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Effect of Forming Method on the Behavior of the Drawing Process of a Complex Shape

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Abstract

This paper aims to produce a complex shape with eight vertices in a deep-drawing process. Two methods were used to perform this study. The first method is called the direct method (drawing process), in which a complex shape was produced directly from drawing metal sheets. The second method called the indirect method (redrawing process) involves producing a complex shape from the re-drawing process of the cylindrical shape previously drawn from sheet metal. The two methods were also compared in terms of drawing force, thickness distribution, stress, and strain distribution. The sheet metal used in this work is made of low carbon steel (1008-AISI) with dimensions of 0.7 mm in thickness and 80 mm in diameter. In the present study, ANSYS 18.0 software was used for simulating the drawing and redrawing process. The results indicate the maximum drawing force with a drawing process (41 KN EXP, 30 KN FES). The effective stress and the effective strain increase until the cup’s end and reach the maximum values of the effective stress (835.23 MPa FES) and the effective strain (0. 442 FES, 0.345 EXP) in the area of the minor axis curvature with the process of re-drawing. The maximum thinning at the corner area with the redrawing process (7. 143% FES, 5.722% EXP) at the zone of the minor axis curvature. Also, the best distribution of thickness, stresses, and strains along the wall of the complex shape with the first method (drawing process).

1. Introduction

In the deep drawing process, the sheet metal is radially drawn into the die cavity by the mechanical action of a punch. As a result, the blank can be formed into various shapes. In this process, the workpiece is placed onto the die and the blank holder is then introduced at the top of the workpiece, which is not deformed by the punch. This results in a plastic distortion, but it may lead to failure when the exertion stress exceeds the yield point, but if the exertion stress is less than the yield point, it does not cause failure according to the method of forming through which the product is produced] [1]. Many studies dealt with the forming methods and some variables that affect the single or multi-stage formation process. Narayanasamy and Loganathan [2] investigated the process of forming the cylindrical shapes from circular sheets of metal using the conical dies and the flat-bottomed punches. It has been revealed that the use of conical dies increases the drawdown ratio when compared with the drawing ratio resulting from the conventional forming process. When the conical dies are used, there is no need to use the blanks holder or clamping rings, which promotes the occurrence of sheet metal wrinkling or buckling failure. However, there was no wrinkling of the thick sheet metal when using the conical die.

Azam, et al. [3] developed a modern method for increasing the formability of square cups in the deep drawing process without using draw beads or blank holders. In this method, a conical die with a square aperture was used with a flat-headed square punch. The results revealed that the new method succeeded in producing the square shapes with a higher drawing ratio than the traditional method for both aluminum and brass. The new method succeeded in producing the square shapes with a higher drawing ratio than the traditional method for both aluminum and brass. The new method also showed a reduction in the drawing force required for the forming process when compared with the drawing force required for the traditional method, and this can reduce some of the defects resulting from the high drawing force.

Abdullah, et al. [4] introduced a modern technique for manufacturing elliptic shapes from the flat-headed elliptic punches, and the conical die with the elliptic apertures without using the blanks holder or draw beads in the drawing process. The results reveal that the punches without Blanks-holder are given better results compared to the traditional drawing processes. With these present geometries, conical cups were successfully drawn without any defects.

A study of a modern method for producing a square shape through a change in the geometric shape of the die using a conical die with a square aperture and square punch was introduced by Walid, et al. [5]. The purpose of changing the shape of the geometric die is to obtain a product with a highest limit of drawing ratio when compared with the traditional method of producing a square shape using a square die and square. In addition, by using this method, the defects associated with the traditional method can be eliminated.

Adnan and Ali [6] studied the effect of the wall corner radius of punch, the thickness of the sheet, and drawing speed in the deep drawing process of the hexagonal cup on the distribution of strain and thickness. From experimental work and simulation results, it has been found that the maximum thinning takes place at the corner of the cup area with a wall corner radius of punch equals to 1 mm and a maximum thickening takes place at the end with a wall corner radius of punch equals to 7 mm. Maximum values of strain (namely: radial, hoop, thickness, and effective) take place at the end of the cup with a wall corner radius of punch equals to 7 mm.

A cylindrical shape for multi-stage deep drawing in the reverse drawing method was achieved by Abdullah [7]. Comparing this method with the traditional method of the drawing process, the new method exhibits an increase in the limit drawing ratio than the traditional method, as well as producing a product with less strain hardening, and this results in less thinning and less stress concentration, especially in areas of curvature. By using this method, the number of drawing stages can be reduced, thus reducing the manufacturing cost.

