Drawing of Hexagonal Cup

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ABSTRACT

The main aim of this work is to produce hexagonal cup drawn from flat sheet (blank Ø80) and effect of wall corner radii of die on drawing process. The dimension of diagonal and side hexagonal cup are (41,36mm) and (36 mm) respectively, and (0.7mm) thickness made from low carbon steel (1006–AISI), has been produced. A commercially available finite element program code (ANSYS11.0), was used to perform the numerical simulation of drawing operation. Two types of wall corner radii of die (R_c=0.7, 4 mm) with constant punch profile radius equal to (R_p =4) mm and die profile radius equal to (R_d =8 mm) were used to investigate the effect of die corner radius on punch force, variation of cup wall thickness and the strain distribution over the cup wall. The numerical results of this model were compared with experimental results and the results show that, the greatest thinning occurs when used wall corner radius of die equal to (R_c= 0.7mm) due to great stretching of the metal over the corner radius. The best strain and thickness distribution over all zones in produced cup obtained when using wall corner radius of die is equal to (R_c= 4 mm).
Keywords: Drawing of hexagonal cup, strain distribution, wall corner radius of die.

INTRODUCTION

In drawing process, the deformation inherently proceeds with the irregular shapes of the cross section and contact conditions that cause failure. Success or failure of the forming process is influenced by many process parameters such as the drawing ratio, the shape of the die including the die radius, the amount of the die clearance, the strain hardening coefficient, formability, the lubrication condition, the degree of ironing [1].

Since a number of investigators have studied the drawing process, the current exposition here will focus only on the researches concerning some of parameters in drawing will be an effective way to prevent thinning and wrinkling in drawing. **E. D. Robert** [2] investigated the influence of material properties, tooling geometry, contact conditions including the effect of lubrication and process boundary conditions on wrinkling in redrawing process of aluminum sheet. The severity of wrinkling increases as the coefficient of friction decreases. The amount of localized thinning also increased with increased the friction. **W. K. Jawed [**3] investigated the effect of some parameters which influence on strain and thickness distribution, such as friction coefficient, blank holder force, punch and die corner by using finite element method. The best thickness distribution and strain distribution were found to have punch and die profile radius of (6, 6) respectively. **H. Gharib** and

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A.S. Wifi [4] developed an analytical model for the cup drawing process to solve the induced stresses and strains over the deforming sheet at any stage of deformation until a full cup is formed. The model uses finite difference approach and numerical procedures to solve equilibrium, continuity, and plasticity equations. The results show that, the incremental analytical model of punch travel, punch force, and circumferential strains distributions show good correlation with the experimental results. **M. Packo** and **M. Dukat** [5] predicted causes of contraction and cracking occurring in deformed product in respect to the changes in friction conditions on tool-drawn part contact surface in multistage deep drawing of AA5754 aluminum alloy box-type part with flange by both experimental and numerical analysis. **E. Mujic** [6] investigated the effect of drawbead location on bead restraining force, thickness distribution and strain distribution in the process of deep drawing. The results show that the thickness in the cup wall decreases with increasing the height of draw bead. **H. Ali** (7) studied the friction between the tool-work interfaces, the corner radius of the die, the punch speed, percentage reduction. The results show that, the maximum drawing force decrease with an increase in die profile radius under constant punch profile. An analytical method for estimating the limiting drawing ratio (LDR) and die corner radius in deep drawing process of axisymmetric components is represented by **A. Fazli1** and **B. Arezoo** (8). It is shown that process parameters such as, coefficient of friction, strain hardening exponent, normal plastic anisotropy ratio, ratio of die radius to blank thickness and ratio of blank thickness to diameter have significant effect on the LDR. **P. M. Patil** and **P. S. Bajaj** (9), investigated the effect of blank-holder forces, die and punch profile radius, deep drawing speed, friction, and lubricant conditions evolution on drawing process to produce cylindrical cup by both experimental and finite element analysis. The results show that, a too high value for the blank-holder force leads to materials rupture, but a too low blank-holder force allows the sheet wrinkling.

This paper aimed to produce hexagonal cup drawn from flat sheet (blank) and effect of wall corner radii of die.

Numerical Simulation

The dimension of diagonal and side hexagonal cup is (41,36mm) and (36 mm) respectively, and (30mm) height, was chosen for detailed analysis of drawing operation. The blank from which it is formed has a diameter of (80mm), with (0.7mm) thickness and is made of low carbon steel of 0.06% carbon content, (125MPa) yield stress, (200GPa) Modulus of elasticity, (0.52GPa) Tangent modulus and of (0.29) Poisson's ratio. A commercial FE package (ANSYS 11.0) was used to simulate the drawing operation. Elasto-plastic behavior for work material was used in the simulation. The 3-D modeling of solid structures element of (SOLID95) was used for the blank. For rigid (tool set)-flexible (blank) contact, target elements of (TARGE170) were used, to represent 3D target (tool set) surfaces which were associated with the deformable of the blank represented by 3D contact elements of (CONTA174). The finite element model of the sheet material and drawing die is shown in figure (1). A friction of coefficient with value (μ=0.1) was employed. Two types of wall corner radii of die (R_c=0.7, 4mm) were used. The clearance between punch and die was set to be (C = 10% of sheet thicknesses).

