Drawing of Hexagonal Shapes from Cylindrical Cups

Dr. Waleed Khalid Jawed
Metallurgy & Production Engineering Department, University of Technology /Baghdad
Email: Drwaleed555@yahoo.com
Sabih Salman Dawood
Metallurgy & Production Engineering Department, University of Technology /Baghdad

Received on: 19/5/2014 & Accepted on:17/12/3015

ABSTRACT
The main aim of this work is design and manufacturing cylindrical and hexagonal dies to produce hexagonal cups from transform the cylindrical cups to hexagonal cups and affect of wall corner radii of die. As well as using some parameters which effect of on the hexagonal deep drawing process, especially on the punch force, strain distribution and variation of the cup wall thickness for three stages such as (wall corner radius of die and punch speed). 3-D models of cylindrical cups of (43 mm) outer diameter, and diagonal and side distance of hexagonal cups are (41and36mm) respectively, (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 deep 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), various drawing speeds equal to (50, 200, and 500 mm/min) were used. From the numerical and experimental results of drawing operation, it, the maximum thinning occurs at cup corner radius when used wall corner radius of die equal to (R_c= 0.7mm). 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) and High drawing speed (v=500 mm/min) leads to increase drawing force and more thinning in cup corner.
Keywords: Deep drawing hexagonal cup, strain distribution, wall corner radius of die.

INTRODUCTION
Deep drawing process, one of sheet metal forming methods, is very useful in industrial field because of its efficiency. The production of optimal products using this process is dependent on the process variables such as wall corner radius of die, blank shapes, profile radii of punch and die, and formability of materials. Of the variables, wall corner radius of die is very important since it controls the formability factor [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 deep drawing will be an effective way to prevent thinning and wrinkling in deep drawing.

F.K. Chen and **T.B. 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

https://doi.org/10.30684/etj.34.6A.17
2412-0758/University of Technology-Iraq, Baghdad, Iraq

fracture. The influence of variable and constant blank holder force on thickness strain distribution, change of final deep drawing depth and change of forming forces in deep drawing process of cup square ware carried out by **S. Aleksrovice** and **M. Stefanovic** [3]. **W.K. Jawad** [4], 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 stresses distribution across the inner and outer wall of the drawn part, the height and amount of spring back of the drawn part. ***C. Ozek and M. Bald*** [5], 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. **B.V.R. Ravindr** and **G.C.M. Reddy** [6] , investigated the effect of tooling parameters like die profile and punch profile on wrinkling and fracture limits. The results show that, the wrinkling limit almost remains constant with the variation of punch corner radius. But the fracture limit decreases with the increase punch corner radius. **P. M Patil** and **P. S Bajaj** [7], investigated the effect of blank-holder forces, deep drawing speed, friction, lubricant conditions evolution and tools geometry 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**. H. Ali** [9] , studied the friction between the tool-work interface, 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** [9]. 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.

