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The Influence of Punch Profile Radius on Deep Drawing Process in Case of a Low Carbon Steel Cylindrical Cup

Abstract - *This research aims to investigate the effect of punch profile radius on the drawing force, cup wall thickness, amount of spring back induced in the drawn cup, contact regions between blank and punch, strain distributions over the cup wall and height of drawn cup, in deep drawing operation. In this study, a commercial FEA software package (ANSYS11.0) was employed to model a deep drawing operation. A 3-D model of cylindrical cup of (53.4 mm) outer diameter and (33mm) height from a low carbon steel (1008–AISI) of (0.7mm) sheet thickness has been developed and then the FE simulations results are compared with experimental results. To carry out the experimental work, six types of punches of (52mm) diameter with various punch profile radius of (4, 8, 12, 16, 20, 26 mm), die of (53.75mm) die opening diameter with die profile radius of (4 mm) and blanks of (95 mm) diameter have been manufactured. The results indicate that the strain distributions for all punches chosen are similar in shape, and have the same trends. The length of contact distance between the punch and blank increases as the punch corner radius increases and its value approximately is equal to punch corner radius. Drawing force dose not significantly influence by punch corner radius. Thinning increases as punch profile radius increases, and the greatest thinning occurs with the hemispherical punch of (R_p= 26mm). The cup height and the amount of spring back percentage increases as punch profile radius increases.*

Keywords - *Contact Regions, Deep Drawing, Punch Profile Radius, Spring Back.*

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1. Introduction

Deep drawing is a forming process where a blank (piece of sheet metal) is shaped into three-dimensional object. During deep drawing process, the punch forced blank material to follow its movement, along its way through the die opening. As a result of the operation, change happens in shape and even thickness of the part [1]. Generally, two main forces contribute to completely drawn the sheet metal blank during the operation. First is the force, which is used for holding the blank sheet in touch with the upper face of the die, which applied by a blank holder, therefore it is recognized as a blank holding force (BHF), the other one, is supplied by a punch, which is forced the blank material to flow plastically into the die cavity [2]. As a result, the blank or sheet metal will be deformed into the wanted shape such as conic, cylindrical, boxed-shaped part as well as complex parts that is normally involve redrawing processes by utilizing multi stage dies [3]. The popularity of deep drawing selection comes from its rapid cycle times of press and its ability to produce complicated geometries and shapes with low cost and labors necessity in which play major role in manufacturing industries. Nowadays, the deep drawing has an extensive role in automobile and aerospace industries to manufacture structural components, in addition, it is used in other industries to fabricate many thinks such as, sinks, oil filters, beverage cans, home décor, etc.The associated defects are the most familiar outcomes in drawing operation which occur in the drawn parts due to many parameters such as die radius, blank holder force (BHF), blank diameter, punch radius, friction between each of (blank – die), and (punch–blank), blank thickness, material properties, and many more [4]. Therefore, the process parameters should be optimized depending on the importance degree of these parameters on the characteristics of the forming operation to avoid defective products and to minimize the cost of production [5, 6]. Numerous studies have been conducted by refer to these parameters to demonstrate the correlations between formability of metal and the processing parameters during the operation. Therefore, the most recently related articles are reviewed here. Fuh-Kuo and Tyng-Bin [7], presented the effects

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of some process parameters, such as punch and die corner radii, and forming temperature, on the formability of the magnesium alloy (AZ31) sheet during drawing of square cup. The results showed that a larger punch radius allowed for a uniform material flow and delayed the occurrence of fracture; as well, the formability was improved as the die profile radius increased up to an optimum value. Jawad [8] confirmed the point that the punch load was decreasing slightly with the increasing in punch radii and vice versa. A finite element program code (ANSYS 5.4), was used to simulate the deep drawing process of cylindrical cup from annealed mild steel of (0.15%) carbon content and (0.5mm) sheet thickness. He examined the influences of punch shoulder radii on interface contact state between blank sheet and punch, thickness variation over a drawn cup wall, also punch load was studied. The results showed that the friction force was present wherever there was a curvature on the surface of the drawn part. Malekani et al. [9] investigated numerically and experimentally the influence of blank holder and die shapes on the drawing force, BHF and limiting drawing ratio (LDR) in deep drawing process to produce a cylindrical cup free of wrinkling defect from low carbon steel (ISO 1624) of 1.5mm thickness. Results show that, wrinkling can be reduced as the slopes of blank holder and die increased to a certain value. Also increasing the slope facilitated material flow and increased LDR. In addition, the optimum value of slope for tools was (6.38 degree). Karem AL-Darraj and Adil Shbeeb [10] investigated experimentally and numerically the effect of radius profile of die and punch and blank shape and size on cup wall thickness, strain distribution, earring shape, punch force, and height of the drawn square cup from Low carbon steel (AISI 1008) of (0.7) mm thickness. The results showed that the circular blank gave the best results for cup height and earring shape. Gowtham et al. [11] examined the die nose radius influence on the formability of Aluminum alloy (6061) in deep drawing process, and keeping each of Punch nose radius, coefficient of friction and blank thickness constant. The finite element program software DEFORM-3D and Aluminum alloy 6061 was used in deep drawing process. They were noted that the drawing forces increasing as the radius of die shoulder decreasing, and results in earring and stretching marks with the drawn part. Purushotham [12] investigated the influence of the friction force and holding force on a pattern of radial and hoop stress and strain distributions during deep drawing process for mild steel and copper materials. It is found that, increases the blank holder force leads to increase the radial strain, decreases thickness at the rim of the cup and increases thinning at punch profile zone, Also it was found, the strains values increased with increasing the value of friction coefficient. El Sherbiny et al. [13] developed a (3-D) numerical simulation model for mild steel sheet metal has anisotropic properties with simplified boundary conditions. For validation of the FE results, experimental tests were carried out. They recommended that The radius of die shoulder should be around "10 times blank thickness", the radius of punch profile should be larger than "4 times sheet thickness" and to avoid increasing the residual stresses and excessive thinning, the blank holding force should be not exceeds "3 tons". Shah et al. [3] used both Experimental and Statistical methods to present the effect of most critical process parameters which results in thinning and defects in the blanks. ANOVA analysis technique was used to determine the percentage contribution of individual parameters. They concluded that the Die radius has (36.44 %) of percentage contribution, Punch nose radius is (8.48%) and (53.39 %) for Blank holding force, with (1.69 %) error for ineffectiveness of human.

