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Numerical Analysis of The Multi-Stage Reverse Deep Drawing Process

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ABSTRACT:

The paper presents an analysis of the multistage deep drawing process considering the three deformation stages namely drawing reverse and reverse redrawing respectively. This work aim to study the mechanism of deformation during the redrawing process where the second and the third stages were done in reverse redrawing and study the effect of this mechanism on produced cup wall thickness, strain distribution across the wall of the drawn part. 2-D model of cylindrical cup (46.75mm) diameter has been developed in the first stage from sheet with thickness (0.5mm) of the low carbon steel (AISI 1008) and (85mm) diameter, while for second and third stages of drawing a punch diameter (32.725mm, 27.489mm) respectively, and inside diameter of dies equal to (33.825mm, 28.589mm) respectively, the clearance is chosen for three stage equal to 0.55mm. A commercial available finite element program code (ANSYS 11), is used to perform the numerical simulation of the multistage deep drawing. The results show that, when considering multi-stage drawing, the task is even more difficult because the strain and thickness distribution resulting from the first stage will influence the subsequent results, increase in thinning in the wall cup will appear in the second and third stages. Finally this work introduces new method (multi reverse redrawing) to produce circular cup throw three stages of drawing reduction in one stroke without the need to the loading and unloading the tools among the stages as in direct redrawing which means reducing the cost, time, efforts and enhancing cup production.

Keywords: Multistage deep drawing, Reverse redrawing, Finite element method.

التحليل العددي لعملية سحب عميق عكسي متعدد المراحل

الخلاصة

يقدم هذا البحث تحليل لعملية سحب عميق متعدد المراحل التي تتكون من ثلاث مراحل للتشكيل هي السحب في المرحلة الأولى والسحب العكسي في المرحل الثانية والثالثة على التوالي. هذا العمل يهدف إلى دراسة إلية التشوه خلال عملية إعادة السحب حيث إن إعادة سحب للمرحلة الثانية والثالثة كانت إعادة سحب عكسي، ودراسة تأثير هذا إلية على توزيع الانفعالات والسمك على طول جدار الوعاء المسحوب، تم تمثيل باستخدام نموذجِ ثنائي الإبعاد (2-

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(Dimensional لكـأسٍ اسطواني بقطر (46.75mm) في المرحلة الأولى من شريحة من فولاذ منخفض الكربون (AISI 1008) بسمك (0.5mm) وقطر (85mm)،بينما خرامات السحب (32.725mm, 27.489mm) قطر في المرحلة الثاني والثالثة، وأقطار القوالب الداخلية (33.825mm, 28.589mm) على التوالي، مقدار الخلوص المختار لمراحل الثلاثة (0.55mm). وذلك باستخدام طريقة العناصر محدودة التي تم تنفيذها باستخدام برنامج) ANSYS11)الخاص بتقنية العناصر المحددة، وأظهرت النتائج عند اخذ بنظر الاعتبار عمليات السحب متعدد المراحل ، إن المهمة تصبح أكثر صعوبة ولذلك لان توزيع الانفعالات والسمك على الوعاء المسحوب في المرحلة الأولى سوف يوثر على النتائج المحصلة في المراحل التالية، تزايد الانخفاض في السمك على جدار الوعاء في المراحل الثانية والثالثة من السحب وذلك. واخيرا هذا العمل يقدم طريقة جديدة (إعادة سحب عكسي متعدد) لإنتاج وعاء دائري خلال ثلاث مراحل من تنقص السحب في شوط واحد بدون الحاجة إلى عمليات تفريغ وتثبيت القوالب بين المراحل السحب كما هو الحال في إعادة السحب المباشر هذا يعني انخفاض بالكلفة والوقت وتعزيز إنتاج الوعاء.

INTRODUCTION

Automotive and auto parts industries have one special interest to the deep drawing operation because many parts produced for their use sheets. The deep drawing operation has been an important role into mechanical industries. In these industries the consumption of steel sheets has been growing in last years with the increase of production. Dies to the stamping processes are expensive, so numerical analysis of stamping processes has one important role during the development of these dies for parts each time more complexes, with less chance of mistakes and one performance [1, 2]. The deep drawing may be performed in a single operation, or in a number of stages. The number of stages depends on the degree of deformation in each step, which is influenced by the piece geometry, the material properties and the technological conditions. It could be evaluated by the drawing ratio defined as β=Do/do (where Do is the blank diameter and d_o the punch diameter). For a certain blank with a certain thickness and material characteristics, it could be defined a limit drawing ratio β_{lim}. If the current drawing ratio is higher than the limit drawing ratio then the part will be produced in more than one operation [3, 4].