Kadhim and Waleed [8] performed the deep-drawing process to produce spline shapes using experimental work and the FE model procedure. In addition, the effect of the wall curvature radius of the punch on the drawing force, and thickness distribution were investigated. From the comparisons between the experimental and finite element results, it was shown that the numerical results of a spline cup deep-drawing are in good agreement with the results of the experiment and lie within an average of 4% - 8%. The drawing force and thinning for the small punch wall curvature radius are higher than the large wall curvature radius of the punch. The maximum drawing force and maximum thinning with the smallest punch wall curvature radius (0.5 mm) of a completely drawn spline cup and effective strains.

Araveeti [9] studied the blank design optimization problem for square cups. The finite element method and experimental work have been achieved with the forming of deep drawing quality (DDQ) cold-rolled steel sheet of 1 mm thickness. The main objective of this study is to maximize the drawing depth without any failure. The blank design for optimum LDR was defined. The optimum shape of the blank profile was found to be the very nearly circular shape of the initial blank. Thus it has been concluded that. The circular shape can be considered to be an overall blank shape for a square cup drawing.

This research aims to design and construct a deep drawing dies to produce a complex shape with eight vertices. Two methods were used to perform this work. In the first method namely the direct method, the complex shape was drawn from a blank, while the complex shape of the second method was producing by converting the cylindrical shape into the complex shape.

2. Theoretical Part

The numerical simulation method was implemented with two methods (drawing and redrawing processes), to manufacture the complex shapes with dimensionsof 41.5mm × 34.69mm, and 30mm height. ANSYS 18.0 software was used for simulating the drawing and redrawing processes, both the blank metal and the drawing tools (punch, die and blank holder) for drawing process, whereas both the cylinder shape-metal and the drawing tools (punch and die) for the redrawing process were constructed in three dimensions. The circular blank sheets for the drawing process and the cylindrical shape for the redrawing process are simulated as the solid body, also the tools (die, punch, and blanks holder) for the drawing process and the tools (die and punch) for the redrawing process are simulated as solid-body as shown in Figure (1).

The meshing process for the elements is completed automatically and body sizing (element size2 mm) was used for the tools of the two methods, while tetrahedral mesh and body sizing (element size 2 mm) were built for the sheet material and the cylindrical shape material of the two methods as shown in Figure (2). The contact technique is done automatically after determining the contact surfaces for the drawing and redrawing processes as shown in Figure (3). In the numerical simulation model for the direct and indirect methods of the blank material and tool (punch, die, and the blank holder), the following assumptions were proposed: (1) Temperature of blank material stayed constant. (2) No heat transfers between blank material and tool-set. (3) The tool (die, punch, and blank holder) was rigid. (4) The punch moved over the y-axis at a constant speed (50-100 mm/min) and the die was stationary during the forming process. (5) The blank was moving in the x-axis direction. The coefficient of friction to be constant as $\mu = 0.1$ in a dry condition at the tools – blank interface for the first stage and at the tools – cup interface for the drawing and redrawing processes. The complete boundary conditions by ANSYS Workbench are shown in Figure (4). Figure (5) shows the successive stages of the complex shape for the drawing and redrawing processes.

