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An Investigation into the Friction Aided Deep Drawing Using Four and Eight Tapered Segments Blank Holder

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Abstract – *In this paper, the friction aided deep drawing using tapered blank holder divided into four and eight segments is studied. Several parameters including effect of blank holder force, radial displacement of blank holder and punch force on cup height are investigated in the four segments tapered blank holder technique. The drawing mechanism and the effects of drawing conditions are also studied using ABAQUS/explicit software to show the merits of the process. Using the four segments type may cause a non-uniform flow of material in the flange portion; however, the eight segments type can overcome this deficiency. Therefore, the drawing mechanism of eight segments tapered blank holder technique and in-flow of material in the flange portion of blank are mainly investigated and compared with those from four segments tapered blank holder. A successful deep cup of drawing ratio 3.67 can be produced without any defect by using eight segments tapered blank holder technique. The cost and time of die fabrication in these techniques are less than the conventional deep drawing.* **Copyright © 2009 Praise Worthy Prize S.r.l. - All rights reserved.**

Keywords: *ABAQUS /Explicit, Friction Aided Deep Drawing, Tapered Blank Holder*

I. Introduction

Friction has both positive and negative roles in metal forming. There are numerous instances where friction opposes the flow of metal in forming processes. However, there are also several instances where the forming process is made possible by friction: rolling and Masllenikov's technique for drawing very deep cups are examples of friction-aided metal forming processes [1].

In sheet metal forming, weight reduction of a formed part is one of the most serious problems, and this strongly requires the use of sheets that are as thin as possible. However, since the formability of sheet metal decreases with decreasing sheet thickness, it is not easy to produce successful parts from very thin sheets or foils [2]. For example, the limiting drawing ratio (LDR) for a soft aluminum sheet achieved by the conventional deep drawing process is about 2.0 for a sheet of 1 mm thickness, but this is less than 1.5 for a sheet of 0.1 mm thickness [3]. Solutions proposed for increasing the drawing ratio generally fall into three categories; change in the material properties of the sheet metal, change in the stress state and change in the frictional state. Based on these fundamental solutions, many special processes have been proposed to increase the drawing ratio [4]. In these processes, large plastic strains could be achieved when the flow stress of material can be controlled in the range below the ultimate strength of material.

As a unique deep drawing process to obtain a deep cup, punchless deep drawing has been proposed by Maslennikov [5]. In this process, a rubber ring is used instead of a metal punch in the conventional deep drawing. Unlike the conventional process, the drawing deformation of a blank is caused by the frictional force induced at the interface between the rubber ring and the flange portion of the blank [6], [7]. Because the drawing of the blank is carried out by the radial compressive force, the fracture at the punch profile portion can be avoided [8]. Therefore, a very deep cup can be produced using only one rubber ring and metal die throughout the drawing process. However, the frictional force induced by the rubber ring is not large enough, and therefore the application of this process is limited to rather soft materials with small deformation resistance. In addition, the short life of the rubber ring is also one of the problems in the practical application. Also, for thin sheets, circumferential fracture was observed at the flange portion [9]. To overcome these problems, a new deep drawing process have been proposed by Hassan et al. [10] which uses a flat metal blank holder divided into four segments instead of the rubber ring in the Maslennikov process. This metal blank holder is made by cutting a conventional steel blank holder into four segments which can move radially inward and outward under a certain blank holding pressure. Unfortunately, this process had one defect during the application of such proposed device which was occurrence of wrinkle due to flowing of flange material into the gaps between the blank holder segments. To overcome this disadvantage of the friction aided deep drawing process using four segments flat blank holder, a new flat blank holder device has been proposed by Hassan et al. [11]. This