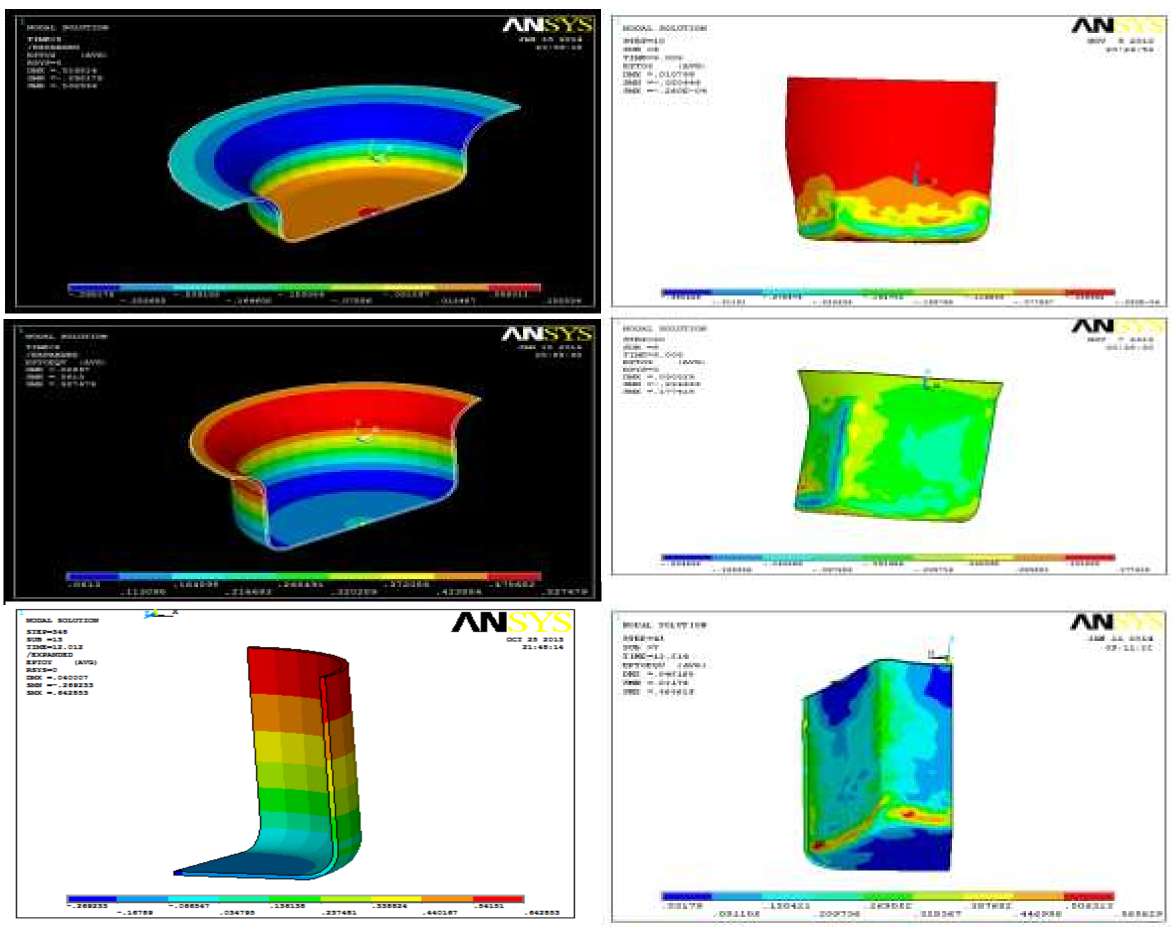
This paper aimed to design and manufacture cylindrical and hexagonal deep drawing dies to produce cylindrical cup and hexagonal cup from transform cylindrical cup into hexagonal cup and affect of wall corner radii of die

Numerical Simulation:

A cylindrical cup of (43 mm) diameter and (30 mm) height, as well as diagonal and side distance of hexagonal cup (43and36 mm), and (30mm) height, were chosen for detailed analysis of deep 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, (0.175GPa) Tangent modulus and of (0.29) Poisson's ratio. A commercial FE package (ANSYS 11.0) was used to simulate the deep drawing operation. Elasto-plastic behavior for work material was used in the simulation. The 3-D modeling of solid structures element of (SOLID45) 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 bank represented by 3D contact elements of (CONTA174). The finite element model of the sheet material and drawing die cylindrical and hexagonal is shown in Figure (1-A, B). A friction of coefficient with value (μ=0.1) was employed. Two types of wall corner radii of die (R_c=0.7, 4 mm), and deferent values of speed (V= 50, 200, 500 mm/min) were used. The clearance between punch and die was set to be (C = 10% of sheet thicknesses). A successive final stage of the deep drawing sheet for stress and radial strains are shown in figure (2 A and B) respectively.

(A) (B)

Figure (1) Finite element model of the sheet material and drawing (A) cylindrical die and punch (B) Hexagonal die and punch



(A) (B)

Figure (2) The successive stage of the deep drawing sheet for (A) cylindrical cup (B) hexagonal cup from transform cylindrical cup

Deep 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, This material is selected because of its good formability, specification and widespread usage in the industry, this material is taken as sheets from light industry company. 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

Deep drawing experiments were carried out to obtain cylindrical and hexagonal cups by mounting deep drawing die as shown in figure (3). 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.

Also to study the effect of drawing speed on drawing operation to produce hexagonal cup from transforming the cylindrical cup, experiments were made at speed (V= 50, 200, 500 mm/min) drawn by using punch when has wall corner radii of die equal to (R_c =0.7, 4 mm).

