Kariem M. Younis

Department of Production
Engineering and Metallurgy,
University of Technology,
Baghdad, Iraq.
Kamarabbas89@yahoo.com

Adil SH. Jaber

Department of Production
Engineering and Metallurgy,
University of Technology,
Baghdad, Iraq.
totelife@yahoo.com

Metal Flow Control in Producing the Non Symmetrical Parts in Deep Drawing Process

Abstract- the quality of the cups drawn in the deep drawing process are secured by the rate of metal flow into the die cavity, efficiently control on the metal flow can reduce and eliminate a lot of defects such as wrinkling, tearing and earing especially in the square deep drawing due to the non-uniform stresses induced along die cavity. This control is obtained using a restraining force supplied by blank holder tool or draw beads or both. Therefore this research focuses on the study these parameters numerically and experimentally. Ansys software based on finite element method was used to model and analyze the influence of blank holder gap and draw bead parameters in the forming process. Appropriate number of the experiments were done to compare and verify the results obtained in the numerical simulation.

Keywords- *blank holder gap, draw bead, finite element method, square deep drawing.*

1. Introduction

In sheet metal forming processes, the rate of metal flow into cavity of the die should be controlled so that a preferable quality can be ensured and defects such as excessive thinning, wrinkling are controlled. In general, the draw beads and blank holder supply the restraining force required to control the flow of material. There are two ways to treat the blank holder in stamping, the first is blank holder force (BHF), which is used widely in sheet metal process, whilst the last is blank holder gap (BHG), known as the constant distance between the die surface and the blank holder surface in the stamping process. Friction between blank holder and sheet generates force, which restrain the material flow. When required a high restraining force, higher blank holder force or small blank holder gap should be utilized to raise the frictional conditions thus increases the resistance force, due to the high frictional conditions between sheet and blank holder might occur galling in sheet and excessive wear in the tooling. In several situations, the required blank holder force might exceed the loading ability of the pressing machine. Hence, desired restraining force for material flowing at relatively low blank holder force can provided by a local mechanism. The draw bead consists of a small groove on the binder or die matched by protrusion on the die or binder. Next the blank holder closing, the blank is drawn through the draw bead and it undergone to a bending and a subsequent unbending around the entrance groove shoulder, bead and at the exit groove shoulder. The

frictional force together with these bending and unbending deformations account for the draw bead restraining force [1-4]. Several studies focus on the investigating the effect on draw bead and bank holder gap on the cup drawn by deep drawing process. The impact of the blank holder gap on deep drawing of square cups from Al sheet was studied by gavas and lzciler [5], different gaps ranging from 1mm to 1.8mm at incremental 0.1mm were studied experimentally. The experimental results were obtained and failure modes explained in these results. It is found that when an increase in the blank holder gap, more flow allowed freely into die cavity without failure but after the BHG=1.3mm the surface quality of the part is spoiled clearly and BHG=1.8 tearing will appear due to excessive wrinkling and bucking which cause failure in the part. Murali et al. [6] studied the effect of locations and shapes of draw beads in the deep drawing process. DYNAFORM and LS-DYNA commercial codes, which based on finite element method, were used to model and analyses this process respectively and experiments were carried out to compare and verify the results obtained from numerical simulations. In this process, different locations of draw beads were simulated to draw hemispherical cup, the optimal location of draw bead is determined depending on who is a cup, which has minimum stress distributions and maximum thickness distributions over its wall. In addition, the authors investigated the influence of profile of draw beads on the strain and thickness distributions of the

products, two profiles studied (circular and rectangular). The results show that good agreement between numerical and experimental methods. The effect of draw bead in the deep drawing process for non-symmetrical parts numerically and experimentally discussed by Mujic et al. [7]. Non-symmetrical parts were investigated, group of numerical simulation based on finite element analysis were performed to determine the optimal values of geometrical parameters of the draw bead in deep drawing process. In addition, few numbers of experiments with only optimal values of draw bead parameters were performed; the main goal of this experimental result was there verification result obtained by numerical simulations. Younis [8] studied the influence of blank holding types (blank holder force, blank bolder gap) on the thickness distributions on the cup drawn. Experimental and theoretical methods were performed in this research. Variable blank holder force and two fixed blank holder gaps were tested. The research displayed that major influence of the type of blank holder on the quality. Mujic et al. [9] reported that the simulation of the square deep drawing operation numerically with discretized and equivalent draw bead for non-symmetrical parts with high deep drawing. The discretized draw bead model is more accurate and reliable than the equivalent draw bead model in the deformation distribution and total drawing force predictions. The equivalent draw bead model is suitable for shallow drawing parts. In this study, the effect of high draw bead on the punch force and thickness distribution over the drawn square cup wall are investigated in the $(0°,45°,90°)$ from rolling direction, also shows the used pieces of draw bead which reduces the earing compared with using complete draw bead. As well as, the effect of type of blank holding (fixed, gap) on the drawn cup numerically and experimentally studied. Ansys software based on finite element method was used to model and analyze the influence of blank holder gap and draw bead parameters in the forming process.