When high drawing ratios are required, the process is decomposed into two or several steps, in order to increase the formability by preventing localization of the deformation in the cup wall. Re-drawing processes are usually sorted out in two categories: direct and reverse re-drawing. The first one corresponds to a process in which the different punches are always in contact with the same blank side whereas during reverse re-drawing, the punch travel occurs in two opposite directions and the outside of the part during the first stage becomes the inside of the part in the second stage. The advantages of the reverse process are a more compact tooling, without new positioning of the part in-between the two stages, a better surface aspect than in the case of a direct process because the outside is in contact only once with the die radius and finally a smaller number of bending–unbending operations [5,6]. Since a number of investigators has studied the drawing process. The current exposition here will focus only on the researches concerning the reverse deep drawing.

Experimental and numerical reverse re-drawing of cylindrical cups are deal by **S. Thuilliera, et al (2002) [7],** Experimental analyses consist of thickness distribution in the cup wall at 0°, 45° and 90° to the rolling direction (RD) and relationship between the force and displacement of the punch during process. The deep drawing process was simulated using both the dynamic explicit finite element code Pam-Stamp and the static implicit home code DD3IMP. Moreover, they investigate the occurrence of strain path changes during the first and the second stage in order to estimate their influence. An experimental investigation of the reverse re-drawing of mild steel sheets has been performed**. Viorel Paunoiu et al (2002) [8]**, presents an analysis of the multistage deep drawing process considering the two deformation schemes namely direct and reverse redrawing experimental and numerical. The material used was A3K steel grade, with a thickness of 0.8 mm. The results of numerical simulation are experimental validated. It is founded when considering multi-stage drawing; the task is even more difficult because the stress and thickness distribution resulting from the first stage will influence the subsequent behavior. Because of the bending differences between the direct and the reverse redrawing, there is also a difference in the level of stresses and strains that appears in material. Finally it is concluded the importance of the material load pattern in the redrawing process toward the parts quality and forces level, the quality of parts, in terms of form errors, obtained in reverse deep-drawing is better in comparison with that obtained in direct redrawing. The thinning is more accentuate in the case of reverse deep-drawing.

The finite element analysis is carried out for a multi-stage deep drawing and ironing process of a rectangular cup with the large aspect ratio using is researched by **Se-Ho Kim, et al (2002) [9]**, the analysis simulates the five-stage deep drawing and ironing process with the thickness control of the cup wall. The analysis reveals that the difference of the drawing ratio within the cross section induces non-uniform metal flow which causes severe local extension. The irregular contact condition between the blank and the die also induces non-uniform metal flow which causes local wrinkling.

M. Kadkhodayan and J.Mosayebi (2009) [10] study the Bauschinger effect in the deep drawing process by using a finite element analysis of the Bauschinger effect in the reverse cup drawing process. In order to, several hardening models are considered such as kinematic, isotropic and combined forms in the linear and nonlinear cases. The numerical results obtained from finite element analysis have been compared with some experimental results reported in literature. The various factors, namely, normalized stress, and the punch forces, for both first and second stages have been calculated for different materials and thicknesses. Results show that the combined model had acceptable agreement with the empirical data through both stages. In this simulation, the predicted thickness distribution by two models shows practically no difference. However, the resulting stresses and punch forces are quite different. **H. Bahon (2014) [11]** analysis of multi stage deep drawing process for cylindrical cup is carried out using finite element method and experimentally. A simplified 2-D axisymmetric model for cylindrical cup of three stages has been built. An available finite element program code ANSYS 11, is used to perform the numerical simulation of the deep drawing operation. A three stages deep drawing tooling was designed and constructed to carry out the experimental work to produce a cup of final inner diameter equal to 32mm and depth equal to 62mm, formed from a circular flat blank 95mm with sheet thickness of 0.6mm composed of mild steel of 0.06% carbon content without any intermediate annealing. In order to visualize the plastic flow, the grid marking technique was employed. In order to get optimum die design and to study the effect of die profile radius on drawing and redrawing process, three types of corner die radii have been chosen for the three stages. It was found, that the drawing force and the strain distribution over the cup wall increase by decreasing the die profile radius. Finally, the result from the numerical analysis shows good agreement with the experimental results, and the cups are produced without any defect. **D.M. Neto, et al (2014) [12]** deals with the three dimensional numerical simulation of the reverse deep drawing process of a cylindrical cup, being the numerical results compared with the experimental ones. The anisotropic behavior of the mild steel sheet is described by both the Hill'48 yield criterion and the more advanced non-quadratic yield criteria Yld'91, in addition to the isotropic von Mises yield criterion. Moreover, the anisotropy coefficients for the Hill'48 function were identified based either on the yield stresses or the r-values measured in three different material orientations from the uniaxial tensile tests. The numerical analysis allows identifying the strain paths associated to each cup region during each forming stage, which are similar in both stages. The material flow between the die and the blank-holder is subjected to uniaxial compression, changing to plane strain in the cup wall. The important strain path changes occur in the die radius, ranging from uniaxial compression to plane strain. Moreover, the cup wall thickness distribution is strongly influenced by the yield criteria, particularly when comparing isotropic and anisotropic behavior.