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 cylindrical and hexagonal cups of deep drawing processes, 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 (4).

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 5 (A, B, C, D).

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).

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

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

$$\epsilon_{\theta} = -(\epsilon_t + \epsilon_r) \qquad (3)$$

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)

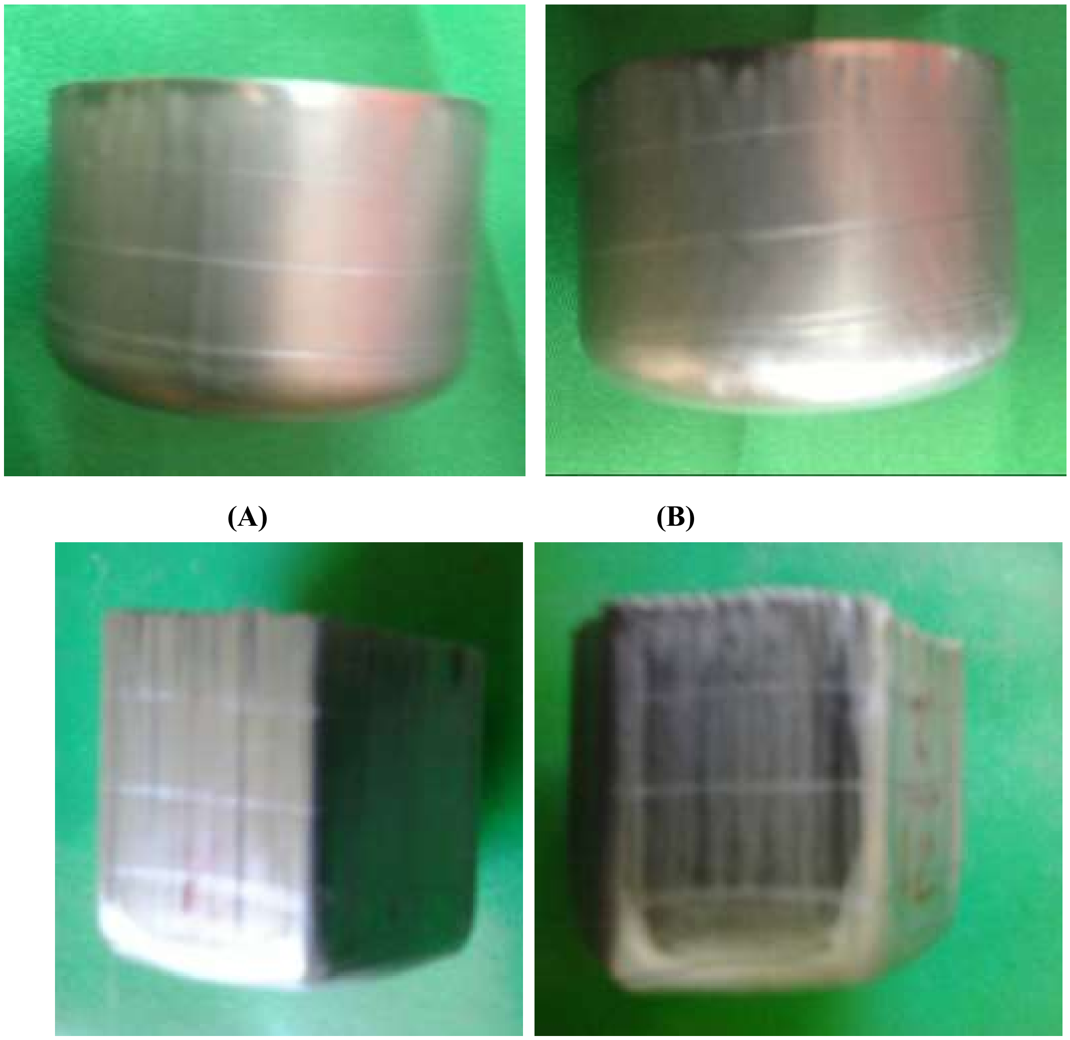
(R) = the instantaneous radius of the ring element, (mm).