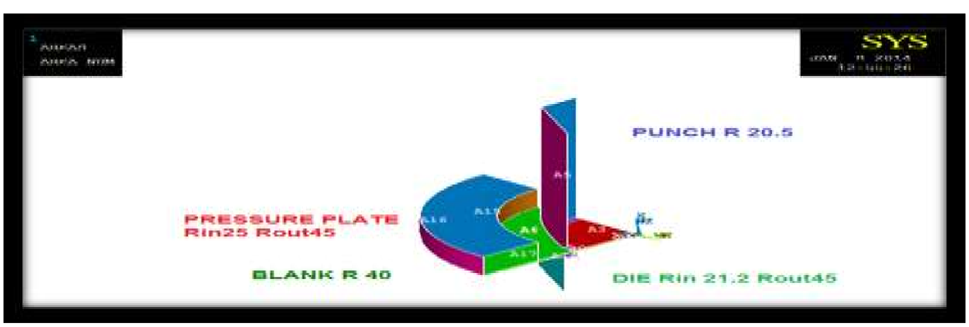


Figure (1) Dies geometry for drawing of hexagonal cup in FEM by ANSYS11.0.

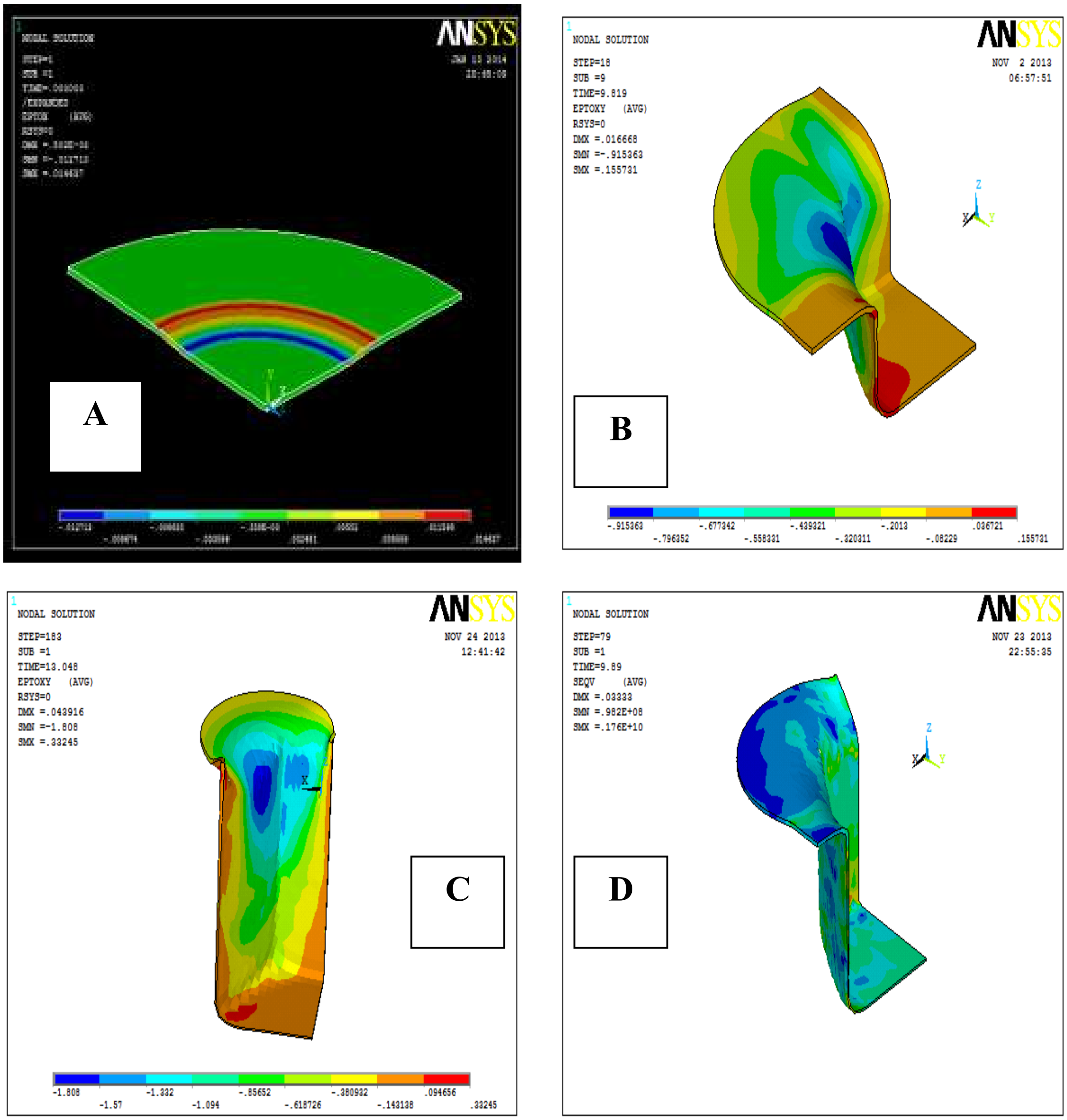


Figure (2) Successive of drawing process to produce hexagonal cup FEM

Drawing Experiment

Material Used

The characteristics of the material to be drawn have a great influence on the success of a drawing operation. Low carbon steel (1006–AISI) is chosen to carry out the work, where this type is used in many drawing application, such as cars bodies, storage tanks and other applications. A chemical composition test was carried out by using spectrometer device to check the manufacture certificate of materials is listed in table (1).

Table (1) Chemical composition of low carbon steel (1006–AISI)

C%		Si%	Mn%	p%	S%	Cr%	Ni%	Mo%	Cu%
testing	0.062	0.026	0.169	0.016	0.006	0.055	0.035	0.002	0.006
AISI	<=0.08	0.01	0.25-0.4	<=0.04	<=0.05				

Experimental Tooling

Drawing experiments were carried out to obtain hexagonal cups by mounting drawing die as shown in figure (3) and the drawing die is shown schematically in Figure (4). The testing machine type (WDW-200E) which has a capacity of (200KN). The die set was mounted on a hydraulic press; the press is equipped with a computer which is reading the punch stroke and the punch load automatically by using load cell. Two types of wall corner radii of die equal to (R_c =0.7, 4 mm) were chosen with fixed punch profile radius equal to (R_p = 4 mm) and die profile radius equal to (R_d = 8 mm) to study the effect of die corner radius on the drawing operation to produce hexagonal cup from forming circular blank.

