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Experimental and Numerical Simulation Procedure of Multi Stage Drawing Operation of a Star Shape

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Abstract
In this paper, the multi-stage deep drawing operation is done to produce the star shape in two methods using experimental procedure and the finite element model. The first method (direct) was implemented out to produce the star shape for the firststagedrawn from the circular blank sheet, while the second and third stage,the shapes are produced by redrawing the star shapes for the first and second stages respectively, the second method(indirect)was implemented by redrawing the cylindrical shapes into a star shapesfor the three stages.The three stages deep drawing operation was completed to do theexperimental procedure required for production a star shapes with inner dimensions (23.4 mm by 19.19 mm),the circular blankssheets (80 mm diameter) of low carbon steel sheets of (0.08%) were used in this research. FE program code (ANSYS 18.0) is used to model the multi-stagedeep drawing operation. The aim of the research is to produce a star shape in two methods (direct and indirect method) for the three stages. From the comparison between the results, it was found that,severe deformationwith the direct method of the second and third stages,the top of drawing load that required for producing the star shape by direct method is higher than the top of drawing load required for produce the star shape by indirect method for the three stages. Also noted produce completely star shape without defects with indirect method when comparing with the direct method for the three stages.

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1. Introduction

In deep-drawing operation of blank metals, the blanks sheets are deformed plastically from their initial flat shape to the final part. It isn't easy for simulation and improvement the operation of the final part at low cost and improve the quality of the part, especially when the part is manufactured across multi-stapes deep-drawing operations. In the multi-stage deep-drawing operations, direct-drawing and/or indirect drawing are included to increase the drawability, which demands the analysis of the operation in sequences to evaluate the final part shape [1]. Many studies have dealt with the multi-stage deep drawing operation in addition to one stage to produce a shape with minimum defects (wrinkling, thinning and tearing). Kim and Kang [2] carried out operation design and numerical analysis for a rectangular shape in the multi-stage drawing operation. From the result, some unforeseen problems like excessive thinning, wrinkling and earing of the intermediate blanks sheetsoccurred. To avoid these defects, a series of changes to the design of punch in the drawing operation has beenaccomplished and applied. Anaraki et al. [3]performed the multi-stage drawing process of the axisymmetric cup by finite element simulation and experimentally.The annealing operation was performed after second, third and fourth steps. It was found the punch force is higher in the first stage and it is decreasing with the proceeding in the next stages. Patil and Bajaj [4] produced two processes are combined as one by changing the tool corner of the punches and dies in the multi-stage drawing operation of the cylindrical shape. In these processes, the tools are modified such that the final shape must be as per requirement and defect free. Kim and Kim [5] investigated the multi-stage deep drawing operation of the rectangular shape from aluminum using the experimental. The results of the finite element analysis and experimental showed that a product could be created using the proposed five-step process. Micro drawing operation of micro conical- shapes using a micro multi stage deep drawing operation was investigated by Gonga, et al [6].They concluded that the micro conical-cylindrical shape withan inner conical diameter 0.4 mm has been successfully drawn using a micro blanking-drawing. Also, the results show that the maximum drawing load increased12.1% with increasing the drawing ratio from 1.8 -2.1. Multi-stages deep drawing process to produce hexagonal cups of low carbon steel from a circular blank sheet investigated by Dawood [7].The results showed that the maximum lamination of cup wall and maximum strain occurred at the wall corner radius of (0.7 mm). The multi-stage deep drawing processes of square cups of pure titanium researched by Harada and Ueyama [8]. The numerical simulation and experimental results showed the pure titanium sheet was successfully drawn at the 2nd stage without the cracks. However, the cracks were observed at the filet at the 3rd stageTetzel, et al [9] investigated multi-stage micro deep drawing operation of circular shape using experimental and finite element analysis. The influence of the coefficient of friction in the first and second stage is studied. The results show that for the maximum drawing load the best fit is for the first stage with the friction coefficient (0.225) and for the second stage with the friction coefficient

(0.211). Younis et al. [10]researchedthe multistage deep drawing process of cylindrical shape using finite element method. The produced cup wall thickness and distribution of the strain over the wall of the cup from low carbon steel (AISI 1008) was evaluated. It is founded more lamination appear in area under the punch filet radius due to severe stretch in this area in the first stage while increase in lamination in the wall cup will occur in the second and third stages. Dawood and Tuaimah [11] studied the influence of the thickness of the sheet on a drawing operation of multi-stage for hexagonal shape using numerical simulation and experimental work. From results, it is clear that, the top of drawing force decreases with the progress of the stages of drawing, higher thinning occur at profile of the shaperegion with the thickness of the sheet equal to (initial sheet thickness 0.5 mm) and higher thickening occur at the at rim shape with the thickness of the sheet (initial sheet thickness 1.2 mm). Hameed [12] carried out themulti stage deep drawing operation of the triangularshape. The influence of filet radius of punch and punch speed on punchload, cup, strains and thickness distribution, and tearing were evaluated. The maximum lamination along the wall shape, uniform distribution of the wall thickness and strains happen when using triangular drawing punches with a small filet radius.

2.Finite Element Model

A starshape of (41.5 mm × 34.96mm) inner dimensions, and (30mm) height for the first stage, (29.3.mm×24.83) inner dimensions, and (47mm) height the for the second stage, (23.4mm×19.51) inner dimensions, and (62mm) height for the third stage was were completed in the process of numerical simulations. The circular blank sheet is formed has a diameter of (82mm) is made of low carbon steel of 0.08% carbon content. The properties of mechanical of the unformed blank and shape all of three stages are listed tables(1-2).FE program (ANSYS 18.0) was utilized to modelthe multi-stage drawing process. The 3-D modeling elements of (SOLID185) wasselected for the circular blank sheet for the first stage and the shapes for the second and third stages. The target element TARGE170 is utilized torepresent the tool (die, blank- holder, and punch) for first stage and rigid tool (die and punch) for second and third stage, while contact element CONTA174 is utilized to represent the flexible circular blank for the first stage and the shapes for the second and third stages. Figure (1) shows the element contact between the tool (punch, die, and blank holder) and circular blank for the first stage and between the tool (punch and die) and shape for the second and third stage used in the analysis. The coefficient of friction (μ=0.11) was chased. The radial clearance between punch and die was selected to be (20% original sheet thickness) of the star shape and (10% original sheet thickness) of cylindrical shape for the three stages. Two types of models(star and cylindrical shapes) for the three stageswere simulated. The successive stages of producing a star and cylindrical shapes for the three stages as illustrated in figure (2).

