AN EFFECT OF WALL CORNER RADIUS OF PUNCH ON THE FEATURES OF THE HEXAGONAL CUP FABRICATED BY THE DEEP DRAWING PROCESS

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ABSTRACT

This work aims to study the effect of different deep drawing process parameters on the distribution of strain and thickness in deep drawing operation, such as wall corner radius of punch, the thickness of the sheet, and drawing speed using experimental and finite element simulation. The deep drawing die was designed and constructed to carry out the experimental work required to produce a hexagonal cup with inner dimensions (41.5 mm by 36 mm), (28 mm) height drawn from a circular flat blank (80 mm diameter), made from low carbon steel (AISI 1008). The analysis program (ANSYS 18.0) to perform the finite element method to perform the analytical side of the search. Four types of wall corner radius of punch ($R_c=1, 3, 5, 7\text{mm}$) with constant punch profile radius equal to ($R_p = 6\text{mm}$) and die profile radius equal to ($R_d=6\text{ mm}$) were used.

From experimental work and simulation results, it has been found that, the maximum thinning take place at corner of the cup area with a wall corner radius of punch equal to ($R_c= 1\text{ mm}$) and maximum thickening take place at the at cup end with wall corner radius of punch equal to ($R_c= 7\text{ mm}$), the maximum values of strains (radial, hoop, thickness and effective) take place at end of cup with wall corner radius of punch equal to ($R_c= 7\text{ mm}$).

KEYWORDS: Deep Drawing of Hexagonal Cup, Strain Distribution & Wall Corner Radius of Punch

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1. INTRODUCTION

The drawing of metal or “deep drawing” is the process by which a punch is used to force sheet metal to flow between the surfaces of a punch and die. A flat sheet is formed into a cylindrical, conic, or box shaped part. With this process, it is possible to produce a final work piece using minimal operations and generating minimal scrap-that can be assembled without further operations [1].

Several researchers investigated the deep drawing process through controlling the process parameters. Chen and Huang [2] investigated the effects of process parameters, such as punch and die corner radii, and forming temperature, on the formability of square cup drawing with AZ31 sheets. The results indicate that, a larger punch radius allows for a uniform material flow toward both of the two principal directions under the punch profile at corners and delays the occurrence of fracture. Jawad [3], investigated the effect of punch profile radius on the interfacial contact between the punch and the blank, punch load, thickness variation over the produced cup wall, localized strains and stress distribution across the inner and outer wall of the drawn part, the height and amount of spring back of the drawn part. He found that, the length of contact distance between the blank and the punch

increases as the punch nose increases and its value approximately is equal to punch nose radius. Malekaniet al [4], investigated the effect of blank holder and die shapes on the punch and blank holder forces, limit drawing ratio in the deep drawing process to produce a cylindrical cup. The results indicate that increasing of slopes has no visible effect on the magnitude punch load and lowers the blank holder force. So the wrinkling will be eliminated by increasing the slopes of the die and blank holder up to an optimum amount. The results show that the maximum effective stress and maximum effective strain occur at the top edges of the product and reduce as the die profile radii increases from (4 to 6mm). Kang and Song [5] used multistage deep drawing process to obtain various non-axisymmetric rectangular cups. This study focuses on the tool design and modification for developing the rectangular cup with an aspect ratio of (5.7). From the results, it is shown that the intermediate blanks could experience failures such as tearing, wrinkling, and earring by excessive thinning and thickening. The effect of some parameters which influence the drawing process such as die geometries, friction coefficient to predict the tearing failure in drawing part was carried out by Faris [6]. The results showed that, the increasing the value of friction coefficient from (0.1) leads to increase the cup height and leads to increase the strains (radial, thickness, hoop, and effective) at cup corner. The thickness of the cup wall increases with increasing die profile radius. The effective strain at cup flange decreases with increasing die profile radius. The more uniform distribution the more reasonable values of thickness and strain are for the value of friction equal to (0.1). Ozek and Bald [7] investigated the effect of die/blank holder profile with variables angles and die/punch with variable profile radii on limiting drawing ratio in the deep drawing process. The experiment results show that, limit drawing ratio increases with increasing die/blank holder and punch radius. Punch force increases with increasing die/blank holder angle. The effect of drawbead location on bead restraining force, thickness distribution and strain distribution in the process of deep drawing were investigated by Mujic[8]. The results show that, the restraining drawbead force decreases with increasing the height of drawbead. The thickness in the cup wall decreases with increasing the height of drawbead. The thickness strain decreases at the cup wall with increasing the height of drawbead. The radial strain increases with increasing the height of drawbead. Al-Saadi and Ameen[9] studied the effect of material type on the drawing force. Three metals were used (low carbon steel (1008) AISI, Austenitic stainless steel (304) AISI, and pure aluminium (1100). The results show that the drawing force for stainless steel is higher than that of the other two metals due to the difference in metallurgical structure. Chao and Dao-chun[1] studied the technological characteristics of the cylindrical cups of open kettles covers. Furthermore, the binding force, friction coefficient, and profile radius of dies were selected as the optimized parameters. Then the orthogonal tests were designed and the above-mentioned parameters were optimized by analysing the maximal thinning and the surface quality. Finally, the part with a satisfactory quality is produced. The influence of tool geometry (diameter and shoulder radius), blank holder force and friction on deep drawing process was investigated by Neto[11]. They concluded that, the variation in the “Die Diameter” is the only parameter affecting the forming process. This influence results from the variation it induces in the gap between the die and the punch. The increase in this gap leads to an increase in the final cup’s thickness and a decrease in the maximum punch force. Regarding the friction coefficient, its increase leads to the higher punch force values and to increase in thickness along the cup’s wall. The effect of die and punch profile radius, friction and blank thickness on deep drawing operation using finite element analysis was carried out by Gowtham and Srikanth[12]. The finite element program software DEFORM-3D is used in material aluminium alloy for deep drawing. The numerical results show that, the die radius is reduced, the amount of force required to draw the material is increased and created stretching marks and earring type quality problems. A die radius of (7) mm gave an optimum deform levels with minimum damage. Reddy et al. [13] studied the blank holder force, sheet thickness, die profile radius, punch profile radius. They found that maximum cup height at the onset of wrinkling increases with Blank holding force,