This research aims to investigate the effect of punch profile radius on the drawing force, cup wall thickness, the amount of spring back induced in the drawn cup, the interfacial contact between blank and punch, strain distributions over the cup wall and the height of drawn cup.

The following parametric study is adopted in this work; The punch profile radius is varied to the following values (R_P = 4, 8, 12, 16, 20, 26 mm) while the die shoulder radius is kept constant to (R_d = 4mm). The Radial clearance between die and punch is set to be (1.25 t_o). The punch stroke is set to be (45 mm) for all experiments tests.

2. Numerical Simulation

Numerical simulation procedure is used to investigate the influence of punch profile radius on the drawing operation of a cylindrical cup of (53.4 mm) outer diameter and (33mm) height is drawn from blank of (95mm) diameter and is comprised of low carbon steel (1008–AISI) of (0.7mm) sheet thickness, This particular cup actually has no flange; it is completely drawn in to the die. Figure 1 illustrates the geometry of the tools used in the simulations. In this study, a commercial FEA software ANSYS11.0 is utilized to simulate the deep drawing operation, Element type (SOLID 185) is employed for modeling blank material.

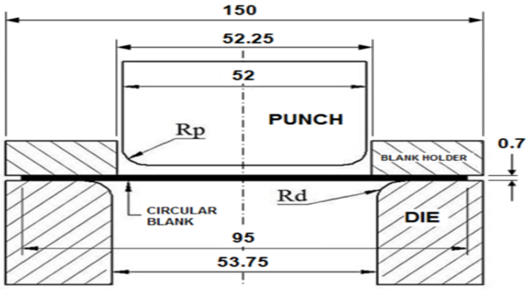


Figure 1: Geometry of the Drawing Tools (Dimensions in mm).

The tools; die, punch and blank holder are assumed as the rigid bodies and represented by Target element (TARGE170), while blank as a deformable body and represented by contact element (CONTA174). The contact and target surfaces constitute a "contact pair", which is used to represent contact and sliding between the surfaces of tools and blank. The motion of the punch is governed by a single node known as a pilot node. The boundary conditions such as displacement and concentrated loads, can be applied to the pilot node, as well as can be employed this node to extract the drawing force during the simulation. For the sake of simplicity, the following assumptions are made; the processes are done at constant temperature (25 C°), so heat effects are ignored, the punch moves down at constant speed (100mm/min) during the drawing operation and the die is stationary, the Coulomb friction coefficient at the blank -tools interface to be same and constant ($\mu = 0.1$) and the blank holder is controlled with a constant force of (4kN). Due to the symmetry of the investigated problem, a quarter of the 3-D model is employed in the numerical analysis to reduce the computational time. The assembly of the Finite element model is shown in Figure 2. The sheet metal response was simulated by using an isotropic strain hardening of elasto-plastic constitutive model. "A Von Mises yield criterion" was employed to model the plastic response, and elastic behavior was considered as linear. Table 1 gives the detail of material properties.

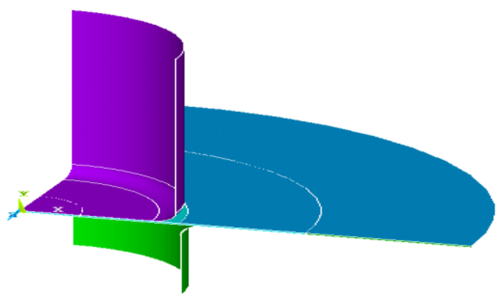


Figure 2: Finite Element Model Assembly used in Simulations.

Table 1: Properties of Material Used in Simulation.

Property	Value
Sheet material	Low carbon steel
Mass density (gm/cm^3)	7.8
Young modulus (Gpa)	200
Yield stress (MPa)	204
Poisson's ratio (ν)	0.3
Tangent modulus (GPa)	0.5

3. Experimental Work

Tools of deep drawing are designed and constructed from high carbon chromium steel to carry out the experimental work. These tools are six types of punches of (52mm) diameter with punch profile radius of (4, 8, 12, 16, 20, 26) mm, die of (53.75mm) die opening diameter with die profile radius of (4 mm) and blanks of (95mm) diameter are cut to perform the experimental tests. Deep drawing experiments are conducted using the die set that is mounted on the testing machine type (WDW-200E) which has a capacity of (200KN). Figure 3 illustrates the drawing die set and tools used experimental work. Drawing speed is kept constant at (100mm/min) for all experimental tests, and a blank holder force of (4 KN) is used during the experiments. A (1008-AISI) low carbon steel sheet metal with thickness of (0.7 mm) is used in the present work. The material properties are the same as that mentioned in Table 1. In order to foresee the contact interface between the punch and blank during drawing operation, the punches are painted with white color. After completing the drawing operation, it has been found that the white paint is removed from the punch nose as result of the blank bending and sliding over the punch nose. In order to study the strain distribution within the cup during drawing operation, a grid pattern of unified center circles, is printed (along 8 intersecting lines, 45 degree apart) on un deformed blanks by using mechanical grid marker as shown in Figure 4-a . To facilitate the measuring process; the drawn cup is divided into two parts by using a wire electro discharging machine and the length of deformed grid radius are measured along the 8 intersecting lines (along the curved line A-B-C-D) as shown in Figure 4-b and the average measured values are taken. From the measured value, the effective strain (ε_{eff}) is determined by using the following equation:

$$|\boldsymbol{\varepsilon}_{\mathbf{eff}}| = \sqrt{\frac{2}{3}\left(\boldsymbol{\varepsilon}_{\mathbf{r}}^{2} + \boldsymbol{\varepsilon}_{\mathbf{t}}^{2} + \boldsymbol{\varepsilon}_{\boldsymbol{\theta}}^{2}\right)}$$

Where; ε_r = radial strain, ε_t = thickness strain and ε_θ = hoop strain.