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Table: 1Showsthe mechanical properties of the unformed blank sheet

property	value
Yield stress (MPa)	220
Young modulus (GPa)	200
Ultimate stress (GPa)	378
Tangent modulus (GPa)	0.5
Mas density $^{gm}/_{cm^3}$	7.8
Poisons' ratio	0.32

Table: 2 Showsthe mechanical properties of the cylindrical shapes all of three stages

stage	Yield stress (MPa)	Ultimate stress (GPa)
first	297.7	491.4
second	304.75	514.02
third	320.6	520.2

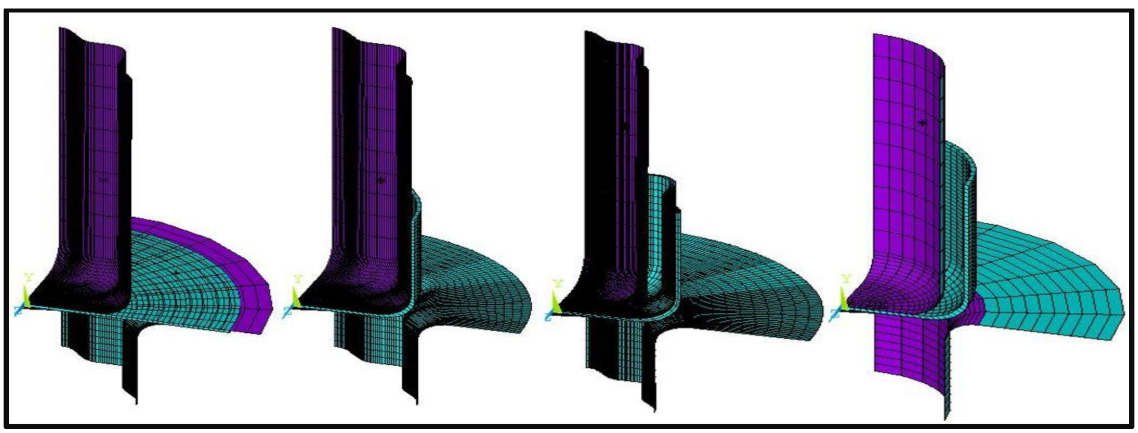

Figure: 1 Shows the element contact between the tool (punch, blank holder, and die) and circular blank for the first stage and between the tool (punch and die) and shape for the second and third stage used in the analysis

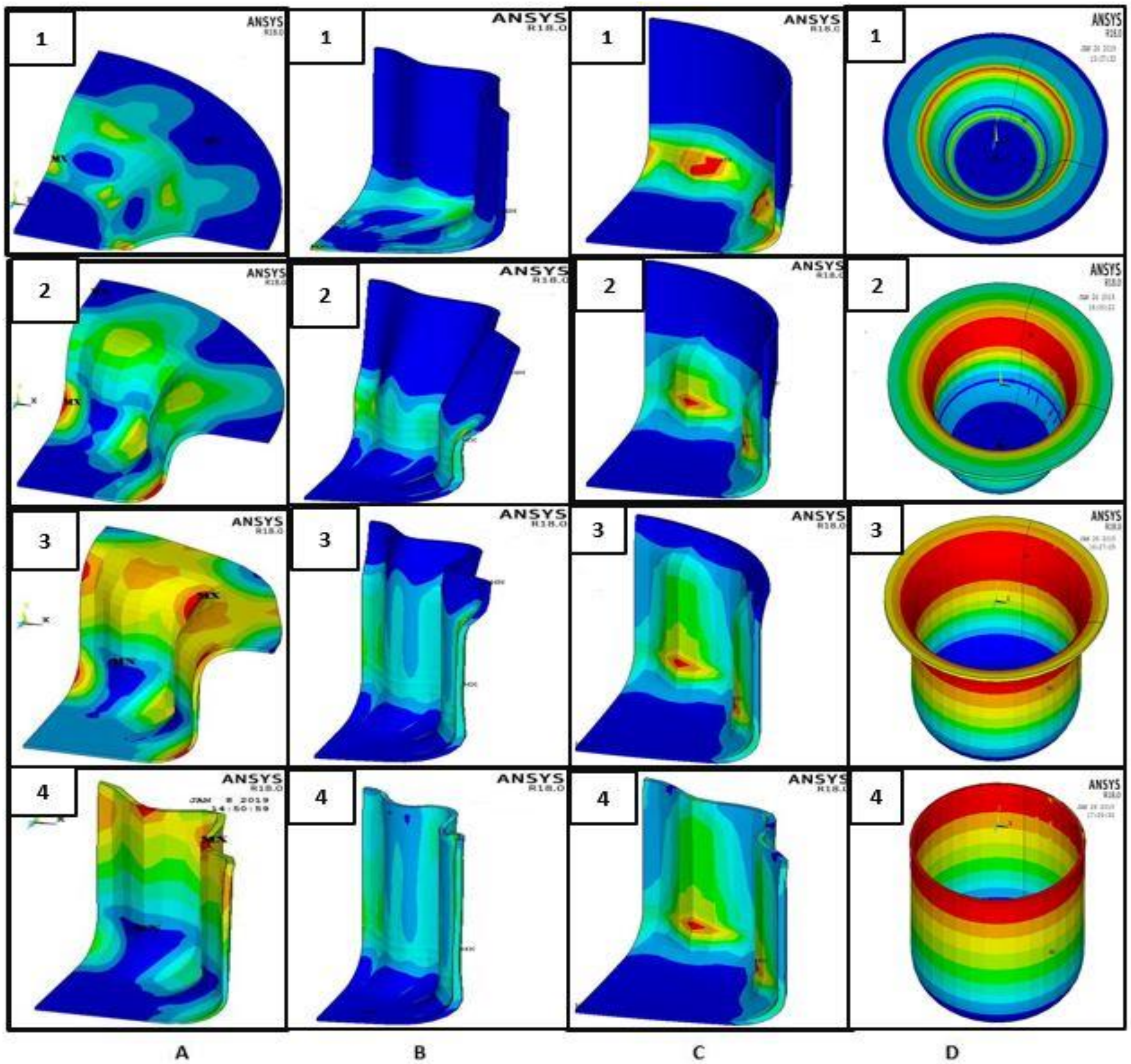

Figure: 2 The successive stages of producing a star and cylindrical shapes for the three stages

