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Redrawing Operation a Star Shape from Cylindrical Shape Using Experimental and FE Analysis

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K E Y W O R D S

Redrawing operation of the star shape, stress and strain distribution

A B S T R A C T

The aim of this paper is to design and fabricate a star die and a cylindrical die to produce a star shape by redrawing the cylindrical shape and comparing it to the conventional method of producing a star cup drawn from the circular blank sheet using experimental (EXP) and finite element simulation (FES). The redrawing and drawing process was done to produce a star cup with the dimension of (41.5 × 34.69mm), and (30 mm). The finite element model is performed via mechanical APDL ANSYS18.0 to modulate the redrawing and drawing operation. The results of finite element analysis were compared with the experimental results and it is found that the maximum punch force (39.12KN) recorded with the production of a star shape drawn from the circular blank sheet when comparing the punch force (32.33 KN) recorded when redrawing the cylindrical shape into a star shape. This is due to the exposure of the cup produced drawn from the blank to the highest tensile stress. The highest value of the effective stress (709MPa) and effective strain (0.751) recorded with the star shape drawn from a circular blank sheet. The maximum value of lamination (8.707%) is recorded at the cup curling (the concave area) with the first method compared to the maximum value of lamination (5.822%) recorded at the cup curling (the concave area) with the second method because of this exposure to the highest concentration of stresses. The best distribution of thickness, strains, and stresses when producing a star shape by redrawing the cylindrical shape into a star shape.

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1. Introduction

The paper should be organized into logical parts or sections. Any subsection is given a brief numbered heading. The contents include the introduction that should clearly define the nature of the problem, and the references should be made to previously published papers. Theoretical, Deep drawing is one of sheet metal forming operations that are widely used because of their applicability to form a variety of shapes such as cylindrical, square, rectangular, conical and hexagonal. Deep drawing is an operation for forming flat blanks into cup-shaped articles without defects or excessively localized lamination. The design and control of a deep drawing operation depend not only on the blank sheet metal but also on the condition of the die– blank sheet interface, the mechanics of plastic distortion, the tool used and the control of metal flow. Many types of research have dealt with the process of deep drawing of different forms, focusing on producing a product without defects [1]. Parka et al. [2] carried out the deep drawing operation of an elliptical cup using technologies including experimental and the FEM. In order to get the optimal parts in the deep drawing operation, elliptical deep drawing experiments were done with various fillet radii of the die and punch. The optimal fillet radii of the die and punch in the deep drawing operation with a non-axisymmetric blank sheet form are proposed. Hezam et al. [3] developed a new process for increasing the formability of square cups in the deep drawing without using a blank holder or draw beads. The new process has demonstrated superiority over traditional methods by achieving a large drawing ratio especially for thick sheets (2–3 mm). The required drawing force in the new process been greatly reduced while the drawing ratio is increased. Hassan and Jafarlou [4] Produced multi-stage traditional deep drawing for producing rectangular shapes with extreme drawing ratio. The non-homogeneous metals flow because of irregular die cross-sectional shape and the contact conditions lead to localize lamination, wrinkle phenomena and finally defect of the drawn products. To remove these defects a novel three stapes deep drawing operation with conical-elliptical die set have been proposed to replace the equivalent six stapes of the traditional multi- stipe operation. Lin and He [5] investigated, two methods to produce elliptical cup, direct elliptical redrawing from elliptical shapes and circular shapes using experimental and FEA. The results showed that the elliptical redrawing from circular shapes reveals excessive lamination at the curve of the major diameter and mild lamination at the curve of the minor diameter. The elliptical redrawing from elliptical shapes can decrease the lamination and hence the danger of fracture at the major diameter -the most vulnerable shape during elliptical redrawing. Ali and Arezoo [6] represented an analytical method for estimating the drawing ratio of the redrawing stapes in the deep drawing operation of symmetric components. It is found that process variables such as strain hardening exponent, the coefficient of friction, normal plastic anisotropy ratio, the ratio of die corner radius to the thickness of blank sheet and ratio of blank sheet thickness to diameter has the greater influence on the drawing ratio. The influence of intermediate annealing operation is also studied. Mahida and Shah [7] introduced deep drawing operation by FE analysis for producing elliptic shapes using the simple die set without draw beads or blank holder using a conical die and simple die. Based on these results, the % lamination and distribution of stress on elliptic shapes using a conical die is less than simple die. The conical die gives a better product than the simply die. Jawed and Salman [8] developed a method to produce hexagonal cups from transforming the cylindrical and compare them to hexagonal cups from a blank sheet in deep drawing operation. From the results, the least excessive metals will appear in the wall curve radius of the major diameter of hexagonal cup produce from transforming the cylindrical cup compared to hexagonal cups produce from the circular blank sheet. The more lamination takes place at the region of the cup curve in hexagonal cups produce from the circular blank sheet compared to the hexagonal cup produce from transforming the cylindrical cup. Singha and Agnihotri [9] carried out EF simulations for symmetric deep drawing to check the influence coefficient of friction on the part quality. Distribution of Thickness and stress and FLD curves were investigated for analyzing the influence of the coefficient of friction. The results indicate that as the coefficient of friction lowers, distribution of thickness and quality of part improve. Moreover, the distribution of stresses also gets decreased at a lower coefficient of friction. Signal [10] researched the reverse and direct re-drawing of cylindrical cups in the multi-stage deep drawing operation. Comparing between the reverse and direct re-drawing in terms of the drawing loads, the change in the thickness along the cup wall, the strain distribution during the deep drawing operation and the kinds of defects produced in addition to the cost of production and the working time also was investigated. It is found that the reverse re-drawing way there is an ability to increase drawing ratio greater than the maximum for the direct re-drawing way. The change of thickness along the cup wall for the direct re-drawing way is higher than that for the reverse re-drawing way. The aim of this study is to produce a star shape by redrawing the cylindrical shape and drawn from the circular blank sheet using FE analysis and experimental work.