sheet thickness and an increase in the die profile radius as well as punch profile radius. Adnan et al. [14] investigated the effects of the die profile radius in the deep drawing of cylindrical brass cups, on thickness strain distribution, drawing force, total consumed work and the quality of produced cups. It was found that, the maximum drawing force is less affected by the punch profile radius as compared to the die profile radius. The optimum value of die profile radius for the used brass material was found at 6 mm which equals about 15 times the original sheet thickness. The effects of punch nose radius, die shoulder radius, the clearance between on the square-cup deep-drawing process for a two-layer aluminium/steel laminated sheet were investigated by Mahmoodi and Sohrabi [15]. Results indicated that the, parameter exerting the greatest effect on thinning defects was punch profile radius. The blank holder force had the highest influence of the wrinkle height of the two-layer aluminium/steel sheet. The optimum parameter values that caused the least wrinkling and thinning defects were 5.35 mm for die profile radius, 8.35 mm for punch profile radius, 6000 N for blank holder force, and (1.3 t) for the clearance between a punch and die.

The present research work focuses on investigating of some variables in the deep drawing process to prevent thinning and wrinkling in drawing operation. The work aims to study the effect of different process parameters on the distribution of strain and thickness such as wall corner radius of punch, the thickness of the sheet, and drawing speed using experimental and finite element simulation

2. NUMERICAL SIMULATIONS

A hexagonal cup of (41.5mm × 36 mm) inner dimension, and (28mm) height was chosen for detailed simulation of deep drawing operation. The sheet from which it is shaped has a diameter of (80mm), (0.7mm) thickness and is include of annealed low carbon steel of 0.06% carbon content, (215MPa) yield stress, (200GPa) Modulus elasticity, (0.51GPa) Tangent modulus and of (0.32) Poisson's ratio. This private cup really has no flange; it is fully drawn in to the die. In this work, a commercial FE package (ANSYS 18.0) is used to simulate the deep drawing process. The 3-D tooling of solid structure elements of (SOLID45), was used for the blank. For rigid (tool set) - malleable (blank) contact, target elements of (TARGET 170) and (TARGET 174) were used, to represent 3D target (tool set) surfaces which were connected with the shapeable of the blank. A coulomb friction law was used to study the influence of friction at the tool material interface ($\mu=0.1$). The blank holding load was ranging from (10- 12 KN) during the full stroke of the process. The clearance between punch and die was set to be (10% original thickness of the blank). The numerical simulation of the blank material and drawing tool hexagonal is shown in Figure 1. Four types of wall corner radius of punch ($R_c=1, 3, 5, 7\text{mm}$), three types of blank sheet ($t=0.5, 0.7, 1\text{ mm}$) and three types of drawing speed ($v = 100, 350, 650\text{ mm/min}$) were applied. The successive step of the deep drawing for strains are shown in figure 2.

Figure 1: The Numerical Simulation of the Blank Material and Drawing Tool

Figure 2: The Successive Step of the Deep Drawing for Strains

3. EXPERIMENTAL WORK

A deep drawing die was designed and built to fabricate hexagonal cups as shown in Figure 3. The deep drawing was carried out by using hexagonal punch with dimensions (41.5mm by 36mm) and die dimensions (43mm by 37.5mm) and dies clearance equal to $(1.1t_0)$ is chosen. The die and punch for hexagonal shapes are pictured as shown in Figure 4.

