Effect of Blank Holder Inclination Angle on Deep Drawing of Round Mild Steel Cup with Flange

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ABSTRACT

The work aim to study the effect of the blank holder slope angle on deep drawing parameters such as: punch force, strain state and thickness distribution along cup wall of drawn part. 3-D model of cylindrical cup of (40mm) outer diameter, and (0.5mm) thickness from mild steel (1008–AISI), has been developed. Due to the symmetry in the specimen geometry, only one fourth portion of the model needed to be analyzed. A commercially available finite element program code (ANSYS14.0), was used to perform the numerical simulation of the deep drawing operation. The numerical results of this model were compared with experimental results. Four types of blank holder and dies with slope angle (0^o, 7.5^o, 15^o, 22.5^o) .the experimental and numerical results show that the required punch force decrease with increase in blank holder slope angle , The best thickness distribution over all zones in produced cup obtained when using blank holder with angle $\alpha = 15^\circ$.

Keywords:-Blank Holder Types. Deep drawing operation. Sloping blank holder. Concave blank holder. Numerical simulation.

تأثير زاوية ميل ماسك الغفل على عملية السحب العميق لقدح دائري من الفولاذ الطري

الخلاصة

يهدف هذا البحث الى دراسة تأثير زاوية ميل ماسك الغفل على متغيرات العملية في عملية السحب العميق مثل القوة اللازمة للخرامة وحالة الانفعالات وتوزيع السمك على جدار القدح .تم المحاكاة باستخدام نموذج ثلاثي الابعاد لكأس اسطواني بقطر خارجي (40mm)وسمك جدار(0.5mm) من فولاذ مطيلي (1008–AISI) وبسبب التناظر في الشكل الهندسي للنموذج تم دراسة ربع واحد فقط وذلك باستخدام طريقة العناصر المحددة باستخدام برنامج (ANSYS 14.0) نتائج المحاكاة قورنت مع نتائج العمل التجريبي .اربعة انواع من ماسك الغفل مع اربعة انواع من القوالب بزوايا ميل هي (0^o, 7.5^o, 15^o, 22.5^o) لمواسك الغفل والقوالب.بينت النتائج العملية و المحاكاة ان القوة اللازمة للخرامة تنخفض بازدياد زاوية الميل كما اظهرت النتائج العملية و المحاكاة ان افضل توزيع للسمك على جدار القدح تم الحصول عليه بماسك غفل ذو زاوية ميل $\alpha = 15^\circ$.

INTRODUCTION

Thinner gauge sheets with high strength are used in sheet metal forming in order to reduce the weight of the products, which leads to formation of buckles and wrinkles during the forming operations. The use of Conventional types of Blank Holding method (flat and gap type) not only prevents wrinkling but also leads to thinning or tearing in the final product, because of low gauge thickness and high limit drawing ratio (LDR). Therefore, many special processes have been proposed to change the situation of applying blank holder force (BHF) that improves metal flow as possible. Many researchers that reported success by using a decreasing BHF profile includes Gunnarsson [1] who concluded that for axisymmetric deep drawing, decreasing BHF from a constant value to zero produced superior results as compared with constant or increasing BHF profile in terms of achieving greater draw ratio without tearing. On the contrary many authors claimed success using increasing BHF trajectories, these include, Hirose et al [2].The work of these author showed that successful cups can be drawn by keeping the BHF at a minimum before wrinkling starts, and then upon detection of wrinkles just raising enough to suppress wrinkling. However, care must be exercised that BHF is not raised so high as to cause tearing. Hishida and Wagoner[3] although achieved success using an increasing BHF profile for automotive fender panels; concluded that, relative effectiveness of increasing or decreasing BHF may be reversed depending on the geometries and strain histories involved. Wang et al. [4] conducted an experimental study on the Process modelling of controlled forming with time variant blank holder force using Response Surface Methodology (RSM). The forming processes with several types of time variant BHF were simulated and compared to find a suitable one to achieve the desired product features. The comparison implied that the staircase-shaped time variant BHF can direct the strain path to the desired place to acquire a targeted product. Savas and Secgin [5] investigated the effects of blank holder and die shapes. The distribution at blank holder force is measured with change in BH shape and the optimal shape had been reached. Koyama et al. [6] obtained a high quality product with higher strength through the implementation of the simulator with the variable blank holding path obtained by the virtual database and FEM-assisted intelligent press control system. Using the database and FEM-assisted intelligent press control system, the process control path was determined without assistance from an engineering expert and high efficiency of our process control system was confirmed. Younis [7] studied of the effect of using constant, variable and non-uniform blank holder force(BHF) between the blank and blank holder on the thickness distribution. the best value of blank holder force were achieved at Variable Non-Uniform type

This paper aimed to study the effect of blank holder inclination angle on deep drawing parameters, and the final product features.

