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## Experimental and Numerical Study of the Earing Defect During Square Deep Drawing Process

**Abstract-** Deep drawing process is a very complex process which controls a lot of parameters and the associated defects. The aims of this research are to discuss the effect of parameters of the process utilized in square deep drawing process such ; material properties, blank size, blank shape on the height and shape of earing defect appear of the drawn cup. Three dimensions model from low carbon steel (AISI 1008) with thickness 0.7mm of square cup (41.4mm by 41.4mm). The finite element software (ANSYS 11) was utilized to carry out the numerical simulation of the deep drawing process, and the experimental work result of earing was compared with numerical of earing shape result. In this work, three types of the radius of die entry of 3, 5, 7mm, three shapes of the blank (circular, octagonal, and square) with various diameters, four types of radius of the punch profile of 3, 5, 6, and 7mm had been selected to form a cup with square sides. The results show that, The circular blank give the best results according to earing defect and useful height of the drawn cup, when square shape of blanks were utilized, excessive earing will show in the square cup, due to non-uniform distribution of blank material around the perimeter of the die cavity, minimum material in the flat side and too much material found in the die corner, while when using octagonal shape of blanks which have a same surface area to the square blank, the earing will reduce in the corner of the cup due to extract of the too much material from the blank corners. The results showed a high agreement between the experimental work and numerical simulation reached to 85 % in terms of the shapes and lengths of the earing appearing in the square cups.

**Key words-** square deep drawing, earing defect, finite element method.

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### 1. Introduction

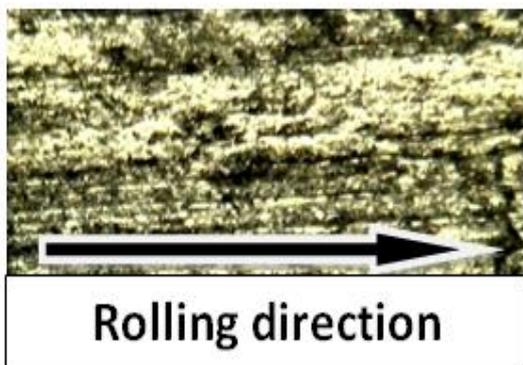
Deep drawing is one of extensively utilized sheet metal forming operations in industries to form cup shaped products. In deep drawing operation, a sheet metal (blank) converted to cylindrical parts by using process in which sheet is drawn into cavity of die to form the sheet metal into desired shape. Earing is one of the significant defects appeared in the drawn cup during deep drawing operation because their anisotropic nature of sheet metal blank. Earing is known as formation of waviness on top portion of drawn cup. Information concerned forming of ears in deep drawing operation permits a pervious alteration of operation, which result in produce final cup with defect less and financial saving and time [1-5]. Many studies have been performed to explain the relationships between earing defect and the parameters of the deep drawing process. Hwang [6] analyzed the influence of the shape of blank in rectangular cup drawing process experimentally. A rectangular cup drawing experiments have been performed to define the optimum shape of blank

for different material and shapes of the blank. The results of the research, which define the optimum shape of blank for stainless steel through rectangular cup drawing experiments. Kishor and Kumar [7] studied the earing defect in the cylindrical deep drawing operation using FE method based code LSDYNA. It was noted that it is possible to decrease the extent of earing defect in deep drawing of highly anisotropy sheets employing a noncircular blank. FE simulation of earing shape in deep drawing process is studied by Saxena and Dixit [8]. In this study the investigate of the geometry of tool and parameters of process on the formation of ears was studied. It was found the ultimate ear height in a cylinder cup are influenced by the anisotropy nature of material, moreover the earing reduces with increase in the radius of the die and punch profile. In this study, investigation the effect of parameters of the process utilized in square deep drawing process such ; material properties, blank size, blank shape on the height and shape of earing defect appear of

the drawn cup. The results show that, The circular blank give the best results according to earing defect and useful height of the drawn cup, when square shape of blanks were utilized, excessive earing will show in the square cup, as well as used a new algorithm to modify the initial blank used with less iteration according to pervious researches.

**2. Experimental Work**

This work aims to describe the experimental procedure in which is used to study the influence of the some parameters of process on the earing defect in the square deep drawing operation. The mechanical properties of the material sheet to be formed has a significant effect on the success of a drawing process. Low carbon steel was selected in this study. The sheet metal thickness, to =0.7mm. To determine the rolling direction optical microscope with 12.5X magnification power was used. Figure 1 shows the direction of rolling for (1008-AISI) low carbon steel.



