mechanical properties of AISI 1008

Item No.	Mechanical Property	Value	Item No.	Mechanical Property	Value
1	Young's Modulus	200 GPa	2	Ultimate Tensile Strength	380 MPa
3	Yield Stress	234 MPa	4	Strain Hardening Exponent	0.214
5	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 punch distances simulated by DEFORM software are shown in Fig. (5). It can be observed that the drawing of the sheet was failed before completing the punch stroke when distances d1 and d2 have been adopted at both speeds. However, FEM results also demonstrate that the simulated cups have been successfully drawn for both stages when distance d3 has been used as shown in Fig. (5-c). 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 drawn cup.

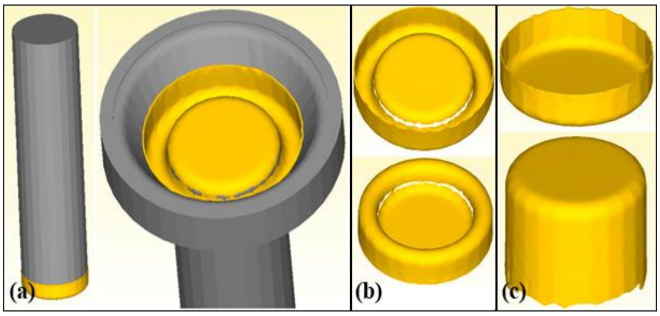
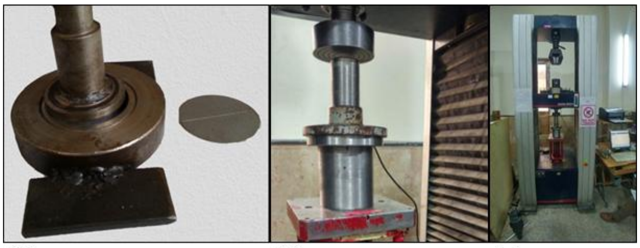


Figure 5: FE simulation of reverse redrawing at both speeds with punch distance; (a) d1, (b) d2, (c) d3

5. 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).



(a) (b) (c)

Figure 6: Drawing equipment's; (a) cutting die for the blank, (b) tools with hydraulic press, (c) the entire setup

The produced cups at both speeds and all punch distances can be seen in Fig. (7).

(a) (b) (c)

Figure 7: The produced cups at both speeds with distances; (a) d1, (b) d2, (c) d3

It can be observed that the sheet has been cracked before performing the punch stroke when distances d1 and d2 have been adopted at both speeds (200 and 500 mm/min). However, the experimental results also demonstrate that the produced cups have been successfully drawn for both stages when punch distance d3 has been used as shown in Fig. (7-c).

6. Results and Discussions

6.1 Punch Distance

Both FEM and experimental results prove that the drawing of the AISI 1008 sheet has failed due to the initiation and propagation of cracks when adopting d1 and d2 distances at both speeds (200 and 500 mm/min) while in case of using the third punch distance (d3), the direct and reverse redrawing processes are successful during both the first and second stages as shown in Fig. (8). The reason behind such situation is that in the former case, the local force required for drawing is increased since the first punch draws the sheet down until reaching the contact zone with the second punch that draws the sheet up simultaneously causing a biaxial stretching to happen leading to the occurrence of cracks at the curved region (profile radius) of punch2 before completing the punch stroke as shown in Fig. (5-a). However, the shallow cup (first stage) and reversely redrawn cup (second stage) have been successfully produced as the first cup is entirely drawn and released from the die cavity at distance d3 before the onset of the reverse redrawing that is intended for producing the second cup.