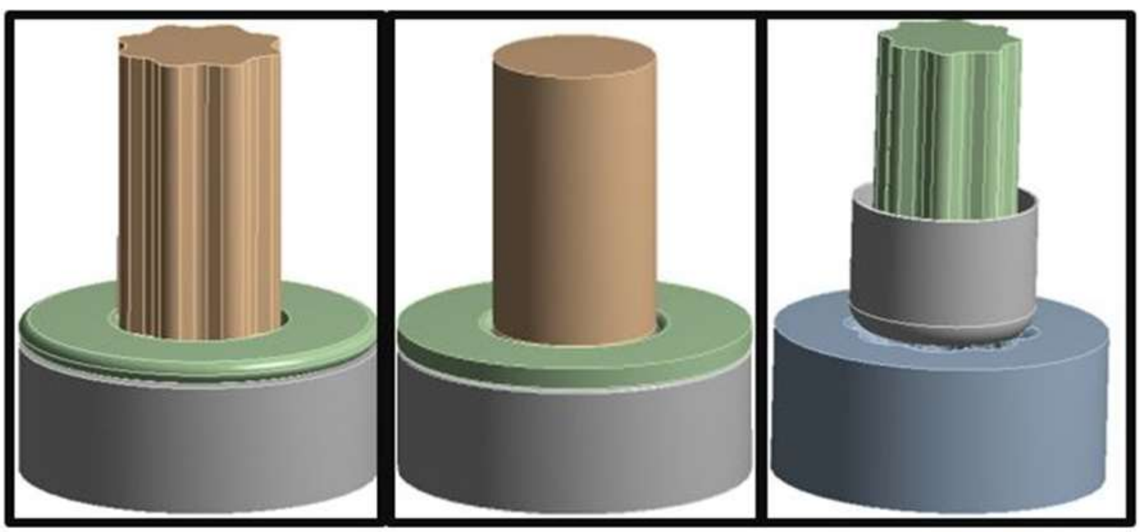

Figure (1). The engineering models of the drawing dies using ANSYS Workbench.

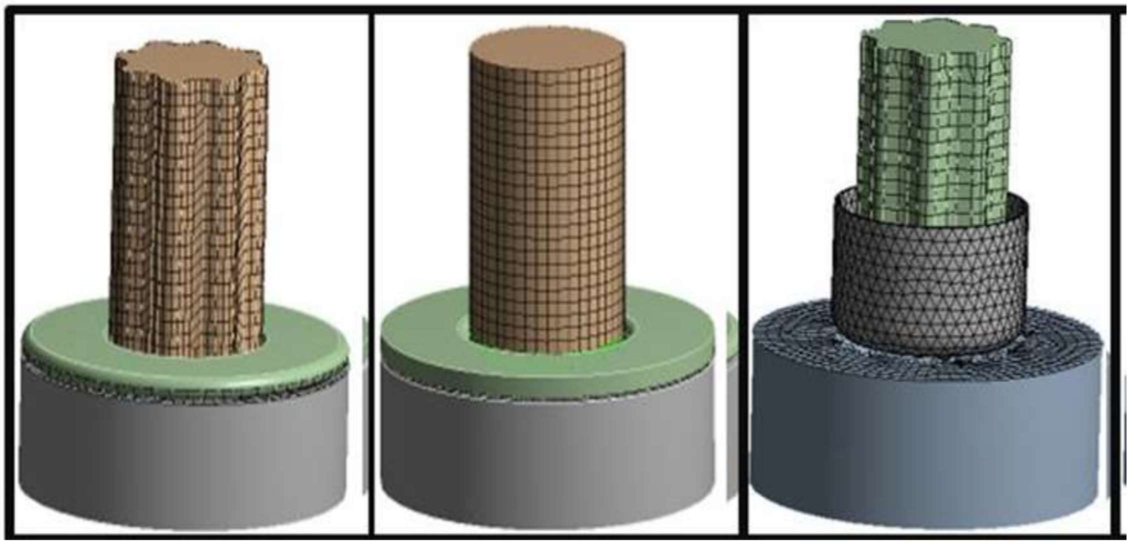

Figure (2). The meshing process for models of the drawing and redrawing dies using ANSYS Workbench.