**Figure 1. Direction of rolling for 1008-AISI Low carbon steel**

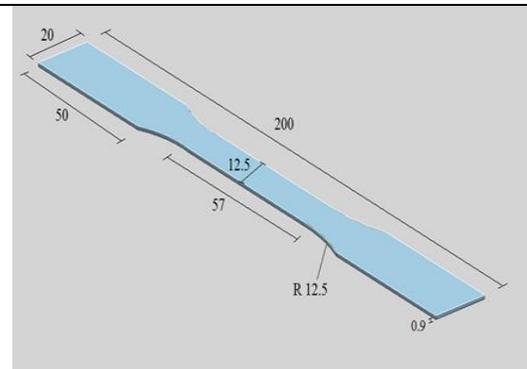
*1. tensile test and coefficient of anisotropy calculations*

Define the properties of the sheet metal (blank), specimens were machined and tested according to ASTM (American society for testing and materials) standard E8M specification as shown in Figure 2. The specimens were tested along the three directions, with the direction of rolling (0°), diagonal (45°), and perpendicular (90°) to the direction of rolling. The standard tensile specimens were tested until fracture occurred. Tensile tests were performed at cross head velocity (2mm/min), by using a universal testing machine type (WDW 200E). Mechanical properties for low carbon steel are shown in Table 1. Figure 3 shows the relationship between true stress-true strain curves for mild steel material at different angles (0°, 45° and 90°) with respect to the direction of rolling, and a chemical composition test to check the manufacture certificate of (1008-AISI) low

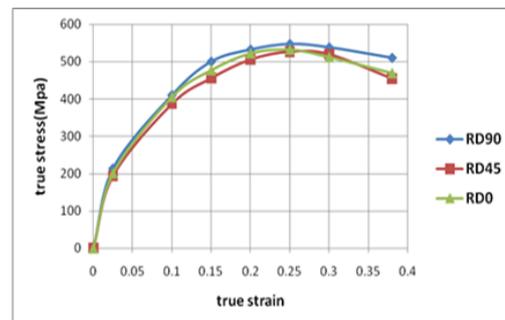
carbon steel were performed by utilizing spectrometer device as shown in Table 2, the magnitude of plastic anisotropy in sheet products, which are considered important factors that have a significant effect on the drawability of the sheet can be determined by measuring the strain of the tensile specimen strained to beyond its yield strength. To obtain the coefficient of anisotropy, volume constant law is used from the measurement of length and width strain at 20 percent from uniform plastic deformation, where the gage length of the tensile specimen is divided into five equal regions, and strained at cross head velocity equal to (2 mm/min). The specimens are taken from three directions (0°, 45°, 90°) with respect to the direction of rolling. The value of the normal anisotropy ( $r$ ), mean normal anisotropy ( $\bar{r}$ ) and the planar anisotropy ( $\Delta r$ ) of low carbon steel material are shown in Table 3.

**Table 1: The mechanical properties of the sheet.**

Property	Exp.	AISI	Unit
Young modulus	200	190-210	GPa
Poisson ratio	0.3	0.27-0.3	mm/mm
Offset yield stress	203	245	MPa
Tensile strength	325	340	MPa



**Figure 2: The dimensions of tensile test specimen according to ASTM standard E8M specification**



**Figure 3: Flow curves at different angles with respect to rolling direction for 1008-AISI Low Carbon Steel**

**Table 2: The chemical composition of the low carbon steel (1008AISI).**

element	C%	Mn%	Si%	P%	S%
measured	0.08	0.32	0.02	0.015	0.021
AISI	$\leq 0.1$	0.3-0.5	0.01	$\leq 0.04$	$\leq 0.05$
element	Cr%	Cu%	Al%	Mo%	Ni%
measured	0.03	0.09	0.05	0.002	0.03

**Table 3: The value of coefficient of anisotropy of (1008) AISI material respects to rolling direction, where ( $\epsilon_w$ =width strain,  $\epsilon_t$ =thickness strain)**

property	Symbol	value	Unit
Plastic anisotropy with 0° from rolling direction	$r_0$	1.395	$\epsilon_w/\epsilon_t$
Plastic anisotropy with 45° from rolling direction	$r_{45}$	1.165	$\epsilon_w/\epsilon_t$
Plastic anisotropy with 90° from rolling direction	$r_{90}$	2.00	$\epsilon_w/\epsilon_t$

*II. Experimental tooling*

Punch and die were designed and built to produce square cup, as shown in Figure 4. The material of tools are made from tool steel (X12 M), and were machined by wire cut machine. Then machining process, these tools were polished to obtain finer surface finish.