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

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

Figure (3) The picture of deep drawing tools used

Figure (4) The blank with grids, by using mechanical grid marker



(A) (B)

(C) (D)

Figure (5) The distortion of grid circles on the (A) (B) cylindrical cup and (C) (D) hexagonal cup from transform cylindrical cup into hexagonal cup.

Results and Discussions

Effect of die wall corner

Figure (6) shows the variation of the drawing force with the punch stroke under different wall corner radius of die. It is clear that the small the chosen wall corner radius of die, the large will be the maximum drawing load under otherwise constant condition, in both experimental and simulation, and that can be explained by sever bending and unbending over the smaller wall corner radius of die.

Figure (7) 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). 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 (8) 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, Under punch profile radius from cup center, the radial strain (ϵ_r) starts to change at the punch profile radius region and increases until becomes maximum value at the cup rim 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). 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 decrease after punch profile radius towards cup wall to have negative value (shrinkage in circumference) because of the compression applied in this direction and it continues to decrease to reach a maximum value at the cup rim 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 and 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).

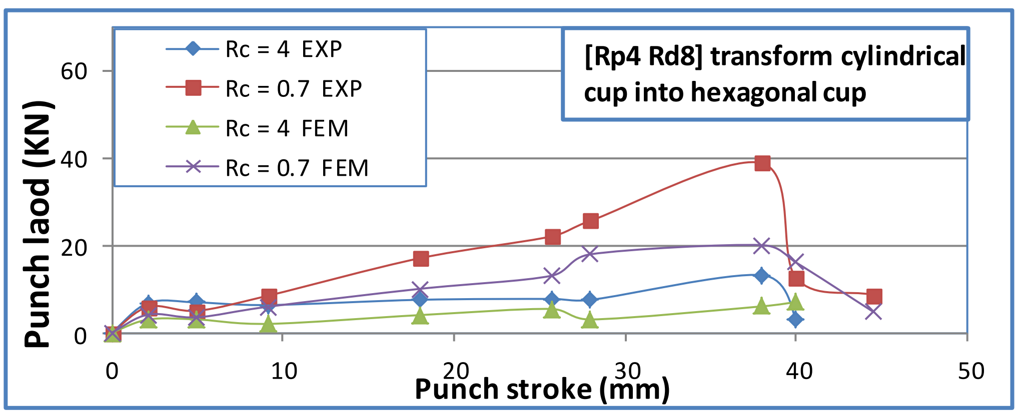


Figure (6) Effect of wall corner radius of die on the drawing force

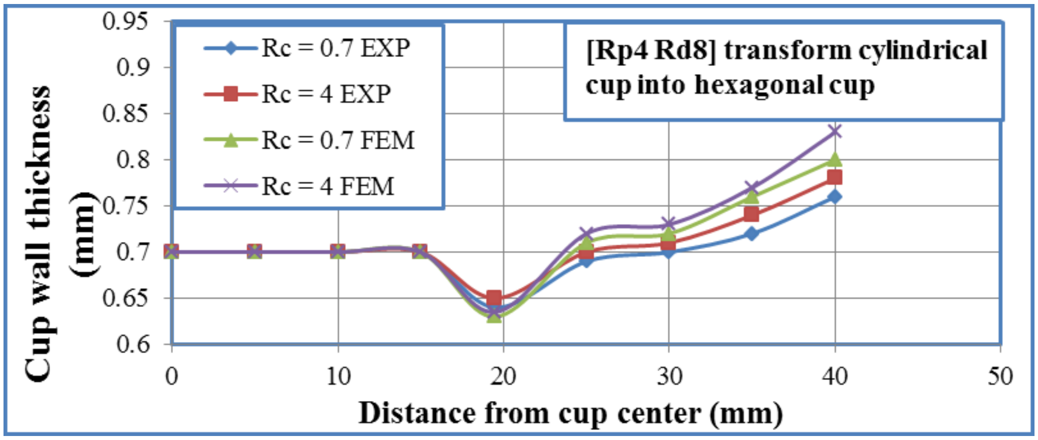
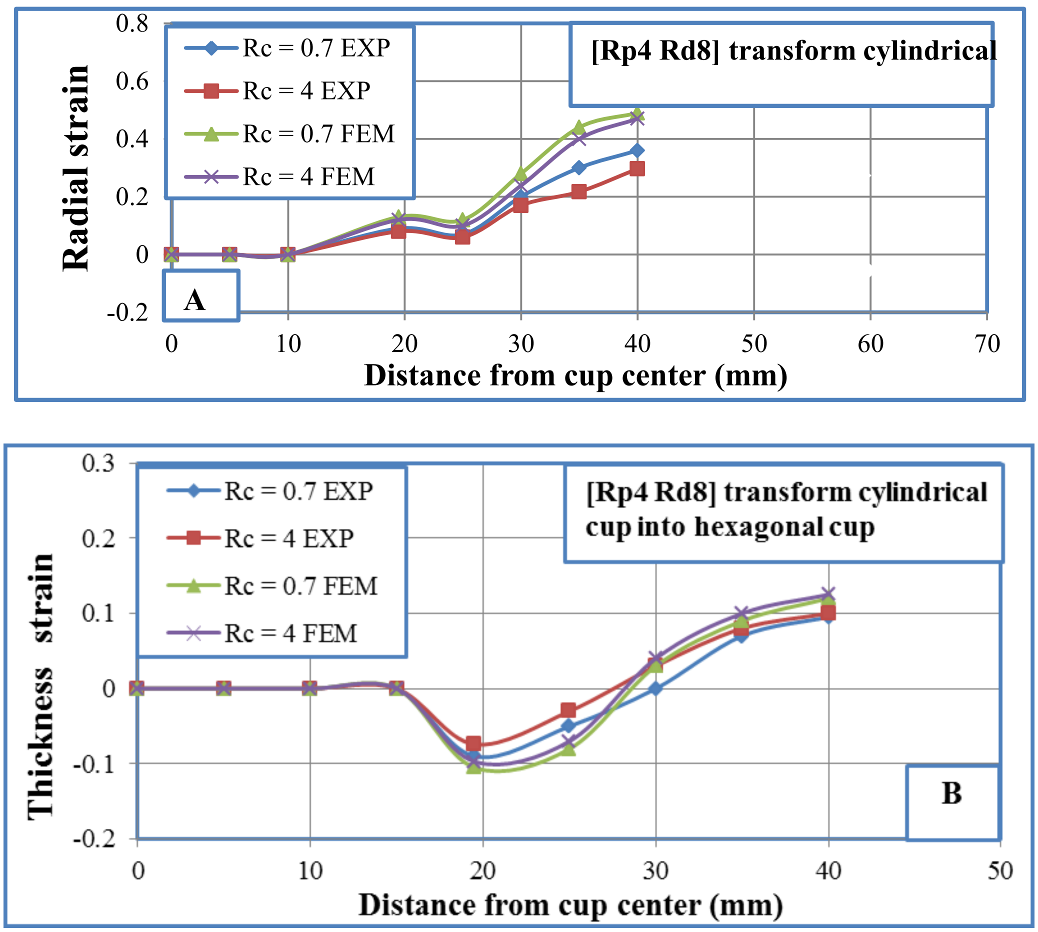