Numerical Simulation

For simulating the deep drawing processes, commercial FEA software ANSYS14.0 was used, in which the "Newton-Raphson" implicit approach was employed to solve nonlinear problem. In this approach, the stroke steps on punch are defined explicitly over a time span. Within each step, several solutions (substeps or time steps) are performed to apply the displacement gradually. At each substep, a number of equilibrium iterations are performed to obtain a converged solution. The 3-D 8-node structural solid element of SOLID45 was used for workpiece (blank).The tool set (punch, die and blankholder) was modelled as rigid bodies. Element sizes are controlled by controlling the division specification of lines. Mesh density of the blank and tools affect the accuracy of the results. So the meshes in the blank are finer. The most important portion of the tool whose mesh density affects the accuracy and reliability of the results is its arc segment and the meshes of this portion are finer than other portions. The movement of the punch was defined using a pilot node; this node was also employed to obtain the drawing force during the simulation. The degrees of freedom of the pilot node represent the motion of the entire rigid surface. Automatic contact procedure in ANSYS14.0 was used to model the complex interaction between the blank and tooling. 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 body (blank) represented by 3D 8-node contact elements of CONTA174. The contact and target surfaces constitute a "contact pair", which was used to represent contact and sliding between the surfaces of tool set and workpiece (blank). A deep drawing model was created. Due to the symmetry in the specimen geometry constraints and boundary conditions, only a one fourth portion of the model needed was analyzed. The finite element model of the sheet material and drawing die is shown in Figure (1). For simplifying the simulation of the deep drawing processes, the following assumptions were made: temperature of workpiece (blank) remained constant, no heat transfers between workpiece and tool set; the dies were rigid, the upper die (punch) moved down at constant speed (55mm/min) during the forming process and the lower die (cavity) was stationary. Bilinear Isotropic Hardening (BISO) option uses the von Mises yield criteria coupled with an isotropic work hardening assumption. This option is often preferred for large strain analyses.

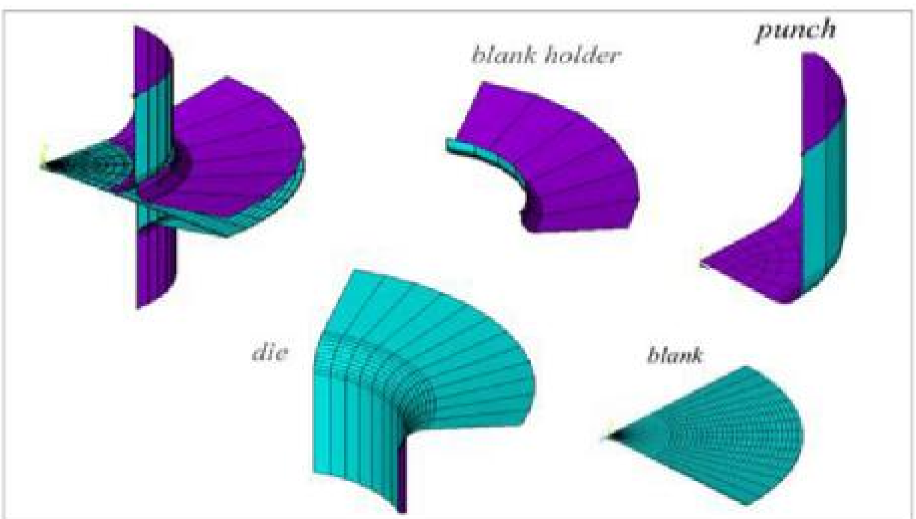

Figure (1) Finite element model of the sheet material and drawing die.

Deep Drawing Experiments

Material

In this study, the test material used is mild steel (1008–AISI) Table 1 show chemical composition, with low carbon and high quality formability and a thickness of 0.5 mm. Tensile tests were carried out in the directions of 0, 45, and 90 to the rolling direction as shown in Figure(2). And the average of these mechanical properties was calculated as indicated in Table 2.