After putting blank on the blank holder surface, die will drop towards the punch; this means inverted drawing die use. The produced cup has 30 mm height.

In order to study the strain distribution in the drawn circular and hexagonal cups, a grid pattern of (5, 10, 15, 20, 25, 30, 35, 40) mm radius circles was printed along (12) intersecting lines, (30) degree a part as shown in figure (5).

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 distorted grid radius were measured along the intersecting lines along the curve as shown in Figure (6).

Thickness strain and radial strain distribution were derived from the measured thickness and deformed grid circles using the incompressibility condition by using the following equations (1) and (2), respectively and then hoop strain by using equation (3).

$$\epsilon_t = \ln \frac{t}{t_\circ} \quad ..(1)$$

$$\epsilon_r = \ln \frac{R}{R_\circ} \quad ..(2)$$

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

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

($t_\circ$) = the original thickness of the blank, (mm)

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

($R_\circ$) = 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 stain dϵ_r, dϵ_θ and dϵ_t remain constant; an equivalent strain (effective strain)(ϵ_{eff}) can be computed.

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

Figure (3) The picture of drawing tools use

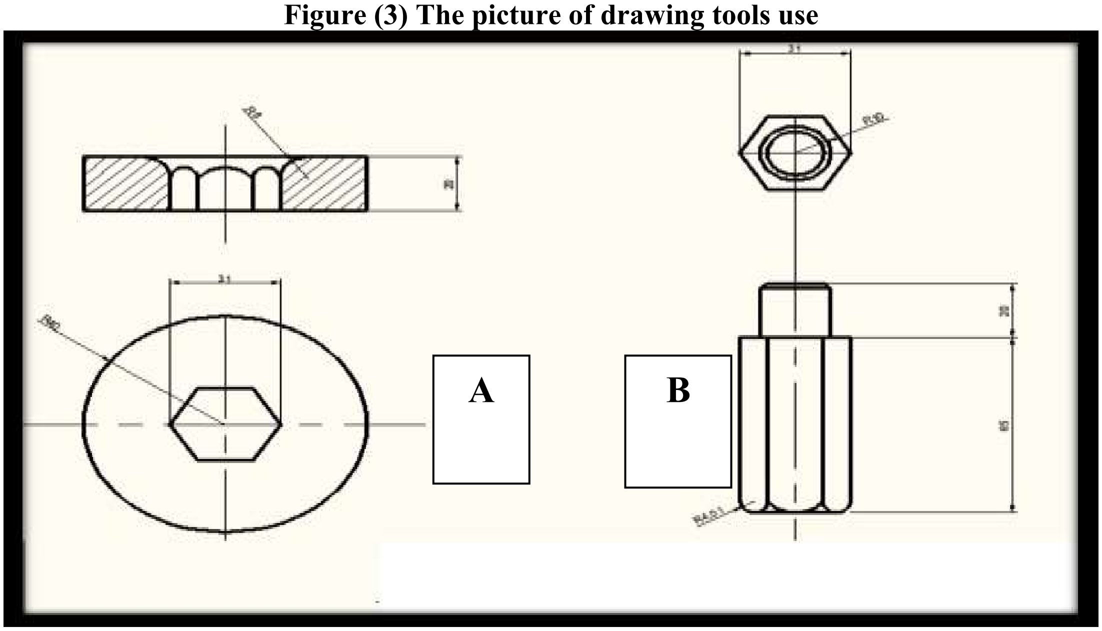
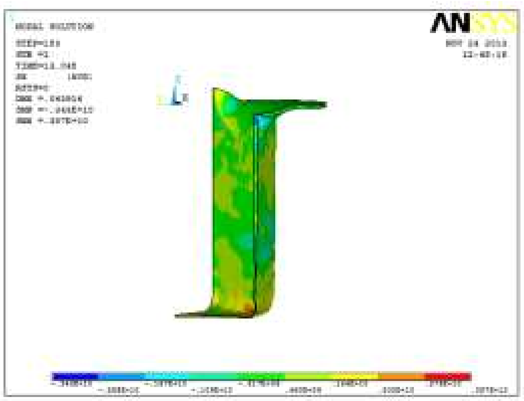
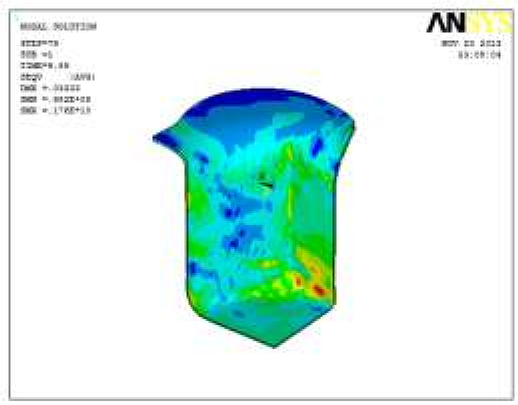