2. Experimental Procedures

I. selection of the material for the sheet

The material to be drawn have a great effect on the success of a drawing operation. A low carbon steel (1008-AISI) is chosen as the material for the sheet in this work. The chemical composition of this material is shown in Table 1. To determine the rolling direction optical microscope with 40X magnification power is used. Figure 1 shows the rolling direction for (1008-AISI) low carbon steel.

II. Material characterizations

In order to determine the important mechanical properties of the sheet used in the current study such as elasticity modulus (E), poison ratio (υ), yield stress (σy), tangent modulus (Et) and anisotropy coefficients (r) for the sheet material. Tensile test was used for this purpose; these values are used in the numerical analysis later the procedure to determine the values of these mechanical properties as follows.

1- Three tensile specimens are cut carefully from the sheet in the rolling direction 0°, diagonal 45° and perpendicular to the rolling direction 90° , and tested according to ASTM (American society for testing of materials) standard E8M specification the dimension of the tensile specimen shown in figure 2.

2- The tensile specimen is fixed in the gripers of the tensile testing machine, and take care about the alignment of this specimen.

3- Adjusting the machine and input of the information about the dimensions of tensile specimen into special software on the computer connected with tensile machine.
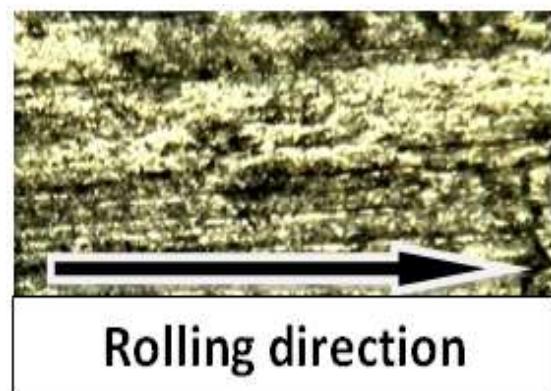
4- The specimens are loaded until fracture occurred.

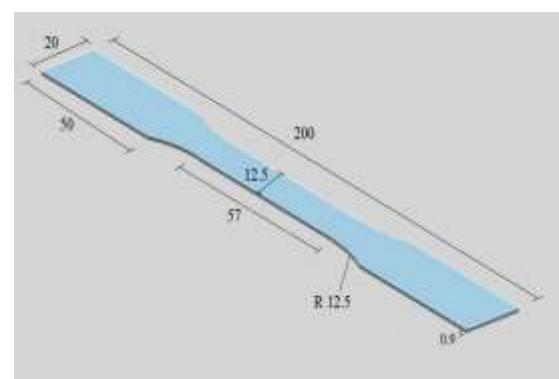**Figure 1: Rolling direction for 1008-AISI Low carbon steel with 40X magnification.**

Figure 2: The dimensions of the standard tensile test specimen.

Table 1: The chemical composition of the low carbon steel (1008AISI).

C%	Mn%	Cr%	Cu%	Al%	Si%	P%	S%	Mo%	Ni%	V%
0.08	0.32	0.03	0.09	0.05	0.02	0.015	0.021	0.002	0.03	0.001

The universal testing machine type (WDW-200E) which can perform tensile, compression and bending test was used in this study. The velocity of test was (2mm/min). Mechanical properties for low carbon steel are shown in Table 2. The tensile test machine directly gives the curves between load-deformation curve and engineering stress-engineering strain curve, and by using the equations (1) and (2) are obtained the data for drawing the flow curve. The true stress-strain curve was concluded from engineering stress-strain curve that obtained directly from testing machine. The slope of linear elastic region define the modulus of elasticity while the slope of the flow curve at specific level of stress (yield stress) is tangent modulus, the yield stress was evaluated by taking the 0.2% offset from this curve,