3-Experimental Procedure

Material characteristics

The properties of mechanical of the blank sheet for the first stage and the shapes for the three stages have a significant effect on the drawing and redrawing in three stages.The circular blank sheet of low carbon steel has (0.7mm) thickness and diameter of (80mm) wereused in this research.The chemical percentages of a low carbon steel sheet were performed using the spectrometer device.The chemical percentages of a low carbon steel sheet are listed in the table (3).In order to be obtained high accuracy of the results of the numerical simulators, tensile samples were taken of the flat sheet and the cylindrical shape of the three stages,where it was cut using a water jet machineaccording to designation number E8M of ASTM standard as illustrated in figure (3).

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Table:3The chemical percentages of low carbon steel sheet

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

Figure:3 Shows the tensile samples were taken of the flat sheet and the cylindrical shape of the three stages

Experimental test

Three stages drawing were done to produce star shape of (41.5 mm × 34.96mm) inner dimensions, and (60mm) heightforthe first stage, (29.3.mm×24.83) inner dimension, and (45mm) height for the second stage and (23.4mm×19.51) inner dimension, and (62mm) height for the third.The shape produced for the three stages of the drawing operation in two methods. In the first method, the star shape is produced drawn from the circular blank sheet for the first stage,whilethe second and third stageshapes are produced by redrawing shapes from the first and second stages, and the second method, transform the cylindrical shape into a star shapeforthe three stages.

The experimental dies were designed and constructed to produce star shape; they are made from tool steel which was machined by wire cut machine. The experiments were performed using the testing machine which has a capacity of 200KN and crosshead speed (100mm/min),the tool of the three-stage drawing operation utilized in theexperimental procedure is illustrated in figure (4).

The three-stagesdrawing werecarried out using the starand cylindrical dies and punches with dimensionsare listed in the table (4).Theradial clearance (20% sheet thickness) is selected for the three stages. The punches and dies of the three stages drawing operation used in the experimental procedure as illustrated in figures (5-6).

Some experimentshave been done on the drawing and redrawing process using the direct method and transform metlodto compare the two methods in terms of drawing force and distribution of thickness and strain over the side wall, the major axis convex and the minor axis concave of the star shape for the three stages.

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In order to study the strain and thicknessdistribution along the side wall, the convex of the major axis and the concave of the minor axis of the drawn shape, grids square was printed on the circular blank with the dimension of (2×2 mm). After the drawing and redrawing operation of the three stages, the grids square distorted and changed their dimensions at the wall of the shape and stay unchanged at the bottom of the shapeas illustrated in Figure (7). Thetool micrometer and tool microscope was utilized to check the change of thickness the grid squire after deformation. The change in longitudinal and circumference dimensions of the grids square used to measure the distribution of radial strain and thickness strain respectively.

Table: 2The dimensions of star and cylindrical punches and dies used

	Stellar shape		Cylindrical shape	
stage	Punch Dimension mm	Die Inner dimension mm	Punch Dimension mm	Die Inner dimension mm
First stage	41.5 × 34.96	43.7 × 36.64	41.6	43.2
Second stage	29.3 × 24.83	31.53 × 26.53	29.4	30.95
Third stage	23.4 × 19.51	25.6 × 21.19	23.5	25.05

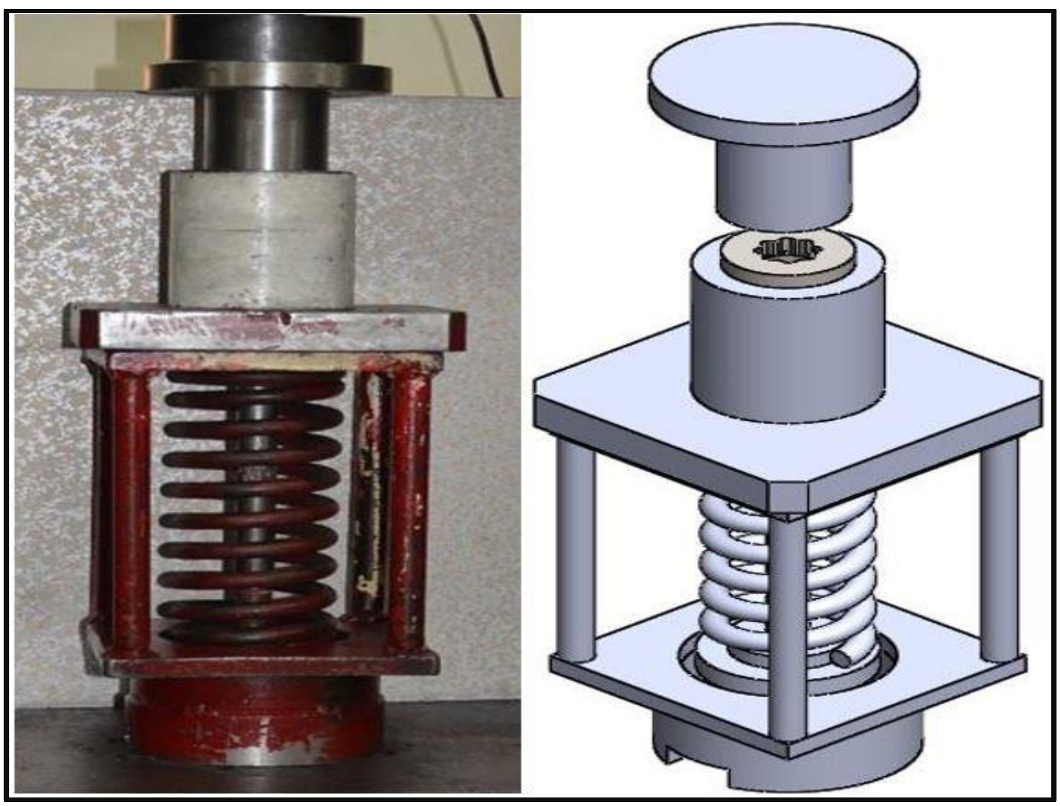

Figure:4 Shows the tool of the three stages drawing operation used

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Figure: 5The star punches and dies of the three stages drawing operation used.