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device is made by fitting four flat small wedges in the gaps between the four flat drawing segments. The only difference between these two techniques is in the number of blank holder segments. Using eight segments flat blank holder for deep drawing process gave good results. However, in the case of using thin sheets, a crack was observed due to the localized intensive shear deformation at the boundaries between the drawing segments and the wedges. In the present paper, firstly a friction aided deep drawing process using a tapered blank holder divided into four segments proposed by Hassan et al. [12] is numerically investigated by ABAQUS software. It is possible to eliminate the defects of localized wrinkling and intensive shear deformation regions that were observed in deep drawing process using flat blank holder divided into four segments and eight segments techniques. Then, drawing mechanism of this new technique will be described. Because a non-uniform flow of material in the flange portion of cup was observed in the friction aided deep drawing process using tapered blank holder divided into four segments, a novel deep drawing process using eight segments tapered blank holder is proposed by authors to defeat this deficiency. The difference between this new technique and the flat blank holder divided into eight segments technique proposed by Hassan et al. [11] is in blank holder shape. In the new technique the blank holder is tapered while previously it was flat. Deformation mechanism and the effects of drawing conditions are investigated by ABAQUS/Explicit for both four and eight segments blank holder techniques in detail and the merits of new deep drawing process are examined.

II. Drawing Mechanism of a Tapered Blank Holder Divided into Four or Eight Segments

Fig. 1(a) shows schematically the proposed four segments tapered blank holder device. This metal blank holder is made by cutting a tapered steel blank holder into four segments. It can move radially inward and outward under a certain blank holding pressure. It consists of a stationary base and four tapered drawing segments that have similar planes of slightly taper angle of 5 degree. All of the segments are level with each other and tapered base is tapered in the same direction. The drawing segments can slide in radial direction under a constant speed over the tapered surfaces of the stationary base. It is important to understand the drawing mechanism and the compound motion of the blank holder segments. In the first drawing step, deformation starts when two facing segments move radially inward to the die opening in the A-direction as shown in Fig. 1(b). The other two segments in the B-direction move in the reverse direction, i.e. downward and radially outward opposite to the drawing direction as shown in Fig. 1(d). Due to this action, the blank sheet and the die in the A-direction are lifted up as shown in Fig. 1(c), while in the B-direction; there is no contact between the blank sheet and the two segments as shown in Fig. 1(d). At that time about 50% of the flange portion which is under drawing segments in the B-direction is not subjected to the blank holder force. On the other hand, the two segments in the A-direction are advancing to the die opening, so that they tightly contact with the blank sheet as shown in Fig. 1(c). As a result, the frictional force generated in the A-direction aids the blank to deform and move toward the die opening. While, the two segments in the B-direction do not generate outward frictional force opposing the blank deformation. Therefore, this technique successfully eliminates the localized intensive shear deformation observed when using the flat blank holder divided into eight segments. However, small wrinkles arise in the B-direction of the flange portion due to the circumferential compressive force. In the second drawing step, the blank holder segments in the B-direction move radially inward to the die opening, while the other two segments in the A-direction move in the reverse direction. Hence, the wrinkles generated in the B-direction in the first drawing step will be simultaneously corrected. Therefore, a complete and successful deep cup can be obtained by repeating these two steps to a certain number of drawings. Fig. 2 shows the essential elements of the test equipment. A sufficient blank holder force (F1) is mainly required for the deformation of blank, while the punch force (F2) is mainly added to enhance the dimensional accuracy of the drawn cup and to help partially the drawing deformation. The blank holder force (F1) is controlled by the pressure valve (17) to obtain appropriate force, while the punch force (F2) is controlled by the valve (16) for the proper use. The radial displacement of the blank holder segments is controlled within the range 0–2 mm using the dial gauge (13) and four adjusting pins (11). The compression tool (5) should be rotated 90 degree after each drawing operation to change the direction of the imposed radial displacement and the holding pressure over blank and blank holder segments. The test rig is assembled on a hydraulic press, which has multi-ranges of axial speeds and maximum compression force of 1000 kN, while the maximum punch force given by a separate pump is 10 kN [12]. In the four segments tapered blank holder technique there is a non-uniform flow of material in the flange portion of cup, Fig. 3. The figure shows that this defect may be observed like a crater at the cup side wall at the direction C (±45 degree directions) after 50 times drawing operations. At this stage of drawing, the radial inflow of material in the C-direction is greater than those in the directions A and B. Therefore, the material coming to the die opening buckles and makes craters in the clearance between the punch and die. However, there are some techniques to solve this problem. One of them is that the craters can be eliminated by rotating the blank sheet through 45 degree with respect to the boundary directions after every two drawing operations. But, this method is a time consuming process.