Figure (4) Schematic representation of actual (A) punch and (B) die.

Figure (5) The blank with grids, by using mechanical grid marker

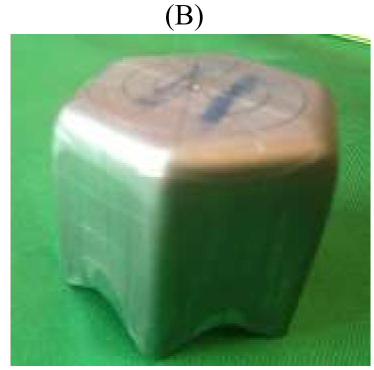


(A)



(B)

(C)



(D)

Figure (6) The distortion of grid circles on the hexagonal cup.

Results and Discussions

Effect of die wall corner:

Figure (7) Shows the effect of wall corner radius of die (R_c) on the drawing force. During the experiment, punch load was recorded along with punch stroke, for the entire dies corner radius chosen. It is seen from this figure, that the drawing force for large wall corner radius of die is lower than that for small wall corner radius of die, in both experimental and simulation, and that can be explained by sever bending and unbending over the smaller die corner radius.

Figure (8) shows the effect of wall corner radius of die on cup wall thickness. It is clear from this figure that; the thickness remains constant under punch face (cup bottom), resulting from the flat face of the punch in contact with blank, and due to the drawing force, friction plays a role preventing any deformation in the metal under the punch, hence there is no changing in thickness. At the punch profile radius thinning will occur, this happens because of stretching exerted by tensile stress in this area afterward at cup wall it becomes compressive stress which causes thickening of the cup wall, also it is clear that the maximum thinning occurs at cup corner with smallest wall corner radius of die value of (R_c= 0.7 mm).

Figure (9) shows the strain distribution over the cup wall of the completely drawn part. It is obvious from the figure that; the whole strains of (ϵ_r, ϵ_θ, ϵ_t andϵ_{eff}) have approximately a value equal to zero at the cup bottom, since there is very small deformation at this zone which cannot be observed. Under punch profile radius from cup center, the radial strain (ϵ_r) will increase and continues to increase to reach a maximum value at the end of cup wall with smallest wall corner radius of die value of (R_c= 0.7 mm). The thickness strain (ϵ_t) starts to change at the punch profile radius and has a negative value because of stretching exerted by tensile stress**.** Afterward the cup wall thickness tends to increase (it becomes positive), and this is caused by compressive stress applied to this region. At the end of cup wall, it is clear the thickness strain increases and the maximum values occurs with largest wall corner radius of die value of (R_c= 4 mm).

Circumferential (hoop) strain (ϵ_θ) begins to increase at punch corner (expands in circumference) due to tension stress in this area, then it begins to decrease towards cup wall and has a negative value (diminishes in circumference) because of the compression applied in this direction and it continues to decrease to reach a maximum value at the and the maximum values occurs with largest wall corner radius of die value of (R_c = 4).

Effective (equivalent) strain (ϵ_{eff}) has a tensile behavior, under punch profile, the effective strain increases due to severe deformation (server bending) in this region. Afterward cup wall effective strain continues to increase to reach a maximum value at the end of cup wall with wall corner radius of die value of (R_c = 0.7).