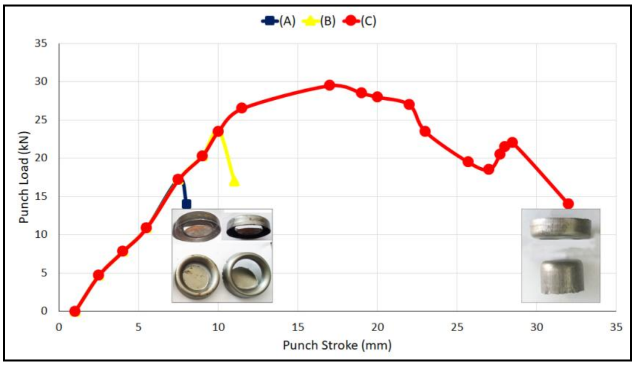
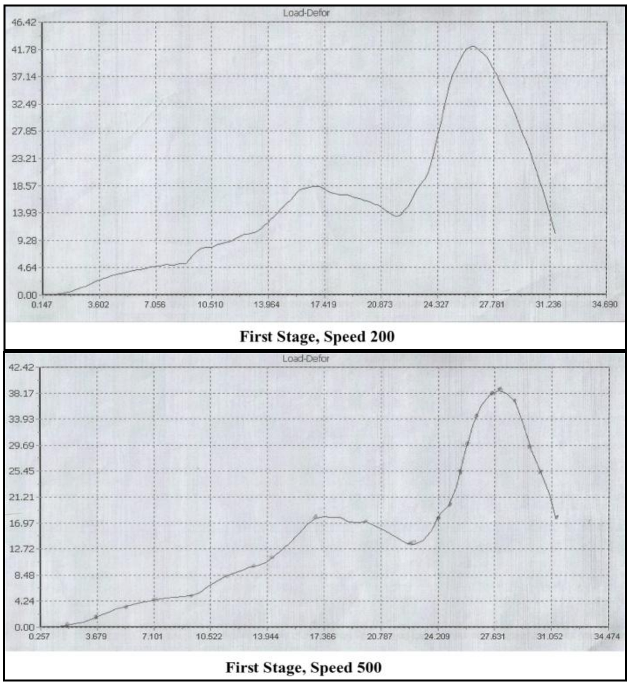


Figure 8: Punch load-stroke for distances; (A) d1, (B) d2, (C) d3

6.2 Drawing Speed

Experimental results for the third punch distance d3 show that as the speed increases the drawing force will decrease because at higher speeds, it will be easier to overcome the friction force generated between the die profile and the blank as shown in Fig. (9).



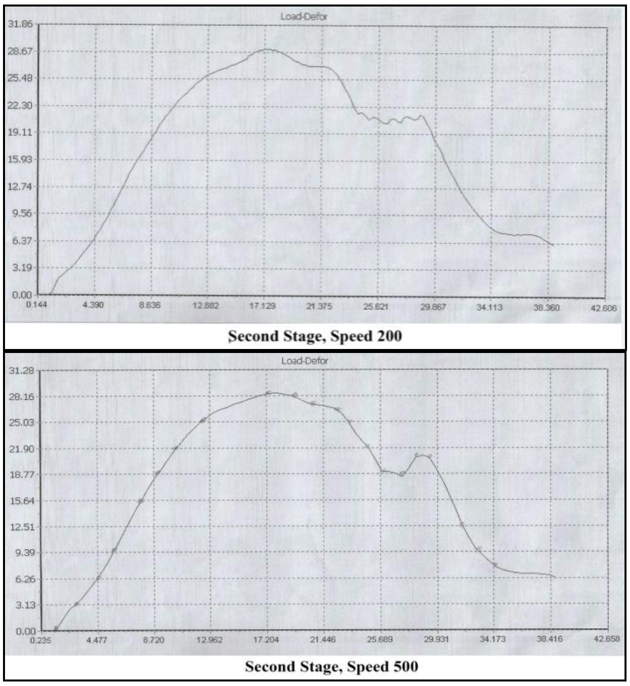


Figure 9: Experimental punch load-stroke at various speeds and stages

6.3 Simulation vs. Experimental Results

A comparison of punch load-stroke can be made between simulation and experimental results as illustrated in Fig. (10). FEM results show a similar behavior to the experimental data. In addition, it can be observed that there is a good agreement between simulation and experimentation for both first and second stages.

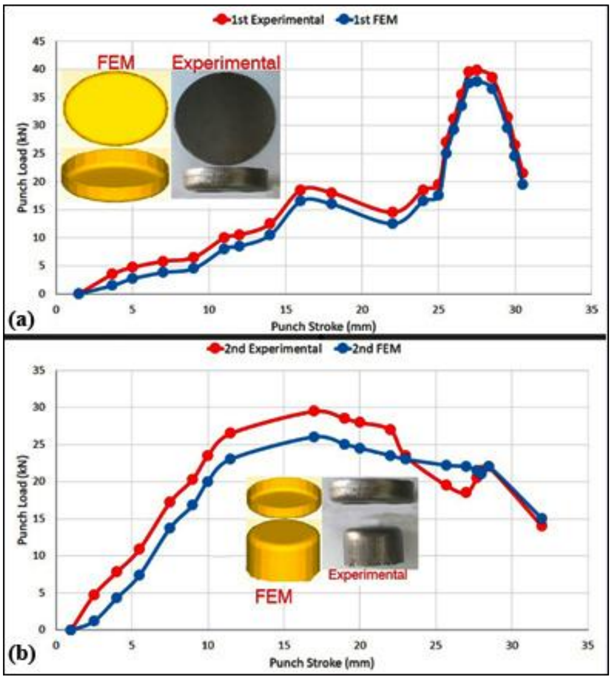


Figure 10: Punch load-stroke by FEM and experiments for; (a) 1st stage, (b) 2nd stage