Hence, in continuance a novel technique is proposed by authors on friction aided deep drawing using eight segments tapered blank holder to defeat this deficiency. Deformation mechanism and effect of number of drawings on radial displacement distribution are investigated by ABAQUS/Explicit for this new technique. The drawing mechanism of this new technique is like the four segments tapered blank holder. The only difference between these two techniques is that in the former, each segment is 90 degree in circle circumference and in each step only two segments move inward but in the latter, each segment is 45 degree and in each step four segments move inward. Fig. 4 shows schematically the eight segments tapered blank holder.

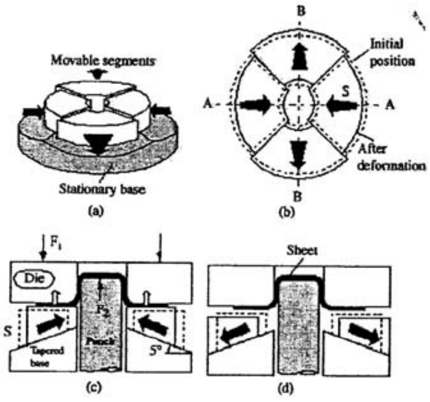


Fig. 1. Schematic of construction and movement of tapered blank folder

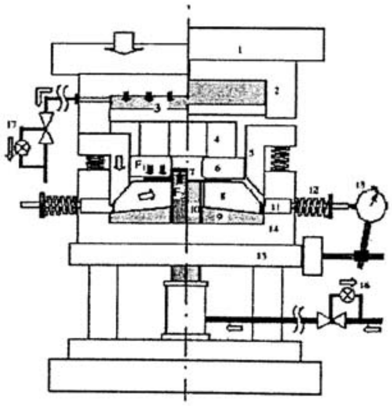


Fig. 2. Schematic diagram showing equipment used for deep drawing test; 1-Press ram, 2- Hydraulic cylinder, 3-Oil pressure, 4-Dummy block, 5-Compression tool, 6-Die, 7-Blank, 8-Tapered blank holder, 9-Blank holder stationary base, 10-Punch, 11-Adjusting pin, 12-Spring, 13-Dial gauge, 14-Container, 15-Die set, 16-Control valve, 17-Relief valve

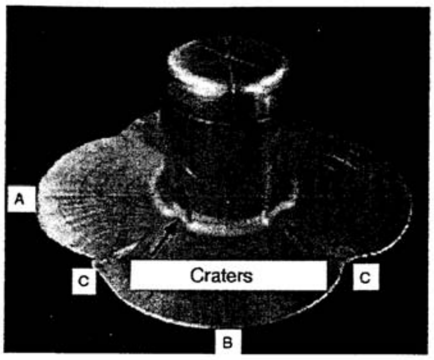


Fig. 3. Craters defect observed in C-directions

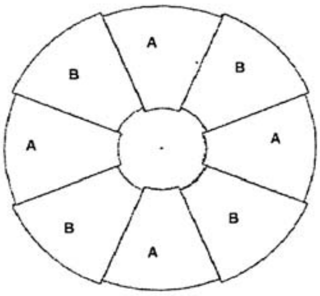


Fig. 4. Schematic of construction of eight segments tapered blank holder

III. Test Material and Numerical Conditions

Soft aluminum (Al-O) blank of 0.5mm thickness is used as a testing material. Tool dimensions are listed in Table I. The material constants F (strength coefficient of blank material), n (work-hardening exponent) and r (normal anisotropy) are listed in Table II. The blank diameter is changed as 86 and 110 mm which give drawing ratios of 2.87 and 3.67.