$$\sigma = \sigma° (1 + e) \tag{1}$$

$$\in = \ln\left(\frac{l}{l°}\right) \tag{2}$$

Where σ = true stress, σ° = engineering stress, ∈ = true strain, e = engineering strain, $\frac{l}{l°}$ = ratio between instantaneous length and original length of the gauge section of the tension test specimen. Due to the subject of the current study which involves the rate of metal flow, it is very necessary to determine the magnitude of coefficient of plastic anisotropy in sheet, these values of coefficient of anisotropy are considered sufficient factors which have a significant influence on the draw ability of the sheet which can be defined as a ratio of width strain to thickness strain of the tensile specimen strained at a particular value, e.g. at strain equal 20%. Experimentally, to obtain the coefficient of anisotropy the gage length of the tensile specimen is divided into five equal regions, and the specimens were loaded unit 20 percent from uniform plastic deformation (20% of the uniform plastic deformation of the specimen loaded until fracture). After this loading, the specimens were deformed without fracture in which the five equal regions in the gage length changed in dimensions. Therefore, to find the measurement of length and width strain can be achieved, in addition with benefit from constant volume law. The specimens are taken from three directions ($0°$, $45°$, $90°$) according to the rolling direction. The value of the anisotropy coefficient (r) for three directions are calculated by using Eq. (3) as follows,

$$r = \frac{\ln\left(\frac{w_0}{w_f}\right)}{\ln\left(\frac{l_f w_0}{l_0 w_f}\right)} \tag{3}$$

Where, w_0, l_0 represent original width and length respectively, w_f, l_f represent final width and length respectively. Table 3 shows the values of coefficient of anisotropy of low carbon steel material with respect to rolling direction.

III. Deep drawing tests

Experimental equipment were designed and implemented to produce square cup, they are made from tool steel which were machined by wire cut machine and polished in order to obtain good surface finish, the operations of the manufacturing of equipment of deep drawing process were done in local market.. Few tests were completed to compare and verify the numerical data obtained from numerical simulation of the square cup drawn. The dimensions of square punch are (40x40) mm as the radial distance between die and punch (clearance) is (0.55) mm therefore the dimensions of the square opening of die (41.55x41.55)mm, the punch profile radius rp= 5mm and die profile radius rd= 5mm.These equipment were setup on the universal tensile machine has a capacity of (20 ton), as shown in figure 3A and engineering drawing of tool in figure 3B. After putting blank on the blank holder surface, die drops toward the punch; this means inverted drawing die use. Drawing speed equal to (60mm/min) selected for drawing.

**Table 2: The mechanical properties of the sheet.**

Property	Symbol	Value	Unit
Young modulus	E	200	Gpa
Poisson ratio	υ	0.3	mm/mm
Offset yield stress	σ_y	203	Mpa
Tangent modulus	E_t	0.5	Gpa

Table 3: The value of coefficient of anisotropy of low carbon steel material respects to rolling direction

property	Symbol	value	Unit
Plastic anisotropy with 0° from rolling direction	r_0	1.395	----
Plastic anisotropy with 45° from rolling direction	r_{45}	1.165	----
Plastic anisotropy with 90° from rolling direction	r_{90}	2.00	---

Figure 3A: The deep drawing tools mounted in the testing machine.
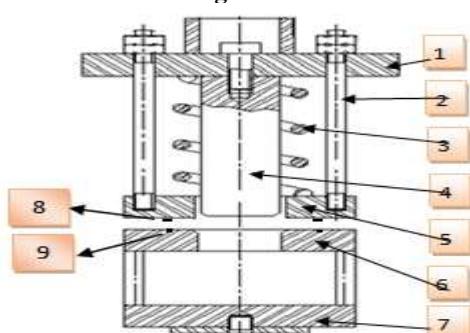
1	2	3	4	5	6	7
Top plate	Guide	Spring	Punch	Plank holder	Die	Bottom plate
8		9				
Draw bead		Bead groove				

Figure 3B: Schematic representation of rig deep drawing tooling

3. Numerical Simulation

Influence of the blank holder type and draw beads in the square deep drawing were studied numerically. For simulating the square deep drawing process, finite element analysis code ANSYS11.0 were utilized, in which the "Newton-Raphson" implicit method were used to solve