Testing machine type (WDW200E), has a capacity of (20ton). The die set was mounted on a hydraulic press; the press is equipped with a computer which reads the punch stroke and the punch load automatically by using load cells. The blank holding force was determined experimentally, it was approximately (10-12KN). Drawing speed equal to (100mm/min) was selected to draw the material.

Deep drawing tests include drawing processes to produce hexagonal cups without flange with dimensions (41.5mm by 36mm) and height of (30mm).

In order to study the effect of the wall corner radius of punch on the deep drawing to produce hexagonal cups, four types of wall corner radii of punch equal to ($R_c = 0, 1, 3, 5$, and 7 mm) were chosen with fixed drawing speed (v) of 100mm/min and blank thickness (t_0) of 6 mm as shown in Figure 5.

Figure 3: Photograph Illustrates the Deep Drawing Tools

Figure 4: Photograph Shows the Deep Drawing Punch and Die

Figure 5: Photographs Refers to Samples of Completely Drawn Hexagonal Cups with Different Wall Corner Radius of Punch

In order to study the effect of sheet thickness and drawing speed on punch, distribution of cup wall thickness and strain distribution to produce hexagonal cup, four types of sheet thickness ($t_0 = 0.5, 0.7$, and 1 mm) and drawing speed ($v = 100, 350$, and 650 mm/min) drawn by using punch when the profile radius ($R_p = 6$ mm), die profile radius ($R_d = 6$ mm) and wall corner radius of die equal to ($R_c = 5$ mm) were used.

For the strain measurement, an advanced grid pattern technique was used to characterize the real metal flow occurring in this deformation process.

When the specimen deforms, the circle will deform with the material and will visualize the deformations imposed on the sheet. In order to measure the cup wall thickness, the drawn cup is cut into two parts by using a wire cut machine.

Thickness micrometer and tool microscope were used to measure the cup wall thickness and change in the grid circles after deformation. Cup thickness and the length of the distorted grid radius were measured.

Radial strain and thickness strain distribution were derived from the measured thickness and deformed grid circles using the incompressibility condition by using equations (1) and (2), respectively, and then hoop (circumferential) strain by using equation (3) also the effective stress by using equations (4) [16].

$$\epsilon_t = \ln \frac{t}{t_0} \quad (1)$$

$$\epsilon_r = \ln \frac{R}{R_0} \quad (2)$$

$$\epsilon_\theta = -(\epsilon_t + \epsilon_r) \quad (3)$$

Where ϵ_r radial strain, ϵ_t thickness (normal) strain, ϵ_θ and hoop (circumferential) strain

(t_0) = the original thickness of the plate, (mm)

(t) = the instantaneous wall thickness, (mm).

(R_0) = the original radius of the ring element, (mm)

(R) = the instantaneous radius of the ring element, (mm).

With the assumption that the principal strain directions and the ratio of the incremental strain $d\epsilon_r$, $d\epsilon_\theta$ and $d\epsilon_t$ remain constant; an equivalent strain (effective strain) (ϵ_{eff}) can be computed [16].

$$\epsilon_{eff} = \sqrt{\frac{2}{3}(\epsilon_r^2 + \epsilon_\theta^2 + \epsilon_t^2)} \quad (4)$$

4 RESULTS AND DISCUSSIONS

4.1 Effect of Wall Corner Radius of Punch

Figure 6 clarifies the influence of wall corner radius of punch on the distribution of wall thickness of the cup. It is noticeable from the figure, there is no change in the thickness of the cup base, resulting from the flat face of the punch, which is in contact with the blank, also due to the friction and punch force plays an important role to prevent the distortion of the metal under the punch in that region, in the curvature area of the cup thinning occurs, this happens because of stretching exerted by radial stress in this area afterward at cup wall it becomes hoop stress which causes thickening at wall of the cup, also it is clear that the maximum thinning occurs at corner of the cup with smallest wall corner radius of the punch value of ($R_c=1$ mm).

Figure 7 shows the strain distribution at the wall of the cup of the completely drawn cup. It is obvious from the figures that; the whole strains of (ϵ_r , ϵ_θ , ϵ_t and ϵ_{eff}) have approximately a value equal to zero at the base of the cup. At curvature area of the cup from the center, the radial strain (ϵ_r) increases and continues until the end of cup wall reaches a maximum value at rim of the cup due to tension in this direction. The thickness strain (ϵ_t) starts to change in the curvature of the punch and became a negative value because of stretching exerted by radial stress. Afterward the cup wall thickness tends to increase (it becomes positive), and this is caused by hoop stress applied to this region. At the end of cup wall, it reaches a maximum value with large wall corner radius of the punch. Circumferential (hoop) strain (ϵ_θ) starts to decrease towards cup wall and has a negative value because of the hoop stress applied in this direction and it continues to

decrease to reach a maximum value at the rim of the cup and this value increases with increasing wall corner radius of the punch. Effective (equivalent) strain (ϵ_{eff}) has a tensile behaviour, under the curvature of punch, the effective strain increases due to severe distortion in this area. Afterward cup wall effective strain continues to increase to reach a maximum value at the rim of the cup wall and this value increases with increasing wall corner radius of the punch.