TABLE I
TOOL DIMENSION

Die	
Outer diameter (mm)	120
Inner diameter (mm)	32
Profile radius (mm)	3
Tapered blank holder	
Outer diameter(mm)	116
Inner diameter (mm)	35
Blank holder force (kN)	40-100
Assistant punch	
Diameter (mm)	30
Profile radius (mm)	3
Punch force (kN)	1-5

TABLE II
MECHANICAL PROPERTIES AND DIMENSIONS OF ALUMINUM BLANK

n-value	0.27
r-value	0.76
F-value (MPa)	220
Young modules (GPa)	70
Thickness (mm)	0.5
Blank diameter (mm)	86-110

IV. Numerical Simulation

Explicit models are nowadays widely utilized to analyze sheet metal forming processes since they allow fully 3-D geometry and complex contact conditions to be taken into account with significant CPU savings with respect to the implicit algorithms [13]. Such models solve a set of independent dynamic equilibrium equations at each time increment in order to upgrade the geometry of the meshed structure. No inversion of the stiffness matrix is needed and no numerical iterative procedure to get a satisfactory solution is required. Hence, the CPU time is saved and the incidence of plastic instabilities can be described well since the analysis continues even if diagonal terms of stiffness matrix approach to zero [14]. Therefore, the finite element software ABAQUS/Explicit is used to simulate these two processes.

The FE model of eight segments blank holder technique is shown in Fig. 5. Because of the symmetry, only one quarter of die is modeled. The type of element used in punch, die and blank holder is discreet rigid element (R3D4) and blank is modeled by using 4-node, shell element (S4R) with the symmetry boundary conditions along the X and Y axes. Twenty nine integration points through the thickness are used in the modeling. The mass scaling is applied to shorten analysis time; however, too much mass scaling causes an improper dynamic effect. Therefore, different mass scaling values are examined to achieve a favorite value. In the simulation, 1859 elements are used in one quarter of blank. In order to model friction at the tool-work piece interface, the coulomb friction model is used. Frictional condition of contact surface is one of the most important factors in this process.

Dry friction condition between the blank sheet and blank holder segments is necessary to increase the induced frictional force. Therefore, with increasing friction coefficient between the blank and blank holder segments, frictional force in this region will be increased; as a result, the blank can move easier to the die opening. On the other hand, decreasing of frictional force between the blank sheet and die can cause easier moving of the blank; thus decreasing of friction coefficient between the blank and die is very important. Therefore, friction coefficient between the blank holder and blank and also between the blank and die are assumed to be 0.3 and 0.03, respectively. Algorithm of contact for these processes is surface to surface contact with penalty method.

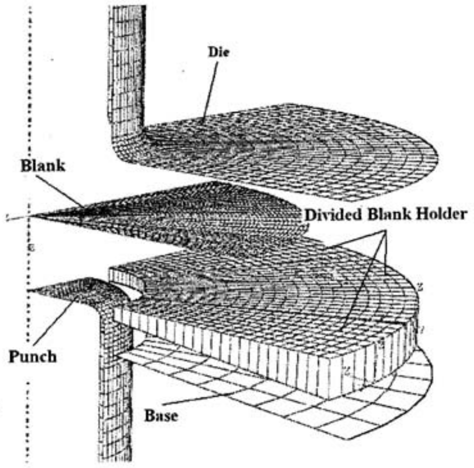


Fig. 5. FE model used in simulation

V. Results and Discussion

V.1. Four Segments Tapered Blank Holder Technique

V.1.1. Effect of Blank Holder Force on Cup Height

Fig. 6 shows the effect of blank holder force (B.H.F) on cup height with the number of drawing operations in both experimental and numerical methods. The obtained numerical results have been compared with experimental data reported by Hassan et al. (2005). As it may be seen, for B.H.F= 40kN, the increase in cup height almost ceases after 21 drawing operations. This is because the frictional force induced between the blank and blank holder is not sufficient to draw the work-hardened blank into the die opening. However, for larger blank holder force, the cup height continues to increase with the number of drawing operations. Moreover, for blank holder force larger than 50kN, the cup height increases linearly with the number of drawing operations. From these observations, it is recommended to use blank holder force larger than 50kN.