nonlinear issue. Modeling of tool, blank, preprocessor stage then solution, post processor were done using Ansys software. The three dimensions 8-node structural solid element (SOLID45 3D LARGE STAIN SOILD) were utilized for sheet. The tool set (die, punch, blank holder and draw bead) were modeled as rigid bodies. The side length of the square punch was 40mm and side length of die cavity was 40.77mm with entry radius for die and punch was 5mm and the corner radius of the punch and die was 5mm. The blank of 86mm diameter with a uniform thickness of 0.7mm, the mechanical properties shown in Table 2 were used to represent on the sheet material in the simulation, Bilinear Isotropic Hardening option employs the hill yield criterion connected with an isotropic work hardening assumption. This option is preferred for large strain analysis. The principal axes of anisotropy coincide with the material (or element) coordinate system. Contact between the tooling and sheet is necessary in the deep drawing process, automatic contact procedure in ANSYS11.0 were utilized to model the complex interaction between the tooling and blank. For flexible blank contact-rigid tool set, target elements of TARGE170 were utilized, to act three dimensions target tool set surfaces which were related with the deformable blank perform by three dimensions 8-node contact elements of CONTA174, the friction coefficient is assumed to be uniform and constant for all contacting surfaces and equal to 0.1. Due to longitudinal and lateral axial symmetry of tool and blank, one-quarter model needed was analyzed, it leads to a sufficient reduction of time necessary for nonlinear finite element analysis. The punch moved down at steady velocity 60mm/min during the deep drawing operation and the die was fixed. The FE model of the drawing tool and blank is shown in Figure 4. The final part produced experimentally and simulation of square deep drawing is shown in Figure 5.

4. Results and Discussion

The efficiently control on the metal flow into die cavity in the deep drawing process is very important to produce cup with defect less, the control on metal flow can be done by applied restraining force supplied either draw bead or blank holder. In this study effect of draw bead and blank holder gap are investigated numerically and verified the numerical experimentally.

I. Effect of draw bead

Researches show the importance of using draw bead in deep drawing process to prevent the

wrinkling, increase the formability, and reduce the earing. For these reasons, draw bead profile is used (circle section along the circumference of the die at distance 30 mm from the center die cavity) with three different high draw beads (Hb=0, 0.5, and 1mm), with tool geometry, punch profile radius (rp=5mm) and die profile radius (rd=5mm), blank diameter (D=86mm), holding force (BHf=15KN), friction coefficient (μ=0.1), punch speed (v=60 mm / min), as shown in Figure 6.
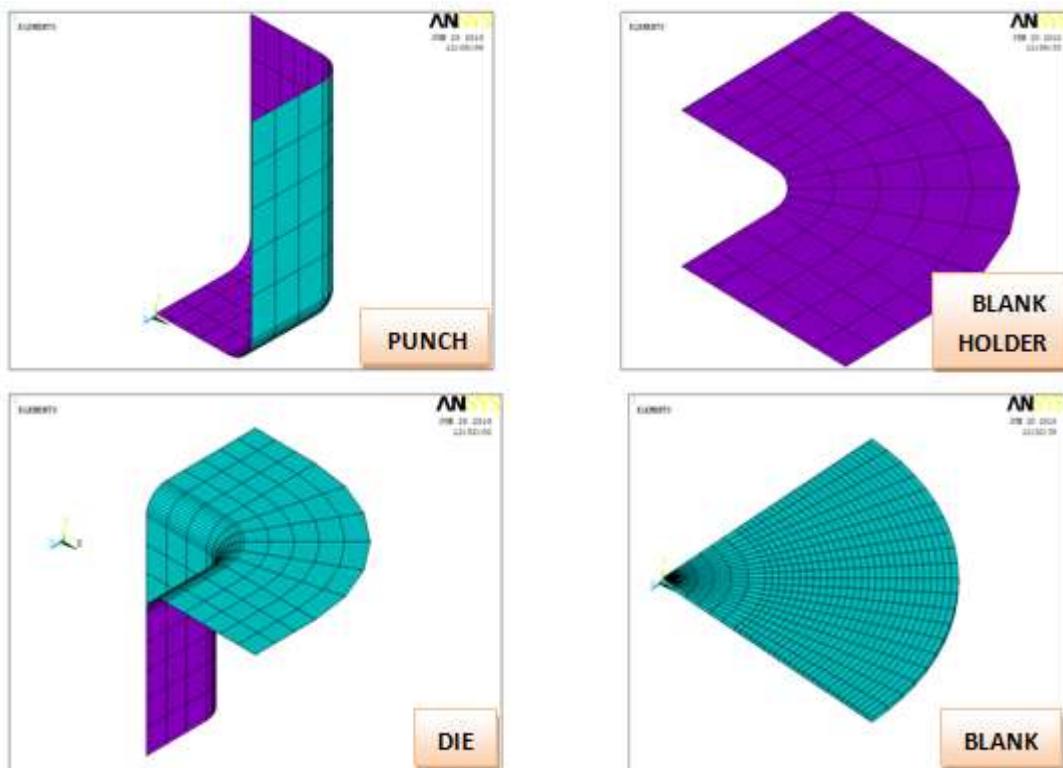