Figure 6: Effect of Wall corner Radius of Punch on Cup Wall Thickness

Figure 7: Effect of Wall Corner Radius of Punch on Strain Distributions
(A) Radial Strain, (B) Thickness Strain,
(C) Hoop Strain, & (D) Effective Strain

4.2 Effect of Punch Speed

Figure 8 represents the influence of punch speed on thickness distribution of the cup wall. It is noticeable from these figures that there is no change in the thickness of the cup base for all the speeds, where no distortion occurs in this area. At the curvature area of the cup, the change in thickness is not significant when the punch speed increases from (100 to

350 mm/min), but when forming at speed of (650) mm/min), it is observed that the maximum thinning will get due to an increase in stretching exerted by the high radial stress in this area. After that the thickness of the cup wall will increase.

Figure 9 illustrates the effect of punch speed on the distribution of strain over the cup wall is completely drawn. It is obvious from the figure that; the all strains (ϵ_r , ϵ_θ , ϵ_t and ϵ_{eff}) of punch speeds at (100,350,650 mm/min) are similar in form, and close in values. But at punch speed equal to ($v=500$ mm/min), it is noticed at the curvature area of the cup, the values of the strains are large compared to their values at the previous speed. This is due to the severe distortion in this region at high punch speed, while at the cup wall the values of strains have the same behaviour, but the values of all strains at punch speed are equal to ($v=650$ mm/min) are larger than the previous punch speeds.

Figure 8: Effect of Drawing Speed on Cup Wall Thickness

Figure 9: Plots Illustrate the Effect of Sheet Thickness on Strain Distribution in (a) Radial Strain, (b) Thickness Strain, (C) Hoop Strain, and (D) Effective Strain

4.3 Effect of Blank Thickness

Figure 10 represents the effect of blank thickness along the wall cup during deep forming process. It is obvious from the figure that, the thinning increases at the cup curvature region and increases with increasing blank thickness, this takes place because of extension done by radial stress in this region, also it is clear that the maximum thinning take place at cup corner with a smaller blank thickness ($t_0 = 0.5$ mm) and maximum thickening take place at cup end with larger plank thickness ($t_0 = 1$ mm).

Figure 11 shows the strains distribution over the cup wall of the completely drawn part. It is obvious from the figure that; under punch profile zone from cup center, the radial strain will increase with increasing plate thickness and continues until the edge of cup reaches a maximum value with a largest plate thickness ($t_0 = 1$ mm).

The thickness strain starts to change at the punch profile zone and has a negative value and also increases with increasing plate thickness. At the edge cup, the higher value occurs with larger blank thickness value ($t_0 = 1$ mm). Circumferential (hoop) strain begins to increase at the punch profile zone (expands in circumference), then it begins to decrease towards cup wall and has a negative value and it continues to decrease to reach a maximum value at the edge of cup with larger blank thickness equal to ($t_0 = 1$ mm). Effective strain has a tensile behaviour, at the punch curvature zone, the effective strain increases due to severe deformation in this region. Afterward cup wall, effective strain continues to increase to reach a maximum value at the edge of the cup and this value increases with increasing blank thickness and maximum value with larger blank thickness equal to ($t_0 = 1$ mm).

Figure 10: Effect of Sheet Thickness on Cup Wall Thickness

Figure 11: Plots Illustrate the Effect of Drawing Speed on Strain Distribution in (a) Radial Strain, (b) Thickness Strain, (c) Hoop Strain, and (d) Effective Strain

5 CONCLUSIONS

- The maximum thickening occurs at the cup rim with a wall corner radius of punch equal to ($R_c = 7$ mm).
- The maximum thinning occurs in the cup corner radius with a wall corner radius of punch equal to ($R_c = 1$ mm).
- The best thickness and strain distribution over all zones in producing cup are obtained when using wall corner radius of punch equal to ($R_c = 5$ mm).
- High drawing speed ($V = 650$ mm/min) leads to more thinning in cup corner and increasing the strain distribution over cup wall of completely drawn cup.
- Experimental and simulated results lie within an average of (15-25%), and the agreement is good
- The best thickness and strain distribution over all zones in produced cup are obtained when sheet thickness equal to ($t_0 = 0.7$ mm).

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