Experimental and Numerical Study the Influence of Sheet Metal Thickness on a Deep Forming Operation of Multi Stages for Hexagonal Cup

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Abstract

In this research, experimental and analytical deep drawing of the several-stages design mold is produce hexagonal cup and also proved the influence of the thickness of the sheet on the allocation of strain and laminating in curvature of the cup area for all stages of the drawing. Three stages deep drawing mold was designed and constructed to carry out the experimental work required to produce a hexagonal cup of (28.25 mm by 24.5 mm) , (60 mm) high drawn from a circular flat sheet (80 mm diameter), made from low carbon steel (1006–AISI). Analysis program (ANSYS11.0) to perform the finite element method to accomplish the analytical side of the search. Three types of thickness sheet ($t_\circ$ = 0.5, 0.7,1 mm) with constant radius of curvature of punch equal to (R_p =4) mm, radius of curvature of die equal to (R_d =8 mm) and radius of curvature of wall of die (R_c= 4 mm) were used.

From the experimental and analytical results of the three stages of drawing, it has been found that drawing load less than the more advanced stages of drawing operation on the wall of cup, maximum laminating take place at curvature of the cup area with sheet thickness equal to ($t_\circ$ =0.5 mm) and maximum thickening take place at the at throat cup with sheet thickness equal to ($t_\circ$ =1 mm), the maximum values of strains (radial, hoop, thickness and effective) take place at throat cup with sheet thickness equal to ($t_\circ$ =1 mm).

Keywords: several stage deep drawing of hexagonal cup, strain allocation, sheet thickness.

1. Introduction

Several stage drawing operation of a sheet material experimental additional complicated distortion in each stage compared to a traditional drawing operation. This process generally includes additional bending, stretching, squeeze and trimming by various drawing ratios through the next drawing step. The distortion naturally yields with the asymmetrical forms of the cross section and environments that cause fault like ripping and creasing. The fault of the formation operation is affected by many operation factors like the drawing ratio in each step, the variation of the drawing ratio within the cross-section, the profile of the die, the strain-hardening coefficient, material, the lubrication environments and the degree of ironing. One of the key factors influencing the drawing operation is the sheet thickness [1].

Since several of researchers have analyzed the forming operation the current exposition here will effort only on the researches about some of factors in deep forming will be an efficient way to avoid lamination and creasing in forming operation.

Y. Marumo and Saiki. H [2], investigated the effect of sheet thickness on sheet holding force and limiting drawing ratio. It shows the creasing height decreases with increasing blank holding force increases as the sheet thickness increased. When the sheet thickness increases, the limiting drawing ratio is robustly affected by the coefficient.

S. Kim, **et al**. [3] studied the die design of several stages deep drawing operation for dissimilar shapes. They used direct and inverse FEA method to optimize the process parameters, such as the intermediate die, punch geometry, sheet shape, sheet thickness, sheet holding force, friction and lubrication. The FEA has introduced an efficient solution to minimize creasing, and for the improve quality product.

A. A. Kumar, [4], investigated the effect of plate thickness and punch grossness on the formability of interstitial-free plate plates in hydro mechanical deep drawing. From the comparison between the results, it has been found out that the minimum required adverse pressure for successful drawing increases with increase in plate thickness. Formability of 1.2 mm plate improved with increase in punch grossness. As the punch grossness increases, the minimum required adverse pressure decreases because of improved friction holding influence. For the same punch grossness, the minimum required adverse pressure increases with increase in blank diameter.

R. Venkat Reddy, et al [5], studied the effect of several parameters such as plate holder force, punch arc, plate thickness, die arc radius, and coefficient of friction on the creasing of cylindrical cups in deep drawing operation.it proves the height of the puckers is minimized by increasing the plate holding force, decreasing friction, increasing the die arc radius and increasing plate thickness.

H. Zein and M. El-Sherbiny [6], studied the effect of die arc radius, punch arc radius, plate thickness, radial clearance, the plate holder force and coefficient of friction on the thickness allocation and thinning of plate metal blank in the deep drawing operation. It has been shown that the cup avalanche due to lamination increases with the increasing of the plate holder force. For fluid lubricant, it has been shown that the allocation in plate thickness decreases with increasing of the coefficient of friction between punch/sheet. For dry lubricant, the allocation in sheet thickness stables with increasing the coefficient of friction between punch/sheet

K. Gowtham, and S. N. Murty, [7], investigated the parameter effecting a drawing operation and analyzing the operation by change the Die arc and keeping the Friction, Punch arc and plate Thickness. It has been proved that as the die arc is reduced, the amount of fore required to drag the material is increased, decreased die arc created extending marks and earring type quality problems, plate thickness is increased , the amount of fore required to drag the plate is increased.

K. Shah, et al [8], studied the influence of several operation parameters such as plate holder load , die arc, punch arc, plate diameter, friction between punch and plate and die, normal anisotropy of material, plate thickness and many more. The main objectives of the present study are to determine the most critical operation parameters that cause cracks and lamination in the plates.

C. P. Singh. and G. Agnihotri, [9], investigated many operation factors and other factors that effect of product quality produced by deep forming such as plate-holder pressure, plate thickness, punch arc, die arc, material properties, and coefficient of friction. It proves plate holder force controls metal flow, it also influence thickness difference, strain path, stress path and creasing behavior, that optimum plate shape reduces forming force , increases forming limits and reduces possibilities of creasing and cracking.

K. N. Joshi, et al [10], studied of the influence of arc of die draw, plate thickness and plate holder load on different in wall thickness of the deep drawn cup and select their optimal values using full parameters design using numerical simulations. The different in wall thickness is reduced perform analysis of difference (ANOVA) for individual parameters and their interactions.

The influence of the arc of die, plate holder and punch load, friction, cup wall, and plate thickness in the process were investigated by **S. Sezeket, et al** [11]. The results showed that the plate holder, die arc and friction have the greatest influence on the lamination of forming cups. The plate diameter of limiting drawing ratio has an effect on the plate holder load and it minimized with increasing die angle (α). The limiting drawing ratio increases with decreasing die angle.

H. Gurun and I. Karaagac, [12], investigated the influence of chamber pressure, die arc and plate thickness on the drewability through hydro-mechanical and convention and deep drawing methods. The results show that, increases die chamber pressure, the forming load increases. In conventional drawing experiments, the highest drawing ratio, 2.16, was obtained in 0.8 mm and 1.0 mm thick plates, which are the higher plate thicknesses, or in bigger die arcs.

This paper aimed to produce hexagonal cup from circular flat blank without any defects such as tearing and creasing.

2. Experimental work

Three stages deep forming experimental were perform to get hexagonal cup of (28.25mm×24.5) outer diameter, and (60mm) height drawn from flat sheet by mounting deep drawing die as shown schematically in figure (1) and picture in figure (2).The experimentation 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. The sheet from which it is formed has a diameter of (80mm), (0.7mm) thickness and is comprised of low carbon steel (1006–AISI) of the following chemical composition is listed in table (1). Three types of sheet thickness equal to (R_c = 0.5, 0.7,1 mm) were chosen with fixed punch curvature radius equal to (R_p = 4 mm), wall curvature radii of die equal to (R_c = 4 mm) and die curvature radius equal to (R_d = 8 mm) to study the effect of sheet thickness on the forming operation, cup wall thickness and the strain allocation over the cup wall of completely drawn and redrawn part.

The first stage of forming was carried out by using hexagonal punch with dimensions (43mm×,37.25mm), die with dimensions (44.5mm× 38.8mm) and dies clearance equal to (10% original thickness of the sheet) was chosen. The second stage of drawing was carried out by using hexagonal punch with dimensions (34mm×29.5mm), die with dimensions (35.6mm×31.1 mm) and dies clearance equal to (15% original thickness of the sheet), while in third stages of drawing hexagonal punch with dimensions 28.25mm× 24.5mm), die with dimensions (29.9mm× 26.2mm) and dies clearance equal to (20% original thickness of the sheet) was chosen as shown schematically in figures (3,4,5).