During the experiment; the punch load as a function of the punch stroke is recorded for all tests, and cup wall thickness, height of the drawn cup, length of contact distance and amount of spring back induced in the drawn cup are measured and compared with the results obtained by the numerical simulation.

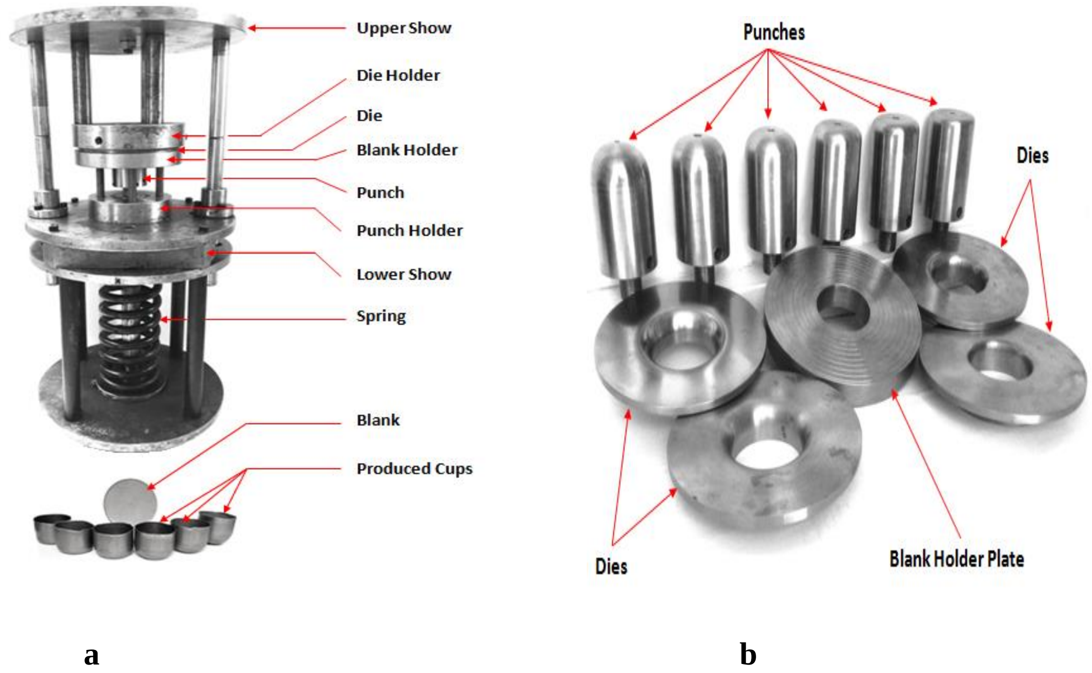


Figure 3: a-Drawing Die Assembly, b-Tools Used in the Experimental Work.

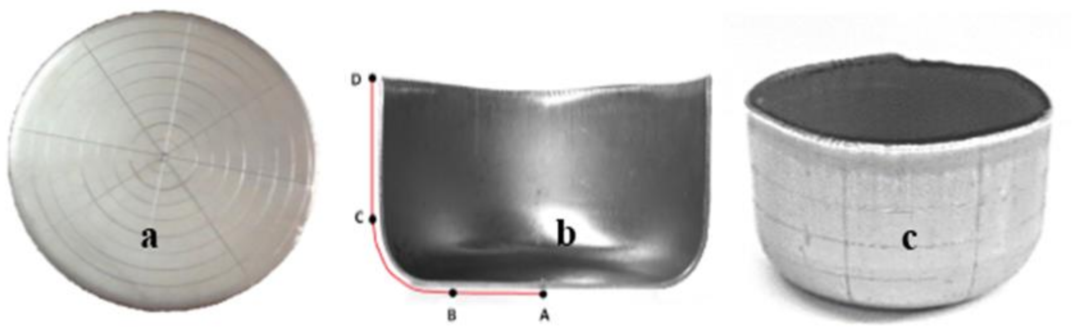
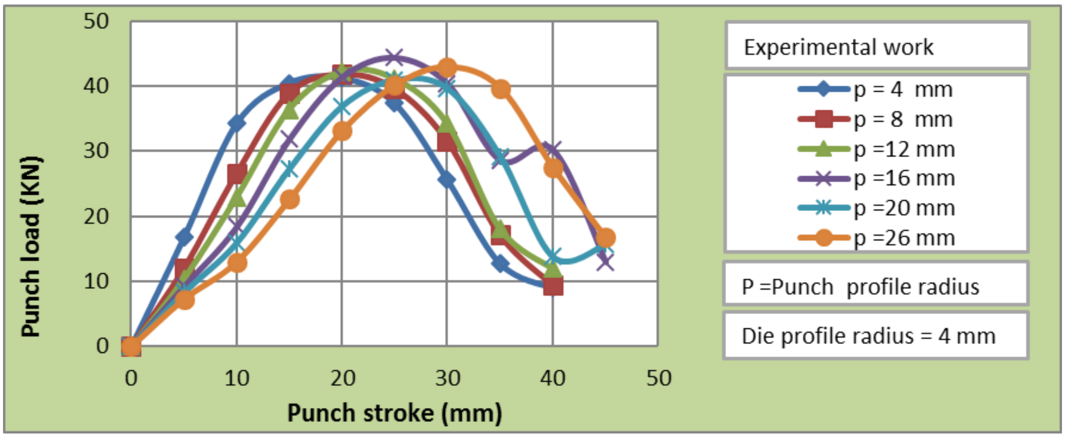


Figure 4: a- Blank with a Circular Grid Pattern, b- Half of a Drawn Cup, c- Completely Drawn Cup.