The rigid square punch is 40 mm by 40 mm, the profile radius is 5 mm and punch corner radius is also 5 mm which gives radial clearance of  $(1.1t_0)$  at assembly with the die which has a flat surface with a square cavity 41.55 mm by 41.55 mm, the profile radius is 5 mm and the radius of die corner is 5 mm. Blanking die is used to produce circular blank, and cutting machine to produce square and octagon blanks, with a thickness of  $t_0 = 0.7$  mm. Deep drawing experiments are carried out to obtain square cup, where deep drawing die is placed on the tensile testing machine (WDW-200E). After putting blank on the blank holder surface, taking into consideration the direction of rolling of the sheet (45° from RD of the sheet form cup corner), die will drop towards the punch, and this means inverted drawing die use. The speed of drawing equal to (60mm/min) was selected to draw for the low carbon steel material. The blank holding force were set as the minimum to prevent wrinkling by trial and error, they were (15 KN) for low carbon steel material. The circular, square, and octagon blanks were drawn with different

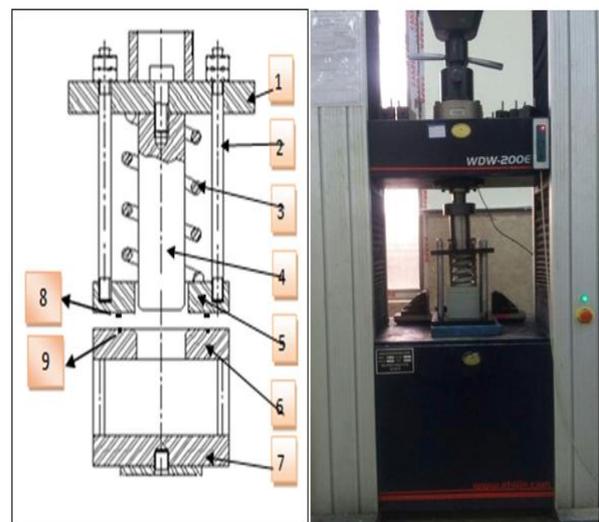
sizes to study the effect of these parameters on the earing in the square cup.

*III. Blank shape design:*

A circular blank shape was chosen to carry out the majority of the work. Other blank shapes were chosen to investigate the influence of the blank shapes: (square, octagonal). The surface area of the circular blank was calculated and then we used two shapes of blanks (square, octagonal) that have an same surface area to the circular blank. Three types of shapes of blank were used as shown in Figure 5. Table 4 showed the dimensions of the different shape used.

**Table 4: The values of the dimensions of the blanks used**

shape	dimension	Value (mm)
circular	Diameter (D)	78,80,82,84 and 86
square	Side length (L)	69,70,72,74 and 76
Octagonal	X <sub>1</sub>	75,77,79,81,83
	Y <sub>1</sub>	31,32,33,34,35



1	2	3	4	5	6	7	8	9
Top plate	Guide	Spring	Punch	Blank holder	Die	Bottom plate	Draw bead	Bead groove

**Figure 4: Graphical representation of rig deep drawing tooling**

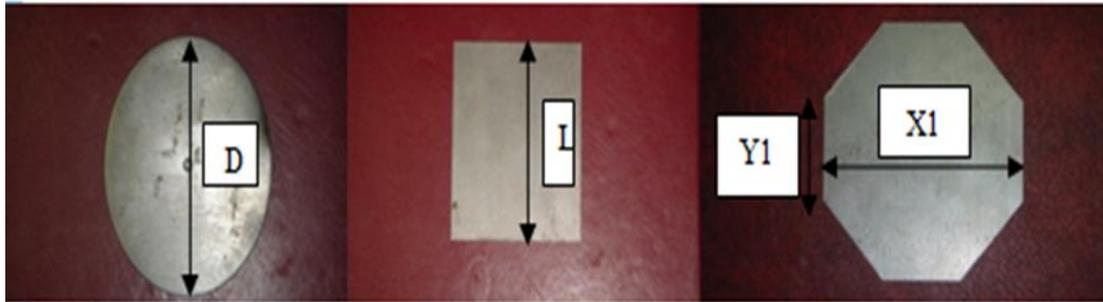


Figure 5: Shape of used blanks

### 3. Numerical Simulation

The deep drawing operation is simulated by finite element analysis software ANSYS11.0, in which the implicit approach "Newton-Raphson" were used to solve nonlinear issues. In these problems, the steps of stroke on punch are determine explicitly over a time extent. Within each step, several solutions (time steps or substeps) are carry out to apply the displacement progressively. At each substep, a number of equilibrium iterations are performed to get a converged solution .