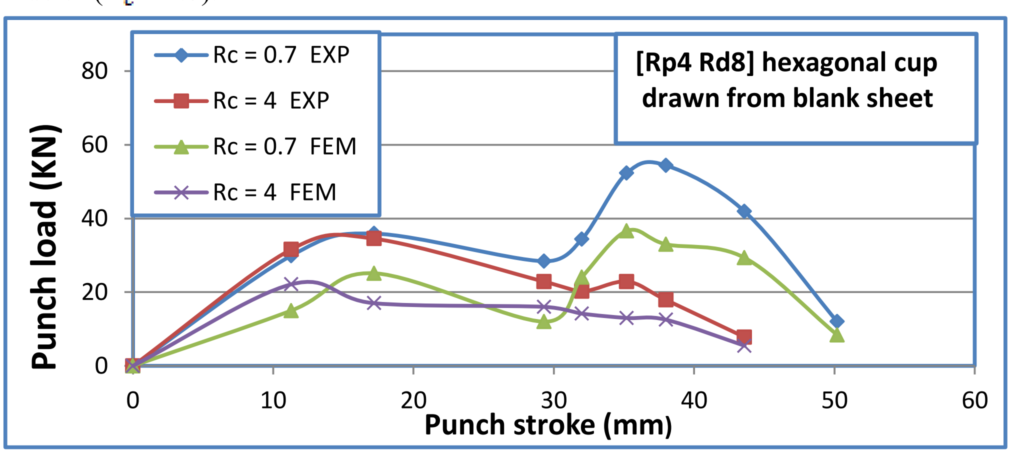


Figure (7) Effect of wall corner radius of die on the drawing force

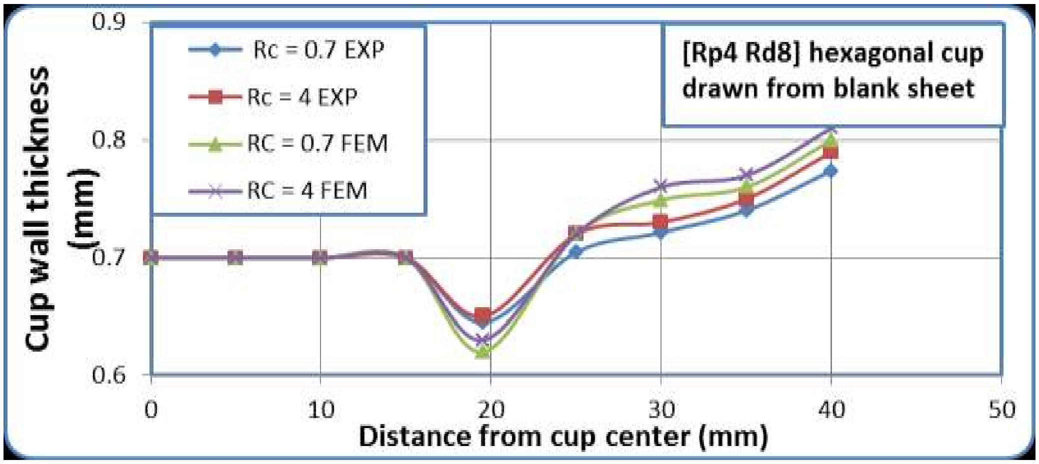
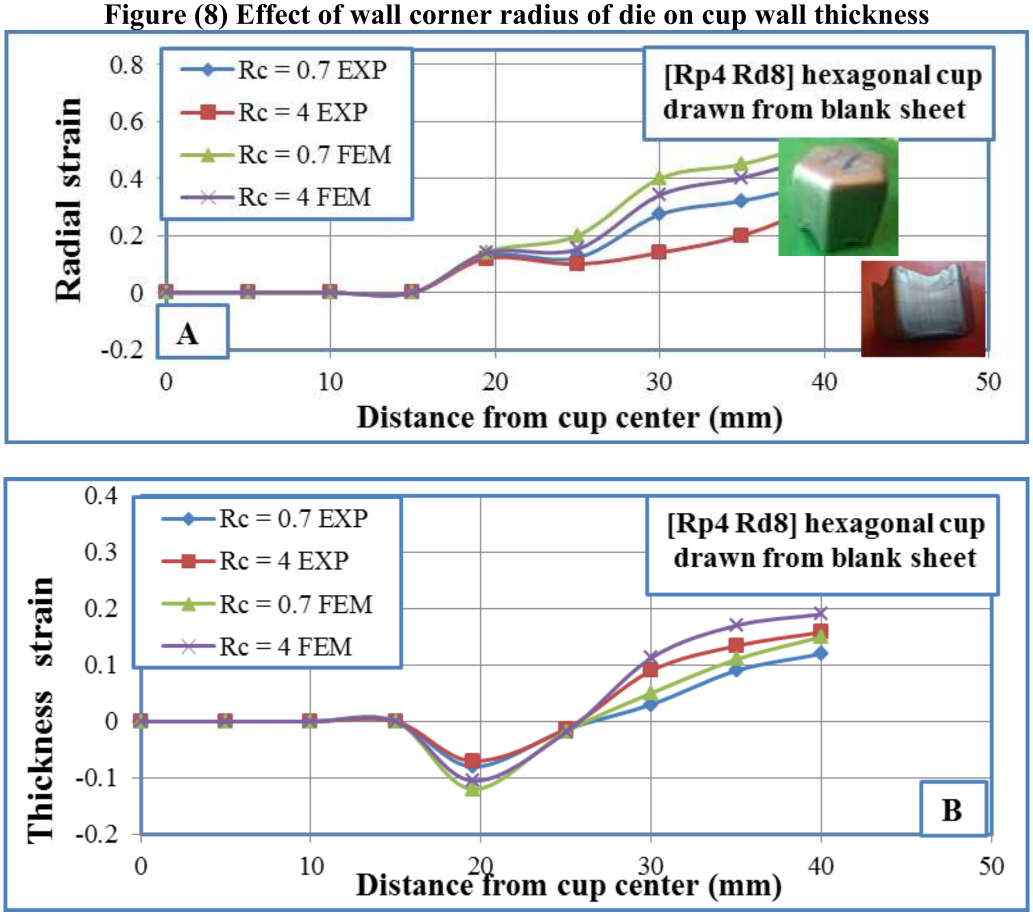