4. Results and Discussion

During the experimental and numerical tests, the punch load as a function of the punch stroke is recorded for all the selected punches. Figure 5 shows the effect of punch profile radius on drawing force. It is apparent from the figure that the punch profile radius has no significant effect on the drawing force and its maximum value, but has an effect on the manner of the transmission of the load. The more generous the punch radius (dome shape punch) the more gradual rise of the punch load and longer the punch travel. It has been found that the optimal punch corner radius which is minimized the required drawing force is equal to (R_p = 8mm), and its maximum drawing force value is equal to (41KN) experimentally and (31 KN) numerically. It is obvious from the figure that the experimental curves and numerical curves have the same trends, except that the experimental values are higher than the numerical values, due to the numerical simulations done at ideal conditions. The produced cups with different punch profile radius are pictured in Figure 6. Figure 7 shows a comparison between experimental work and FE simulation for the length of contact distance between punch and blank. It is obviously that the contact state focuses at the curved portion of the punch or at the curved portion of drawn part where the tension force at this region attains high values as a result of excessive bending and sliding of metal over the punch nose. The length of contact distance increases as the punch nose increases and its value approximately equal to punch nose radius. Since the results of FE simulations match the experimental results very well, so the contact state in this work can be found numerically without further experiments. Thickness of produced cup wall is measured and compared with the thickness obtained by FE simulation as shown in Figure 8. It is clear from figure that the initial blank thickness (0.7) at the region under a flat bottom face of the punch, slightly changes or does not change and almost remains uniform. This is because the flat face of the punch is in contact with blank, and due to the drawing force, friction comes in to play, which prevents any deformation of the metal under the punch. At the punch corner (necking point) region, thinning of initial blank thickness will occur, due to stretching exerted by tensile stress in this region. Afterward, stress is altered into a compressive stress, which causes an increase in thickness of wall and flange regions. Near the top of the cup section and at the flange rim, blank sheet undergoes the most severe shrinking and thickening occurs due to the friction at (die-blank sheet-blank holder) interface, and the circumferential forces. It is observed that the thinning increases with increasing of punch profile radius, and the greatest thinning occurred with hemispherical punch (R_p= 26mm) as a result of great stretching of the blank metal over the punch head. The amount of thinning reaches to about (9, 16, 22) % numerically, and (7, 9, 13) % experimentally, for punch profile radii (R_p=16, 20, 26) mm respectively. The best thickness distribution over wall of the produced cup occurs with the punch profile radius of (R_p= 8mm). Figure 9 shows the thickness values over the produced cup wall obtained by FE simulation.

Figure 10 shows the effect of punch profile radius on the effective strain (ε_{eff}) distribution over the cup wall of completely drawn cup. It is observed that an increase in the punch profile radius results in an insignificant increase in the maximum effective strain at the cup rim. It is apparent that, the more uniform and more reasonable values of effective strain with the punch of (R_p= 4 & 8 mm), i.e. when the values of punch profile radius is equal to (6-11) times the sheet thickness, which is in good conformation with practical values. Figure 11 presents the effective strain distribution over the drawn cup wall obtained by FE Simulation with tools of (R_P = 12 mm& R_d =4 mm). Figure 12 shows a comparison between experimental work and FE simulation for the effect of punch profile radius on the height of the produced cup. It is observed that an increase in the punch profile radius results in increasing the cup height due to excessive stretching of metal over the large punch corner radius, which contributes to an increase in the area of base radius and hence the height of the cup. It has been found that, the value of cup height increasing reaches to about (25% for experimental work and 34% for FE simulation), i.e. the maximum percentage of discrepancy reaches to about 9% for the punch profile radius ranging from (4 – 26) mm. Figure 13 shows a comparison between experimental work and FE simulation for the effect of punch profile radius on the amount of spring back induced in the drawn cup. The amount of spring back percentage is calculated as follows: Spring back % = {(Measured diameter of the drawn cup – Nominal diameter of cup) / Nominal diameter of cup}. It is shown that the spring back percentage is increasing, due to excessive bending, sliding and stretching of the metal over the punch nose radius. It has been found that the amount of spring back percentage increasing reaches to about (0.7% for experimental work and 0.8% for FE simulation) for the punch profile radius ranging from (4 – 26) mm.



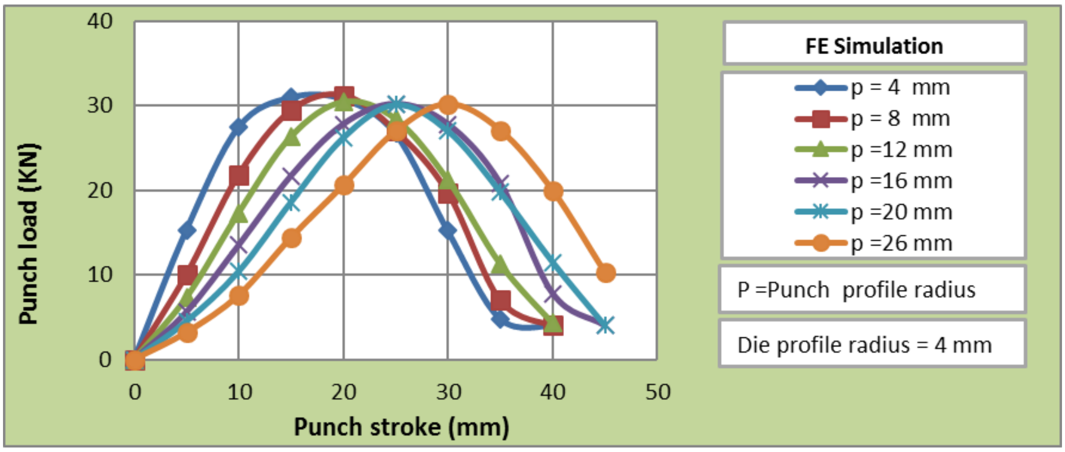


Figure 5: Effect of Punch Profile Radius on Punch Load (Comparison of Experimental Work and FE Simulation).