2. Numerical Simulation

In this study, the FE model is performed via mechanical APDL ANSYS18.0 to modulate the redrawing and drawing operation. The blank sheet used in the drawing and redrawing process is (0.7 mm) thickness and (80 mm) diameter is made of low carbon steel. The mechanical properties of the unshaped blank and cylindrical cup are listed in Table 1. Element type SOLID 185 was used for simulating circular blank. The tools (punch, die and blank holder) are assumed as rigid bodies, while circular blank material as a deformable body. The contact interface between the tools (punch, die and blank holder) and circular blank can be simulated automatically with ANSYS18.0. Target element TARGE170 is utilized to represent the rigid tools (die, punch and blank holder) for drawing operation and represent the rigid tools (die and punch) for redrawing operation, while contact element CONTA174 is utilized to represent the deformable circular blank for drawing operation and represent the deformable cylindrical cup for redrawing operation. The punch moves at the constant speed (50 mm/min) on the y-axis direction, while the die is stationary. The circular blank moves on the x-axis for the drawing operation, while the circular cup moves on the x-axis for the redrawing operation. Figure 1 indicates the engineering numerical models of drawing and redrawing operation. The friction coefficient at tools (punch, die and blank holder) - circular blank interface with a constant value ($\mu = 0.1$) and the blank holder set with the constant force of (4kN). Figure 2 shows the sequential stage of drawing and redrawing operation of a star shape.

Table 1: Mechanical properties of unshaped blank and cylindrical cup

Property	value
yield stress of blank (MPa)	218
Yield stress of cylindrical cup (MPa)	279
Young modulus (GPa)	200
Tangent modulus (GPa)	0.5
Mass density (gm/cm^3	7.8
poison's ratio	0.5

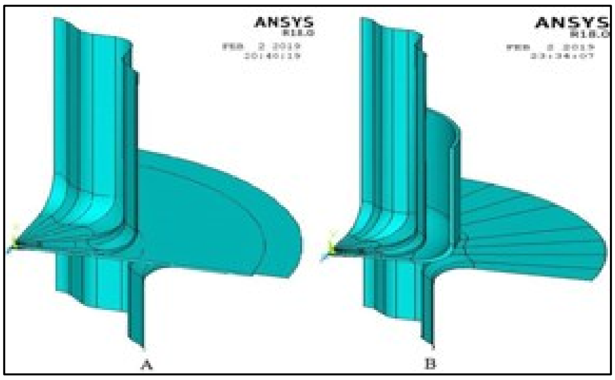

Figure 1: The geometry of the model used in drawing operation and redrawing operation.