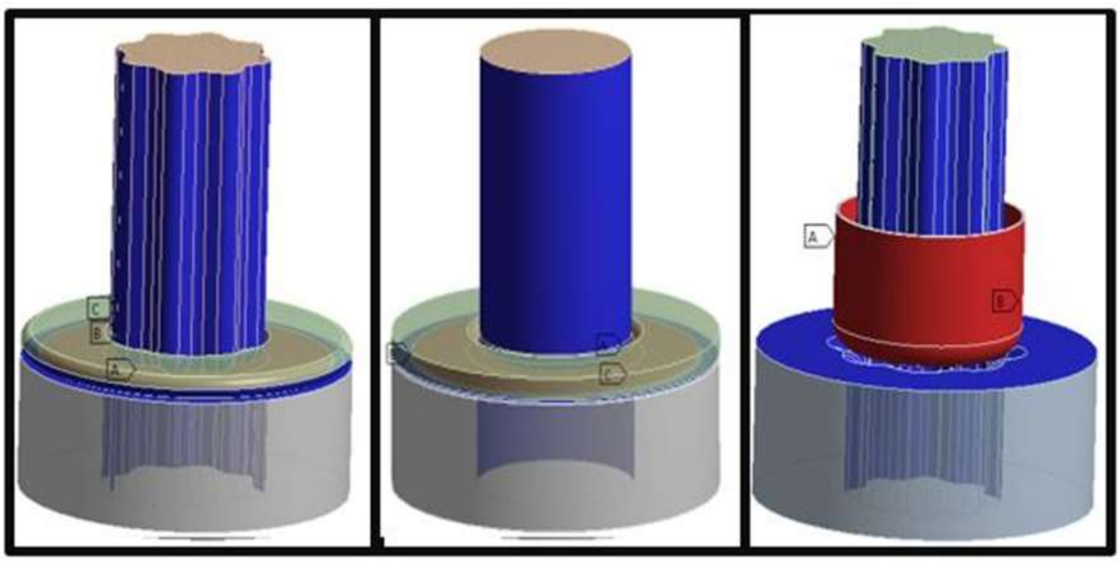

Figure (3). The contact process for the models of drawing and redrawing dies using ANSYS Workbench.

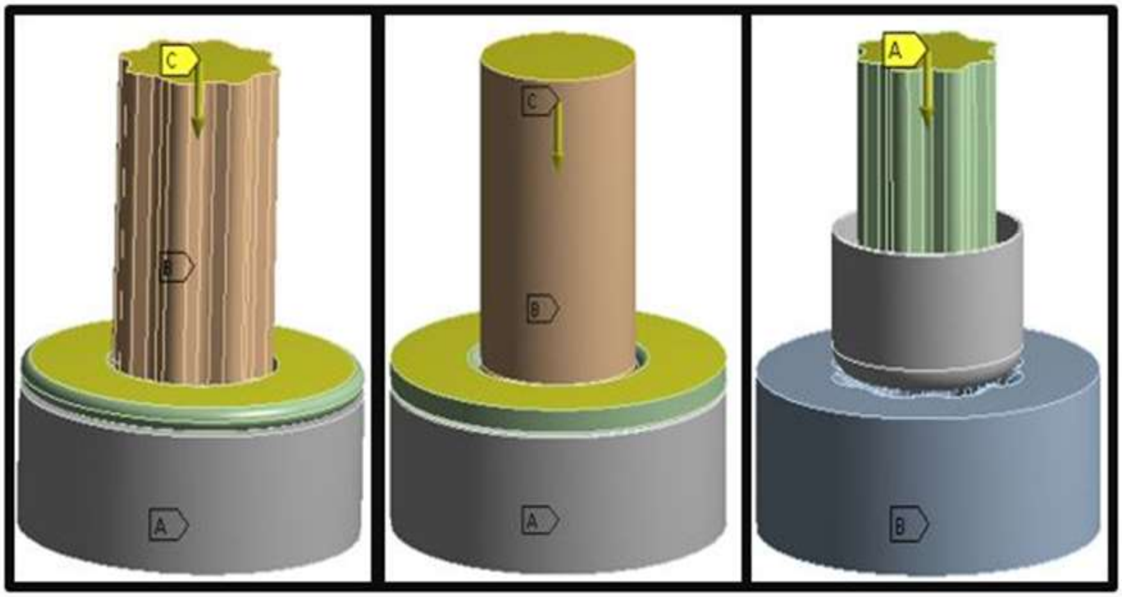

Figure (4). The boundary condition for models of drawing and redrawing dies using ANSYS Workbench.