In order to study the strain allocation in the hexagonal cups 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 (6).

Thickness micrometer and tool microscope were used to measure the cup wall thickness and change in the grid circles after distortion. Cup thickness and the length of disfigured grid radius in three stages were measured along the intersecting lines along the curve as shown picture in Figure (7) and schematically in figure (8).

Thickness strain and radial strain allocation were derived from the measured thickness and disfigured 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 sheet, (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.

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

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

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

3. Numerical Simulation

A hexagonal cup of (43mm × 37.25mm) outer diameter, and (30mm) height for first stage, (34mm×29.5) outer diameter, and (45mm) height for second stage, (28.5mm×24.25) outer diameter, and (60mm) height for third stage, was chosen for detailed analysis of the three stages drawing operation. The blank from which it is formed has a diameter of (80mm) is made of low carbon steel of 0.08% carbon content and mechanical properties as list in table (2)[13]. 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 elements of (SOLID45), (PLANE82) and (SOLID95) were used for the blank. For rigid (tool set)-flexible (blank) contact, target elements of (TARGE170) and (TARGET 169) 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) and(CONTA174 . The finite element model of the sheet material and drawing die hexagonal is shown in Figure (8). A friction of coefficient with value (μ=0.11) was employed. The clearance between punch and die was set to be (10% original thickness of the blank) for first stage, (15% original thickness of the blank) and (20% original thickness of the blank) for third stage[13]. Three types of sheet thickness (R_c= 0.5, 0.7,1 mm) were used. A successive final stage of the deep drawing sheet are shown in figure (9 A and B) respectively.

Table (2): Mechanical properties of low carbon steel (1006–AISI)

Property	Value
Young modulus (Gpa)	200
Position ratio	0.29
yield stress (MPa)	125
tangent Modulus (GPa)	0.52