Figure 4: FE model of the sheet material and drawing die parts.
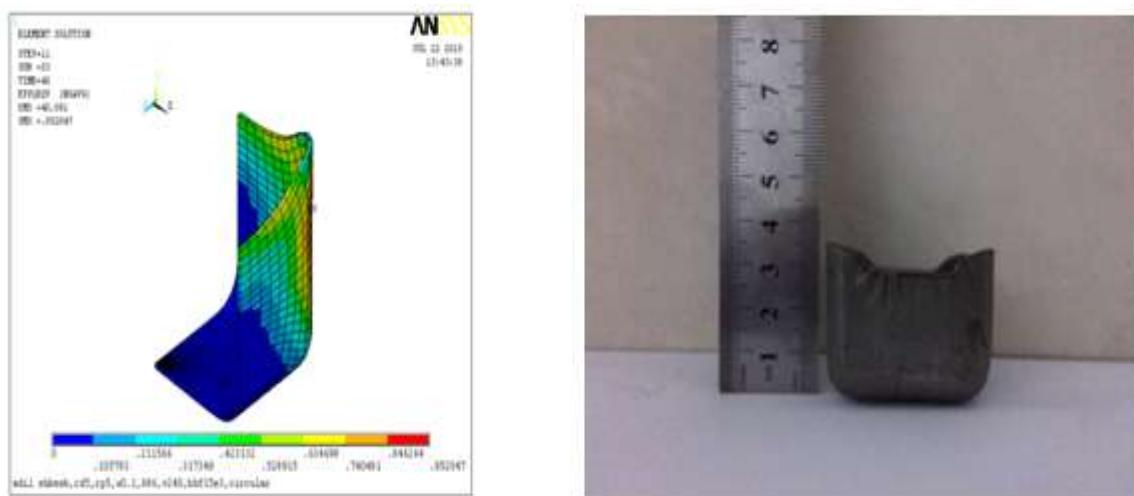
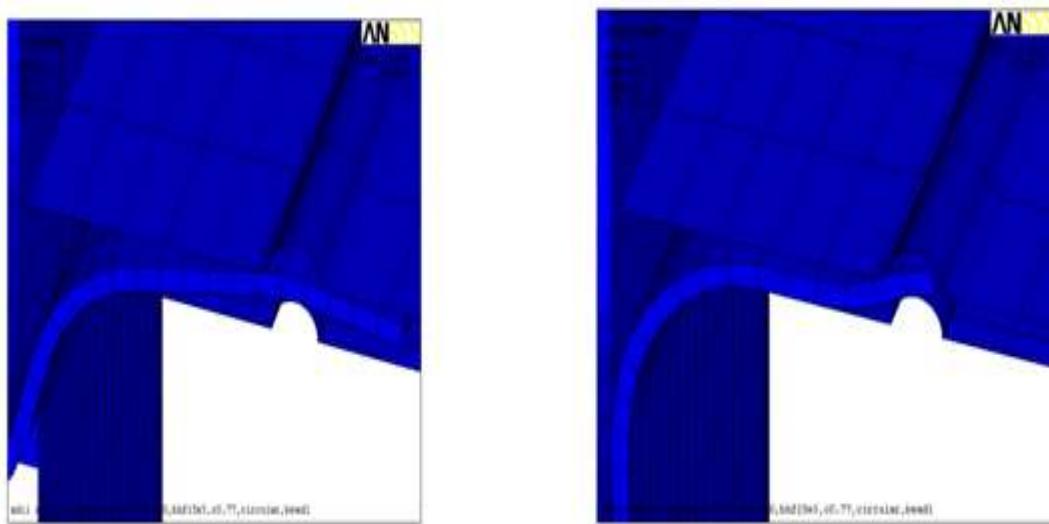**Figure 5: Cup drawn by numerical simulation and experimental.**

Figure 6: Simulation of the metal flow through the draw bead.