Figure: 6 The cylindrical punches and dies of the three stages drawing operation used.

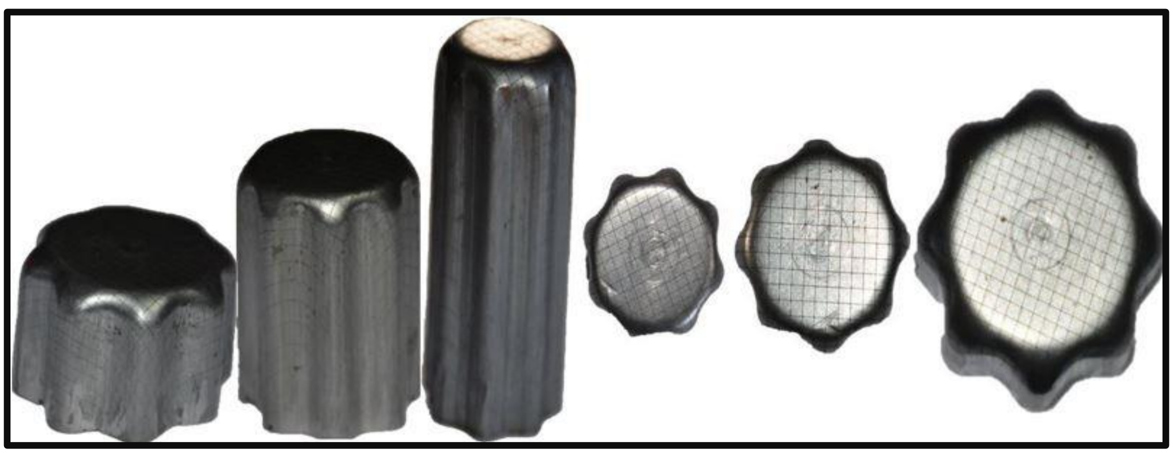

Figure: 7The square grid at the wall and brace of the shape after the deep drawing of three stages.

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4-Results and Discussion

In order to produce a star shape with minimal defects, two methods were completed Figure (8) shows the direct method where the severe thinning and tearing at the wall shape for the second and third stage. Figure (9) illustrates the indirect method where the shape produced for the three stages absence of tearing, thinning wrinkling.When the two methods were compared, the distortion in the direct method of the second and third stages is due to the difference between the centering of the convex and concave areas of both the punch and, die and starshape.

Figure(10)indicatesa comparison of the drawing load with punch stock requiredby star shape by direct method and star shape by indirect methodof the three stages. It was found from these figures that, the top of drawing load that requiredfor a product the starshape by the direct method is higher than thetop of drawing load required for produce the starshape by indirect method for the three stages. This is due to the star shape produced by the direct method is subjected to high bending and unbending more than to star shape produced by indirect methodfor the three stages.Also,a note from these forms that the drawing load decreases with the progress of the stages of the draw because of the percentage of the reduction of the shape decreases with the progress of the stages of the draw.

Figures(11-12) showcomparisonof the distribution of the thickness over the side wall, the major axis convex and the minor axis concave of the starshape produced by direct method and transform method for the three stages of deep drawing.Note from this figure, there is no variation in the thickness at the shape bottom until the shape corner for the three stages of deep drawing. After then the laminating takes placefor both methods and reaches its maximum value with the starshapeproduced by direct method at the minor axis concave area.This is due to the difficulty of the flow of metal in the areas of major axis convex and the minor axis concave of the starshape produced by direct method resulting from the concentration of high stresses in these areas. The best thickness distribution is obtained at the starshapewall produced by indirect method when compared with the starshape produced by the direct method.

Figures(13-14) show comparison thebehavior of effective strain distribution along the side wall, the major axis convex and the minor axis concave of the starshape produced by direct method and transform methodfor the three stages of deep drawing. It clear from these figures that, the effective strain at shapebottom is equal to zero. After that effective strain begins to rise from the shapecorner area to the rim of theshape. The greatest value of the effective strain with the starshape produced by the direct method, especially over minor axis concave when compared with the transform method due to the tensile stresses in the areas of curvature of the starshape produced by the direct method.