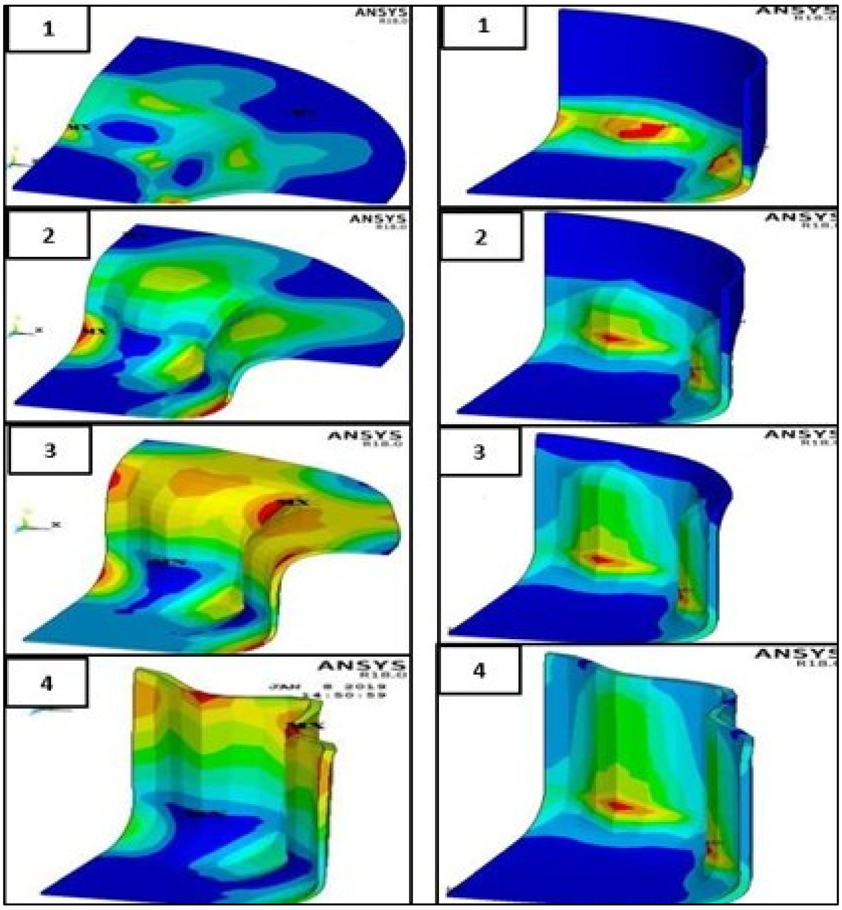

Figure 2: The sequential stages of drawing and redrawing operation of a star shape

3. Experimental Procedure

I. Material characteristics

The mechanical properties of the blank and cylindrical cup material have an important influence on the drawing and redrawing process. The blank sheet metal made of low carbon steel (1008-AISI) with the thickness of (t_o = 0.7 mm) and diameter (80 mm) is used in this work. The chemical composition of low carbon steel is done using the spectrometer device. The chemical composition of low carbon steel used in the drawing and redrawing process is listed in table 2. To obtain more accurate results for the FE analysis, the specimens of unshaped blank and specimens were taken from the cylindrical cup are cut using a wire cut machine according to designation number E8M of ASTM standard as shown in Figure 3.

II. Experimental test

A star and cylindrical die are designed to produce a star and cylindrical cups. The dies are made of tool steel and machined by the wire cut machine and CNC turning. The punches and dies of the star and cylindrical shapes used in the experimental study are shown in Figure 4. The drawing and redrawing process was completed in order to produce a star cup with a dimensions of (41.5 × 34.69 mm) and a height (30 mm) in two ways; in the first method, the star cup drawn from circular blank, the second method was carried out to produce a star cup by redrawing the cylindrical cup into a star cup. The drawing and redrawing operation were accomplished by a deep drawing tool a testing machine as shown in Figure 5.

In order to measure the distribution of thickness and strains along the wall of the mug, the grids square with dimensions ((2×2 mm) were printed on the surface of the circular blank as shown in Figure 6 A. After the process of drawing the grids square are distorted and change its dimensions along the wall of the cup, while the base of the cup remains grids square without change as shown in Figure 6 B. The radial and circumference strains were measured by measuring change in radial and circumference dimensions of grids square, while thickness was measured by micrometer tool.