The 3-D 8-node structural solid element of SOLID45 were utilized for meshing the workpiece (blank).The tool group (die, blank holder and punch) were modeled as rigid bodies. Size of the elements are planned by controlling the division specification of lines. Size and number of element of mesh of the blank and tools influence the accuracy of the results. Therefore, the meshes in the workpiece are finer. The most significant part of the tool whose mesh density influences the accuracy and reliability of the results is its arc segment and the meshes of this part are finer than other parts.

The punch stroke was defined by using a pilot node; this node was also used to get the force of drawing throughout the simulation. The pilot node has degrees of freedom for representing the motion of the total rigid surface, including one rotational and two translational degrees of freedom in two dimension, and three rotational and three translational degrees of freedom in three dimension. You can apply boundary conditions (displacement), rotations, concentrated loads, etc. to the pilot node.

Procedures of automatic contact in ANSYS11.0 were utilized for modeling the complicated interaction between the tool group and blank. For rigid (tool group)-flexible (blank) contact, target elements of TARGE170 was utilized, to represent three dimension target (tool group) surfaces which were associated with the deformable body (blank) represented by three dimension 8-node contact

elements of CONTA174. The target and contact surfaces constitute a "contact pair" that were utilized for representing sliding and contact between the surfaces of blank and tool group. A deep drawing model were generated. Due to the symmetry in the specimen geometry, constraints and boundary conditions, only a one-fourth part of the model needed was resolved. The finite element model of the sheet material and tool group are shown in Figure 6. A Coulomb friction law was employed to investigate the influence of friction at the tool-material interface, the law of friction is assumed constant at the blank surface-tools interface.

Bilinear Isotropic Hardening (BISO) option employs the Von Mises yield criterion connected with an isotropic work hardening assumption. This option is oftentimes preferred for large strain analyses. The BISO can be combined with Hill anisotropy options to simulate more complicated behaviors of the material. The principal axes of anisotropy coincide with the material (or element) coordinate system. For simplifying the deep drawing operation simulation, the following assumptions were made.

1. The temperature of blank remained without change (constant).
2. Not heat transfers between and tool set and blank.
3. The punch moved down at constant velocity (60mm/min) and the dies were rigid and stationary during the forming process.

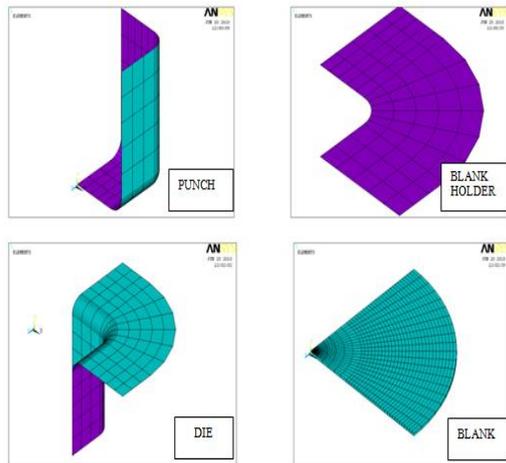


Figure 6. Finite element model of the sheet material and drawing die

## 4. Result and Discussion

### 4.1. Earing prediction

The numerical analysis were performed utilizing the Hill's model as implemented in ANSYS 11 finite element code, because the Hill's model takes the  $r$ -value in account. Figure 7 shows the comparison of cup shape between FEM model and experimental for different blank shapes. Mild steel materials have the Lankford values of  $r_0$ ,  $r_{45}$ , and  $r_{90}$  for 1.395, 1.165, and 2.00 respectively, and tool geometry with (punch and die profile radius in mm) [rp5rd5], (blank diameter in mm) D80, (blank holder force in KN) bhf15, (coefficient of friction)  $\mu$ 0.1, (punch speed in mm/min) v60, and different blank shapes were chosen to predict the earing defects on deep drawing process by FEM, and then the numerical results were compared with the experimental. The blank was placed onto the die with taking into consideration direction of rolling of the sheet ( $45^\circ$  from RD of the sheet form cup corner).