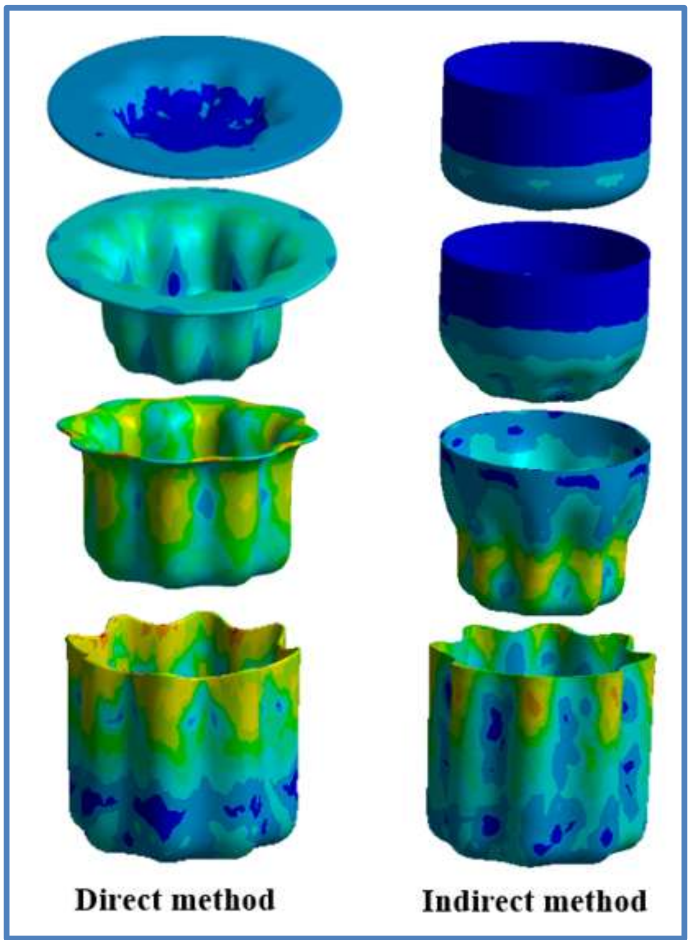

Figure (5). Successive stages of the complex cup for direct and indirect methods.

3. Experimental Procedure

The circular metal sheets made of cold rolling, low carbon steel (1008-AISI) of 0.7 mm thickness and 80 mm diameter was used to accomplish the experimental procedure. The chemical composition of the used sheet metal is listed in Table (1).

To get accurate results of the simulation process during the drawing and redrawing process, tensile strength specimens were taken for both metal sheets and cylindrical shape to obtain accurate mechanical properties. These specimens shown in Figure (6) were cut using a wire cut EDM machine. Some mechanical characteristics of the blank sheets and cylindrical shapes were listed in Table (2).

Table (1). Chemical composition of the low carbon steel used in this study.

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

Figure (6). Tensile strength test flat specimens taken from sheets of metal and cylindrical shapes according to ASTM standard E8M specification.

Table (1). Mechanical properties of tensile strength test specimens taken from sheet metal and cylindrical cups.

Method	Yield stress (MPa)	Ultimate tensile stress (MPa)	Tangent modulus (GPa)
direct	226	380	0.5
indirect	308	515	0.72

The experimental procedure for obtaining the complex shapes is accomplished by placing the drawing tool on the test machine. The drawing and re-drawing tests were performed using a complex and cylindrical die with dimensions shown in Figure (7).

The complex shapes with dimensions of 41.5 × 34.69 mm and a height of 30 mm were produced practically in two methods. The first method is called the direct method (drawing process) in which the complex cups were produced by drawing the sheets of meta using the complex die. The second way is called the indirect method (redrawing process) in which the complex shape was produced by redrawing the cylindrical shape previously drawn from the sheets of metal using the cylindrical and complex dies as shown in Figure (8).

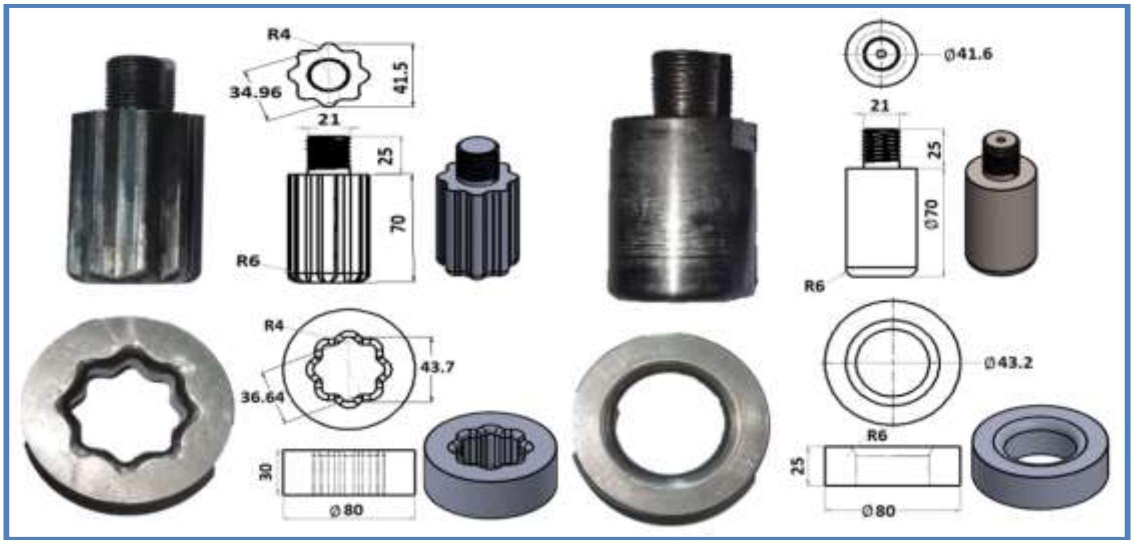

Figure (7). Dies and punches used for direct and indirect methods.