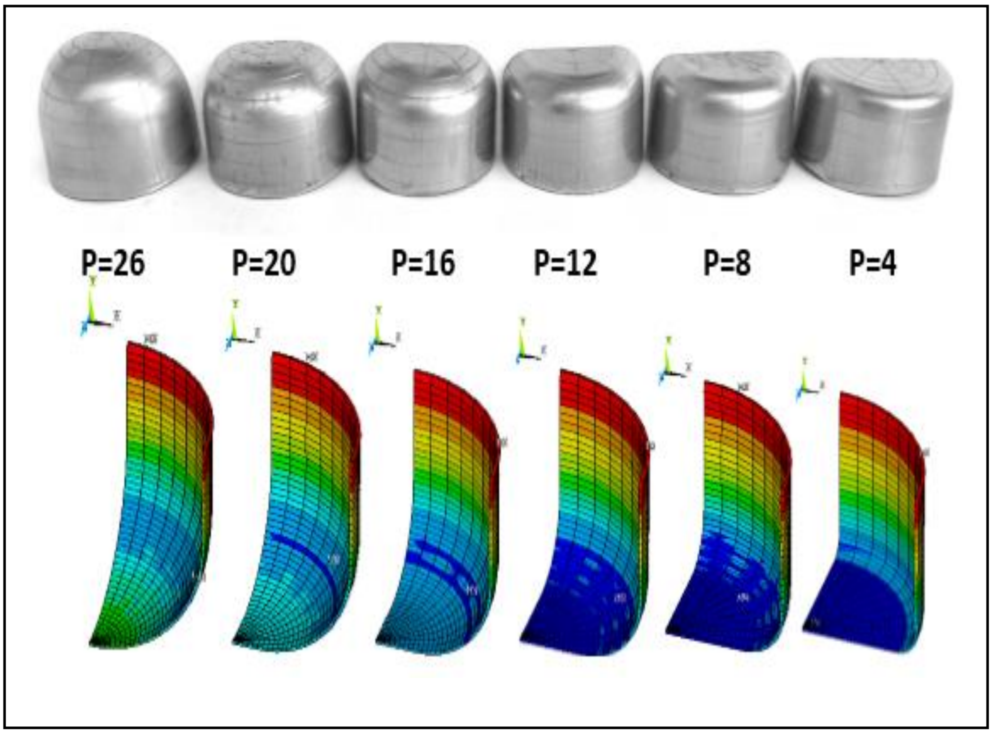


Figure 6: Produced Cups with Various Punches Profiles Radii by both Experimental Work and FE Simulation.

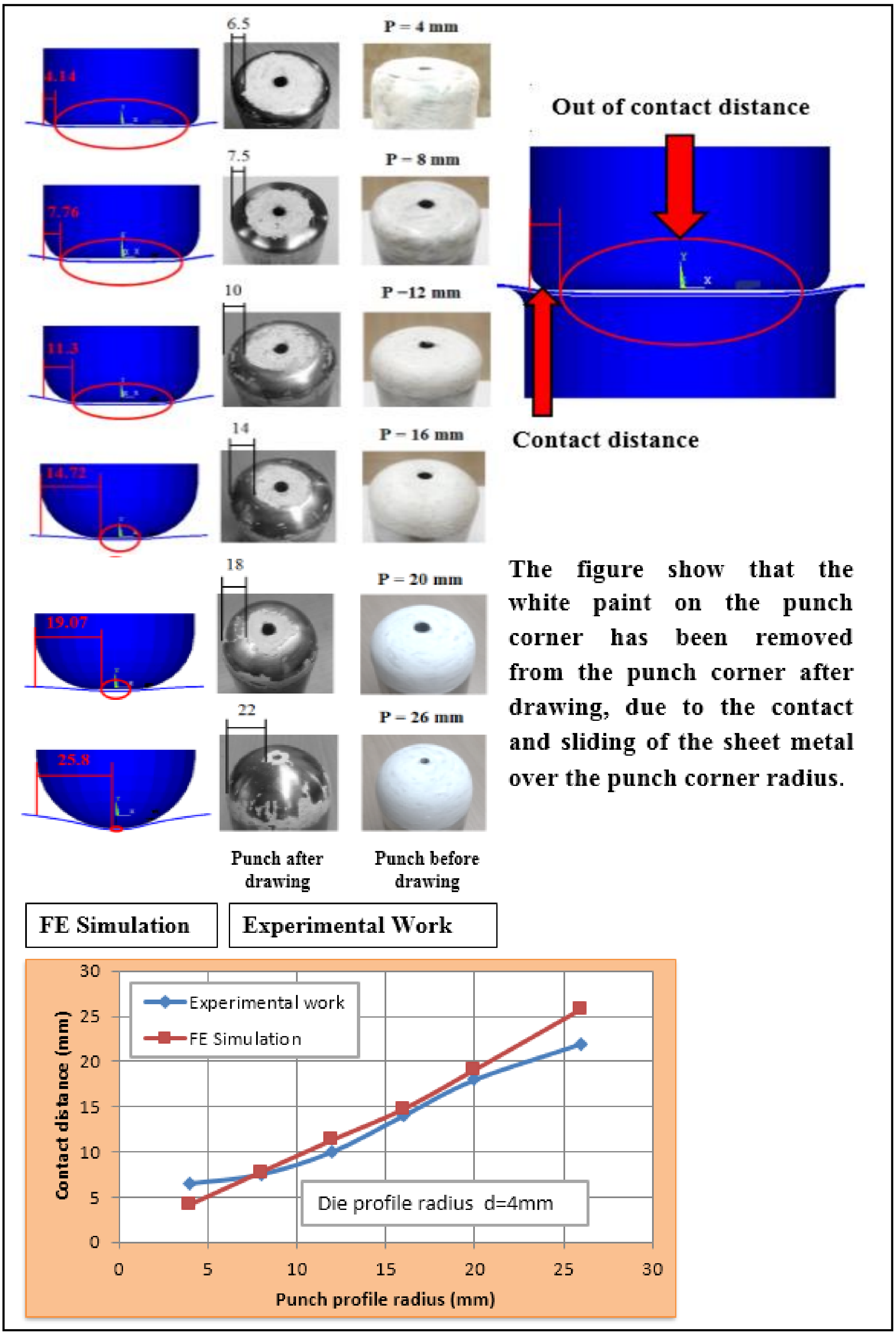


Figure 7: Effect of Punch Profile Radius on Length of Contact Distance between Punch and Blank (Comparison of Experimental Work and FEM).