Earing defect is unfavorable, as it required trimmed some metal from the top of the cup. This expends time and money. There are some methods to reduce this defect; one of these methods to avoid this defect is to adjust the shape of initial blank to product a final cup that is ear less. In this section, a benefit was obtained from the researcher's work [9]. Author considered the case of design of optimal blank for square drawn cup, included the effect of friction and anisotropy. The material considered for the simulations is low carbon steel (1008-AISI). The circular shape is selected as initial blank shape. FEA are carried out to simulate the square deep drawing operation. An error metric is used to measurement the amount of earing, is construction for the resulting cup. This error metric is then utilized to redesign the initial blank shape. The cycle is iterative until the error metric

satisfies a preset convergence criterion (in this study 0.004 of the cup height). This iterative design operation leads to shape of optimal blank. Two main steps involved are, numerical analysis utilizing FEM and shape error definition and creation of a novel modified blank shape. The shape of initial blank is a perfect circle, when this circular blank is undergone to a FE deep drawing simulation, the cup that forms shows severe earing as can be seen in Figure 8a, the maximum error (maximum peak to valley discrepancy) after this first iteration is close to 2.25mm. Therefore, modification in the shape blank done to reduce the maximum error as shown in Figure 9 until reaches the optimum bank shape, which gives the target cup with maximum error, is 0.004mm as shown in Figure 8d.

Figure 10 represents the effect of  $r$ -value on the cup height with different degrees from direction of rolling; planar anisotropy ( $\Delta r$ ) of the sheet produces the earing, and correlates widely with the angular variation in  $r$ -value. At angular positions have minimum  $r$ -values, more decreasing in thickness occurs, while the heights of cup wall are higher, and at positions of maximum  $r$ -value, the walls become thicken and lower, according to this role which is mentioned above the earing must appear in the cup at  $90^\circ$  from rolling direction, because it has maximum  $r$ -value, and lower height in the cup at the  $45^\circ$  from rolling direction because this direction has minimum  $r$ -value, but it is noted that from the figure the earing appears in the cup corner ( $45^\circ$  from rolling direction) and this is opposite to that mentioned above, to describe this affair there are important points which must be considered in the square deep drawing process which the deformation modes alter along the cavity of die. Corners of square cup experience excessive deformations compared to cup-side walls. Therefore during deformation, the flow of metal at the cup side walls ( $0^\circ$  and  $90^\circ$  from rolling direction) is more easier and uniform than that in the corners of cup ( $45^\circ$  from rolling direction). It can be concluded that the earing appears in the square cup corner ( $45^\circ$  from rolling direction) due to the metal flow in this location. The flow is difficult and slower than the metal in the square cup flat wall (at  $0^\circ$  and  $90^\circ$  from rolling direction), and the cup height at  $90^\circ$  from rolling direction is higher than the cup height at  $0^\circ$  from rolling direction in spite of its having the same flow conditions, but the  $r$ -value in the  $90^\circ$  is greater than  $r$ -value in the  $0^\circ$  from rolling direction. The predicted earing from FEM model has same trends with experimental, except that the FEM model always was lower than experimental earing, this may be because to the loss of accurate information

about friction condition and material properties, and in the practical problems the center lines of blank, die, and punch often are different for each other.