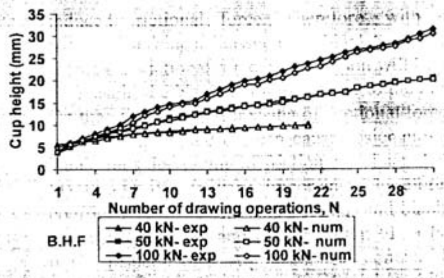


Fig. 6. Effect of blank holder force on cup height, exp (experimental result), num (numerical result)

V.1.2. Effect of Radial Displacement of Blank Holder on Cup Height

Fig. 7 displays the effect of blank holder displacement (S) on the cup height under constant drawing conditions of blank holder force and punch force in both experimental and numerical methods. An obvious increase in cup height is obtained as the displacement increases. For example, 14mm cup height is obtained after five drawing operations when S = 2.0mm, while the same height is achieved after 10 drawing operations for S = 1.0mm and after 20 drawing operations for S = 0.5mm. However, when the radial displacement of blank holder is large, a problem arises on the occurrence of wrinkle at flange portions of blank which are not subjected to blank holder force. For instance, when displacement increases from 0.5 to 2 mm the wrinkle height increases, Fig. 8 shows this problem in obtained cup in both experimental and numerical methods. Since the wrinkle must be eliminated by the next drawing step, the height of wrinkle should be suppressed to a certain value. Therefore, the blank holder displacement S = 1.0 mm is recommended to compromise between the increase in cup height and the elimination of wrinkle.

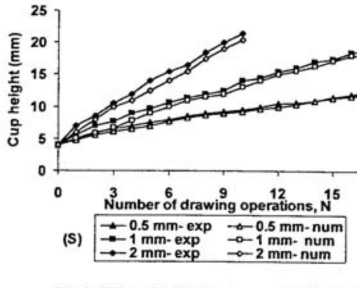
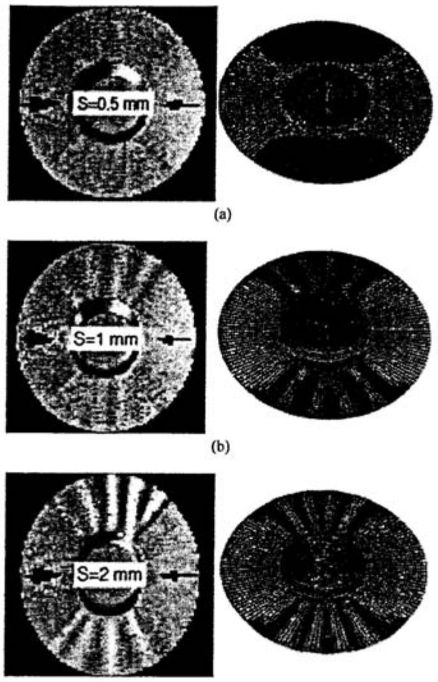


Fig. 7. Effect of radial displacement of blank holder (S) on cup height

V.1.3. Effect of Punch Force on Cup Height

The main role of punch in this process is moving of flowed material by blank holder segments into die. Also, assistant punch is needed to correct the shape and the dimensional accuracy of the drawn cup. At the beginning of the drawing process, a constant punch force is imposed to the blank sheet. If this force is been too much, a fracture in the blank occurs around the punch shoulder. If this force is been too low, punch can not move flowed material into die; so these materials are accumulated in die profile region and cup is wrinkled in this region. Fig. 9 illustrates the effect of punch force on cup height through 10 drawing operations in both experimental and numerical methods. Cup height already exists even without any drawing operations due to the initial action of the punch force. It can be observed that as the punch force increases, the cup height for a given number of drawing operations raises. Moreover, under the same conditions of blank holder displacement and blank holder force the drawing efficiency is significantly improved by increasing the punch force.