Figure (8) Effect of wall corner radius of die on cup wall thickness



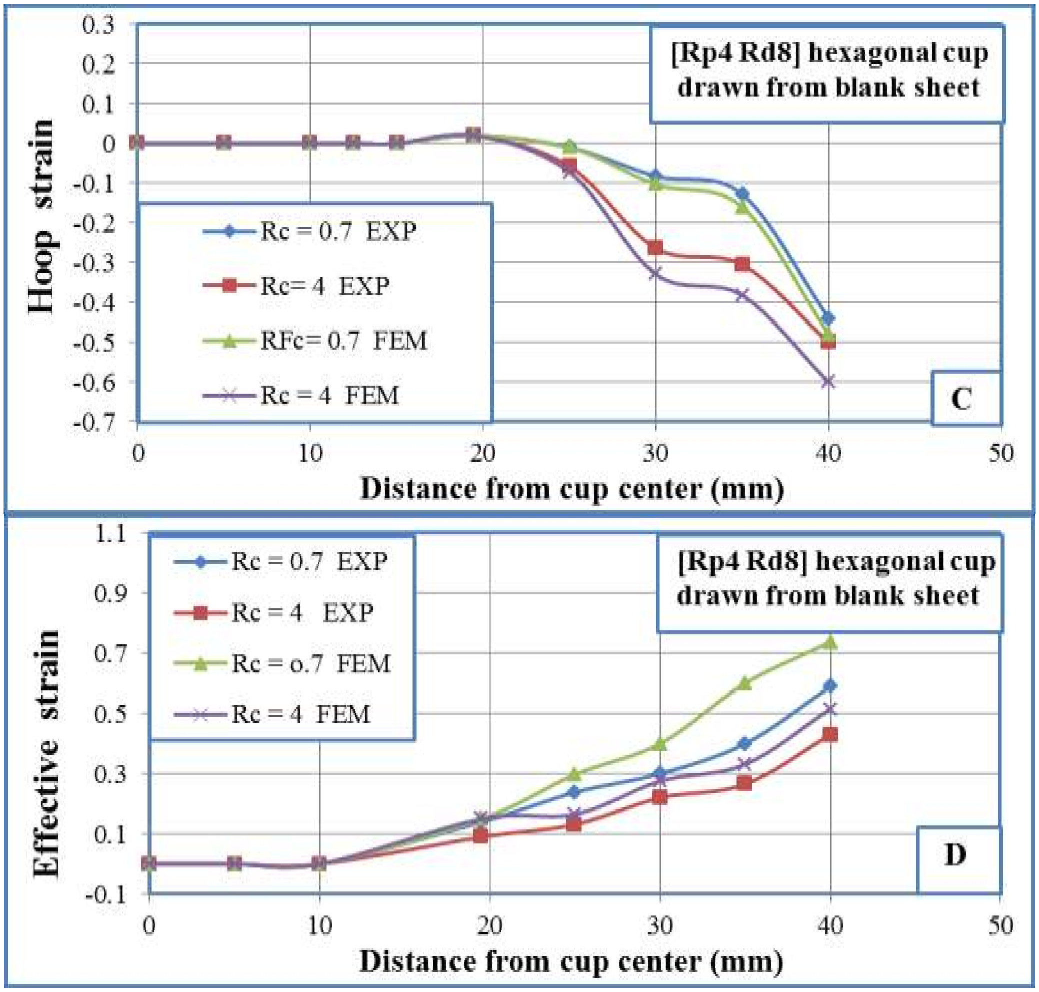


Figure (9) Effect of wall corner radius of die on (A) radial strain (B) thickness strain (C) hoop strain (D) effective strain

Comparison between corner radius region (diagonal) and side region of hexagonal cup:

Figure (10) presents comparison thickness distribution over the hexagonal cup wall between corner radius region and side region. It is evident that; the thickness at the region of a flat bottom face of the punch does not change and remains almost constant. At the punch profile radius thinning will occur, this happens because of stretching exerted by tensile stress in this area afterward at cup wall it becomes compressive stress which causes thickening of the cup wall, also it is clear that the maximum thinning occurs at cup corner with corner radius region of hexagonal cup.