7. Conclusions

This work deals with exploring the effects of some process parameters namely, drawing speed and punch distance, 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 and experimental investigations that have been performed allow concluding the following remarks:

1) Both FEM and experimental results prove that the drawing of the AISI 1008 sheet has failed due to the initiation and propagation of cracks when either adopting a distance, that punch2 overlaps or touches die1 at both speeds (200 and 500 mm/min).
2) Both simulation and experimentation show that in case of adopting a distance where punch2 is away from die1 by the cup depth, the drawing process will succeed during both stages as the first cup is entirely drawn and released from the die cavity before starting the reverse redrawing for the second cup.
3) Experimental results for the successful drawing demonstrate that as the speed increases the drawing force will decrease because at higher speeds, it will be easier to overcome the friction force generated between the die profile and the blank.
4) There is a good agreement between simulation and experimental work for both first and second stages. In addition, FEM results show a similar behavior to the experimental data.
5) The utilization of a traditional single action press is easy to use and maintain, cheap in price, and it can be used for producing a cup by more drawings.

References

[1] Sachin S Chaudhari & Navneet K Patil "Effect of Process Parameters on Spring Back In Deep Drawing: A Review" International Journal of Engineering Development and Research, Vol. 3, Issue 4, pp. 906-912, 2015.

[2] Gonfa Angasu and K. Srinivasulu Reddy "Deep Drawing Process Parameters: A Review" International Journal of Current Engineering and Technology, Vol.6, No.4, pp. 1204-1215, 2016.

[3] Mengdi Gao, Haihong Huang, Qingyang Wang, Zhifeng Liu & Xinyu Li "Energy consumption analysis on sheet metal forming: focusing on the deep drawing processes" The International Journal of Advanced Manufacturing Technology, Vol. 96, Issue 9–12, pp 3893–3907, 2018.

[4] A. R. Joshi, K. D. Kothari and Dr. R.L. Jhala "Effects of Different Parameters on Deep Drawing Process: Review" International Journal of Engineering Research & Technology, Vol. 2, Issue 3, pp. 1-5, 2013.

[5] Zhichao Zhang, Yongchao Xu and S. J. Yuan "Analysis of Temperature and Stress in Differential Temperature Reverse Deep Drawing of 5A06 Aluminum Cup" The Journal of The Minerals, Metals & Materials Society (TMS), Vol. 68, Issue 9, pp. 2483-2491, 2016.

[6] S. Thuillier, P.Y. Manach, L.F. Menezes & M.C. Oliveira "Experimental and numerical study of reverse re-drawing of anisotropic sheet metals" Journal of Materials Processing Technology, Vols. 125–126, pp. 764–771, 2002.

[7] Z.Keran, M. Skunca & M. Math "Finite Element approach To Analysis Of Axisymmetric Reverse Drawing Process" METALURGIJA, Vol. 45, No.4, pp. 341-346, 2006.

[8] S.D. Zhao, Z.Y. Zhang, Y. Zhang & J.H. Yuan "The study on forming principle in the process of hydro-mechanical reverse deep drawing with axial pushing force for cylindrical cups" Journal of Materials Processing Technology, Vols. 187–188, pp. 300–303, 2007.

[9] Roberto Bortolussi, Sandro G. Solosando, Luis F. M. Martins & Ricardo B. Árias "Simulation of reverse deep drawing of cylindrical cups" V Congresso Brasileiro de Engenharia de Fabricação, 1 4 a 1 7 de abril de 2009, Belo Horizonte MG.

[10] Raman Goud. R, Eswar Prasad. K & Swadesh Kumar S. "Redrawing of EDD steel at elevated temperature" Advanced Materials Manufacturing & Characterization, Vol. 4, Issue 1, pp.75-80, 2014.

[11] Dr. Kariem M. Younis, Adil S. Jaber & Ammar M. salah "Numerical Analysis of The Multi-Stage Reverse Deep Drawing Process" Eng. & Tech. Journal, Vol. 34, Part (A), No.3, pp. 613-622, 2016.

[12] Khadija Ben Othmen, Kacem Sai, Pierre-Yves Manach and Khaled Elleuch "Reverse deep drawing process: Material anisotropy and work-hardening effects" Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 2017.