Table (1) Chemical composition of mild steel (1008–AISI).

C %	Si %	Mn %	S %	P %	Cr %	Ni %	Mo %	V %	Cu %	Al %
0.06	0.02	0.32	0.024	0.014	0.035	0.032	0.002	0.001	0.072	0.044

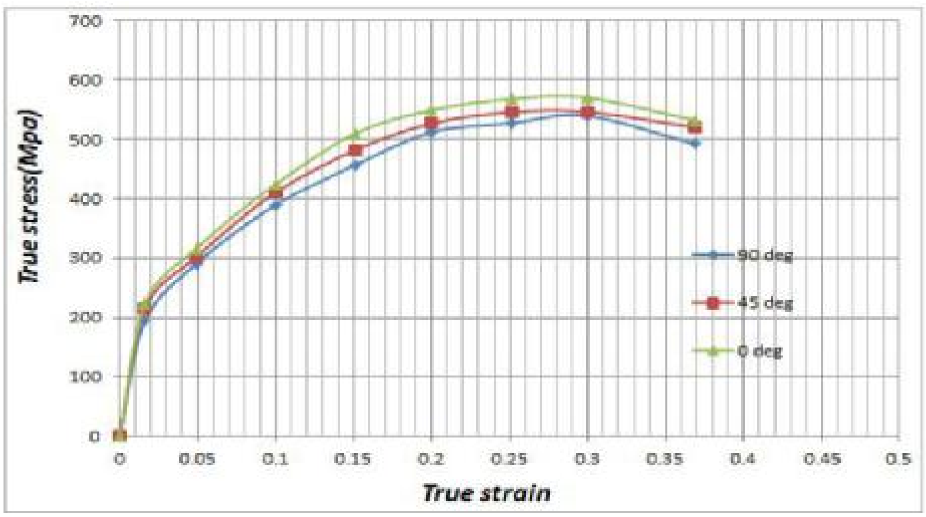

Figure (2) True stress-true strain curves at different angles with respect to rolling direction.

Table (2) The properties of mild steel used in current study.

Property of material	Modulus of elasticity (E)	Poisson's ratio(ν)	yield stress (σ_y)	Tangent modulus(E_t)
value	200 GPa	0.3	196 MPa	1.53 GPa

Experimental method and procedure

A new deep drawing die was designed and manufactured .The dimensions of punch (d=40mm), as the clearance between punch and die C=0.55 the diameter of die =41.1mm .The die profile radius R_d =6mm and punch profile radius R_p = 6mm.

In order to achieved three planned goals with blank holder as following

1. Controlling metal flow to prevent wrinkling.
2. Do not restrained metal flow.
3. Perform preparation deforming on the sheet metal blank.

Figure (3) illustrated these three steps

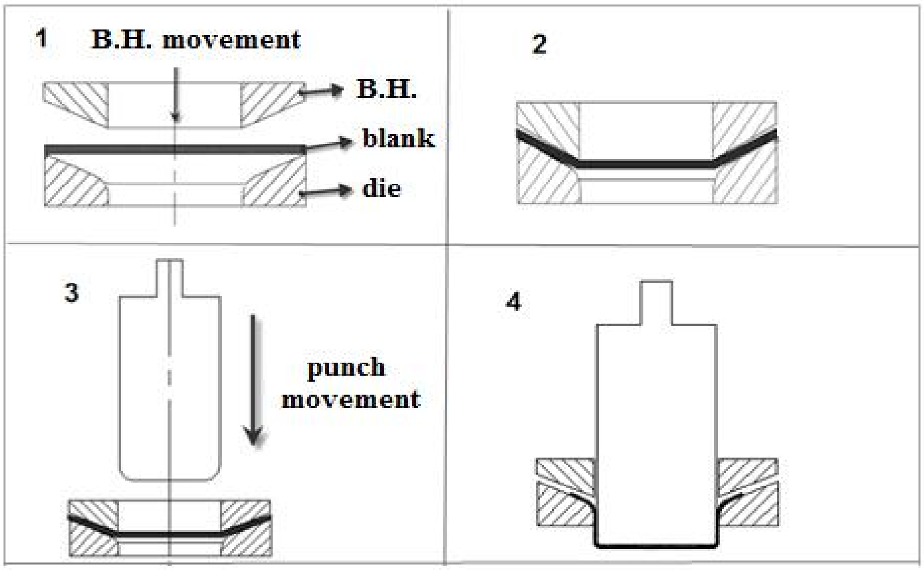

Figure (3) Deformation steps in new design deep drawing die.