Figure (8). Complex cup produced in direct and indirect ways.

To expose the limits of stresses and strains within the permissible limits of the product manufactured by the forming process, grids were printed on the surface of the sheet metal with dimensions of 2.5×2.5 mm using a fiber laser machine as shown in Figure (9 A). After the drawing and re-drawing process, a change occurs in the dimensions of the grids on the surface of the base and the surface of the wall of the completely drawn shape as shown in Figure (9 B & C).

The dimension change resulting from the grids has been measured by the projector profile device. As for the change in thickness, it was measured after cutting the resulting shape into two halves and comparing it to the original dimension of the grids before the forming process. The thickness strain, radial strain, hoop strain, and effective strain were calculated using equations (1, 2, 3, and 4), respectively as follows [10]:

$$\epsilon_t = \ln \frac{t}{t_\circ} \qquad (1)$$

$$\epsilon_r = \ln \frac{R}{R_\circ} \qquad (2)$$

$$\epsilon_\theta = -(\epsilon_r + \epsilon_t) \qquad (3)$$

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

Figure (9). The grid's square before and after distortion.

4. Results and Discussion

Figure (10) indicates the effect of the drawing and redrawing process on the relationship between drawing force and displacement, measured from beginning to end of the formation. Note from the figure, the drawing and redrawing force begins to increase until it reaches its maximum value and then falls. This was due to the decrease in friction between the surface of the sheet metal and of punch for the drawing process and the cylindrical shape base and the base of punch for the redrawing process when the drawing and redrawing process progresses. The maximum value of the drawing force was associated with the drawing process compared to the redrawing process in both finite element simulation and experimental tests. This is due to several reasons, including the process of redrawing is a process of bending more than a process of drawing, increasing strain hardening and a decrease in the percentage of reduction in the redrawing process.

Figure (11) describes the effect of the forming process on the thickness distribution along with the sidewall, the curvature of the major axis, and the curvature of the minor axis of a completely drawn shape for both numerical simulations and experimental work. The change in thickness was measured from the center to the end of the rim of the completely drawn shape. The change in thickness was also measured along the minor axis curvature, major axis curvature, and the sidewall of the shape. It is clear from the figure that there is no change in the thickness of the shape base resulting from the drawing and redrawing process due to the friction between the punch base and the base of the shape, which plays an important role in preventing distortion. After that, the thickness takes a negative value in the region of the corner. This explains the difficulty of the flow of the metal due to the maximum stress concentrated in this region as illustrated in the figure moreover, the thickness varies from one region to another due to the severity of the tension varies from region to region. More thickening occurs at the throat in the region of the minor axis curvature with the redrawing process due to compressive hoop stress.

Figure (12) explains the influence of the forming process on the effective strain distribution along the sidewall, the curvature of the major axis, and the curvature of the minor axis of a completely drawn shape for both numerical simulations and experimental work. The effective strain distribution was measured from the center to the rim. The effective strain is equal to zero in the shape base area. This is a result of friction that prevents distortion in the contact area between the sheet metal and the punching noise for the drawing process, as well as the base of the cylinder cup and the base of punch for the redrawing process. After that, the effective strain increases until the end of the shape and reaches the maximum value in the area of the minor axis curvature with the process of re-drawing. This is due to the maximum value of the tensile stress to which the metal is exposed with the indirect method

Figure (13) refers to the influence of the forming process on the effective stress distribution along the sidewall, the curvature of the major axis, and the curvature of the minor axis of a completely drawn shape for both numerical simulations and experimental work. The effective stresses were measured from the center of the base to the shape end. The results show that the equivalent stress is equal to zero under the flat face of the punch in both methods. After that, the effective stress starts to increase up to its maximum value at the top of the shape and its value varies from one region to another of the wall of the shape. Also, the results reveal that the equivalent stress along the wall of the shape of the redrawing process and over the wall of the cup of the drawing process has the same behavior and the same shape but its value is uneven and has a maximum value at the top with the indirect method, especially towards the minor axis curvature.

Figure (10). Effect of the drawing and redrawing process on the relationship between drawing force and displacement.