Figure (7) Effect of wall corner radius of die on cup wall thickness



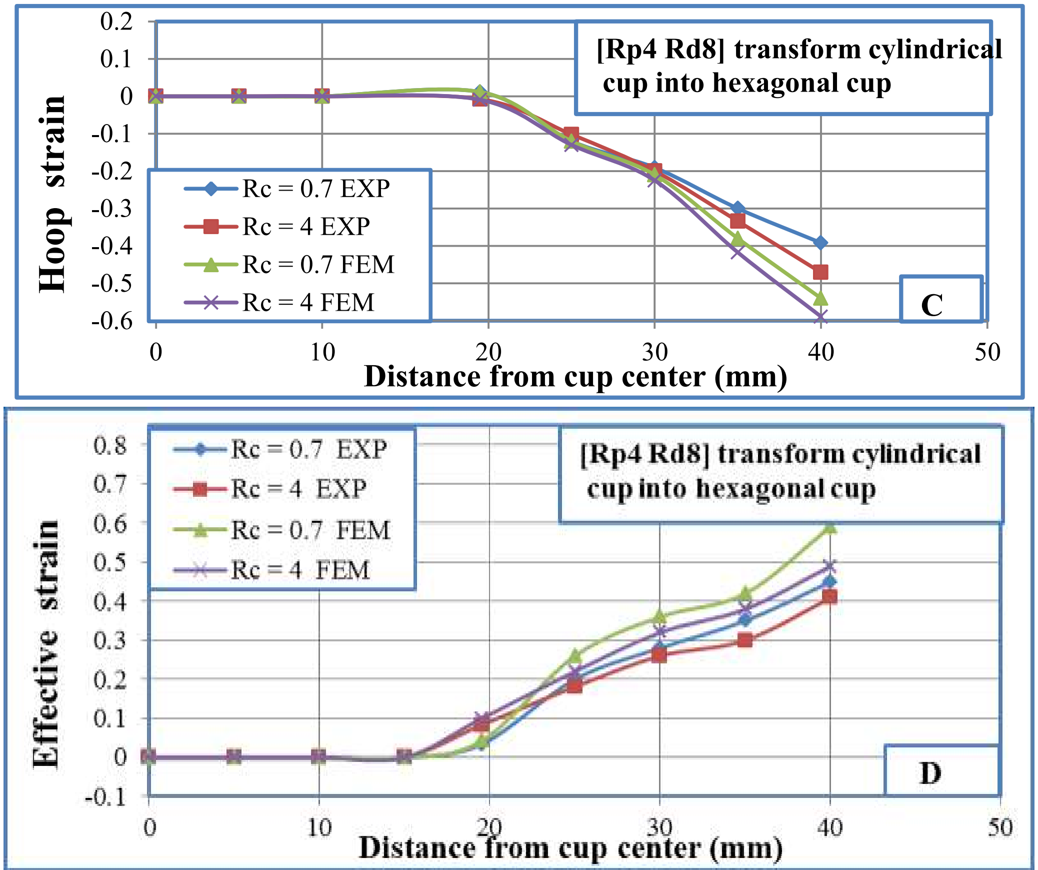


Figure (8) Effect of wall corner radius of die on (A) radial strain (B) thickness strain (C) hoop strain (D) effective strain

Effect of drawing speed

Figures (9) show the effect of drawing speed, on the punch force. It is evident from those figures that with an increase in drawing speed, drawing force will increase. This occurs because of the increase in strain hardening of material with drawing speed, which leads to an increase in drawing stress and finally increasing drawing force.

Figures (10) represent the effect of drawing speed on the cup wall thickness. It is evident that; the thickness remains constant under the punch face (cup bottom) for all the speeds, where no deformation occurs in this area due to friction which prevents any deformation of the metal under the punch. At the next zone (punch corner), the thinning increases with increasing drawing speed ,it is noticed that the maximum thinning will occur due to an increase in stretching exerted by the high tensile stress in this area. Afterward the cup wall thickness will increase because of the applied compressive stress in this region and maximum thining with larger drawing speed equal to (500 mm / min).

Figures (11) represents the effect of drawing speed on strain distribution over the cup wall of the completely drawn part. It is obvious from the figures that; the whole strains (ϵ_r, ϵ_θ, ϵ_t andϵ_{eff}), with increasing the drawing speed, the values of all the strains will increases because the increasing of the drawing speed gives less time for deformation, so the deformation become more severe, then the metal not have sufficient time to deformed uniformly and lead to increase the strains and maximum values of strains with larger drawing speed equal to (500 mm / min).