Figure 3: The specimens of unshaped blank and specimens were taken from a cylindrical cup

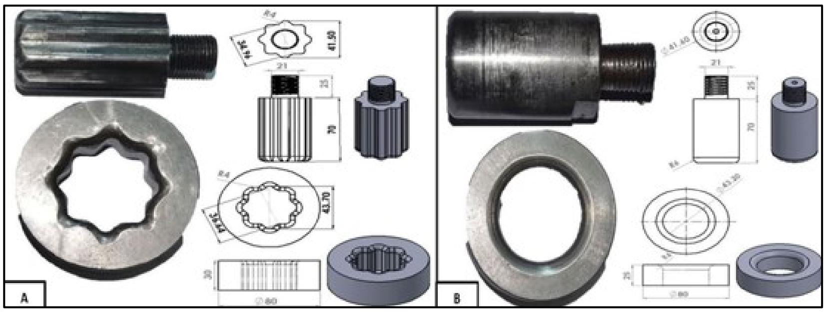

Figure 4: The punches and dies of the star and cylindrical shapes used

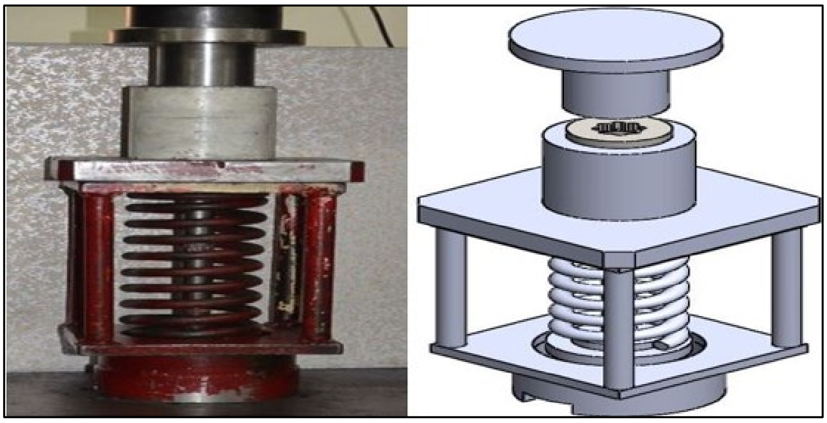

Figure 5: The deep drawing tool used

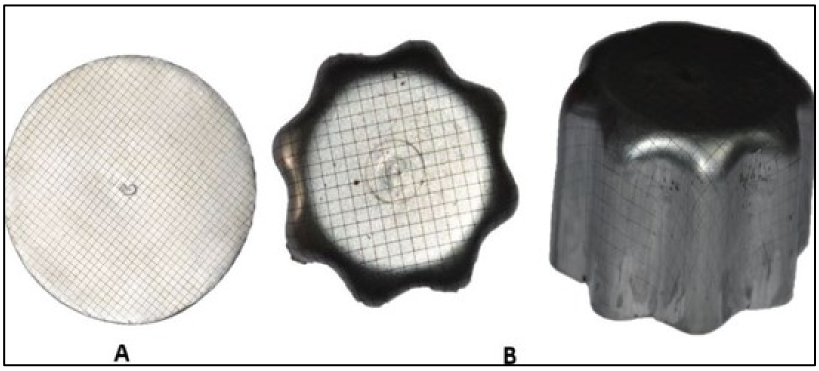

Figure 6: The grids square before and after drawing and redrawing operation

3. Results and Discussion

A star cup was produced in two methods in both FE analysis and experimental work. The first method, which is called the drawing operation, was carried out to produce a star shape drawn from the blank sheet. The second method, which is called the redrawing operation, was completed to produce a star shape by redrawing cylindrical shape into a star shape as shown in Figure 7.

Figure 8 represents the relationship between punch forces and punch travel (displacement) under the effect of drawing and redrawing operation in both FE analysis and experimental. It is clear from this figure that the punch force increases and reaches the maximum value. Then, it falls because of the decrease of the diameter of the blank with the progress of the stock and reduces the friction between the blank and die. We also note from the figure that the maximum punch force (39.12KN) recorded with the production of a star shape from drawn the blank when comparing the punch force (23.33KN) recorded when redrawing the cylindrical shape into a star shape. This is due to the exposure of the cup produced drawn from the blank to the highest tensile stress.