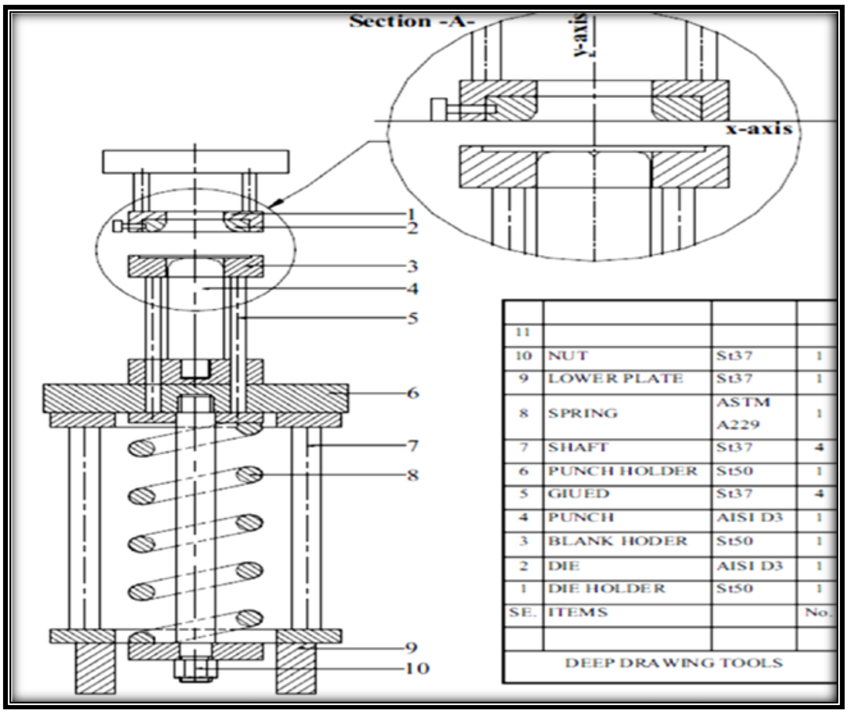


Figure (1): The schematic of deep drawing tools used

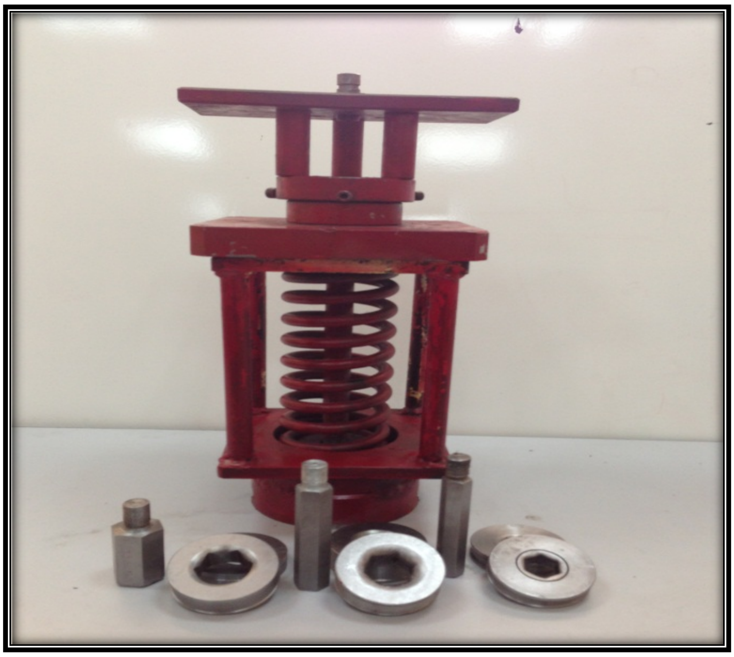


Figure (2): The picture of deep drawing tools used

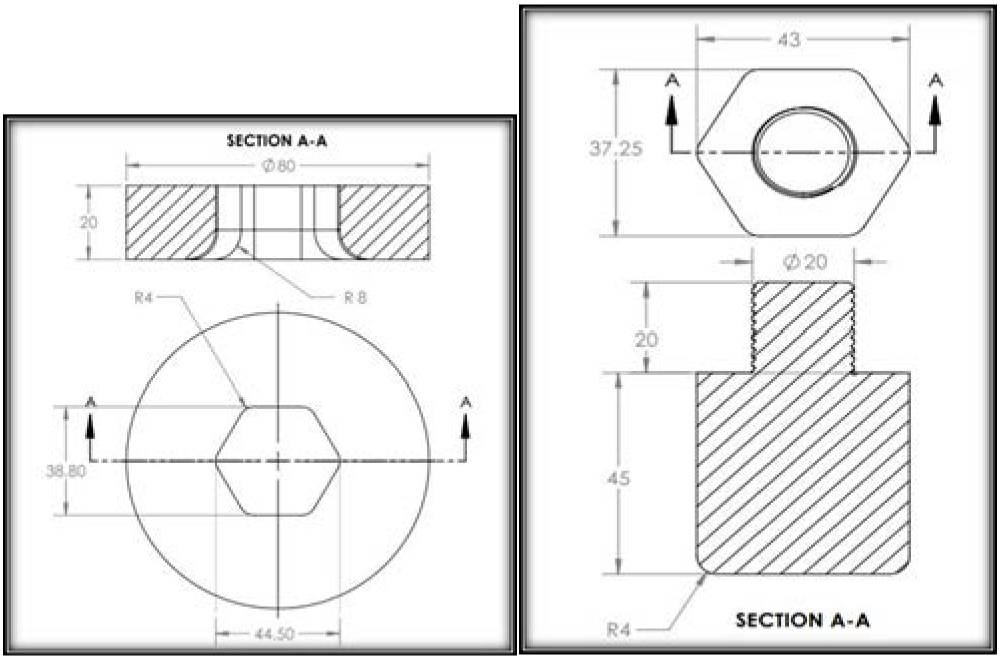


Figure (3): The die and punch in first step schematically

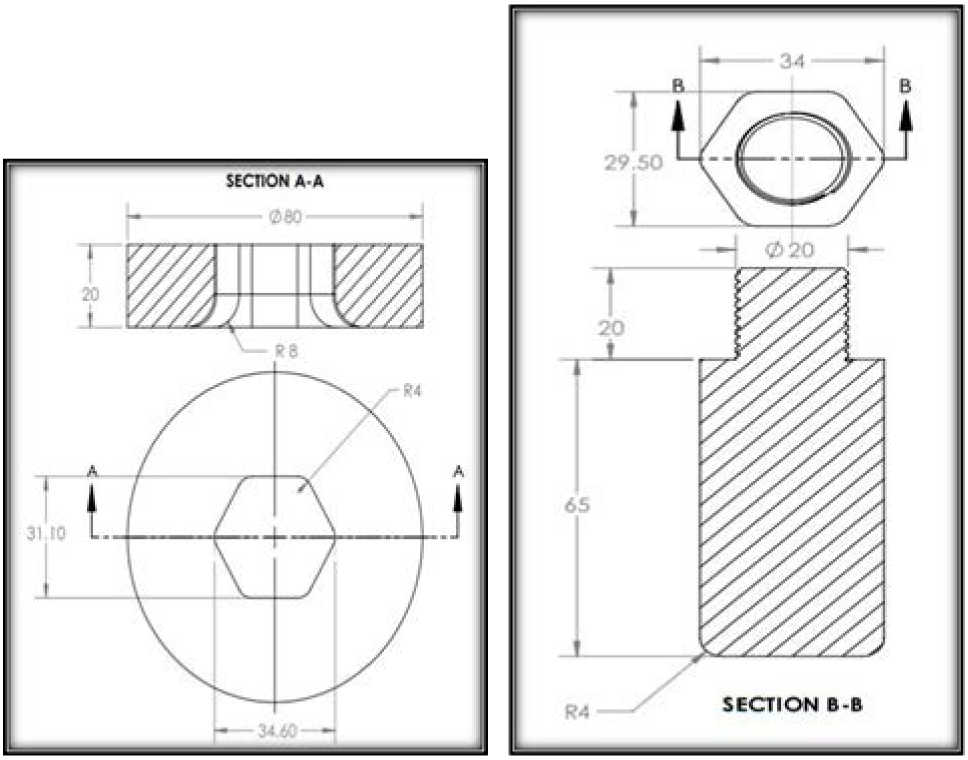


Figure (4): The die and punch in second step schematically

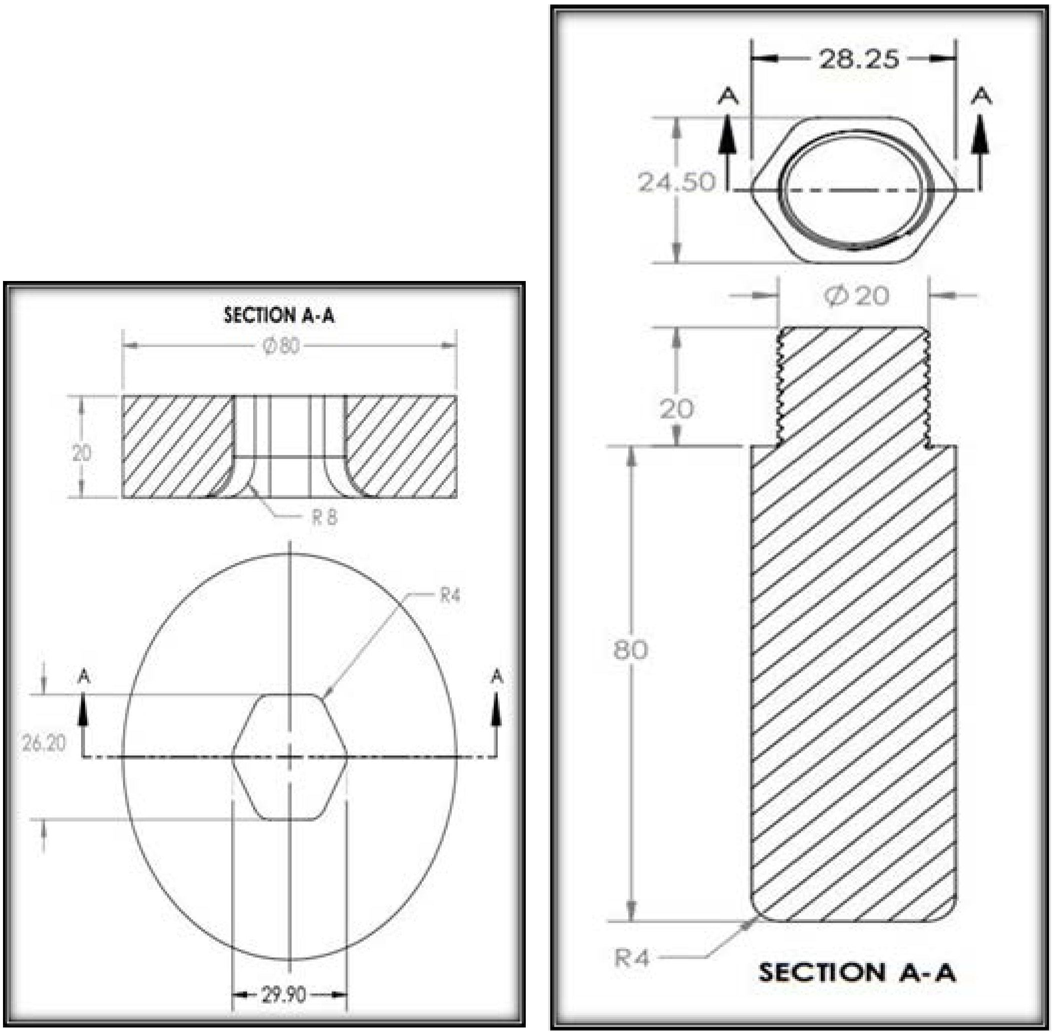