Figure (11) shows comparison the strain distribution over the hexagonal cup wall between corner radius region and side region. It is obvious from the figure that; the strain distribution of all cases chosen is similar in shape, and has approximately the same trend. The whole strains (ϵ_r, $\epsilon_\theta, \epsilon_t$ andϵ_{eff}) have approximately a value equal to zero at the cup bottom, since there is very small deformation at this zone which cannot be observed. under punch profile radius, the radial strain (ϵ_r) begins to rise to get a maximum value at the end of cup wall, because of tension at this direction, but the value of radial strain at side region of hexagonal cup is less than that corner radius region of hexagonal cup. The thickness strain (ϵ_t) also starts to change at the punch profile radius and has a negative value due to stretching, and then an increase occurs because of circumferential compressive stress to reach a maximum value at the end of cup wall, but the value of thickness strain at side region of hexagonal cup is higher than corner radius region of hexagonal cup. Circumferential (hoop) strain (ϵ_θ) begins to increase at punch corner (expanding circumference) due to small tensile stress behavior in this area and then the next zone cup wall begins to decrease and has a negative value at the cup rim because of the compression exerted at the circumference of the cup, but the value of hoop strain at side region of hexagonal cup is higher than corner radius region of hexagonal cup.

Effective strain (ϵ_{eff}) has a tensile behavior since it is the resultant of the three strains. Under punch face (cup bottom) effective strain has a positive value and a continuous increase to reach a maximum value at the end of cup wall, but the value of effective strain at side region of hexagonal cup is higher than corner radius region of hexagonal cup.

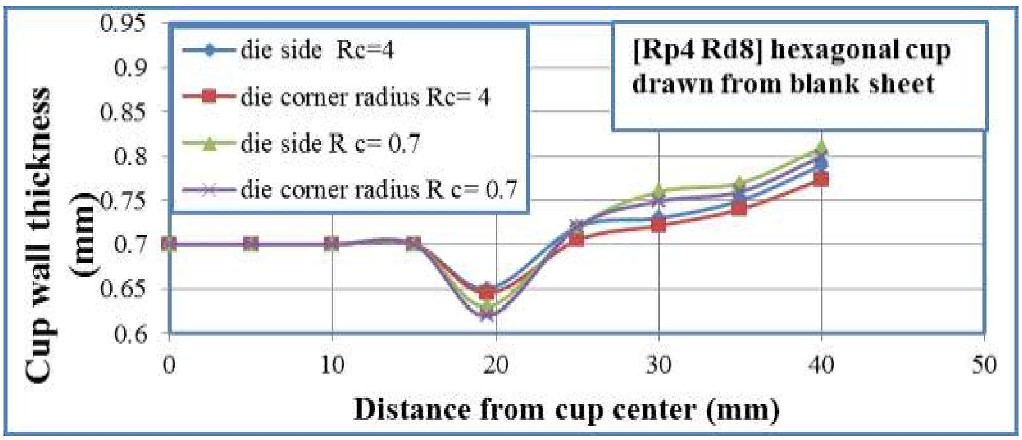
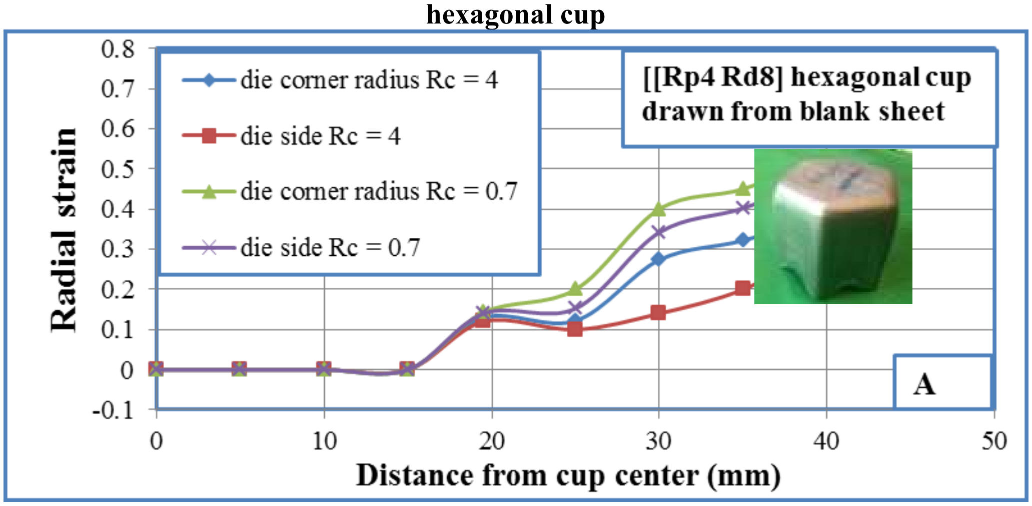