To achieve three goals already mentioned four sets of blank holder and die with slop angle (0^o, 7.5^o, 15^o, 22.5^o). Deep drawing experiments are carried out to obtain cylindrical cups by mounted deep drawing die on the testing machine as shown in figure (4). The testing machine type (WDW-200E) which has a capacity of (200KN).

Figure (4) Deep drawing die attached to computerized testing machine.

After putting blank on the blank holder surface, die will drop towards the punch; this means inverted drawing die use. The produced cup has 25 mm height.

In order to study the strain distribution within the cup during drawing operation, a grid pattern of (5, 10, 15, 20, 25, 30and 35mm) radii circles, was printed (along 8 intersecting lines, 45 degree apart) on unreformed blanks, by using mechanical grid marker as shown in Figure (5.a). In order to measure the cup wall thickness, the drawn cup was divided into two parts by using electro discharging machine WEDM ,Digital thickness micrometer and tool microscope were used to measure the cup wall thickness and the changes in the grid circles during the deformation. Cup thickness and the length of distorted grid radius were measured along the 8 intersecting lines. Thickness strain and radial strain distribution were derived from the measured thickness and deformed grid circles using the incompressibility condition by using these equations:

Figure (5) a-Circular blank with printed mechanical grid. b- Cups with flange.

$$e_r = \ln \frac{r}{r_0} \quad \text{..... (1)}$$

$$e_t = \ln \frac{t}{t_0} \quad \text{..... (2)}$$

The volume constancy condition

$$e_r + e_t + e_q = 0 \quad \text{.... (3)}$$

Then the hoop strain

$$e_q = -(e_r + e_t) \quad \text{... (4)}$$

Where

t_0= the original thickness of the blank (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).

Finally, Figure (5.b) shows the sample of completely drawing cups with flange.

Results and Discussions

The sheet metal blank with conventional type blank holding methods (flat when slop angle =0^o) deformed to final shape with punch travel only and blank holder(BH) perform one function of which holding metal in the flange to prevent wrinkling with blank holder pressure. The blank holder with sloping angle (0^o, 7.5^o, 15^o, 22.5^o), not only prevents wrinkling but also performs the preparation to deformation process in a way to improve metal flow towards die cavity. So that the sheet metal reached the final shape with two deformation steps: first, small deformation or preparation step with BH second, large deformation step with punch travel Figure (6) shows the two steps, first with BH, second after 5mm punch travel.

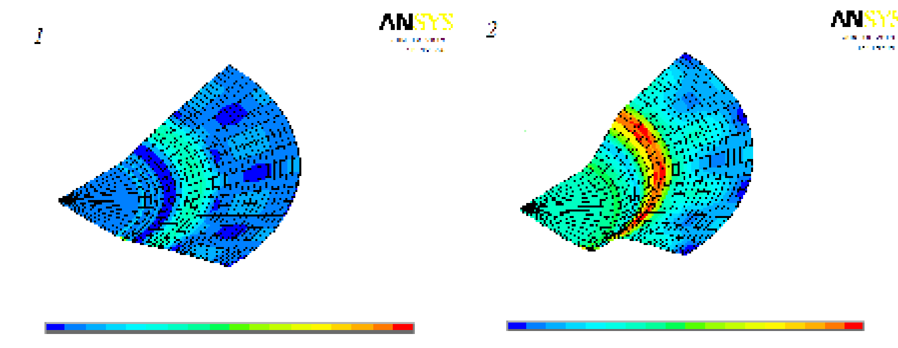

Figure (6) Deformation steps with sloping type BH.

Effect of blank holder slope angle on Punch force

Figure (7) shows the effect of change in blank holder slope angle (α) on the punch force. Figure (7.a) shows the relationship between punch stroke and punch force for four sloping blank holder with angle ($0^{°}$, $7.5^{°}$, $15^{°}$and 22.5^{o}). It is clear from the figure that the maximum punch force decreased with increased in blank holder angle, this reduction in punch force resulting from the enhancement in metal flow and reduce the direct effect of blank holder force with increased in slope angle (α). The numerical resulting of effect of slope angle (α) in the Figure (7.b) ensure the experimental results in decreasing maximum punch force with an increase in slope angle.