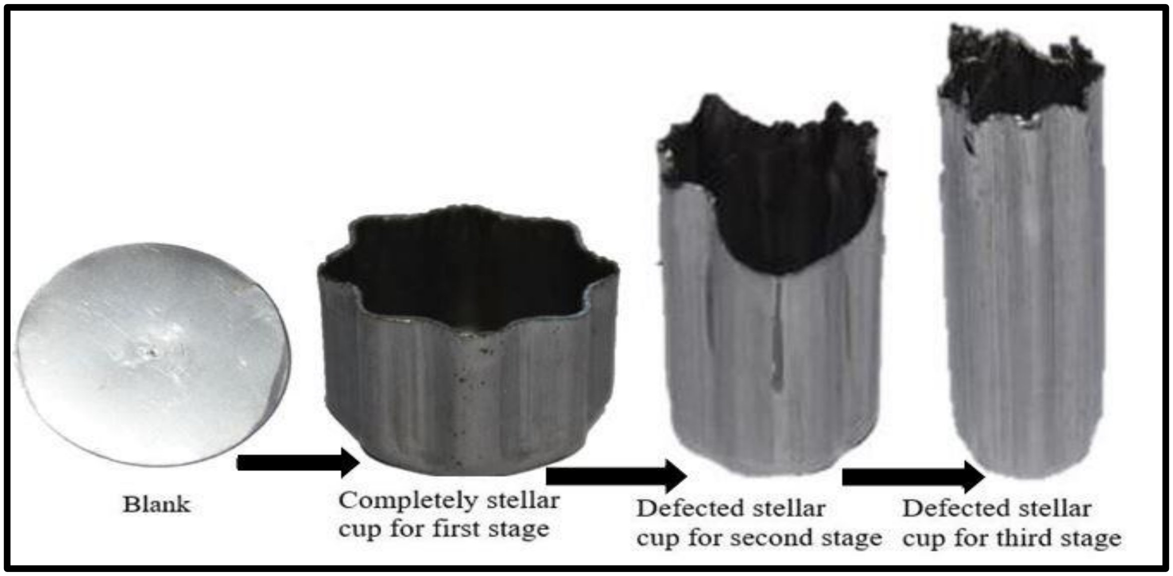

Figure: 8The direct method of producing the starshape of the three stages

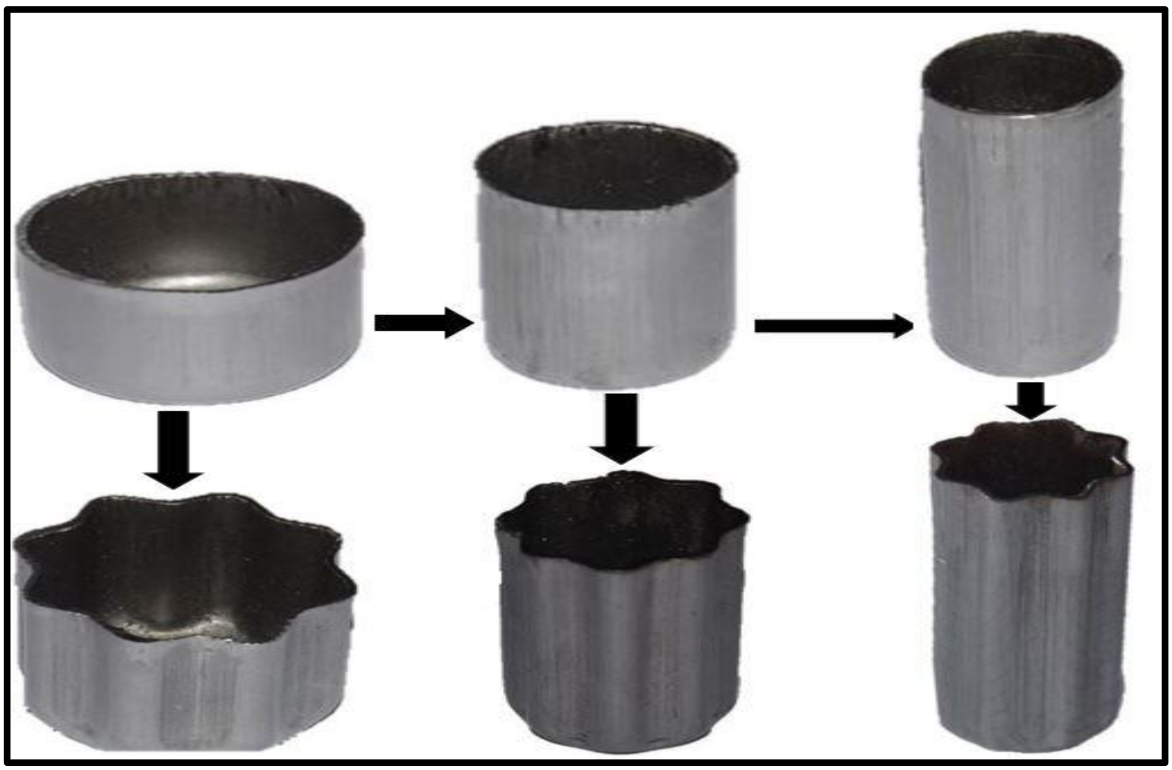

Figure: 9 Theindirect method of producing the starshape of the three stages

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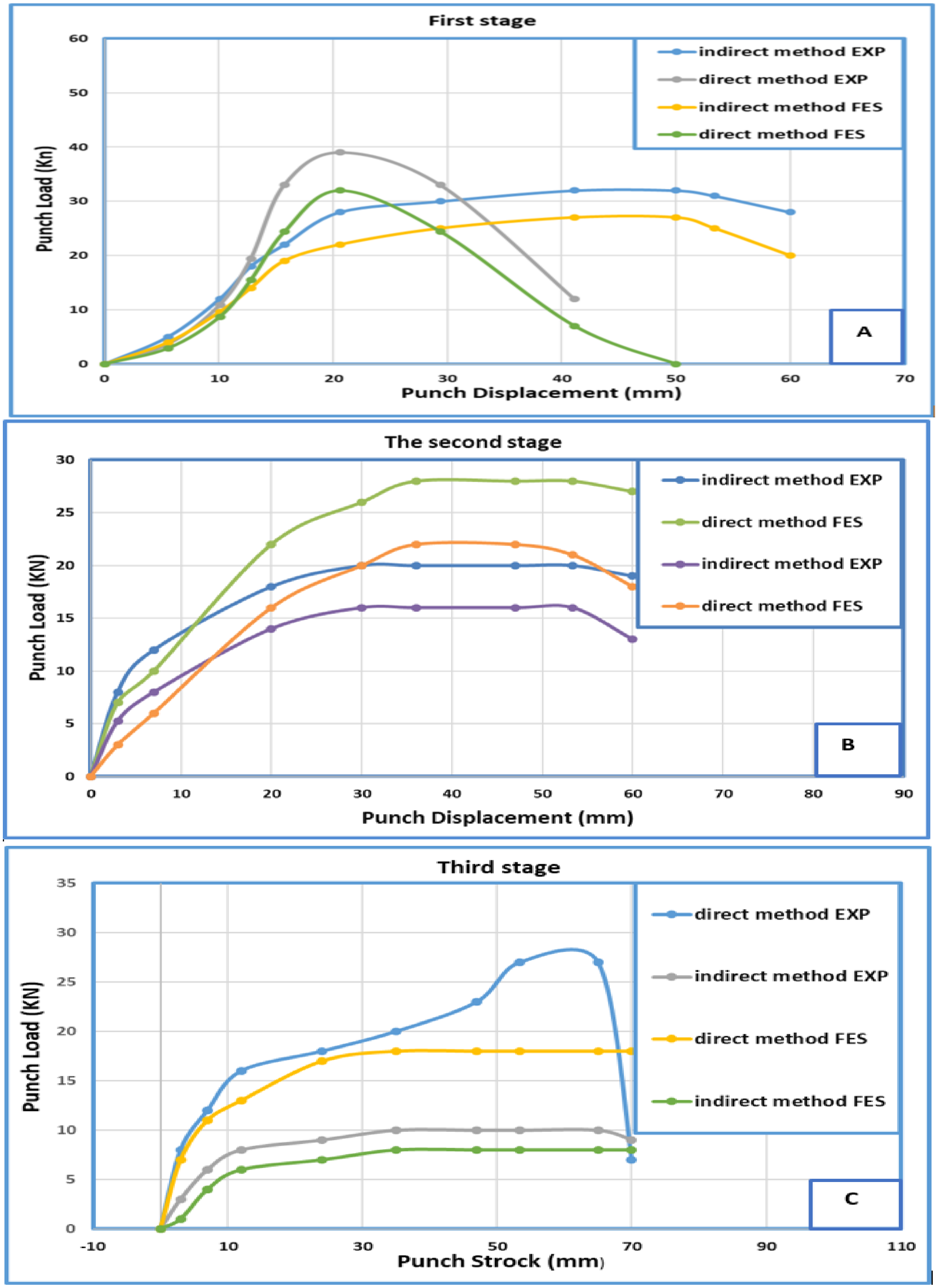