Figure (5): The die and punch in third step schematically

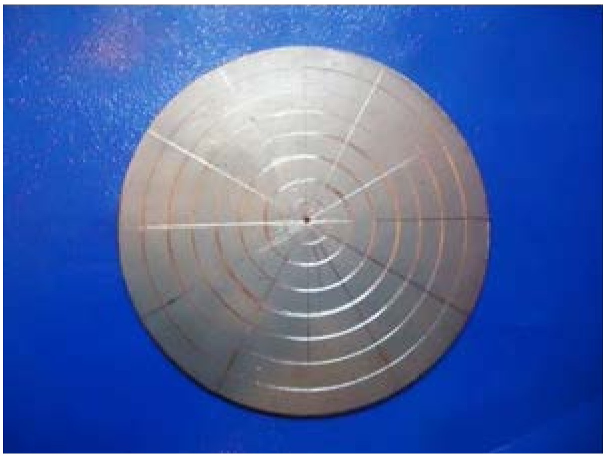


Figure (6): the sheet with grids, by using mechanical grid marker

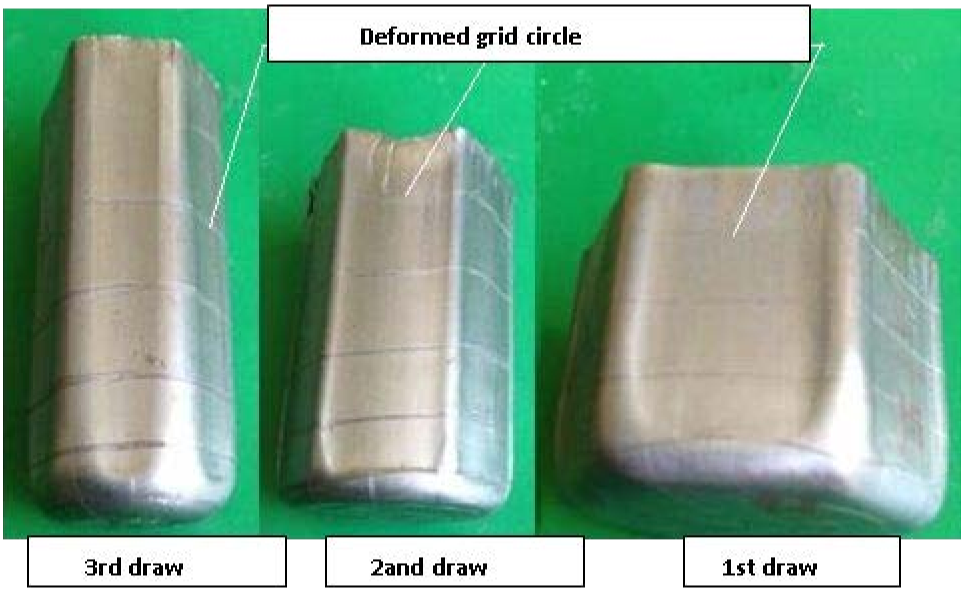


Figure (7): the distortion of grid on hexagonal cup in three stages.

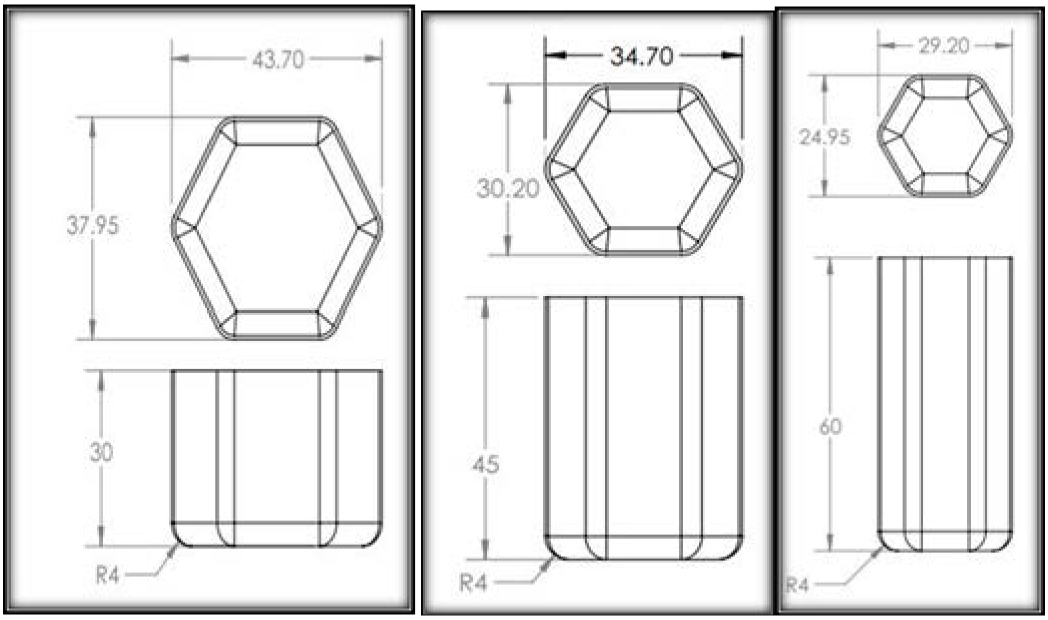


Figure (8): The cup for three steps schematically

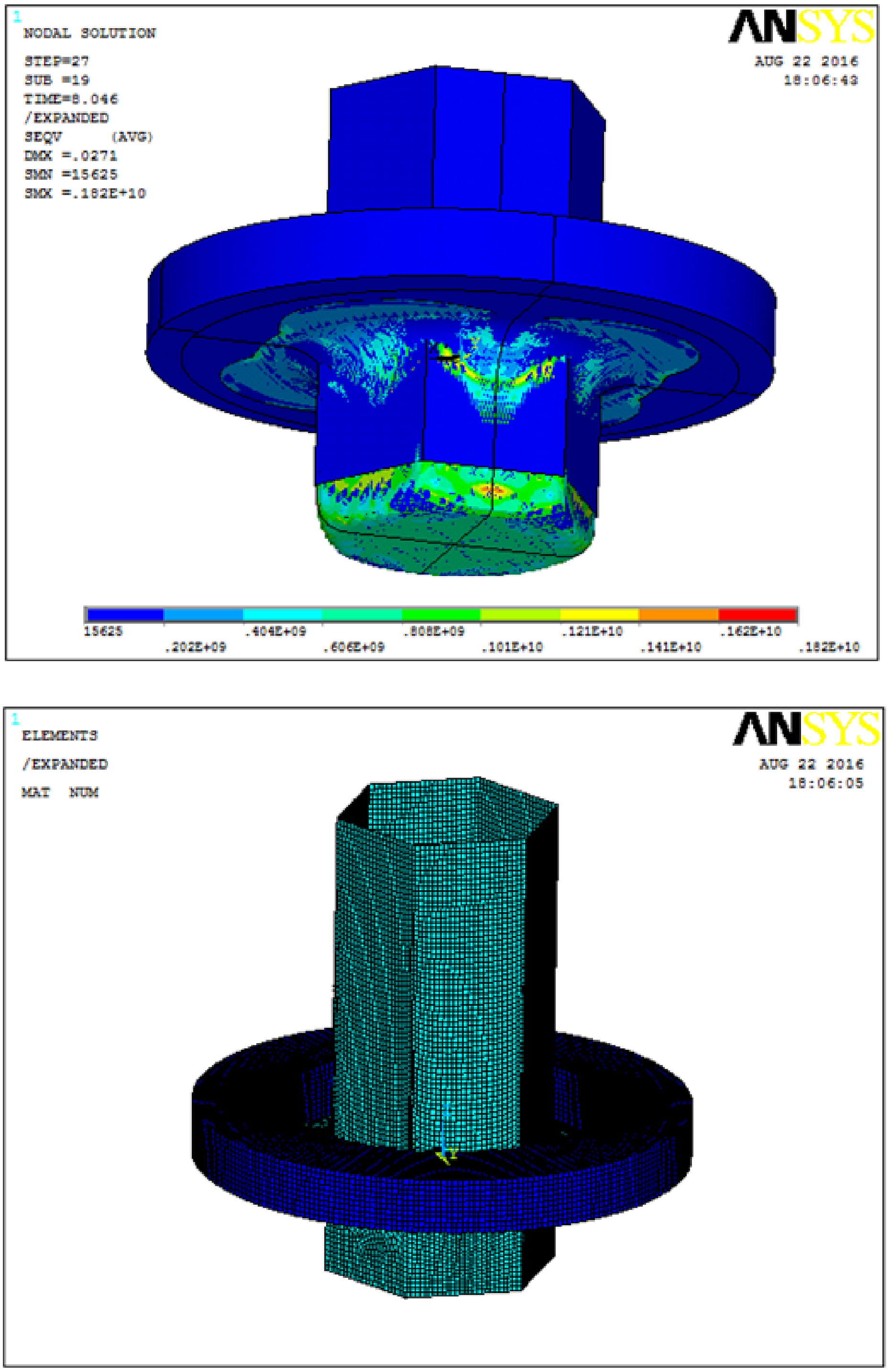
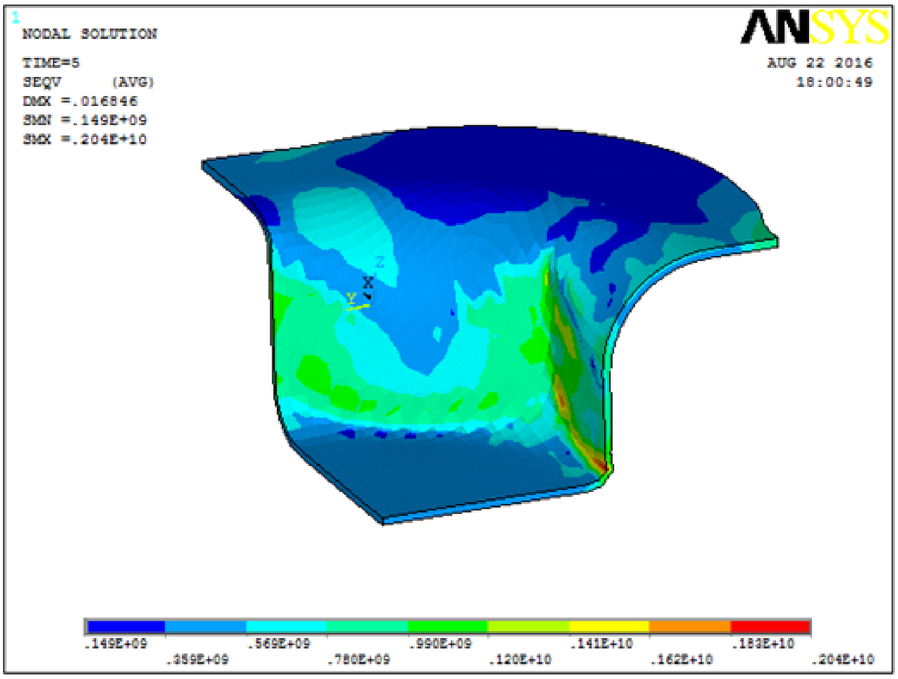