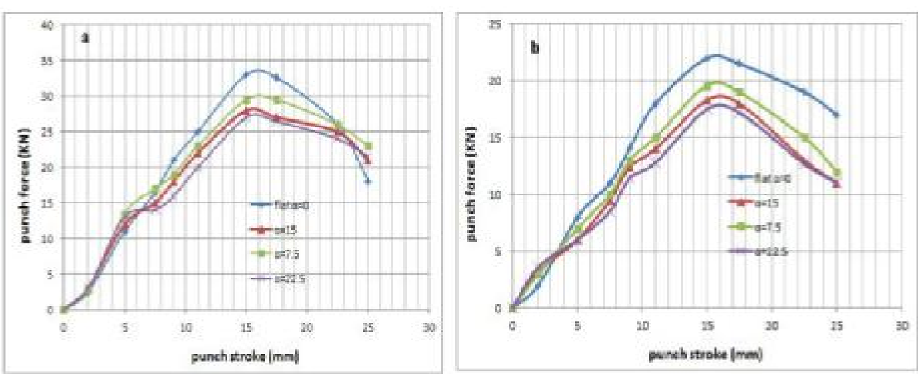

Figure (7) Effect of blank holder slope (α) angle on punch force (a- experimental, b-FEA).

Effect of blank holder slope angle on thickness distribution

The change in blank holder alters the thickness distribution in punch profile zone and flange zone as the stress was changed due to change of geometry of blank holder and die. Figure (8.a) show the change in the thickness distribution along the cup with change in blank holder slope angle (α) from this figure cleared that change in BH slope angle this improve thickness distribution in two important zones along the produced cup :

1. Reduce thinning in punch profile zone as the metal drawn in the die cavity more easily with increased BH slope angle and this lower the stretching of the metal by bending along punch profile radius.
2. Reduce thickening in the flange zone as the metal in the flange was deformed in preparation deformation by blank holder and this lower the influence of thickening in flange due to decreasing in hoop stress with increased in slope angle (α).

But there are no further thickness improvement when slope angle (α), increased from ($15^{\circ}$to 22.5°).The FEA results in the Figure (8.b) also show this improvement in thickness distribution in these two zones but slightly in die profile zone.

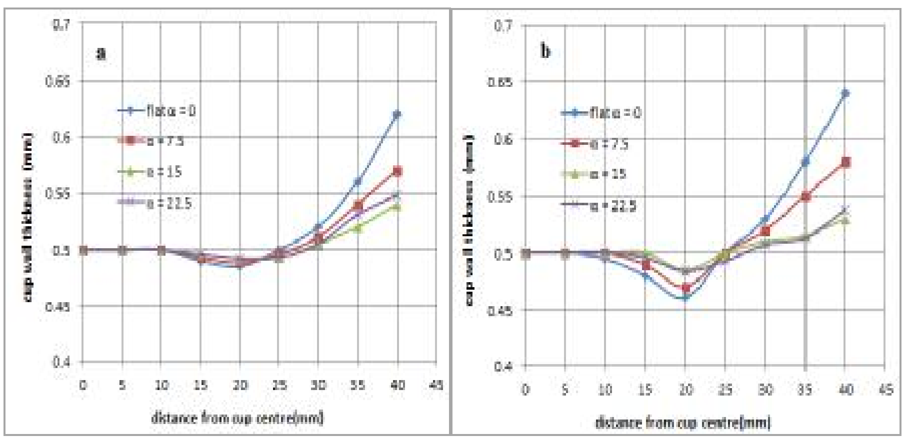

Figure (8) Effect of blank holder slope angle (α) on thickness distribution (a-experimental, b-FEA).

Effect of blank holder slope angle on strains along the cup

Figure (9) shows the strain distribution on the successful drawn cup in the FE model for flat and sloping BHT.Figure (10) show the strain distribution over the cup wall in the final drawn part for sloping blank holder with angles ($\alpha=0^{\circ}$, $\alpha=7.5^{\circ}$, $\alpha=15^{\circ}$ and $\alpha=22.5^{\circ}$) it is clear that the radial strain (ε_r) decreases with increasing the blank holder (BH) slope angle α this situation result from easy metal flow into die cavity accompanied with the decreasing in tensile stress which required to draw the flange. Hoop strain (ε_θ) also decreasing with increasing BH slope angle α that due to good gradual diminution in circumference of blank to die cavity and that is one of the most important benefits for inclined path geometry. Also it is in the figure (10.a) there is reduce in radial strain at the flange zone and it will continuous to flange rim for all types of sloping BH especially at angles ($\alpha=7.5^{\circ}$ and $\alpha=15^{\circ}$) the reduce is due to following reasons:

1- The flange zone was not completely drawn as the final product in the current research is cup with flange that made the radial strain in this zone less than in the nearby die profile zone.
2- The non-deformed zone in flange subjected to less effect to radial stress with an increase a slope angle.