Figure (10) Comparison cup wall thickness between corner radius region and side region of hexagonal cup



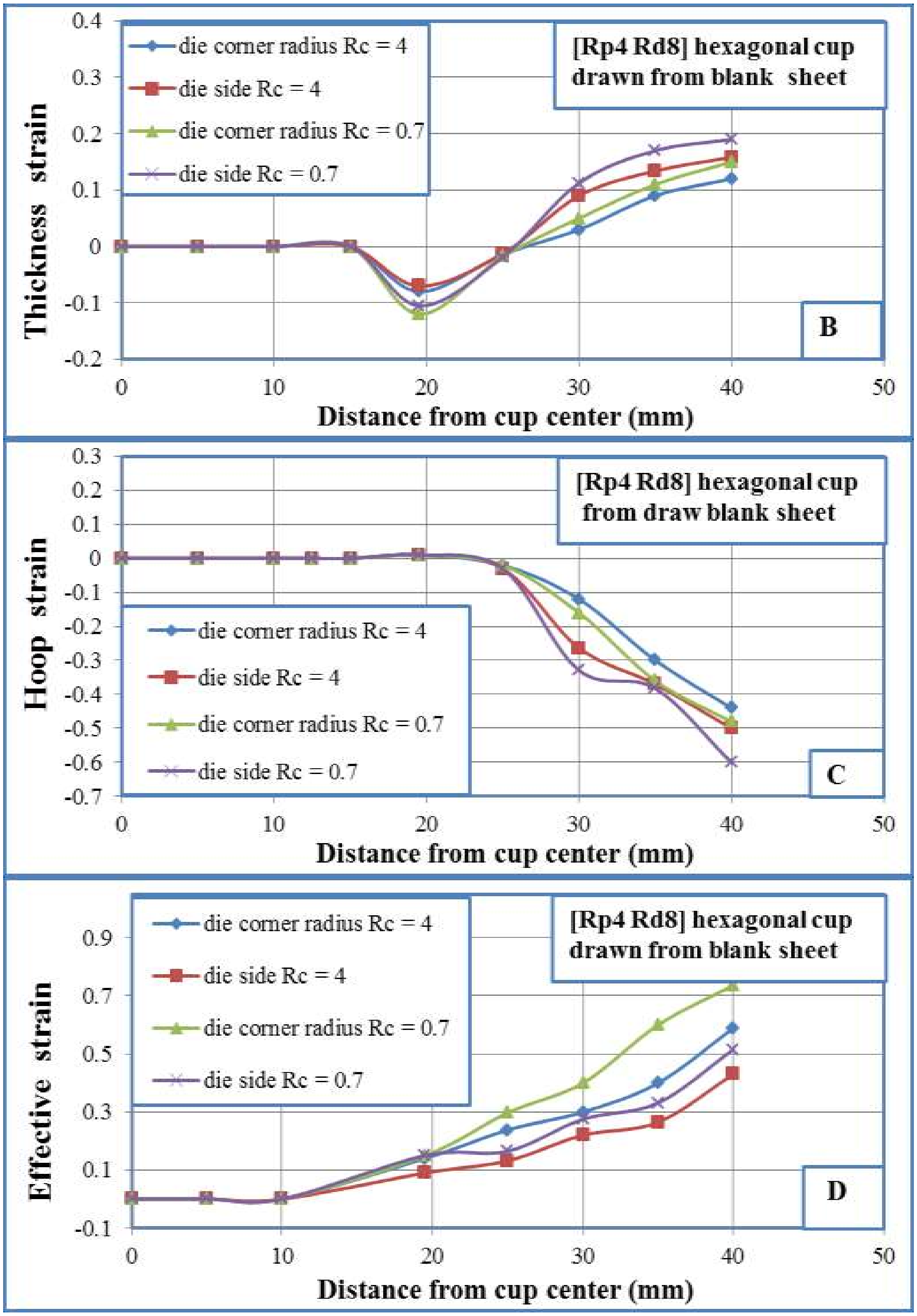


Figure (11) Comparison between corner radius region(diagonal) and side region of hexagonal cup (A) radial strain (B) thickness strain (C) hoop strain (D) effective strain

CONCLUSIONS

1. The maximum thinning occurs at region of cup corner with wall corner radius of die (R_c= 0.7mm) due to flow metal in wall corner of die
2. The maximum radial and effective strain occur at rim cup region with wall corner radius of die (R_c= 0.7mm), while the maximum hoop and thickness strain occur at rim cup region with wall corner radius of die (R_c= 4mm)
3. The best strain distribution and thickness distribution over all zones in produced cup obtained when using wall corner radius of die is equal to (R_c= 4 mm)
4. The least excessive metals will appear in the diagonal hexagonal cup with wall corner radius of die (R_c= 0.7 mm)

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