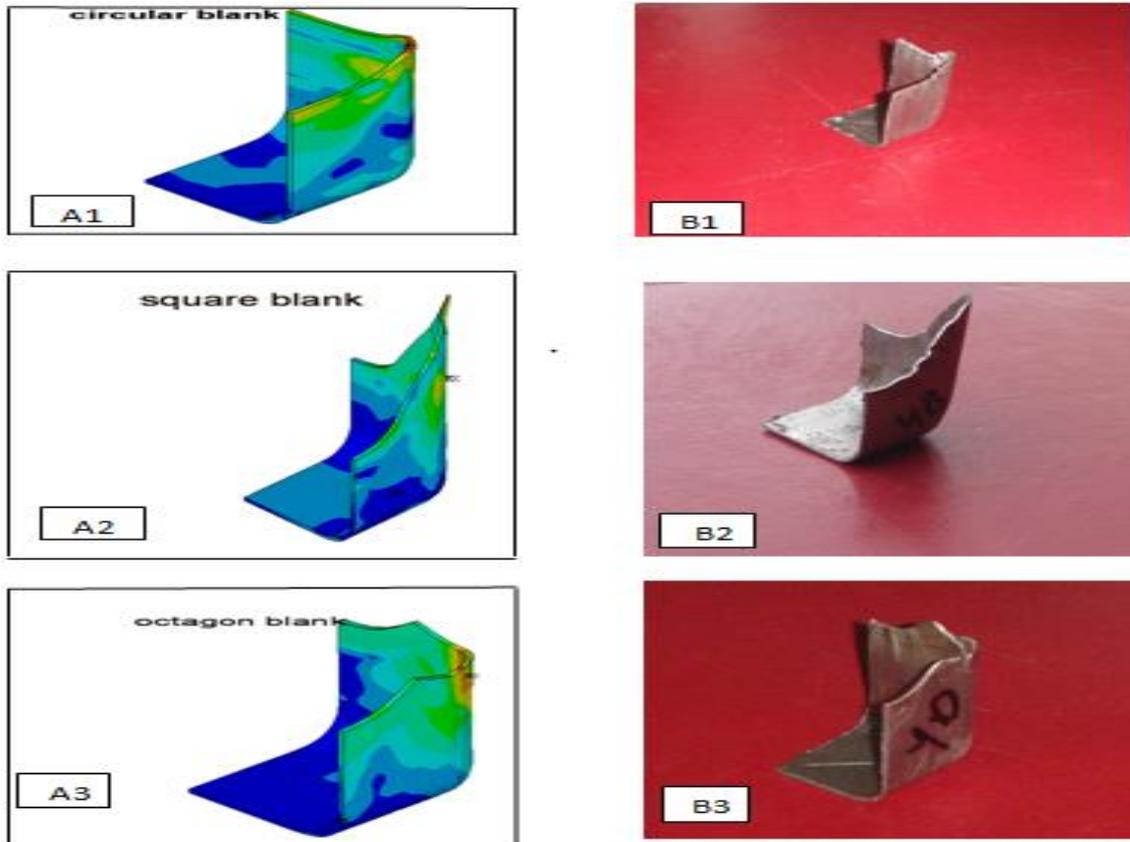


Figure 7. The earring shape, A1-A3) Hill's Model, and B1-B3) experimental, (die and punch profile radius equal to 5mm, head velocity equal to 60mm/min, blank holder force equal to 15kN).

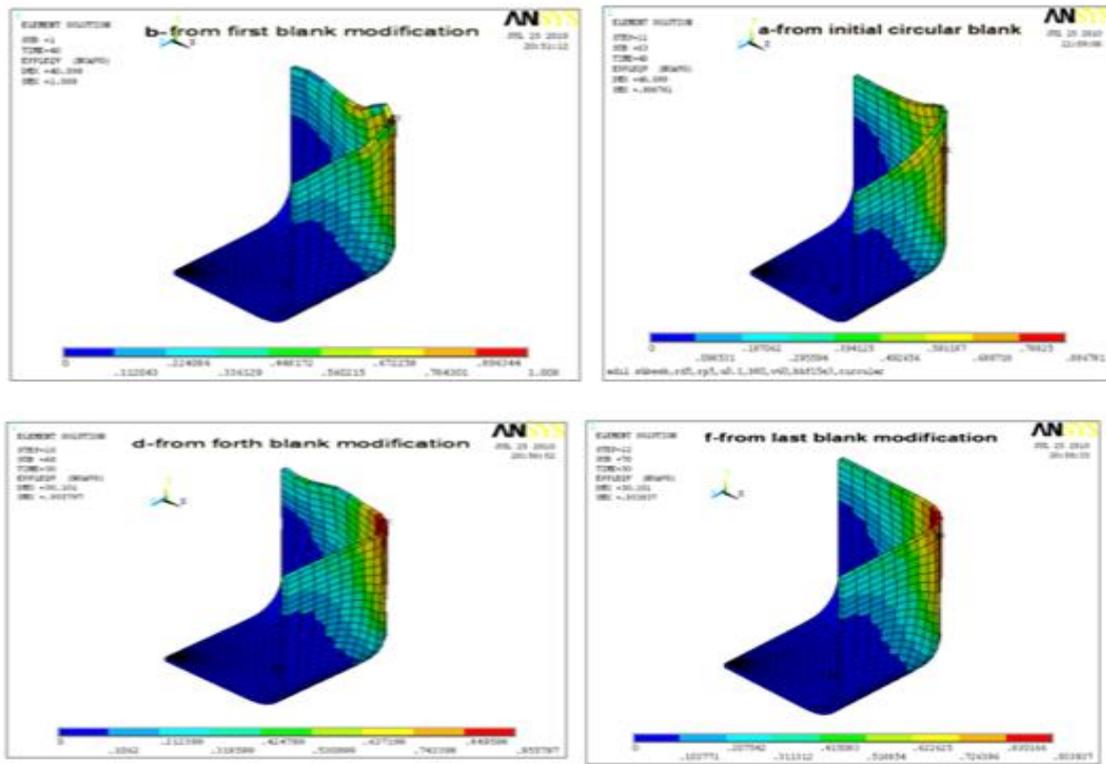


Figure 8. Deformed cups from the modify blank shapes for square deep drawing.