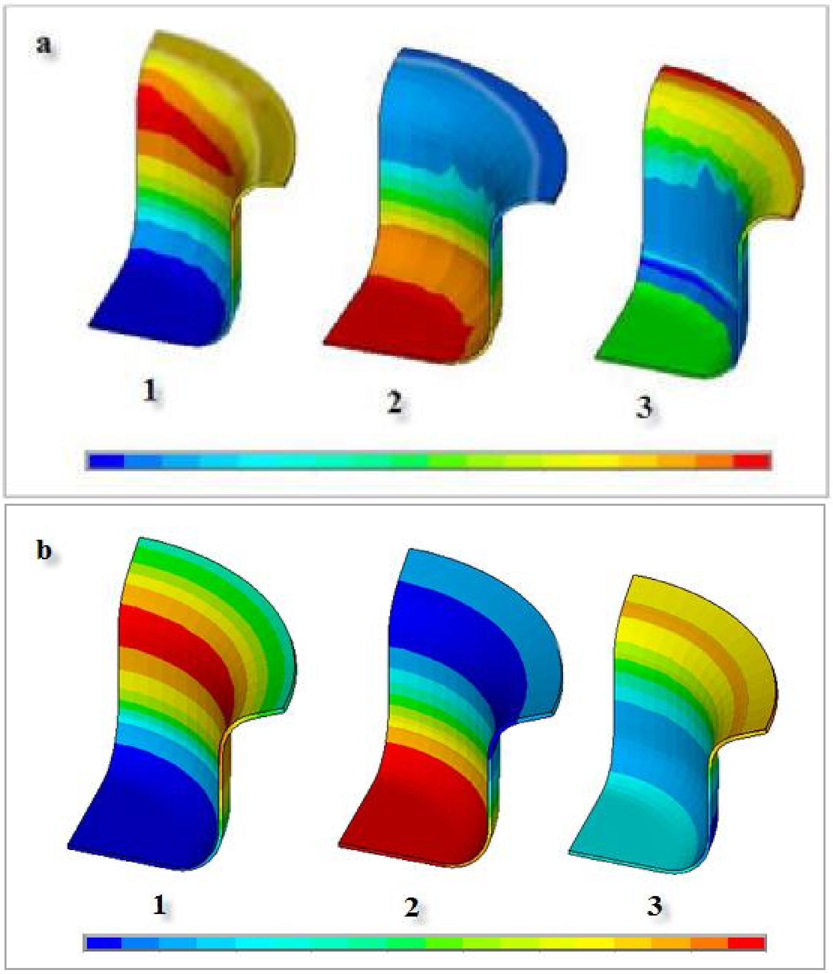

Figure (9) The strain distribution on the successful drawn cup (a-Flat model α=0°) (b-Sloping model α=22.5°) for 1- Radial strain.2-Hoop strain 3- Thickness strain.

Figures (10.b) and(10.c) shows the influence of slope angle (α) on hoop and thickness strain (ε_t) at observation the two figures gives clear notice that with increase BH slope angle lead to decrease (ε_t) in very important zone (die profile zone) where stretching on this zone decrease due to decrease in radial stress with increased in slope angle, also seen from these figures that (ε_t) decreasing with decrease slope angle in flange zone that mean the preparation deformation has good effect to increase the act of BHF to decrease the thicken in flange. Figure (11) shows FE results of strains distribution.