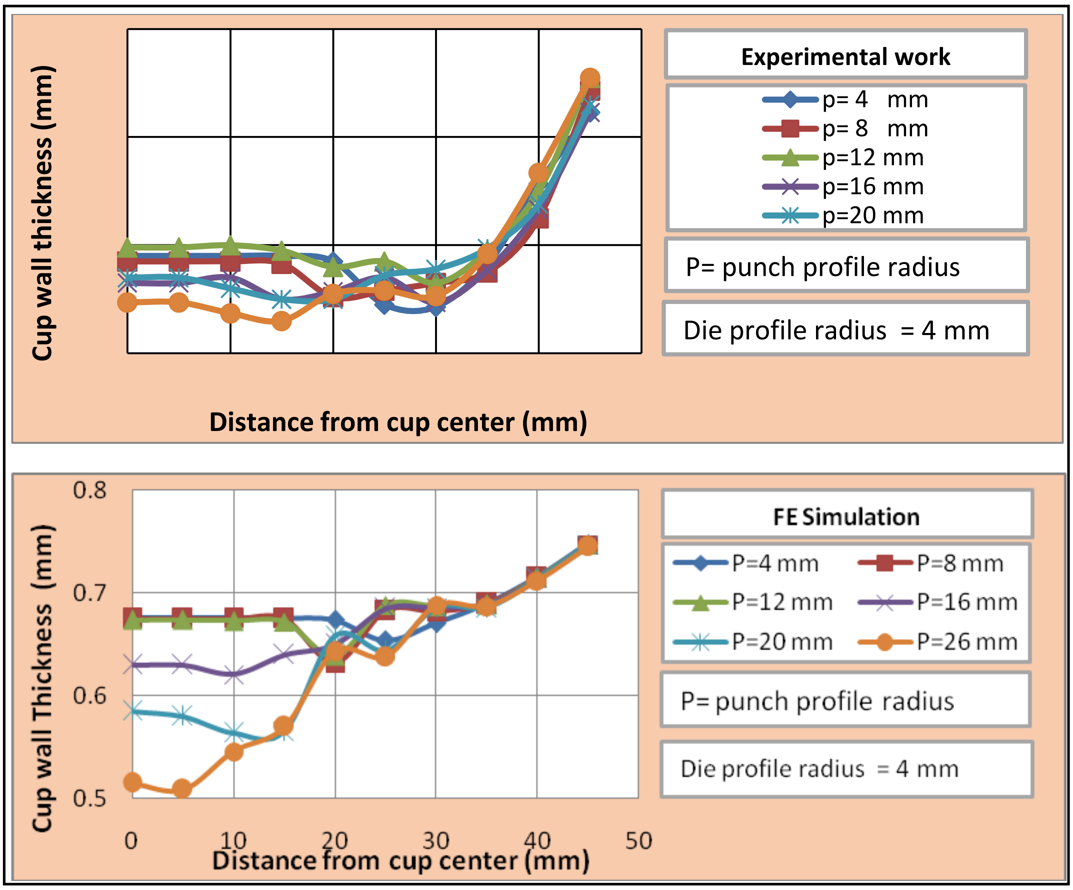


Figure 8: Effect of Punch Profile Radius on Cup Wall Thickness (Comparison of Experimental Work and FE Simulation).

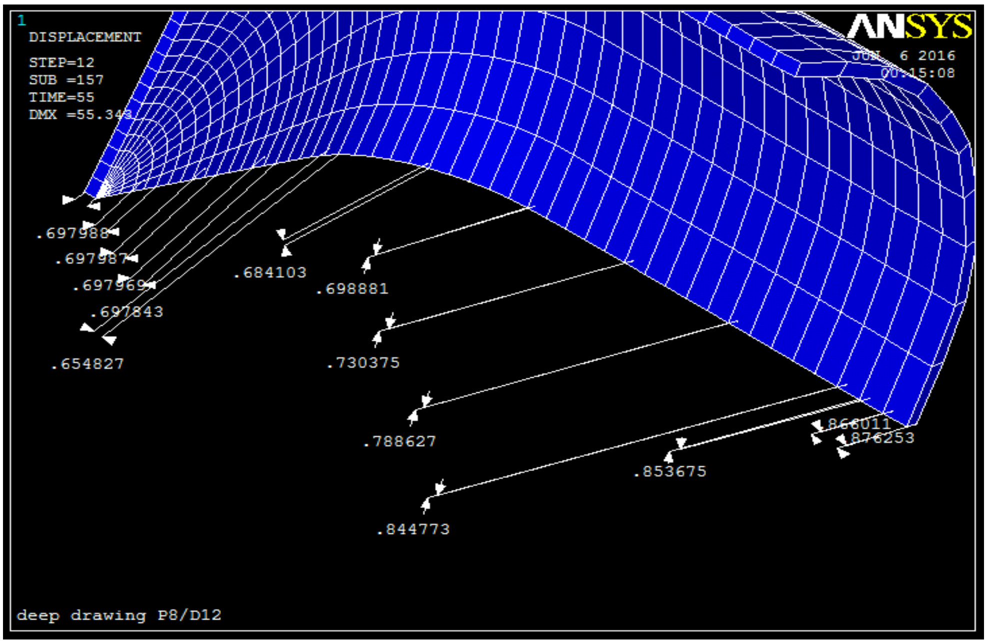


Figure 9: Thickness Variation over the Produced Cup Wall Obtained by FE simulation.