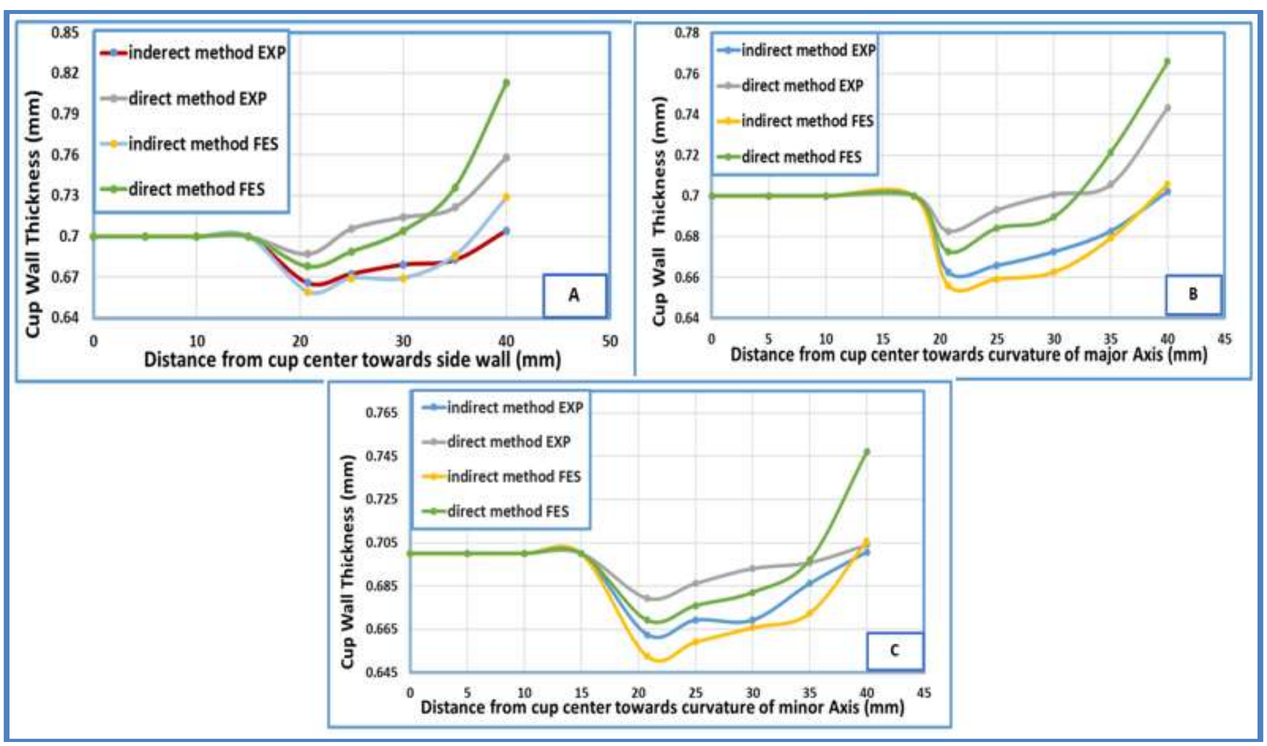

Figure (11). Effect of the drawing and redrawing process on thickness distribution.