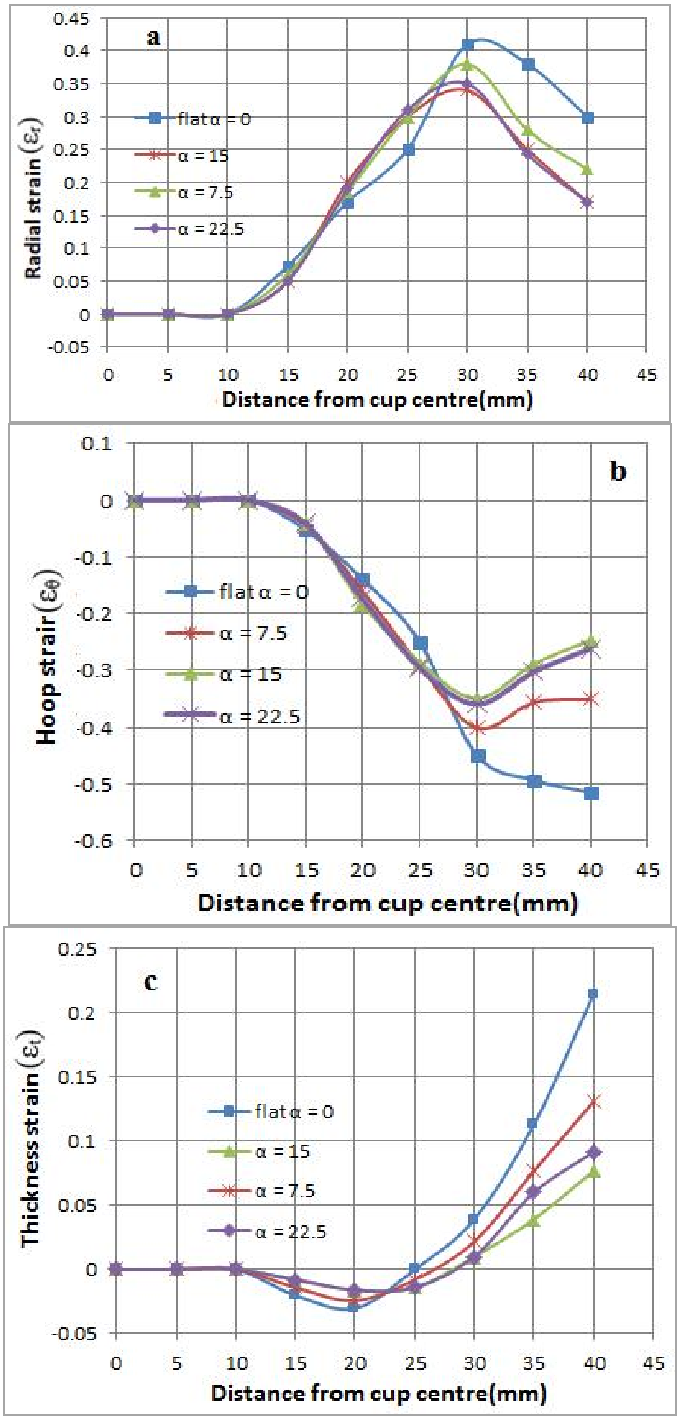

Figure (10) Effect of blank holder slope angle (α) on a- radial strain. b-hoop strain c- thickness strain. (Experimental results)