From figure 7, it is clear that the punch force in (Hb=0) without draw bead is much higher than that when using draw bead due to full contact between blank-blank holder and blank-die. The punch force increases with increasing high draw bead because of increasing in the amount of stretching during flow over draw bead which has more height. It is noted that punch force is increased suddenly in last stage of stroke because of appearance of small wrinkling at flange rim (removed by ironing at the final stages of drawing operation) when using draw bead. Figure 8 illustrates the distribution of the thickness of the cup wall. It is clear from this figure that the thickness in the cup wall for (Hb=0 mm) has a value less than (Hb=0.5, 1 mm). This is due to the full contact of the blank with tools that increases the friction and restrains the movement of the material. Therefore, stretching increases. It is noticed the thinning at punch profile radius region will reduce with Hb=0.5mm more than Hb=1mm due to the stretch reducing during flow over draw bead which has low height. The simple idea were motivated to use of draw beads for decreasing the ears in the cup drawn is the earing occurs because different of metal flow along the die cavity, several regions of the sheet metal flow more slowly than anther regions into the die cavity due to anisotropy property in the rolled sheet blank and addition to variable flow conditions along die cavity especially when drawn square parts. A simple idea is to use the draw beads to provide the restraining force in the region which flow faster only thus make metal flows into die cavity uniformly in all directions. This goal comes from the idea of using draw beads as a solution for reducing the earing defects. In this work, the earing appears at cup corner (45˚ from RD). Therefore, the applied restraining forces are created by draw beads at flat sides (0˚ and 90˚ from RD) where those parts of the metal flow faster, and not applied restraining force by draw beads on these parts which flow slower. Consequently, the material flows uniformly into the die cavity. Along the die cavity as shown in Figure 9, the maximum peak to valley discrepancy along the perimeter of the square cup is (3.967 mm) without using draw bead, whereas when using draw dead in (0˚ and 90˚ from RD) this value will reduce to (1.885 mm). Figure 10 shows the used pieces of draw bead which reduces the earing compared with using complete draw bead. Table 4 presents comparison between without draw bead, completely draw bead and pieces draw bead.
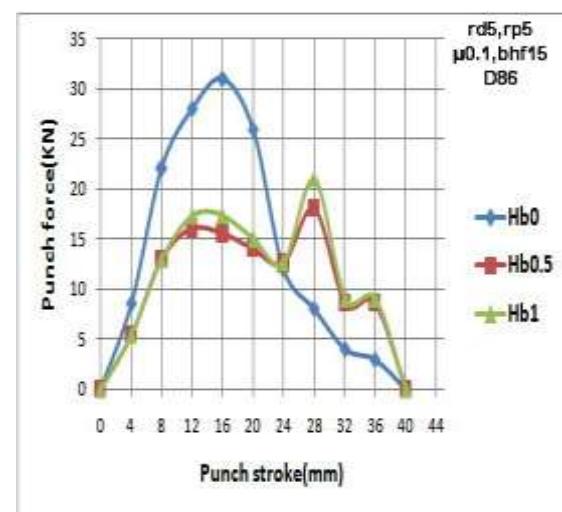

Figure 7: The effect of high draw bead on punch force.

II. Effect of blank holder gap

Blank holder type in deep drawing and its simulation can be treated in two ways, the first is BHF while the second is BHG. To investigate the blank holder gap on the cup height, three models of it (0.7, 0.91, 1.26) were used for analysis using FEM. Figure 11 shows the investigate of BHG on the cup height. It is shown when the BHG decreases the height of cup increases. It is very easy to note when BHG is 0.7mm (equal to the sheet thickness) high friction conditions it will be obtained between sheet and tool causes restraining of the flow of metal into die cavity.