Figure 9 represents the distribution of thickness along the cup wall (areas of the concave, convex and the sidewall of the cup) achieved by the first method (the star cup drawn from the blank) and second method (redrawing the cylindrical cup into the star cup) in both FE analysis and experimental. The thickness measures from the center of the cup until the top end of the cup. The value of the thickness does not change at the bottom of the cup due to the friction, which plays an important role in not changing the thickness. The maximum value of lamination (8.607%) is recorded at the cup curling (the concave area) with the first method compared to the maximum value of lamination (5.822 %) recorded at the cup curling (the concave area) with the second method because of this exposure to the highest concentration of stresses. The maximum value of the thickness was recorded at the end of the cup (sidewall area) with the second method compared to the first method because of this exposure to the highest value of the compressive hoop stress.

Figure 10 represents the comparison of the change in the distribution of effective strain along the cup wall (areas of the concave, convex and the sidewall of the cup) achieved by the first method (the star cup drawn from the blank) and second method (redrawing the cylindrical cup into the star cup) in both FE analysis and experimental. The effective strain measures from the cup center until the top end of the cup. The maximum value of the effective strain (0.751) recorded with the first method at the end of the cup (the concave area) because of the exposure to the highest radial stress.

Figure 11 shows the effect of drawing and redrawing operation of the product star cup on the distribution of effective stress along the cup wall (areas of the concave, convex and the sidewall using FE analysis. The effective stresses were measured from the center of the cup to its top. The highest value of the effective stress (709) recorded with the first method (the star cup drawn from the blank) compared with the second method (redrawing the cylindrical cup into the star cup) at the cup rim (the concave area). Table 3 shows the maximum values for recorded results for practical tests and numerical simulators.

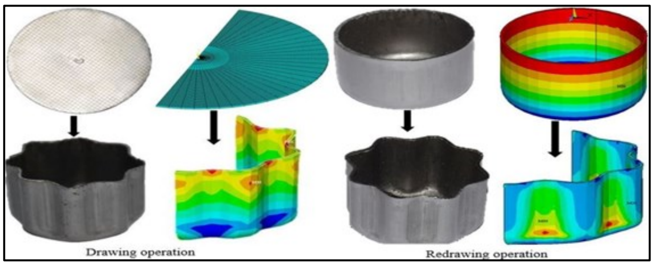

Figure 7: The star cup was produced in drawing operation and redrawing operation

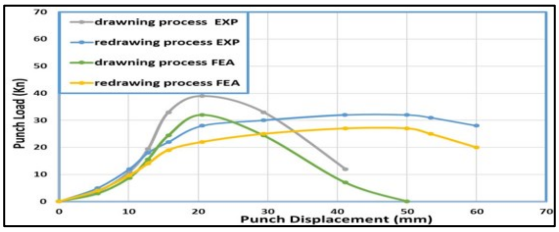

Figure 8: The relationship between punch loads and punch travel under different radial clearances

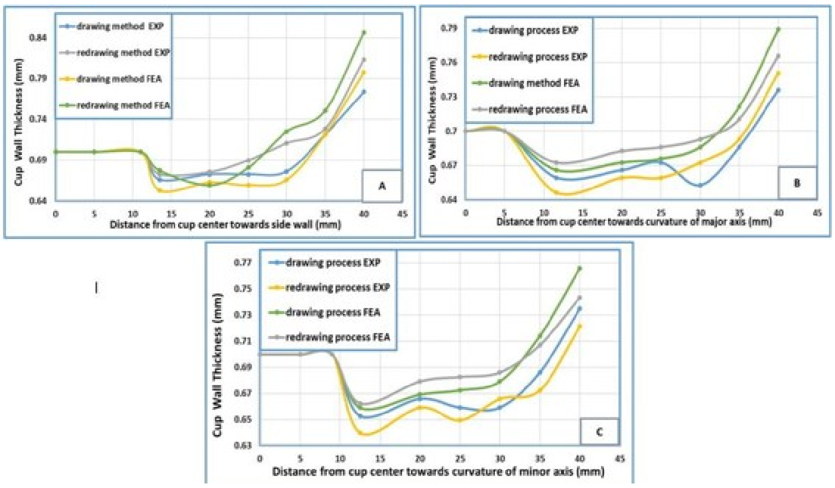

Figure 9: The difference of the distribution of the thickness after drawing operation under various radial clearances