Figure: 10Comparison of the drawing load with punch stock required by star shape by direct method and star shape by indirect method for the three stages.

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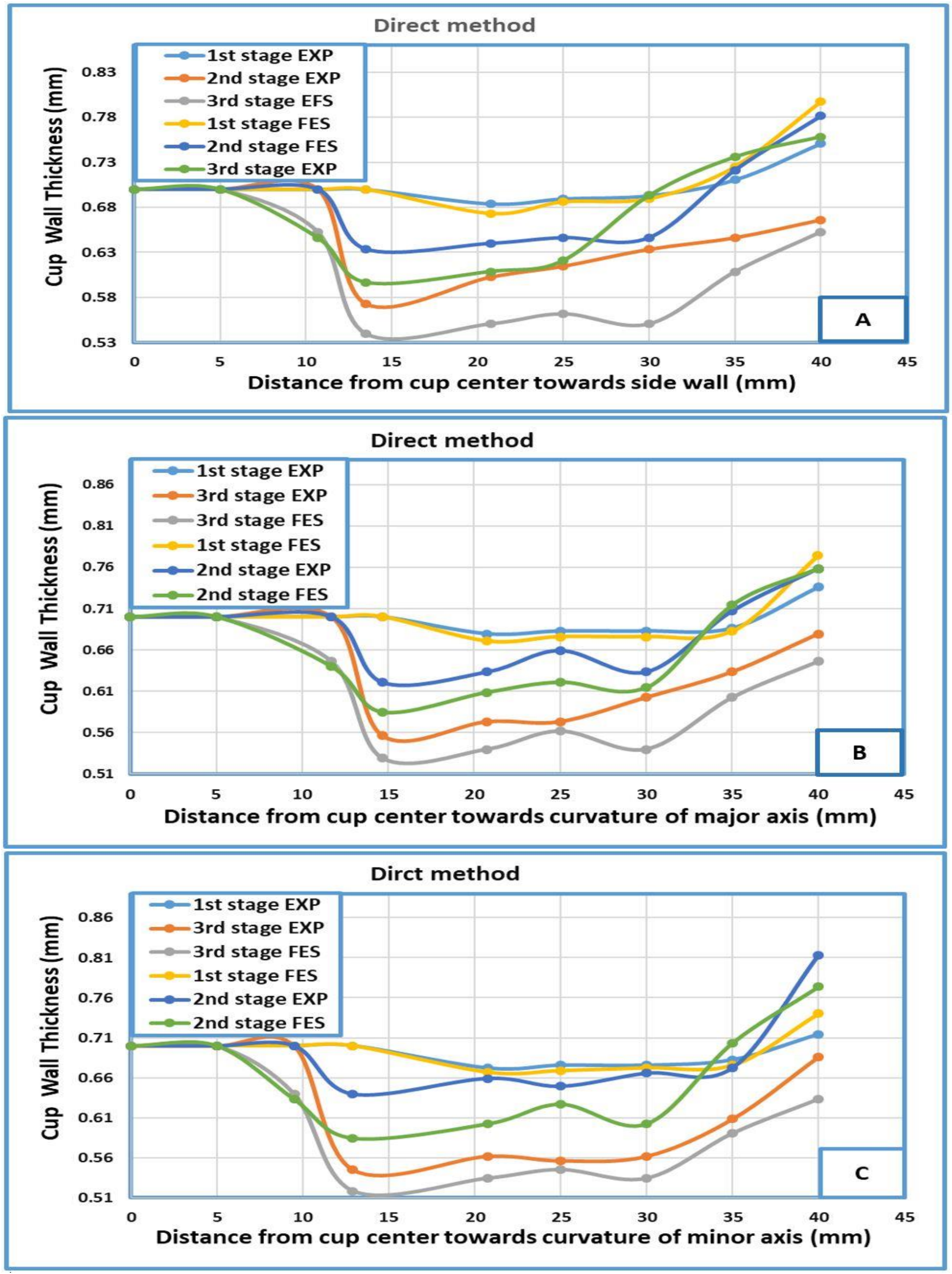

Figure:11 show comparison the behavior of effective strain distribution along the side wall, the major axis convex and the minor axis concave of the starshape produced by the direct method for the three stages.