Figure (8): Finite element model of the sheet material and forming Hexagonal



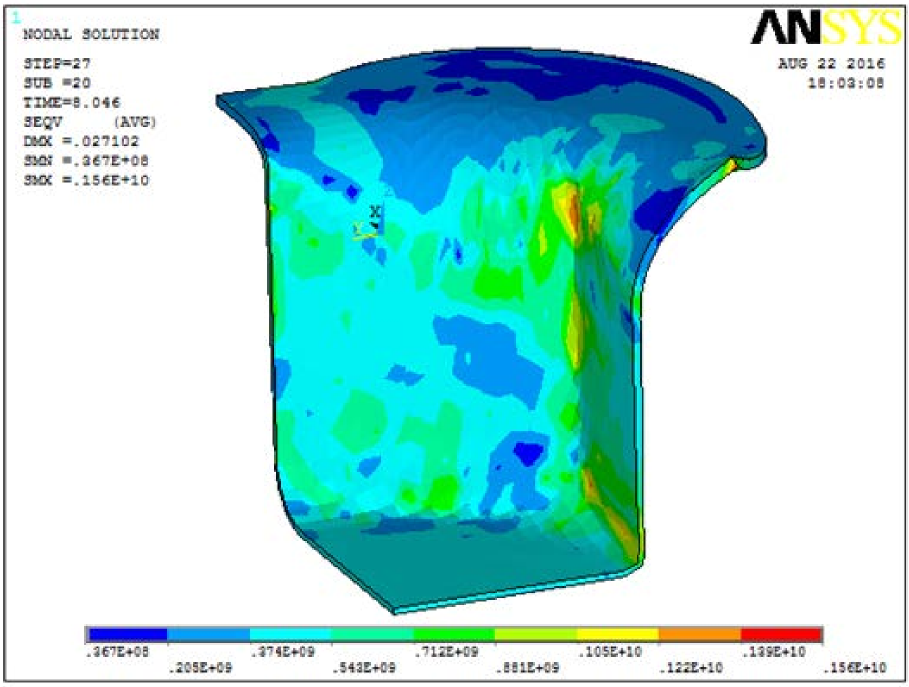


Figure (9): A successive final stage of the deep forming sheet

4. Results and Discussions

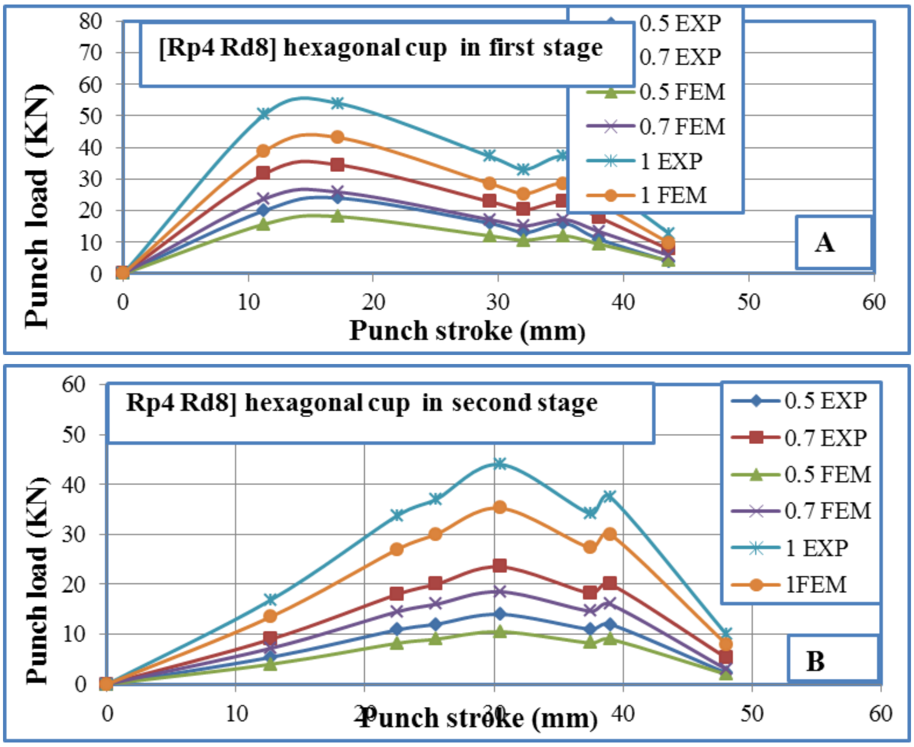
Figure (10) shows the variation of the forming load with the punch stroke under different sheet thickness for three stages during several stages deep forming. It is clear that the forming load less than the more advanced stages of drawing operation this is because reducing ratio between following step of drawing as well as amount of metal drawn in each following drawn is less than previous, the deformation lead to reduce contact condition between cup produced from following step and die, fore there reduce the drawing force. This mean that the drawing force decreases with each following step[13], the forming load increases with increasing sheet thickness and maximum value with larger sheet thickness equal to ($t_\circ$ =1 mm), in both experimental and numerical.

Figure (11) represents the effect of sheet thickness along the wall cup for three stages during several stages deep forming deformation.

It is obvious from the figure that, the lamination increases in every stage of drawing process at the punch curvature radius and increases with increasing sheet thickness, this happens because of extension pended by tensile stress in this zone [13], also it is clear that the maximum lamination take place at cup curvature with smaller sheet thickness ($t_\circ$ = 0.5 mm) and maximum thickening take place at cup end with larger sheet thickness ($t_\circ$ =1 mm).

Figures (12 to 15) show the strain allocation 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}) increasingly more advanced stages o of forming operation. Under punch curvature zone from cup center, the radial strain (ϵ_r) will increase with increasing sheet thickness and continues until the edge of cup reaches a maximum value with largest sheet thickness ($t_\circ$ =1 mm). The thickness strain (ϵ_t) starts to change at the punch curvature zone and has a negative value and also increases with increasing sheet thickness**.** Afterward the cup wall zone thickness tends to increase, and this is caused by compressive stress applied to this zone. At the edge cup, it is clear the thickness increases with increasing sheet thickness and the higher value occurs with larger sheet thickness value ($t_\circ$ = 1mm). Circumferential (hoop) strain (ϵ_θ) begins to increase at punch curvature zone (expands in circumference), then it begins to decrease towards cup wall and has a negative value (diminishes in circumference) and it continues to decrease to reach a maximum value at the edge of cup and this value increases with increasing sheet thickness and maximum value with larger sheet thickness equal to ($t_\circ$ = 1 mm). effective (equivalent) strain (ϵ_{eff}) has a tensile behavior, punch curvature zone, 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 edge of cup and this value increases with increasing sheet thickness and maximum value with larger sheet thickness equal to ($t_\circ$ = 1 mm). The influence of different sheet thickness on strains (radial, hoop, thickness and effective) is seen in every stage of the deep forming operation.