Consequently, the amount of stretching increases and produce more height and thinning of cup. While if the BHG are 0.91 and 1.26mm, i.e. (1.1 and 1.8 from sheet thickness), its effect on the cup height is little and similar because the distance between sheet and blank holder is very high and the material in the flange flows freely in to die cavity with few of restrain with large possible to occurs wrinkling.
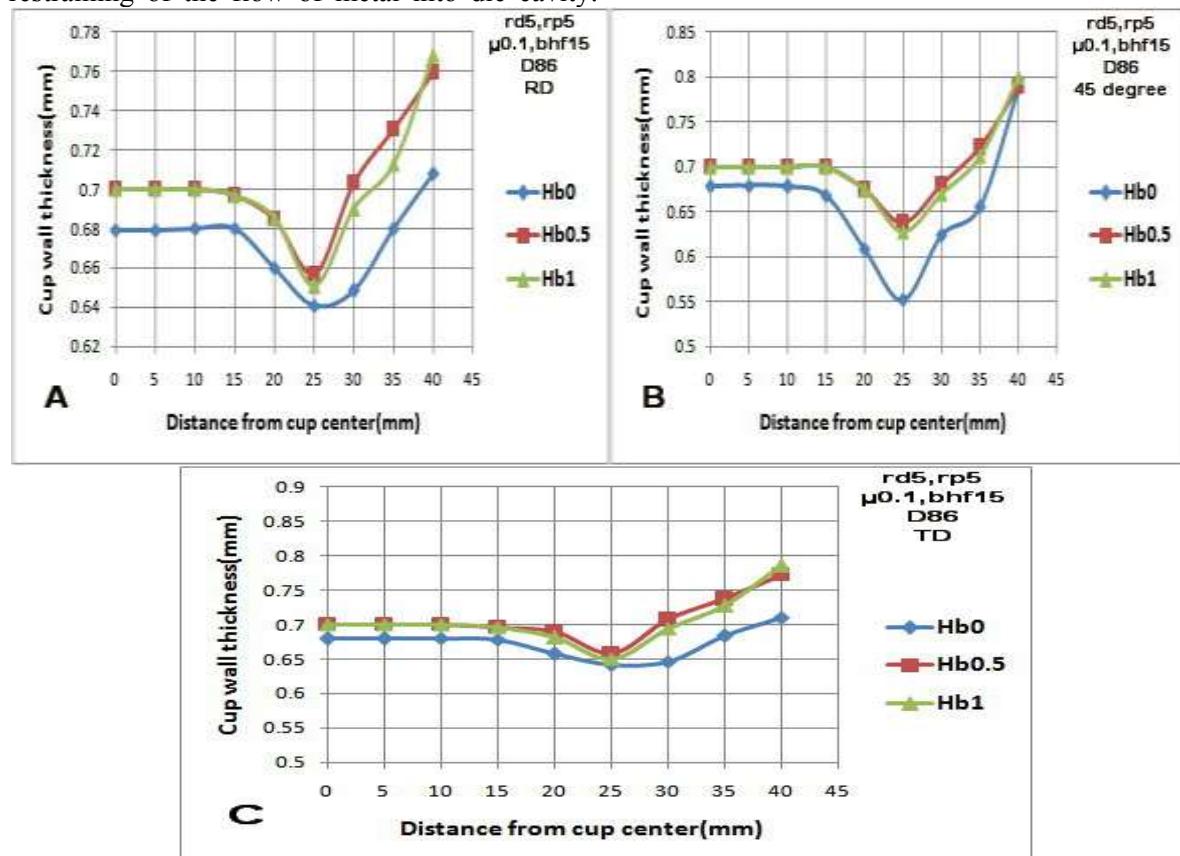

Figure 8: The effect of high draw bead on the cup wall thickness along, A) rolling direction, B) 45˚ from RD, C) transverse direction.

Table 4: Comparison among drawing process without draw beads, with draw beads and with pieces draw beads.

	Useful height	Maximum peak to valley discrepancy	Maximum height in the cup
Without draw bead	24.073mm	3.967mm	28.04mm
Completely draw bead	24.629mm	2.391mm	27.02mm
Pieces draw bead	24.856mm	1.885mm	26.741mm
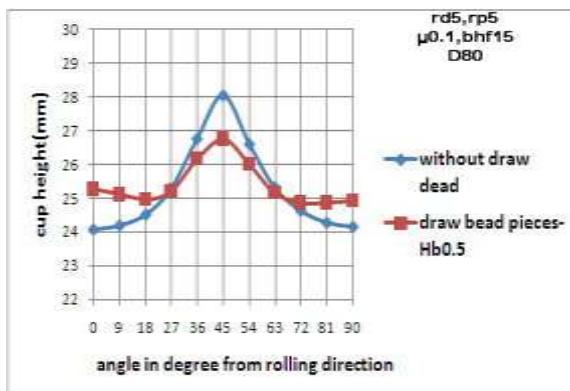
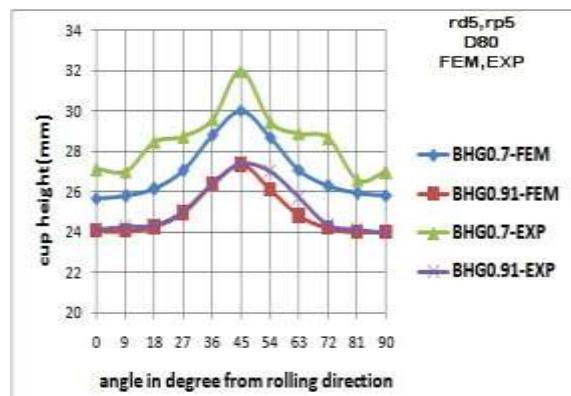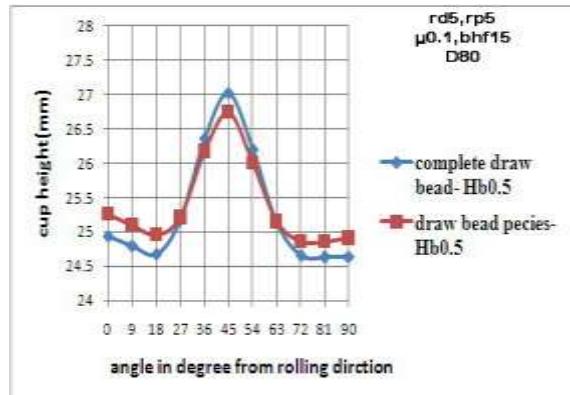**Figure 9: The effect of draw bead pieces on the earing**