(a)

(b)

(c)

Figs. 8. Experimental and numerical results of effect of blank holder displacement (S) on wrinkle formation, (a) S=0.5 mm, (b) S=1 mm, (c) S=2 mm

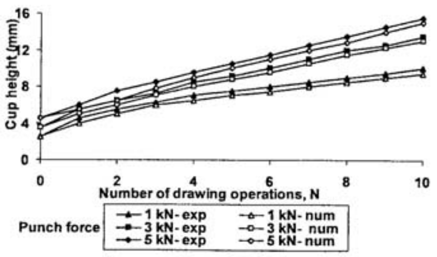


Fig. 9. Effect of punch force on cup height

V.1.4. Effect of Number of Drawing Steps on Radial Displacement Distribution of Blank

In order to investigate the deformation behavior of blank, concentric circles of 2 mm apart are initially marked on the blank surface as shown in Fig. 10. The smallest circle diameter is 40 mm and the largest one is 80 mm. In addition, three radial directions A, B and C are marked on the blank surface. Directions A and B receive imposed radial displacement during odd and even steps of drawing, respectively, while the direction C corresponds to the boundary between the blank holder segments.

Fig. 11 demonstrates the measured radial displacement of flange in the A-direction shown in Fig. 10 in both experimental and numerical methods. Positive values of displacement imply that the flange moves to the die opening, while negative values indicate that the flange moves to the outward direction. In the odd steps of drawing, flange material in the A-direction is displaced to inward direction. While, in the even steps of drawing, grids of radii from 20 to 27 mm are displaced to the die opening but those greater than 27 mm are displaced radially outward. This is because at the odd steps of drawing about 50% of the flange area in the A-direction is subjected to the frictional force, and also the blank is subjected to the tensile punch force. On the contrary, at the even steps of drawing, about 50% of the flange area in the A-direction is neither subjected to the frictional force nor receiving any imposed radial deformation. Similarly, Fig. 12 exhibits the deformation behavior of flange in the B-direction for the odd and even steps of drawing. The only difference between the Figures 11 and 12 is that the B-direction receives radial deformation during the even steps of drawing. Therefore, at the even steps of drawing, the flange in the B-direction is displaced to the die opening, while it is moved to the outward direction in the odd steps of drawing.

The distribution of radial displacement of flange in the C-direction is shown in Fig. 13. It is observed that the radial movement of flange at this direction does not depend on the number of drawing steps. The flange material in the C-direction is displaced progressively inward in all drawing steps toward the die opening. An example of produced cup in intermediate stages by friction aided deep drawing using four segments tapered blank holder technique is shown in Fig. 14.