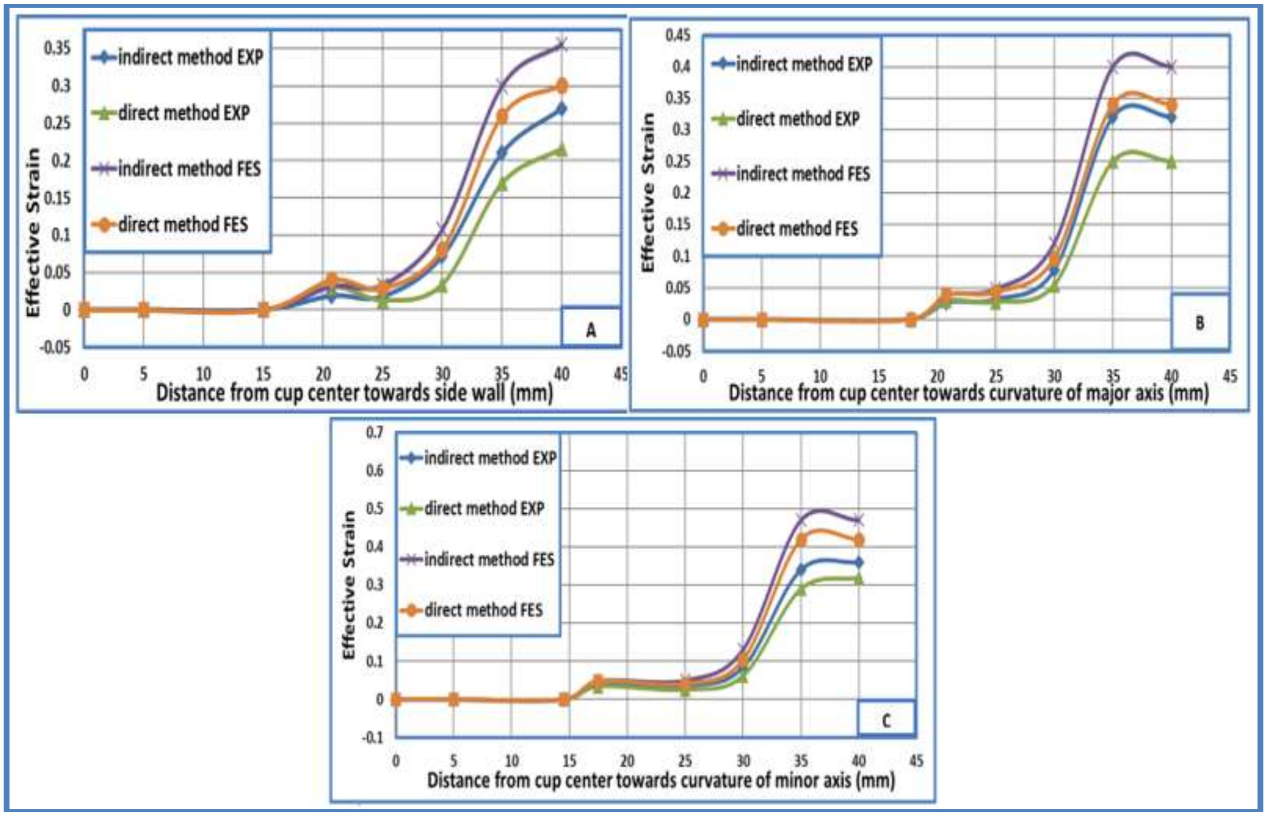

Figure (12). Effect of the drawing and redrawing process on effective strain distribution.

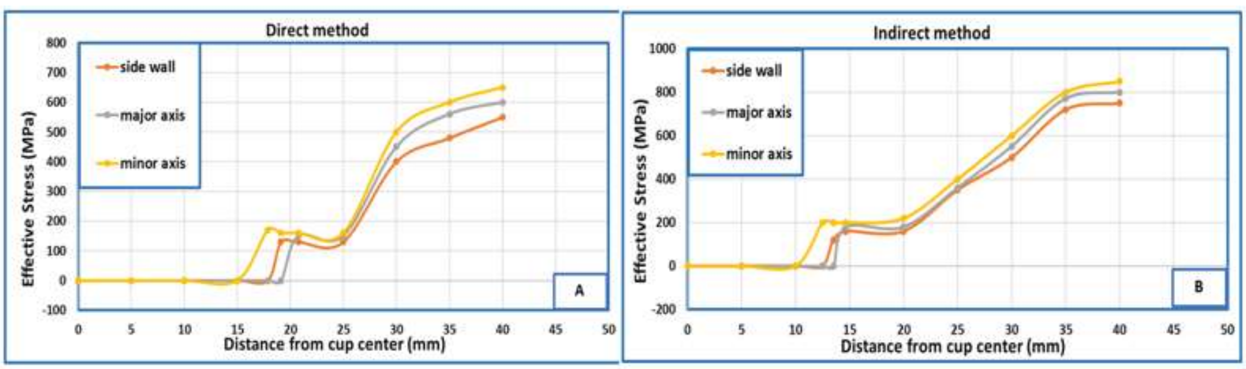

Figure (13). Effect of the drawing and redrawing process on effective stress distribution

5. Conclusions

A complex shape was produced in two methods, the direct and the indirect method, and the two methods were compared and the following was concluded. The indirect method is better than the direct method in terms of lower drawing force, thickness distribution, stress, and strain distribution. The direct method is not suitable for complex shapes if it is a multi-stage drawing process because it is difficult to control the centering between the die and the product. The direct method is suitable for cylindrical shapes if the process of drawing is multi-stage for easy control of the centering between the die and the product. The maximum value of the drawing force was associated with the direct method and higher than the indirect method because the indirect way is a bending process more than the drawing process, while the direct method is the drawing process. The maximum value for thinning thickness was associated with the direct method because it is a result of the drawing process of the cylindrical shape from the metal sheets, and then the redrawing to the complex shape.

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