Figure 10: Comparison between complete draw bead around the circumference die surface and pieces draw bead in the 0° and 90° from RD.
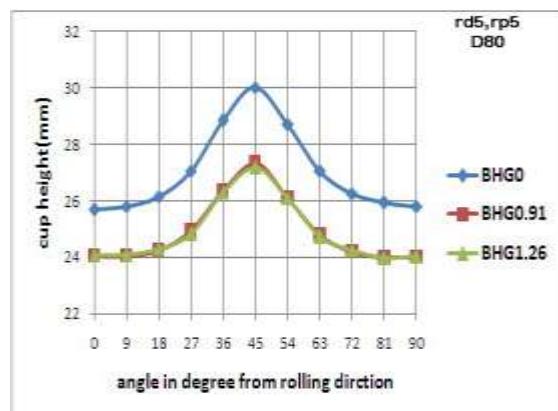
III. Experimental results

So as to confirm the FE simulation results, the actual square cup drawings for mild steel materials have the Lankford values of r_0, r_{45}, and r_{90} are 1.395, 1.165, and 2.00 respectively, and tool geometry [rp5rd5] (punch and die profile radius mm), in different blank shapes and sizes were also conducted and the experimental result was compared with the FE simulation data. Figure 12 represents the comparison between cup height for different blank holder gap experiment and numerical.

Figure 11: The effect of blank holder gap on the height of cup.

Figure 12: The effect of blank holder gap on cup height (experimental and numerical)

5. Conclusion

The following conclusions can be drawn from this study

1- The draw bead and blank holder gap have significant effects on the quality of cup drawn

2- Use of the draw bead reduces the drawing force and thinning.

3- Increase in height of draw bead increases in thinning and cup height due to excessive stretch occurs for metal through pass over the highest bead.

4- Increase of blank holder gap increases thinning but over increasing occurs wrinkling.

References

[1] A. Dahham, A. Rafat, M. Jaber, "Finite Element Analysis of Draw Beads in Deep Drawing Process," J. of AL- Rafidain, Univ. of Mosul, Vol.22, No.1, 2104.

[2] E.N. Duarte, S.A.G. Oliveira, R. Weyler and L. Neamtu, "A Hybrid Approach for Estimating the Draw bead Restraining Force in Sheet Metal Forming," J. of the Braz. Soc. of Mech. Sci. & Eng, Vol. XXXII, No.3, pp. 282-291, 2010.

[3] K.M. Younis, J.J. Shukur, "Effect of Blank Holder Inclination Angle on Deep Drawing of Round Mild Steel Cup with Flange,"Eng. & Tech. Journal, Vol.32, Part (A), No.7, 2014.

[4] W.K. Jawad, "Investigation of contact interface between the punch and blank in deep drawing process," Eng. & Tech. Journal, Vol.25, Part (A), No.3, 2007.

[5] M. gavas, M. lzciler, "Effect of Blank Holder Gap on Deep Drawing Square cups," Materials and Design 28, pp.1641-1646, 2007.

[6] A. Murali G., B. Gopal M. and C. Rajadurai A, "Analysis of Influence of Draw Bead Location and Profile in Hemispherical Cup Forming," IACSIT International Journal of Engineering and Technology, Vol.2, No.4, August 2010.

[7] E. Mujic, M Nozic, H. Djukic, "Measurement and Verification of Deep Drawing Force in Case of Non-

Symmetric Parts," 6th International Research/Expert Conference, Trends in the Development of Machinery and Associated Technology, TMT 2012, Dubai, UAE, 10-12 September 2012.

[8] K.M. Younis, "Effect of Blank Holder Type on Deep Drawing of Cups," The Iraqi Journal For Mechanical and Material Eng., Vol.13, No.1, 2013.

[9] E. Mujic, M. Nozic and H. Djukic, "Numerical Simulation of Deep Drawing Process with Discretized Draw beads," 17th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT 2013, Istanbul, Turkey, 10-11 September 2013.

Author(s) biography

K.M. Younis holds bachelor's and master's degree in Production Engineering, from Department of Production Engineering & Metallurgy, University of Technology, from Baghdad –Iraq.

A.SH. Jaber holds bachelor's and master's degree in Production Engineering, from Department of Production Engineering & Metallurgy, University of Technology, Baghdad, Iraq.