From the experimental and analytical results of the three stages of drawing, it has been found that numerical simulation results more accurate than experimental results because the numerical simulation gives perfect results while the experimental results of the sampling error for the biggest result of the movement during the measurement process and the lack of accurate measurement devices.



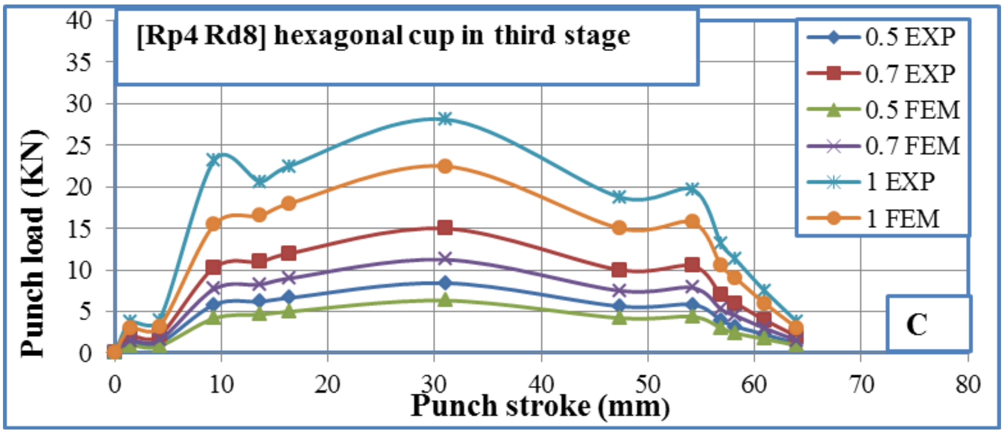