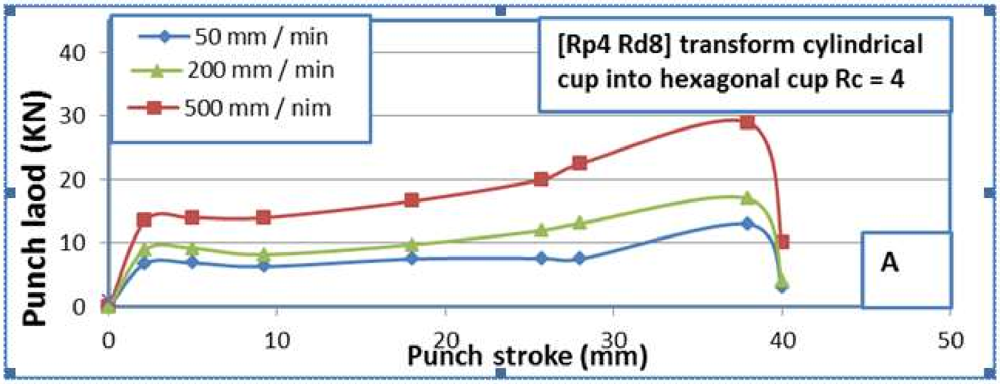


Figure (9) Effect of drawing speed on the drawing force

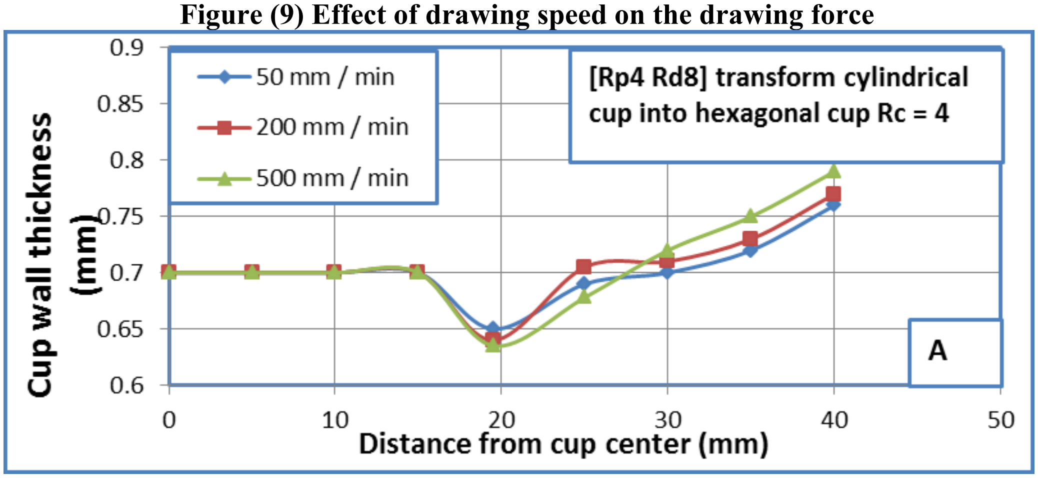
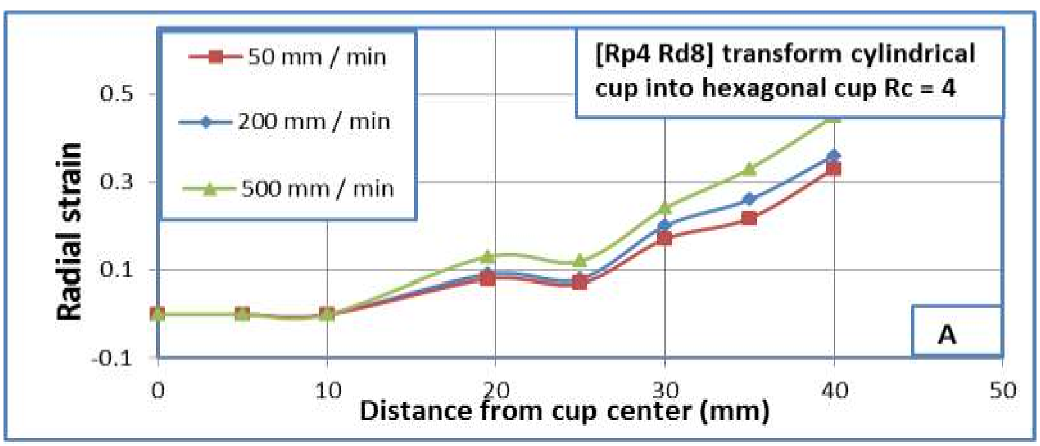