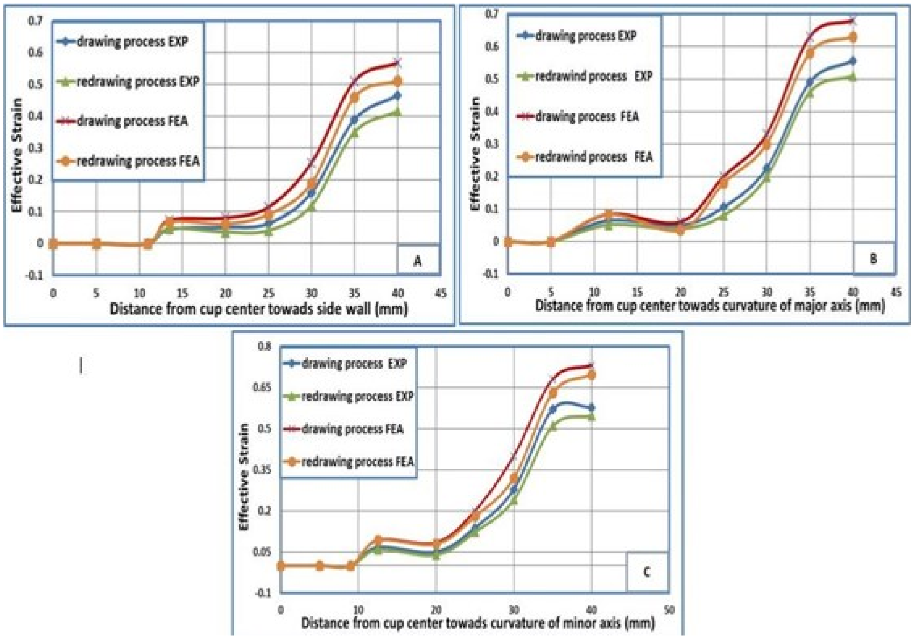

Figure 10: The influence of radial clearance on the effective strain

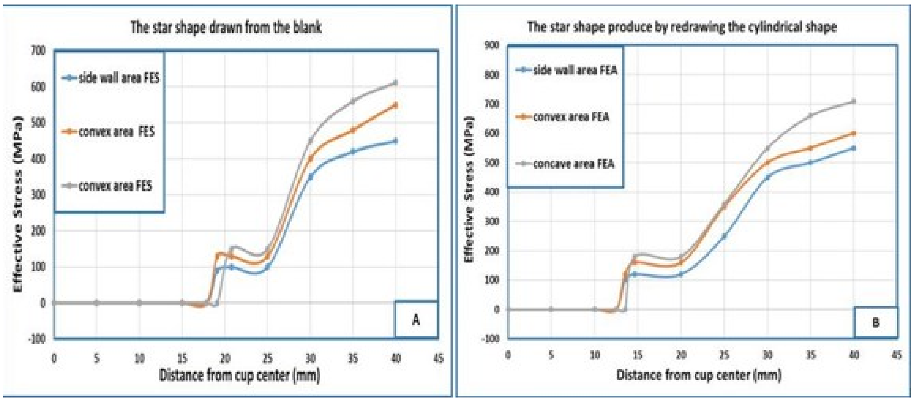

Figure 11: The influence of radial clearance on effective stress.

Table 3: The maximum values for recorded results for the practical tests and numerical simulation

Drawing method	Drawing load) (KN)		Max effective strain (mm)		Max thinning %		Max effective stress (MPa)
	EXP	FES	EXP	FES	EXP	FES	FES
Drawn from blank	39.12	32.32	0.593	0.751	5.351	5.822	709
Redrawing from cylindrical shape	32.33	27.17	0.536	0.687	6.765	8.607	608

4. Conclusions

1. The maximum lamination (8.607%) is recorded at the curling area of the cup produced by drawing operation (the star cup drawn from the circular blank sheet) because of the curling area of the cup (the concave area) exposure to the highest concentration of stresses.
2. Maximum drawing force (32.33KN) achieved for redrawing operation (the star shape produced by redrawing cylindrical shape into a star shape) is lee than maximum drawing force achieved for drawing operation because the cup achieved for redrawing operation is less bending and unbending and less tensile stress than the cup achieved for drawing operation.
3. The maximum value of the effective strain (0.751) recorded at the end of the cup (the concave area) achieved for drawing operation because the cup produced by the drawing operation (the star cup drawn from the circular blank sheet) is subjected to the highest concentration of stresses
4. The highest value of the effective stress (709 MPa) recorded at the end of the cup (the concave area) achieved for drawing operation due to the cup is subjected to the highest tension.
5. Redrawing operation is the best method to produce complex shapes (star shape) in terms of the distribution of stress, strain, and thickness.
6. The drawing operation is the appropriate method to produce simple shapes (cylindrical).

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