Figure (10): influence of sheet thickness on punch force in three stages

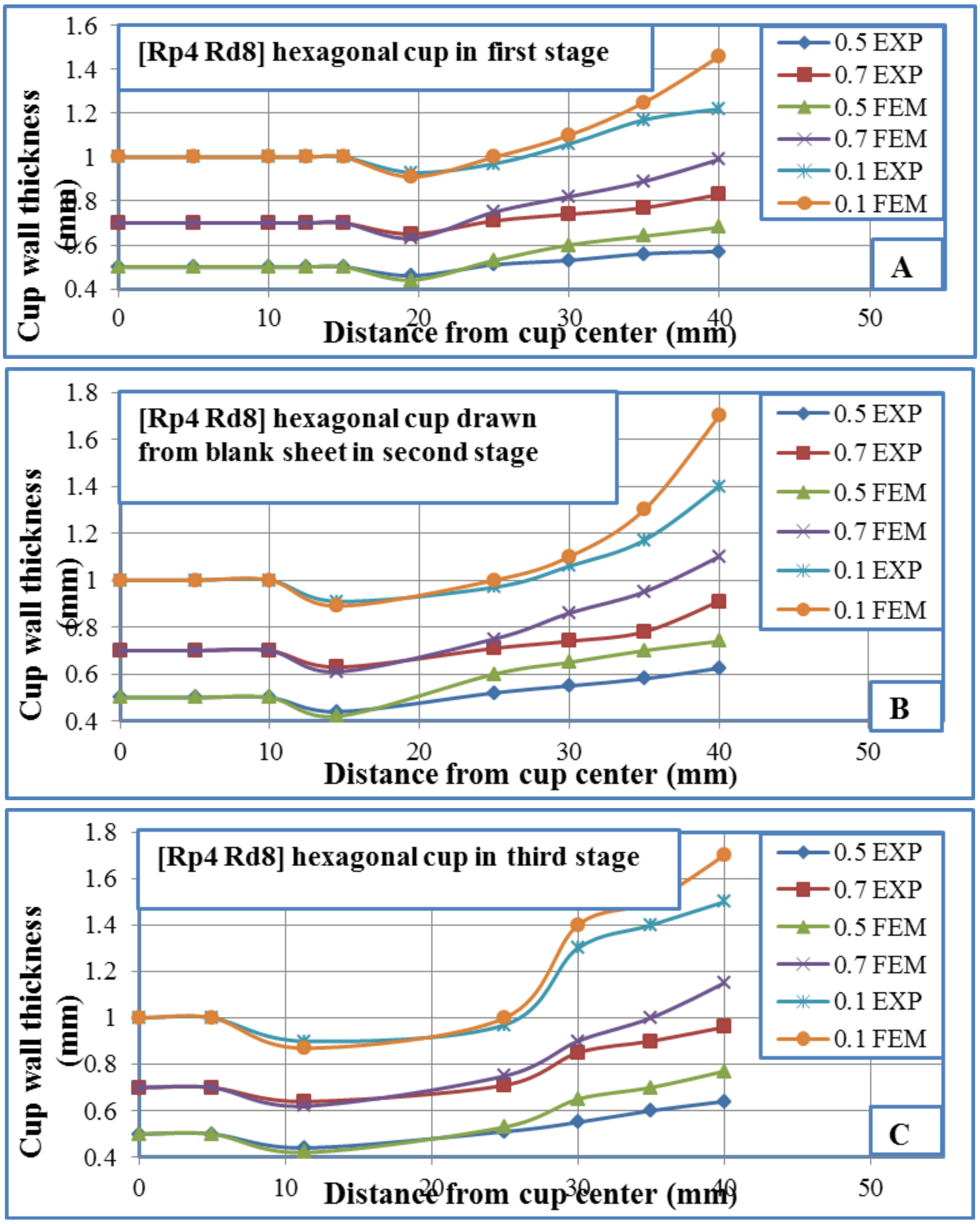


Figure (11): Influence of sheet thickness on cup wall thickness in three stages

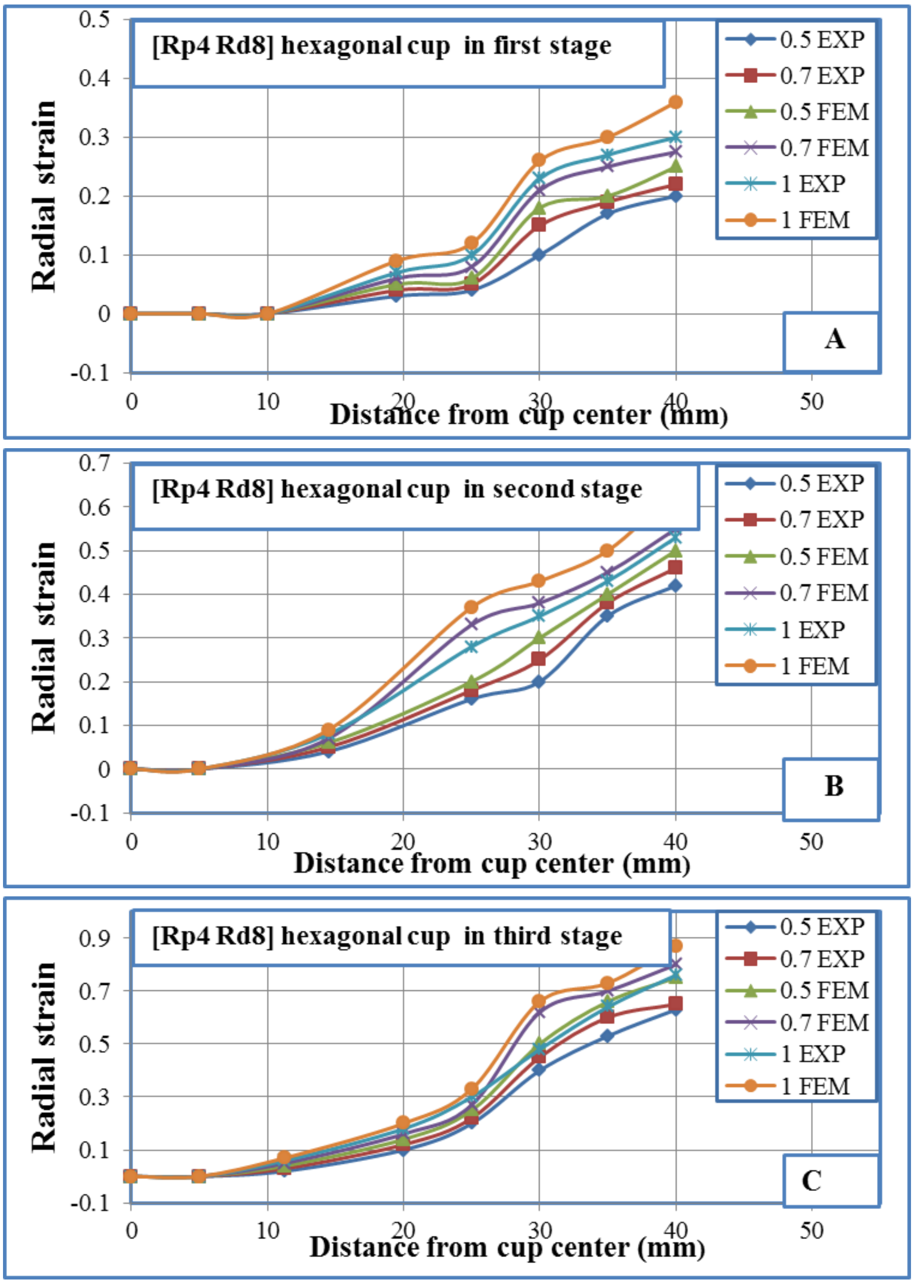
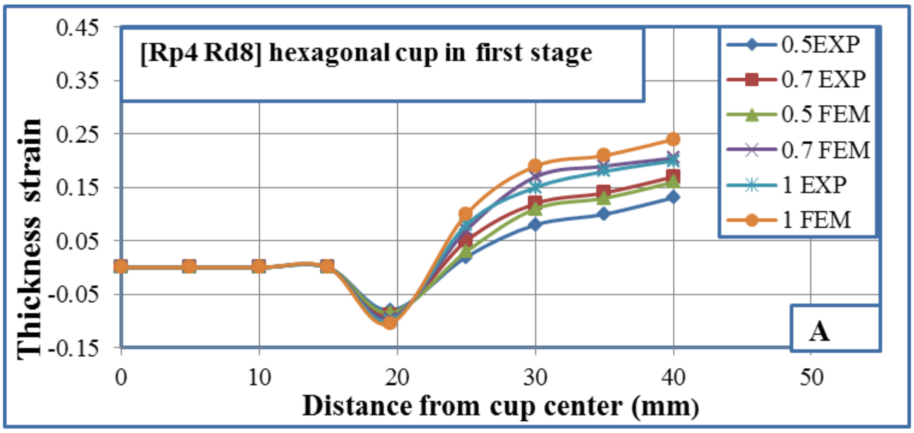


Figure (12): Influence of sheet thickness on radial strain in three stages



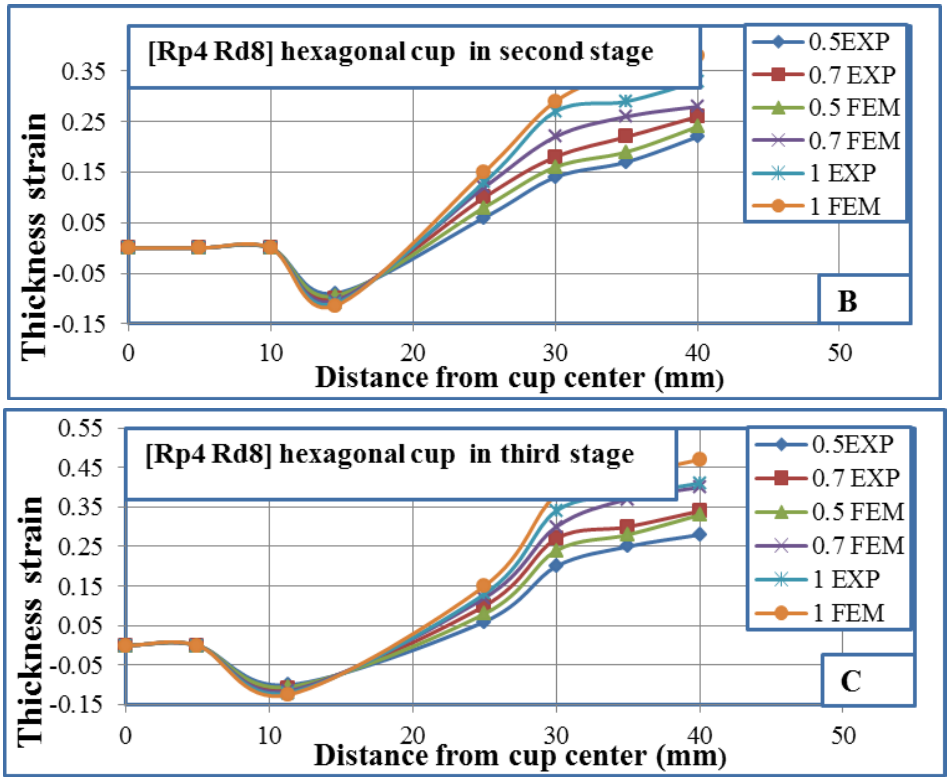
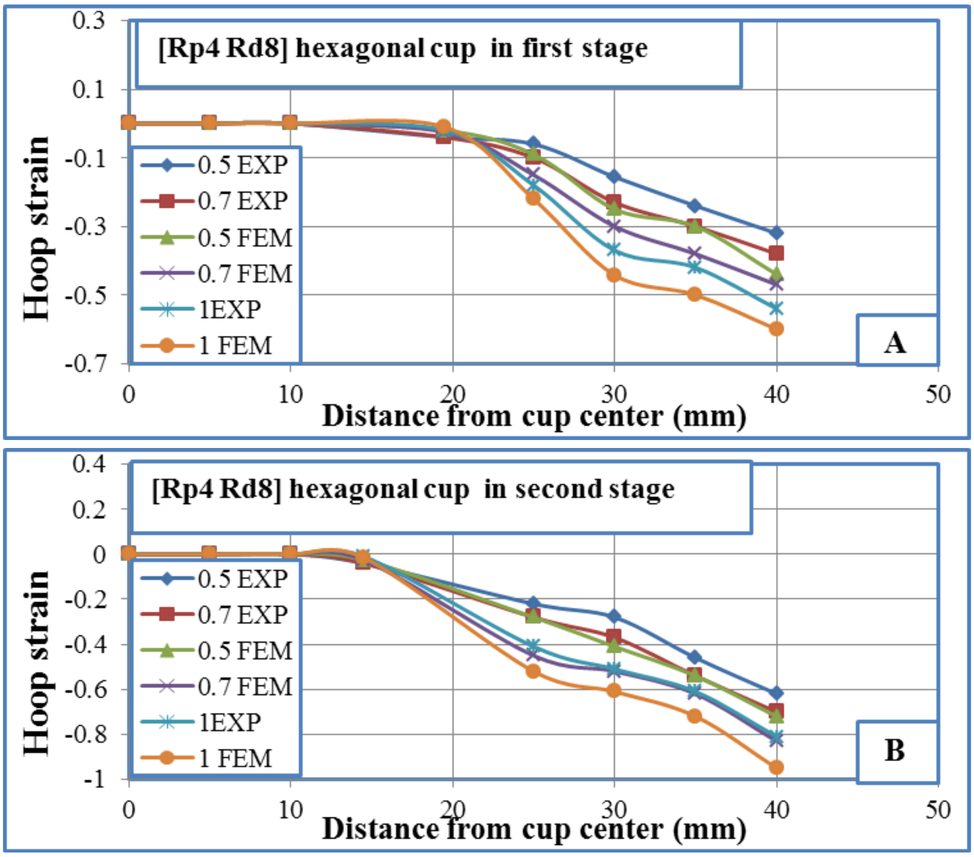