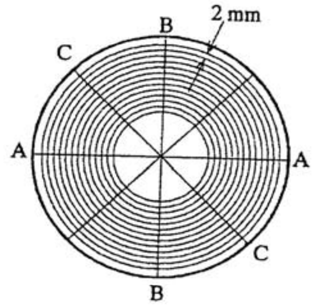


Fig. 10. Circular grids and prescribed directions marked on blank

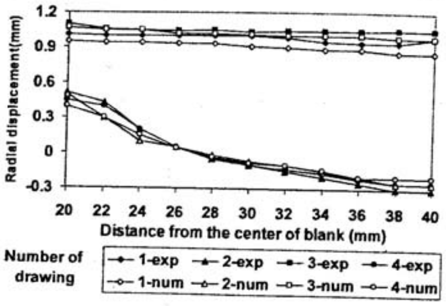


Fig. 11. Radial displacement of flange in A-direction of blank

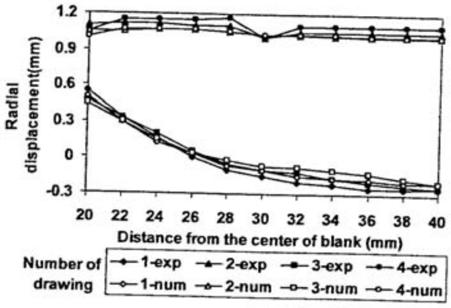


Fig. 12. Radial displacement of flange in B-direction of blank

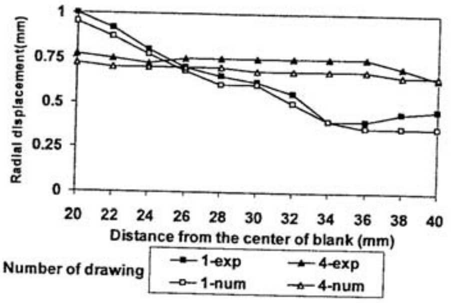


Fig. 13. Radial displacement of flange in C-direction of blank

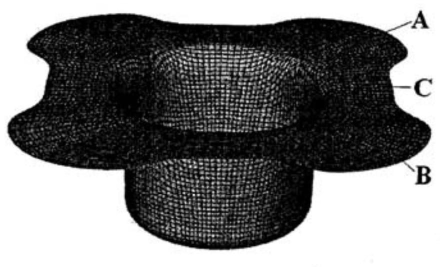


Fig. 14. A cup during intermediate steps

V.2. Eight Segments Tapered Blank Holder Technique

V.2.1. Effect of Number of Drawing Steps on Radial Displacement Distribution of Blank

In order to investigate the deformation behavior of blank, concentric circles of 2 mm apart are initially marked on the blank surface, Fig. 15 .The smallest circle diameter is 40 mm and the largest one is 80 mm. In addition, three radial directions A, B and C are marked on the blank surface. Directions A and B correspond to the centerline of blank holder segments and receive imposed radial displacement during the odd and even steps of drawing, respectively, while the direction *C* corresponds to the boundary between the blank holder segments.

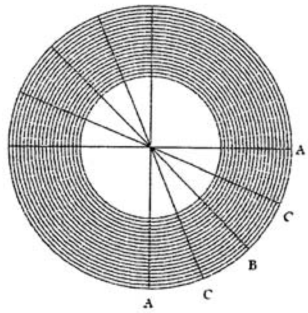


Fig. 15. Circular grids and prescribed directions marked on blank.

Fig. 16 demonstrates the measured radial displacement of flange in the A-direction in both four and eight segments tapered blank holder techniques. In the odd steps of drawing, flow of material in eight segments blank holder technique is more than four segments one. Moreover, in the even steps of drawing, flow of material in eight segments blank holder technique is less than the four segments one. As a result, flow of material in eight segments blank holder technique is much more uniform. This point is also true in the B-direction. Similarly, Fig. 17 exhibits the deformation behavior of flange in the B-direction for the odd and even steps of drawing. The only difference between the Figures 16 and 17 is that the B direction receives radial deformation during the even steps of drawing and the flange is displaced to the die opening; while, it is moved to the outward direction in the odd steps of drawing. The distribution of radial displacement of flange in the C-direction is shown in Fig. 18. It is observed that with increasing of blank holder segments from four to eight, the number of boundaries increases; as a result, flow of material in this direction decreases. In addition, the flange material in the C-direction is progressively displaced inward in all drawing steps toward the die opening.

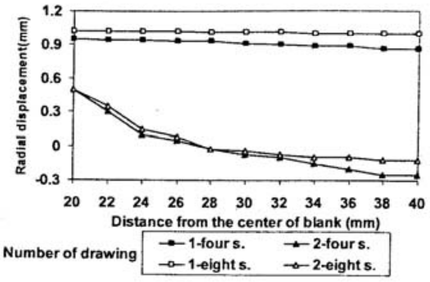


Fig. 16. Radial displacement of flange in A-direction of blank, four s. (four segment), eight s. (eight segment)

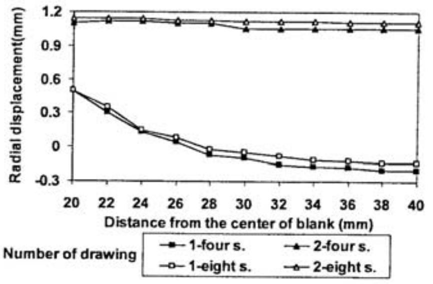


Fig. 17. Radial displacement of flange in B-direction of blank.