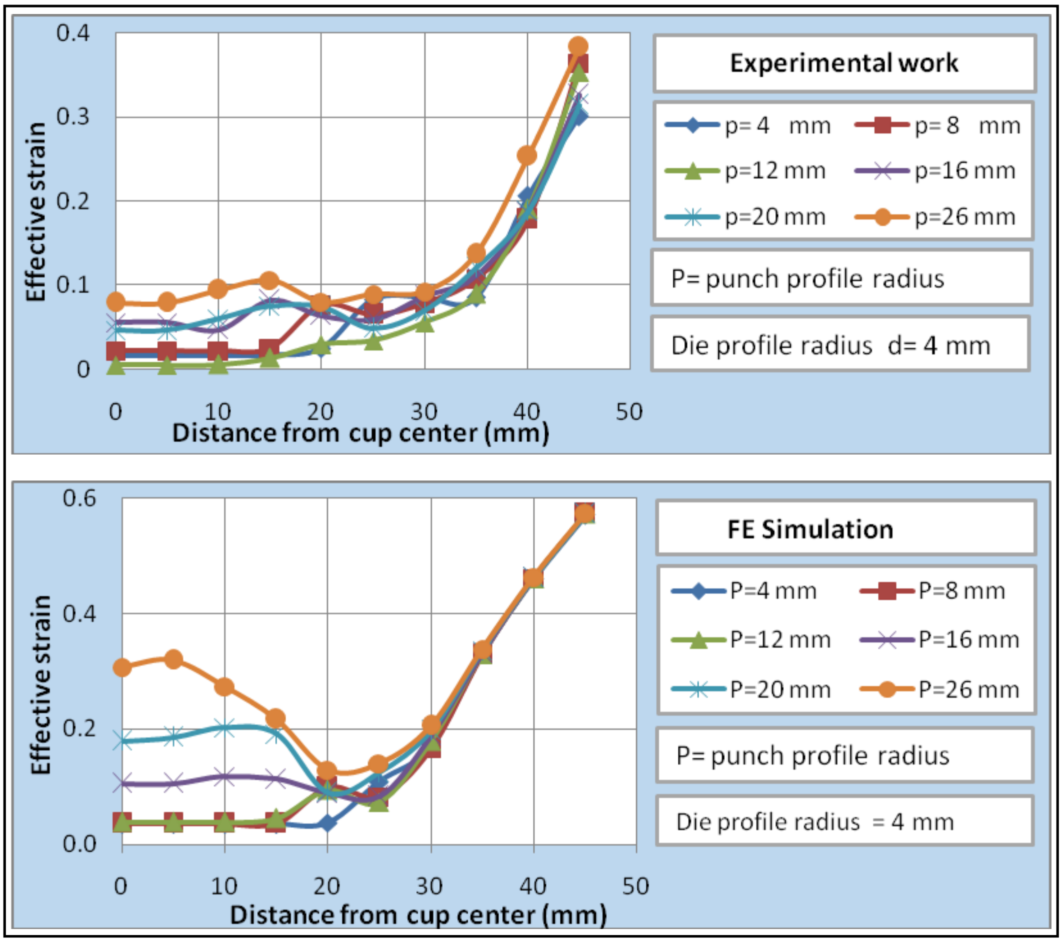


Figure 10: Effect of Punch Profile Radius on Effective Strain (Comparison of Experimental Work and FE Simulation).

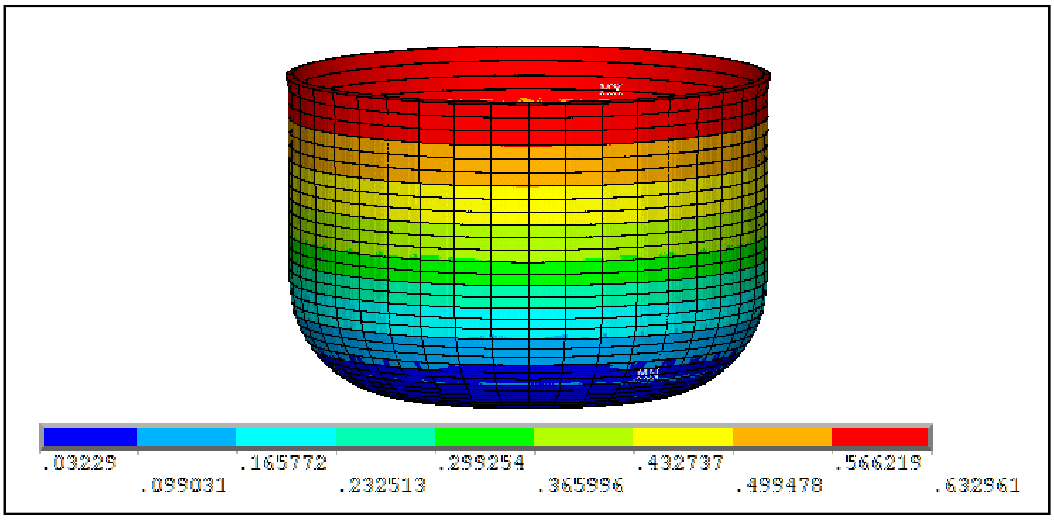


Figure 11: Effective Strain Distribution on the Completely Drawn Cup Produced by FE Simulation with Tools of (R_p=12 mm &R_d = 4mm).