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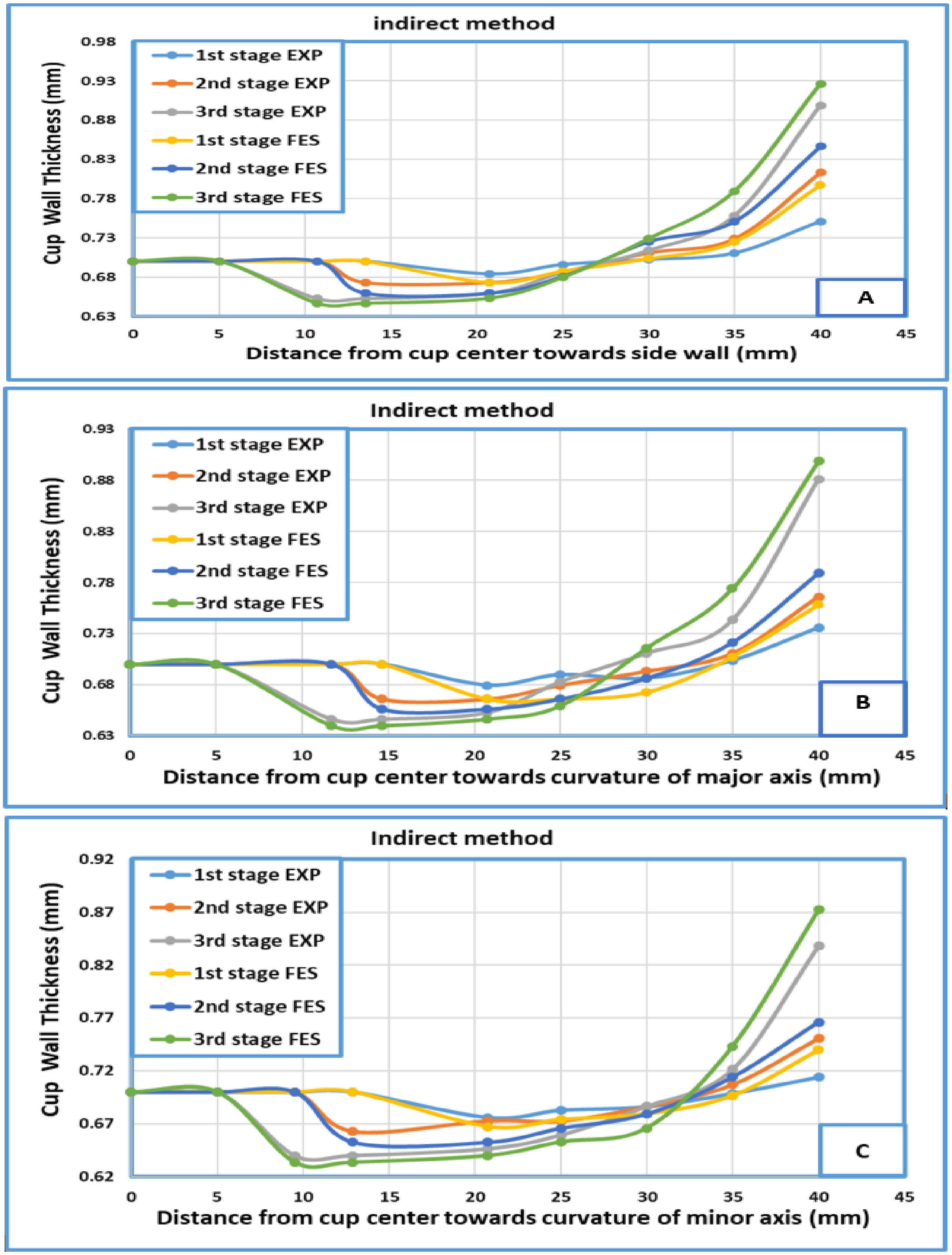

Figure:12Comparison the behavior of effective strain distribution along the side wall, the major axis convex and the minor axis concave of the starshape produced by indirect method for the three stages.

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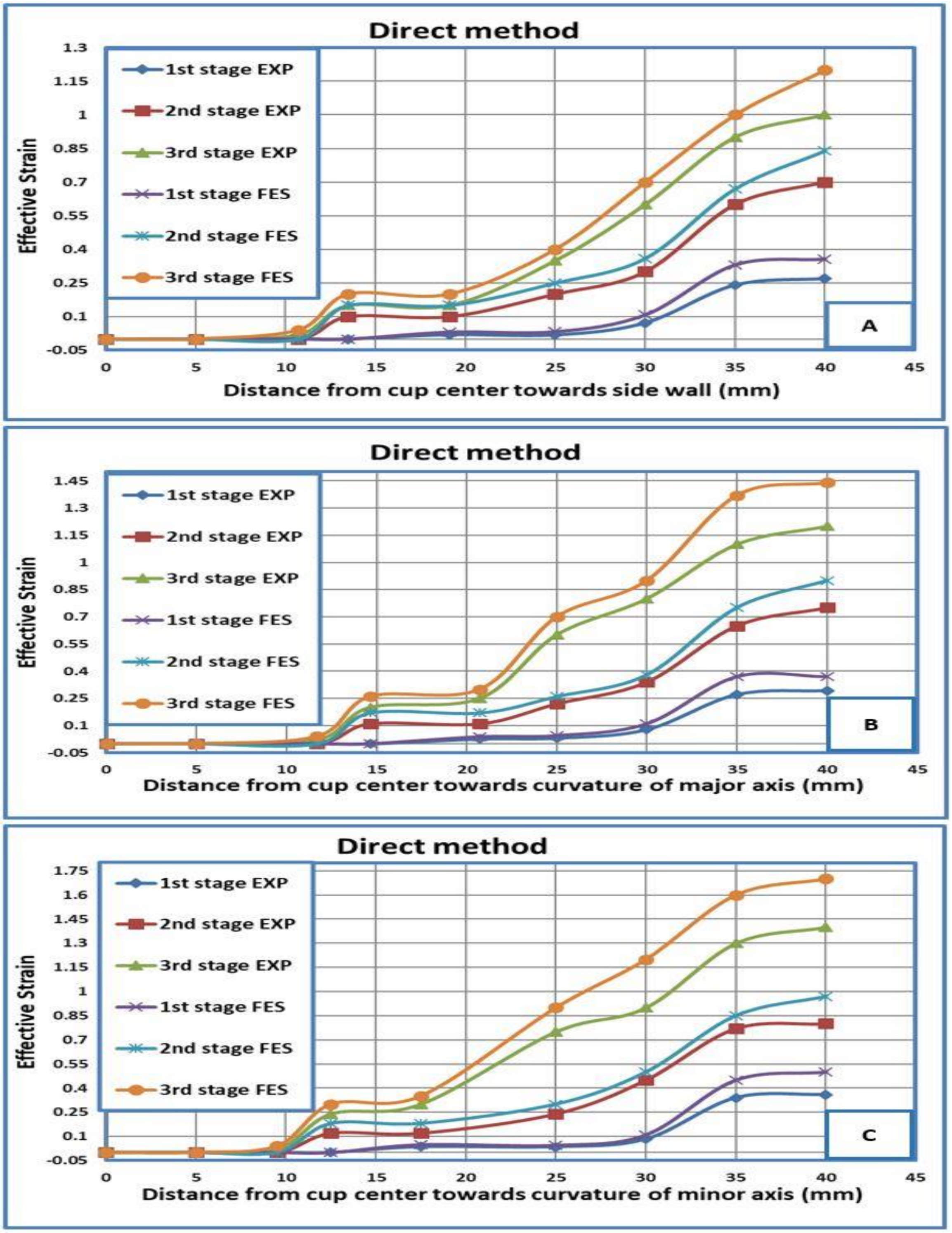