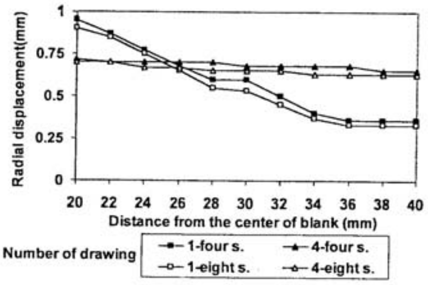
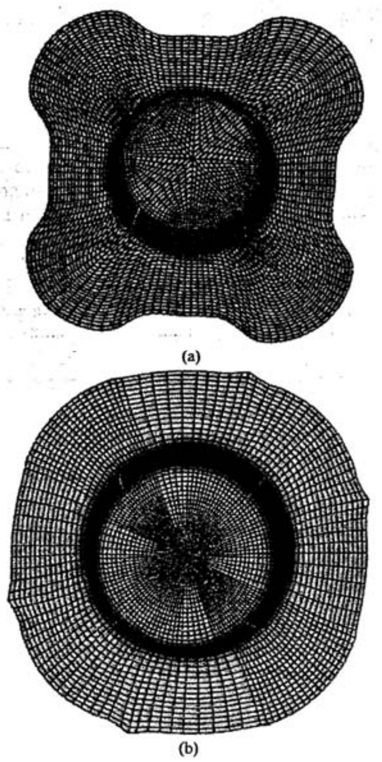


Fig. 18. Radial displacement of flange in C-direction of blank

Displacement of blank edge in both four and eight segments blank holder techniques are shown in Fig. 19. It is observed that radial flow of material in eight segments blank holder technique is much more uniform. It may be concluded that distortion of grids in the cup wall for eight segments tapered blank holder technique is less than that for four segments blank holder technique. Also, an example of successful produced cup without any defect by friction aided deep drawing using eight segments tapered blank holder technique is shown in Fig. 20.



Figs. 19. Edge displacement in (a) four segments blank holder technique, (b) eight segments blank holder technique

Fig. 20. A successful produced cup with drawing ratio 3.67, N=84

VI. Conclusion

In this paper, friction aided deep drawing using tapered blank holder divided into four segments was analyzed by 3-D finite element simulation method. The drawing mechanism and the effect of drawing conditions such as punch force, blank holder force and radial displacement of blank holder were investigated and the obtained results matched with the experimental results well within normal operating conditions. Decreasing of blank holder force and also increasing of radial displacement of blank holder can cause wrinkling and also increasing of punch force can cause tearing of blank. Also, increasing of blank holder force and radial displacement of blank holder and punch force can increase cup height. Therefore, the drawing efficiency significantly increased when using blank holding force over 50 kN together with an assistant punch force of 5 kN. This technique was achieved by overcoming the defects of localized wrinkling and intensive shear defamation observed when using flat blank holder divided into four and eight segments developed previously.

In continuance, a newly developed tapered blank holder divided into eight segments has been used to obtain successful deep cups. This was achieved by overcoming the defect of non-uniform flow of material in the flange portion of cup observed when using four segments tapered blank holder technique. It was concluded that flow of material in eight segments tapered blank holder technique is much more uniform than that for four segments tapered blank holder technique. Also, distortion of grids in the cup wall for eight segments technique is less than that for four segments technique. The obtained successful cup of 3.67 drawing ratio confirms the possibility of the present technique in producing deep cups and shows that this process can noticeably increase the drawing ratio. On the other hand, in these techniques only one set of rigid tools is used throughout the drawing process; therefore, the cost and time of die fabrication is less than that for the conventional deep drawing.

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