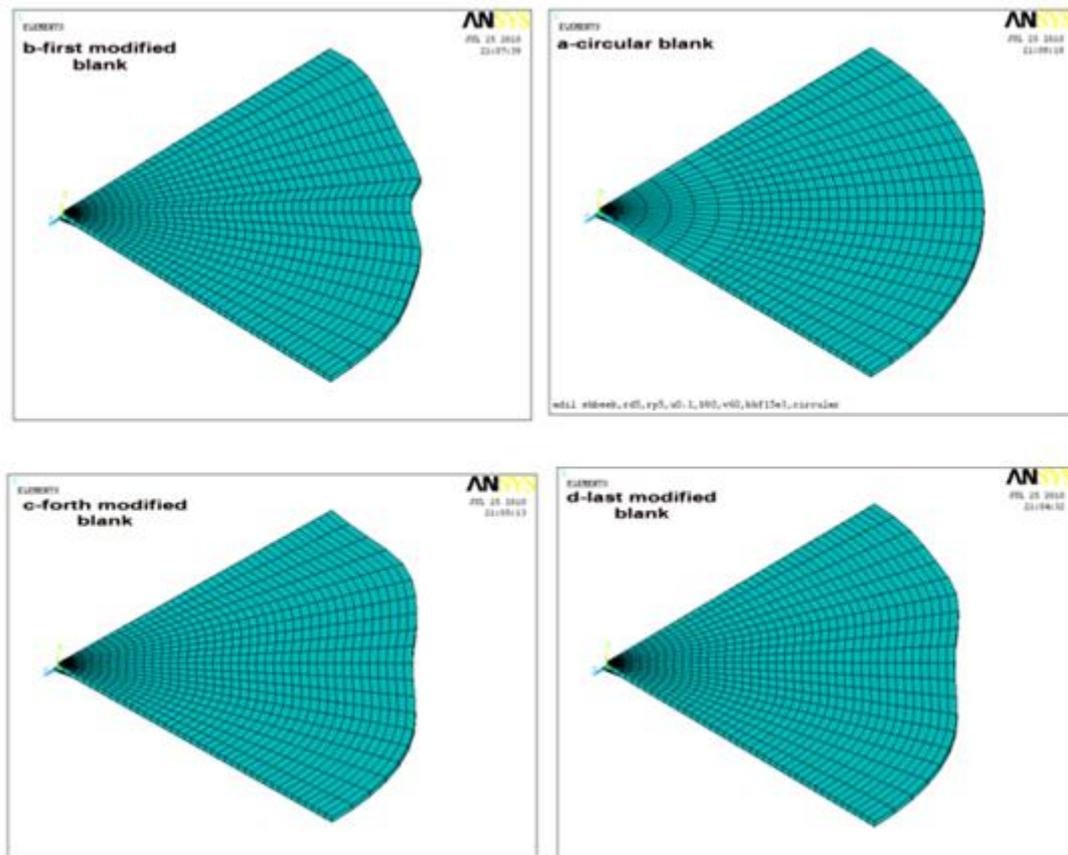


Figure 9. Evaluation of the blank shapes for the drawing of square cup that is ear less.