Figure:13 show comparison the behavior of effective strain distribution along the side wall, the major axis convex and the minor axis concave of the starshape produced by the direct method forthe three stages of deep drawing.

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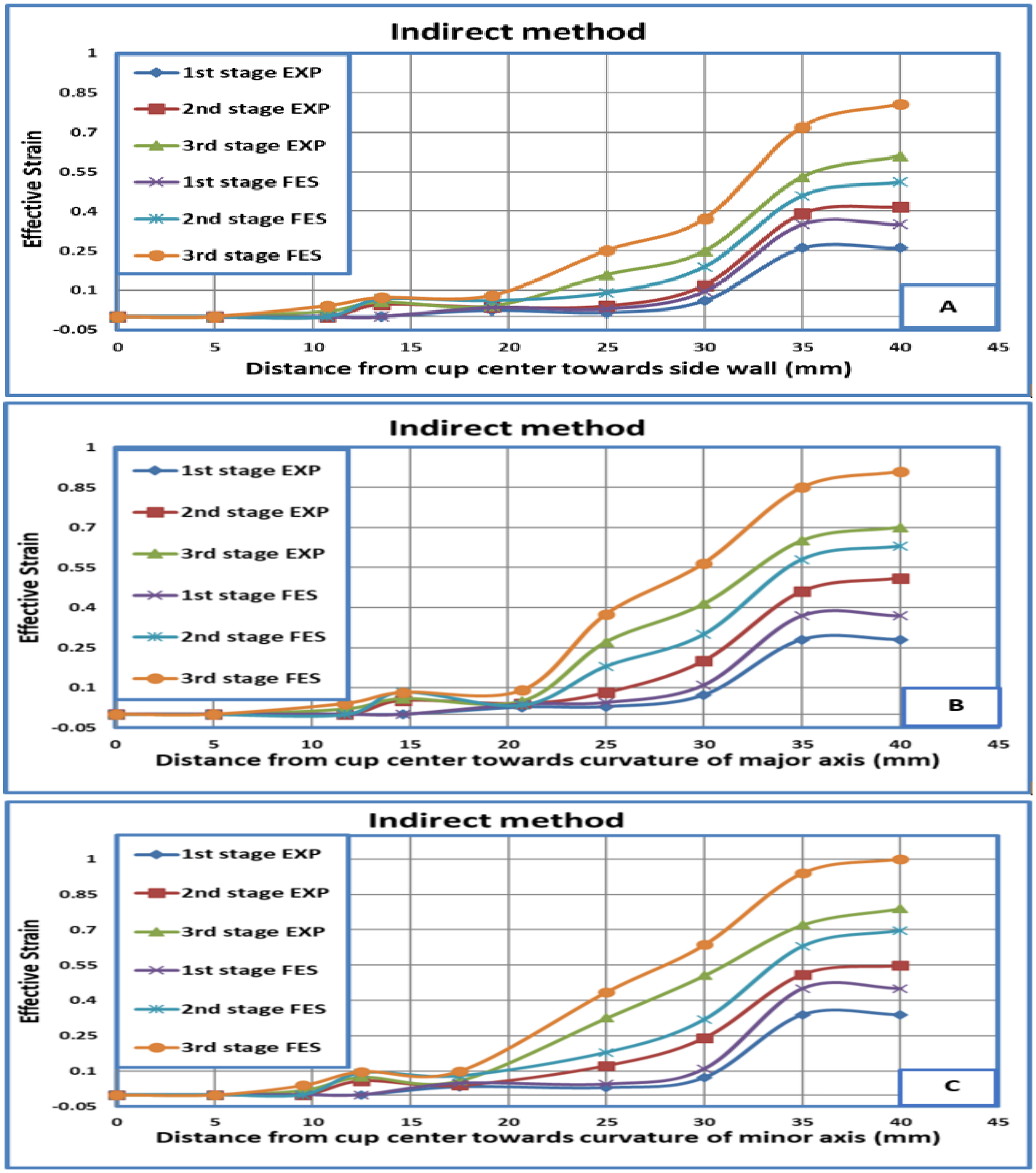

Figure:14Comparison the behavior of effective strain distribution along the side wall, the major axis convex and the minor axis concave of the starshape produced by indirect method for the three stages of deep drawing.

5. Conclusions

[1]The severe thinning and tearing at the wall shape produced by the direct method for the second and third stage.

[2]Absence of tearing, thinning wrinkling at the shape produced by indirect method for the three stages.

[3] The top of the drawing load that required for a product the star shape

by the direct method is higher than the top of the drawing load required for produce the star shape by indirect method for the three stages.

[3] The greatest value of the effective strain with the star shape produced by the direct method, especially over minor axis concave when compared with the transform method for the three stages.

[4] Maximum lamination with the star shapeproduced by direct method at the minor axis concave area.

[5]The best strain and thickness distribution are obtained at the starshapewall produced by indirect method when compared with the star shape produced bythe direct method.

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