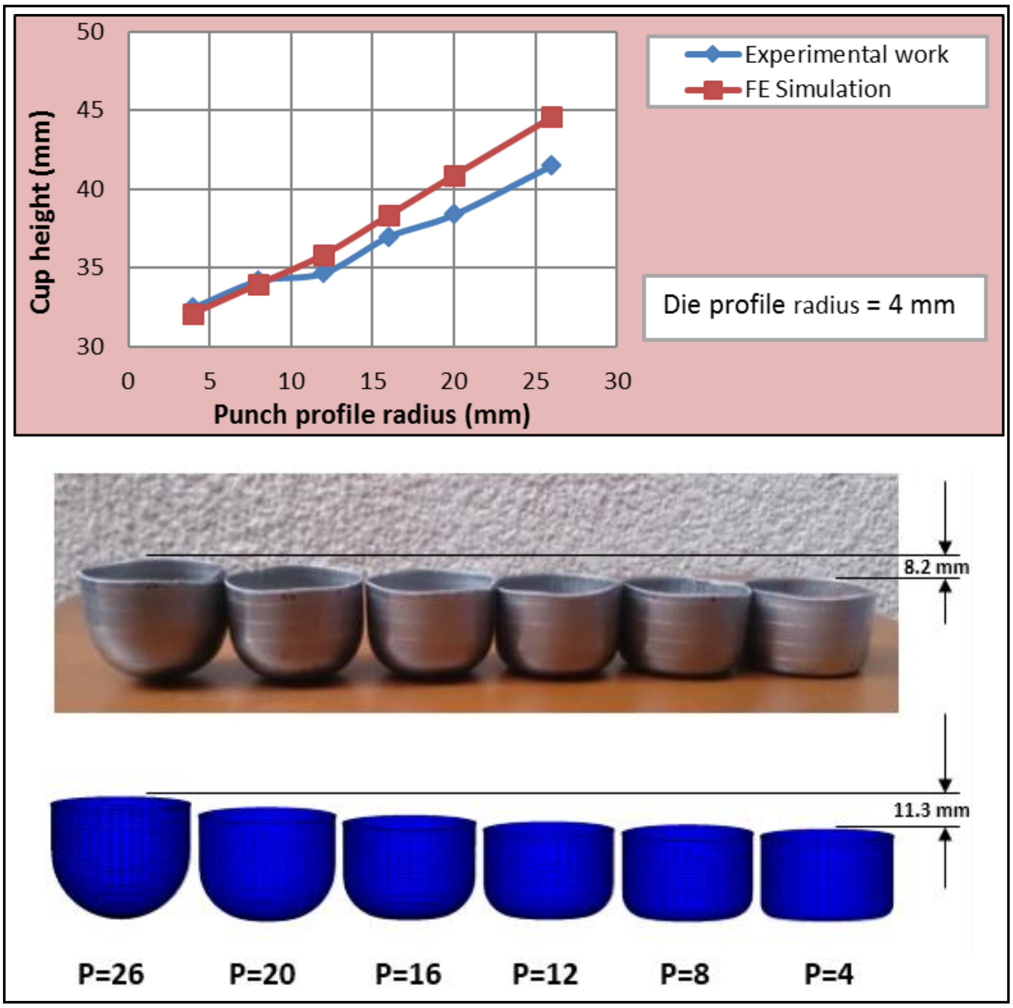


Figure 12: Effect of Punch and Die Profile Radii on the Height of Produced Cup (Comparison of Experimental Work and FE Simulation).

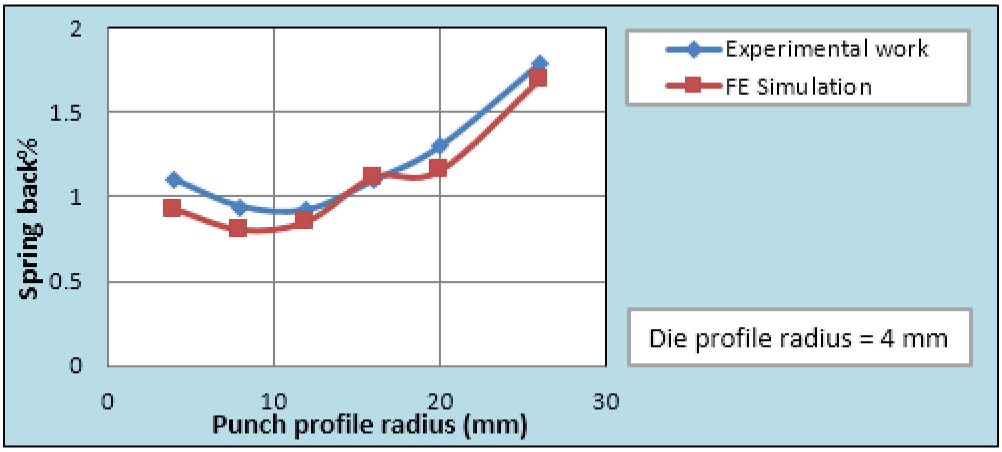


Figure 13: Effect of Punch Profile Radius on the Amount of Spring Back Induced in the drawn Cup (Comparison of Experimental Work and FE Simulation).

5. Conclusions

The results indicate that:

1. The strain distributions for all punches chosen are similar in shape, and have the same trends and approximately the same values, except for large punch profile radii (R_p=16, 20, 26) mm, where high stress and strain concentrations are present at the corner of the produced cup due to excessive stretching and sliding of metal over the punch nose.
2. The more uniform and more reasonable values of strain distributions over the drawn cup wall with the punches of (R_p= 4mm & R_p= 8mm), i.e. when the values of punch profile radius are equal to (6-11) times the sheet thickness, which is in good conformation with standard values.
3. The length of contact distance between the punch and blank increases as the punch corner radius is increased and its value approximately equal to punch corner radius.
4. The punch profile radius has no significant effect on the drawing force and its maximum value,
5. Thinning increases as punch profile radius increases, and the greatest thinning reach to about (22%) numerically, and (13%) experimentally with the hemispherical punch of (R_p= 26mm), and The best thickness distributions occur with the punch of (R_p= 8mm).
6. An increase in the punch profile radius leading to increase in the cup height, and the value of increasing reaches to about (25% for experimental work and 34% for FE simulation) for the punch profile radius ranging from (4 – 26)mm).
7. The amount of spring back percentage increases as punch profile radius increases.

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