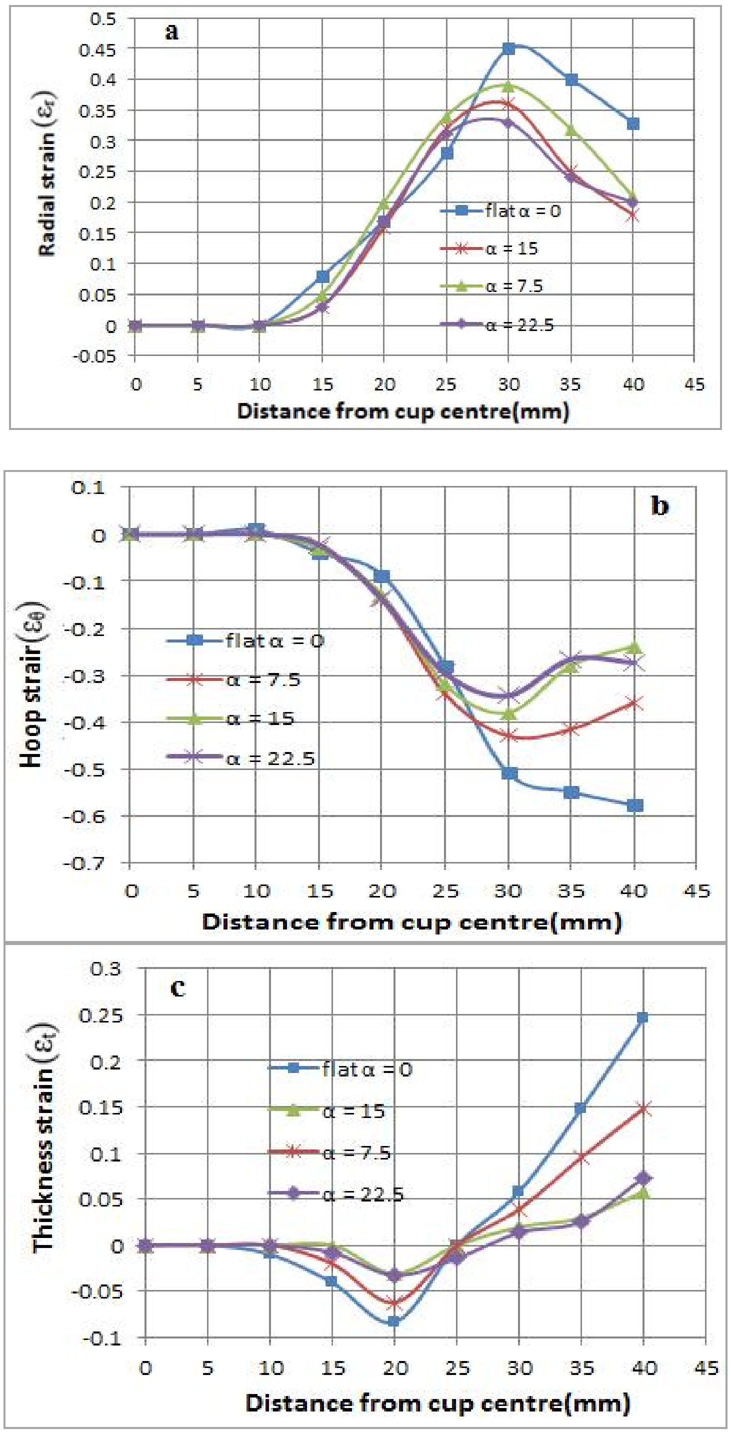

Figure (11) Effect of blank holder slope angle (α) on a- radial strain. b-hoop strain c- thickness strain. (FEA results)

CONCLUSIONS

1. The punch force decrease with the increase in blank holder slope angle.
2. The best thickness distribution over all zones in produced cup obtained when using blank holder with angle $\alpha = 15^{\circ}$.
3. The radial strain decrease with increase in blank holder slope angle as reducing in stretching of flange result from easy metal flow over inclined surface.
4. The hoop strain decrease with increase in blank holder slope angle result from gradual diminution in circumference of flange.
5. The normal strain has significantly decreasing in very important zone (punch profile zone) with increase in sloping angle.

REFERENCES

[1] L.Gunnarsson E. Schedin, "In-process control of blank holder force in axisymmetric deep drawing with digressive gas springs". Proceedings of the 19th Biennial Congress IDDRG, International Deep Drawing Research Group, Eger, Hungary, pp. 89–100, (1994).

[2] Y. Hirose, Y. Hishida, S. Ujihara, "Research on techniques for controlling body wrinkles by controlling the blank holding force". Proceedings of the Fourth Symposium of the Japanese Society for Technology of Plasticity, Tokyo, (1996).

[3] Y. Hishida, R.H. Wagoner, "Experimental analysis of blank holding force control in sheet forming". Society of Automotive Engineers Technical Paper No. 930285, Warrendale, PA, (1996).

[4] Wang, L., L.C. Chan and T.C. Lee, " Process modelling of controlled forming with time variant blank holder force using RSM method" Int. J. Mach. Tools Manuf.,47 (12-13):(2005).

[5] Savas, O. Secgin, "A new type of deep drawing dies design and Experimental results". Int. I. Mat. Design, 28 (4): 1330-1333, (2007).

[6] Koyama, H., R.H. Wagoner and K. Manabe, "Blank holding force control in panel stamping process using a database and FEM-assisted intelligent press control system" Int. J. Mat. Process. Technol152 (2): 190-196. (2007).

[7]A. D. Younis "The effect of using Non-Uniform Blank Holder Force in Deep Drawing process on the thickness distribution along the cup" Al-rafidain Engineering, Volume 20, No. 2 (2013).