Figure (10) Effect of drawing speed on cup wall thickness



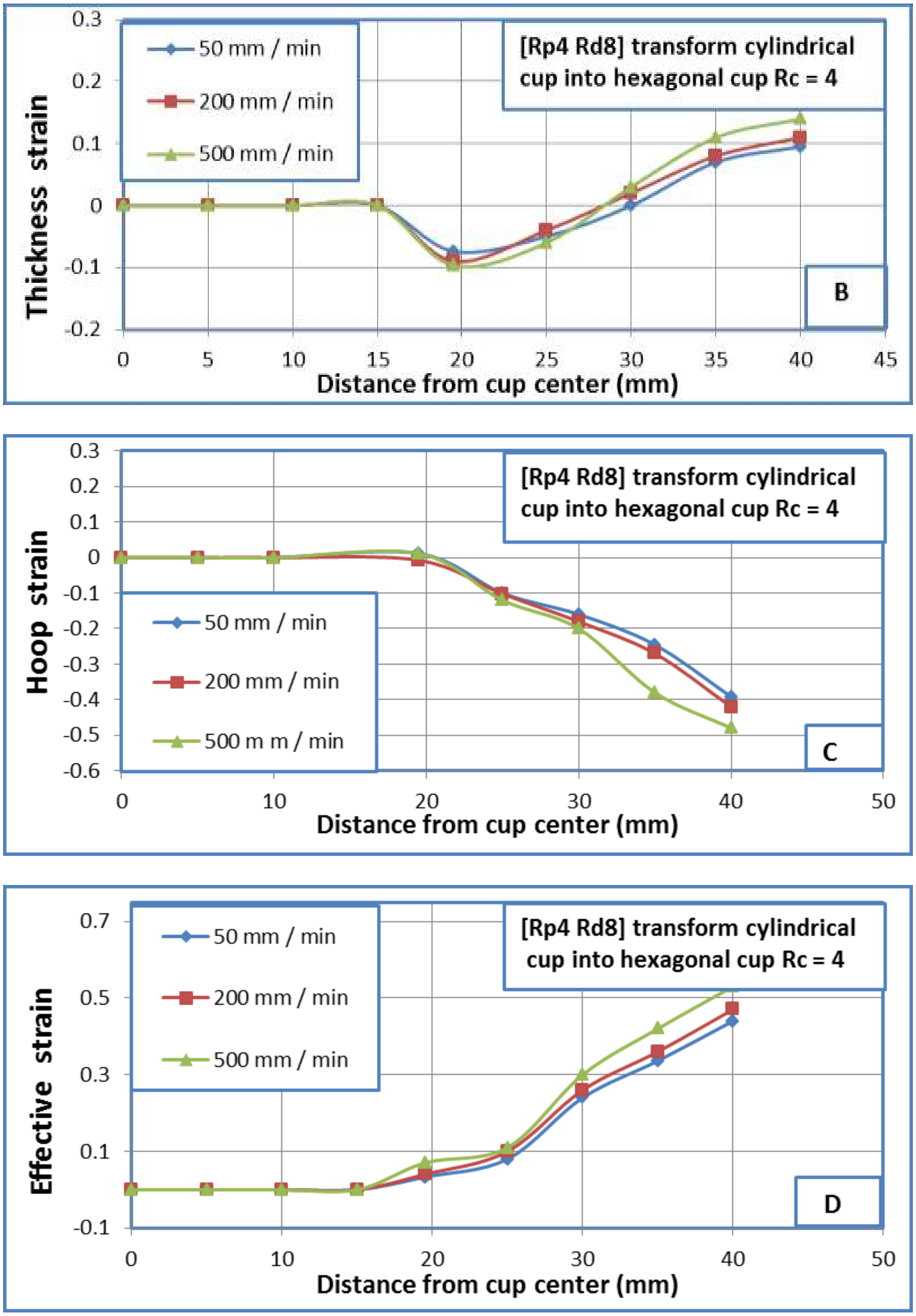


Figure (11) Effect drawing speed on (A) radial strain (B) thickness strain (C) hoop strain (D) effective strain

CONCLUSIONS

1. The maximum thinning occurs at region of cup corner with wall corner radius of die (R_c= 0.7mm)
2. The whole strains (ϵ_r, ϵ_θ, ϵ_t and ϵ_{eff}) increase with increasing drawing speed and the maximum strains at cup rim with larger drawing speed equal to (500 mm / min).
3. The more uniform of 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. High drawing speed (V=500 mm/min) leads to increase drawing force and more thinning in cup corner.
5. 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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