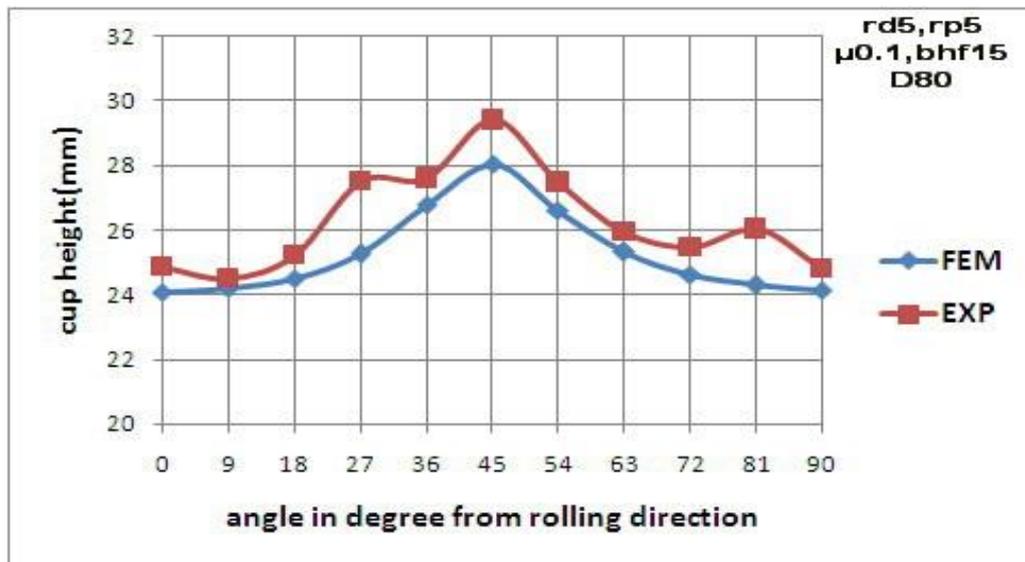


Figure 10. The influence of the r-value on the cup height.

Figure 11 displays the influence of initial blank shape on the earing pattern during square deep drawing processes, in this work three different blank shapes (octagonal, circular and square) are used, all blanks have the same volume to study the influence of the blank shape on the earing defect in the final cup. However, square cups have curved and flat sides, due to this, the plastic deformation characteristics are non-uniform about the periphery of the square cup. It is noted that from the Figure 11, when the square blank is prepared for square deep drawing excessive earing is shown in the square cup corner since the metal flows have been difficult in the cup corners. It means that it is too already late to pass into die cavity and the metal is pinched in these zones, whereas flat sides flow in better condition compared to the corner zones, the material starts for flowing at the regions where it flows easily. At these regions, outer edges of the square blank are closest to the die opening, in other words, the width of the blank at these regions is minimum. As a result, the cup height of cup in the corner direction is more than the height of cup in the flat side for the square cup when square blank is used. The maximum peak to valley discrepancy along the perimeter of the square cup was found about of (22.219 mm), this value is very large, and means, the useful drawing height is unsatisfactory, and the material is lost by trimming. Therefore, the square blank shape should adjusted to get smaller contact surface at the cup corners, therefore the octagonal blank was used in which the distance between corners of the die and inclined sides of the blank constitutes the shortest distance, it is found when this type of blank shape is used, there are less earing defect due to extract of the too much material from the blank corners. The presence of little material makes the

flow of material easily, whereas the flat side of the die metal can flow quickly, but the earing appears at (27° from rolling direction) due to additional material in this location, the maximum peak to valley discrepancy along the perimeter of the square cup was found to be about of (5.161 mm). Therefore, the useful drawing height is higher than that attained in the square blank. Moreover, another blank shape is taken when the blank is designed circular, more useful drawing height have been obtained, and the earing occurs in the corners slightly. The maximum peak to valley discrepancy along the perimeter of the square cup is (3.967 mm) which is less than that obtained in the square and octagonal blank chosen. Consequently, the worst results were obtained from the square blank used, while when used circular blank the best results were obtained, Generally, as a result of the above a circular blank is prepared for square deep drawing operation for studying the effect of different parameters below.

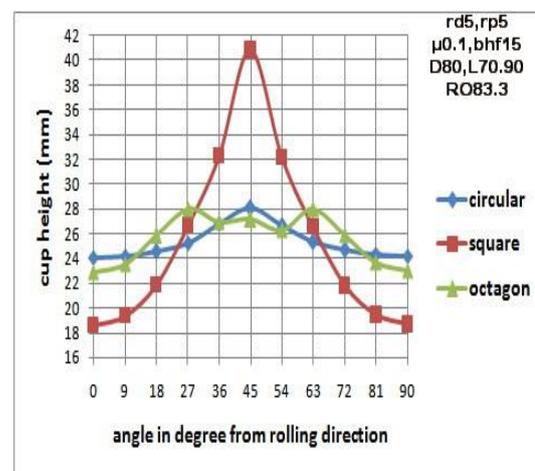


Figure 11. The effect of the blank shape on the cup height.

## 5. Conclusions

1. The deformation modes alter along the cavity of square die, the flow on metal at the cup sidewall is easier and uniform than that in the cup corner. Therefore, almost earing defect is concentrated at cup corners.
2. The position of earing which appears along the perimeter of the square cup are varied according to planar anisotropy, initial blank shape and condition which control the metal flow in the die cavity .
3. Earing appears at cup corner (45 degree from rolling direction) although this direction has lower r-value .
4. Excessive earing is shown in the square cup when using square blank shape because to excessive amount of material in the corner of cup and minimum material in the flat side.
5. The worst results obtained from the square blank used, and the best results are obtained from the circular blank used according to useful drawing height and earing.

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