Figure (13): influence of sheet thickness on thickness strain in three stages



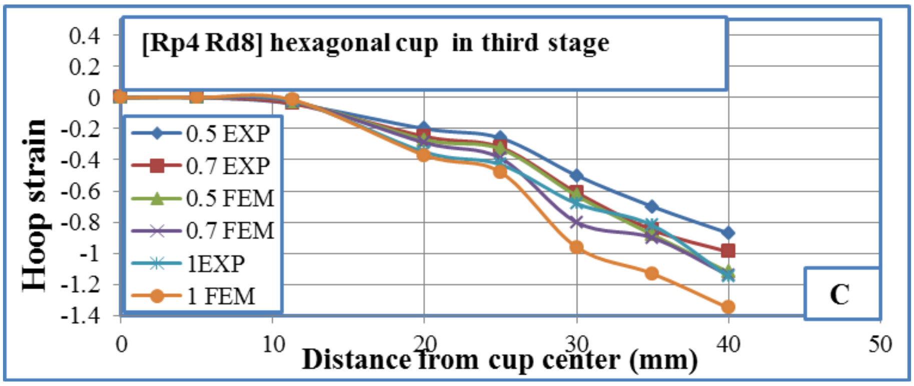


Figure (14): Influence of sheet thickness on hoop strain in three stages

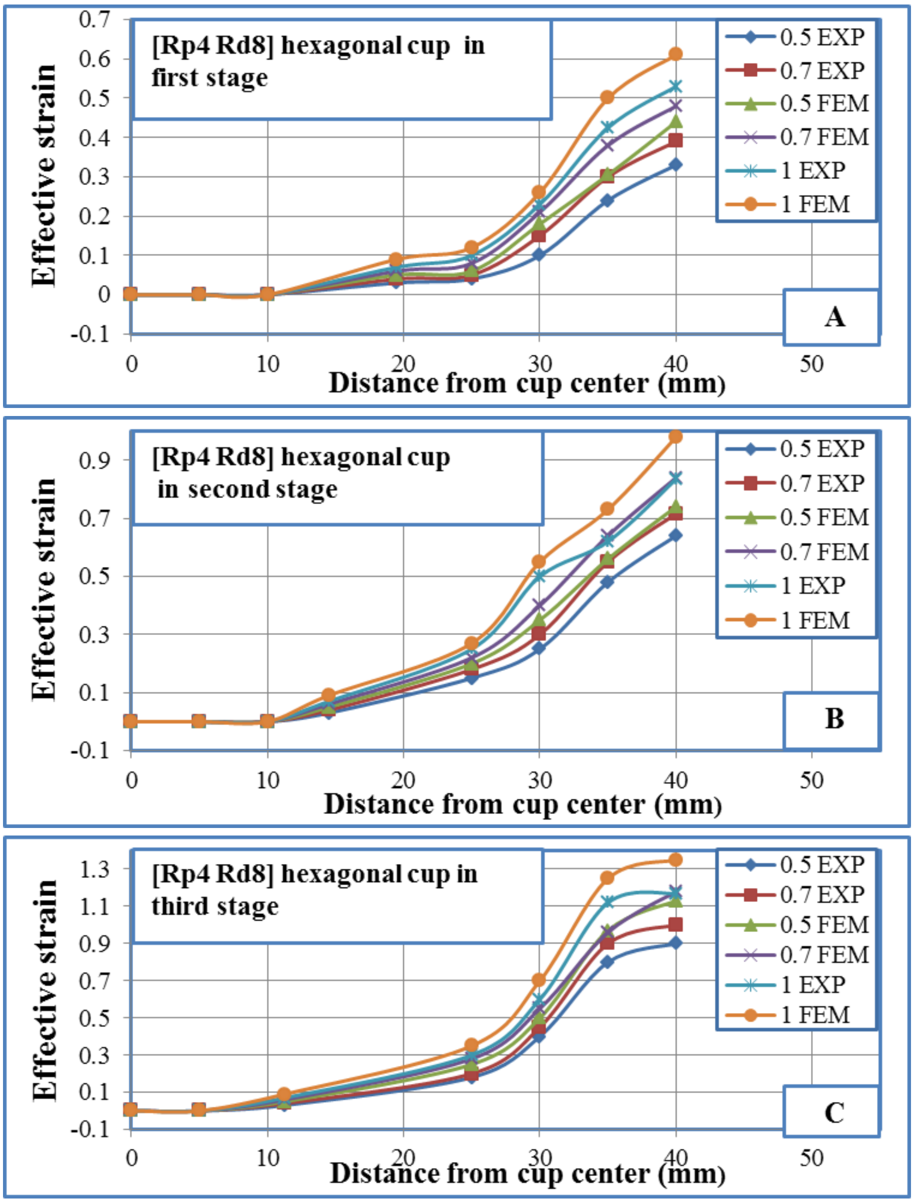


Figure (15): Influence of sheet thickness on effective strain in three stages

5. Conclusions

1. The maximum lamination occurs at region of cup curvature with sheet thickness (1 m)
2. The whole strains (ϵ_r, ϵ_θ, ϵ_t andϵ_{eff}) increase with increasing sheet thickness and the maximum values of strains at edge of cup with larger sheet thickness (1 mm)

3. the drawing load less than the more advanced stages of forming operation, and increases with increasing sheet thickness, maximum value with larger sheet thickness equal to (=1 mm)
4. It can be concluded that the more lamination take place in the cup curvature and continuous the lamination when drawing second and third stage.

6. References

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دراسة عملية ونظرية لتأثير سمك الصفيحة على عملية السحب العميق لشكل سداسي

صبيح سلمان الغراوي
أمانة بغداد

علي طعيمة
وزارة الصناعة والمعادن

الخلاصة

في هذا البحث، تم دراسة عملية السحب العميق ولعدة مراحل لتصميم قالب سحب ولثلاث مراحل لانتاج قدح سداسي بابعاد (24.5 mm x 28.25 mm) وبارتفاع (60 mm) من صفيحة معدنية دائرية من حديد منخفض الكربون. طريقة العناصر المحددة تم تنفيذها باستخدام برنامج (ANSYS11.0). تم استخدام ثلاث أنواع من سمك الصفيحة (70mm, 80, 90) مع نصف قطر تقوس القالب الذكر (4= mm) ،نصف قطر تقوس القالب الأنثى (8= mm) ،نصف قطر تقوس جدار القالب. (4 = mm) بمقارنة النتائج النظرية والعملية للمراحل الثلاثة وجد حدوث انخفاض في قوة السحب مع توالي المراحل المتعاقبة على جدار القدح ، أقصى ترقرق يحدث للسمك في منطقة تقوس القدح مع استخدام سمك صفيحة مساويا ل (0.5= mm)، أقصى قيم الانفعالات (الانفعال القطري ،المحيطي ،السمك والمكافئ) في منطقة حلق القدح مع استخدام سمك صفيحة مساويا لـ (1= mm).