Numerical simulation

For simulating the multistage deep drawing processes, commercial FEA software ANSYS11.0 was used, in which the "Newton-Raphson" implicit approach was employed to solve nonlinear problem. In this approach, the stroke steps on punch are defined explicitly over a time span. Within each step, several solutions (substepes or time steps) are performed to apply the displacement gradually. At each substep, a number of equilibrium iterations are performed to obtain a converged solution. In this study every three stages (drawing, reverse redrawing and then reverse redrawing) were modeled in one step, first deep drawing produced cylindrical cup from sheet, after the completion of the first stage starts second stage reverse redrawing and then followed the third stage reverse redrawing to produced final product. The 2-D 4-node structural solid axisymmetric element (VISCO106 2D LARGE STAIN SOILD) was used for workpiece (blank).The tool set (punch, die and blank holder) was modeled as rigid bodies. Element sizes are controlled by controlling the division specification of lines. Mesh density of the blank and tools affect the accuracy of the results. So the meshes in the blank are finer. The most important portion of the tool whose mesh density affects the accuracy and reliability of the results is its arc segment and the meshes of this portion are finer than other portions. The movement of the punch was defined using a pilot node. The degrees of freedom of the pilot node represent the motion of the entire rigid surface. Automatic contact procedure in ANSYS11.0 was used to model the complex interaction between the blank and tooling. For rigid tool set-flexible blank contact, target elements of TARGE196 were used, to represent 2D target tool set surfaces which were associated with the deformable body blank represented by 2D 8-node contact elements of CONTA175. The contact and target surfaces constitute a "contact pair", which was used to represent contact and sliding between the surfaces of tool set and blank. A deep drawing model was created. Due to the symmetry in the specimen geometry, constraints and boundary conditions, an axisymmetric model needed was analyzed. The finite element model of the drawing die for first deep drawing is shown in Figure (1). For simplifying the simulation of the deep drawing processes, the following assumptions were made: temperature of workpiece (blank) remained constant, no heat transfers between workpiece and tool set, the dies were rigid, the punch moved down at constant speed 60mm/min during the forming process and the die was stationary. Bilinear Isotropic Hardening BISO option uses the von Mises yield criteria coupled with an isotropic work hardening assumption. This option is often preferred for large strain analyses. The principal axes of anisotropy coincide with the material (or element) coordinate system. Elasto-plastic constitutive model with isotropic strain hardening was used to simulate the sheet response. The elastic behavior was taken to be linear and the plastic response was modeled using von Mises yield criterion. The friction coefficient is assumed to be uniform and constant for all contacting surfaces and equal to 0.1. The flow diagram illustrating an example of such methodology is shown in figure (1). The finite element model of the tools and blank sheet for multi deep drawing is shown in Figure (2). In this work were done the simulation of direct deep drawing and the reverse re-drawing of a cylindrical cup of low carbon steel sheet. Tensile test was done to determine mechanical properties for the steel sheet. Mechanical properties for low carbon steel are shown in Table (1).

Result and Discussion

In this multistage deep drawing, the blank is a circular plate having a diameter of 85mm and thickness 0.5mm is placed over a die which have internal diameter 47.85mm and the blank is held in place with a blank holder which applies the restraint force for preventing the folds formation, while hollow punch have 46.75mm external diameter and 33.825mm internal diameter has two functions: at the exterior side (external diameter) of the hollow punch plays the role of the change the shape of the blank to the cup when which went down to form the blank in the first stage and the inside side (internal diameter) of the hollow punch play a role as a die to reverse redrawing the cup produced in first stage to the other cup which have lesser diameter in the second stage. The drawings with dimensions of die set used in the process are in die and punch profile radius equal to 4mm for all stage.

For the second stage (reverse redrawing) of deformation, the blank is the cylindrical ones cup1 obtained in the first stage of deformation has an inside diameter of 47.75 mm. The cup after deformation in first stage is drawing by another hollow punch found in the die used in the first stage, this hollow punch have external diameter 32.725mm to produce the cup2 and internal diameter 28.589 plays as a die for third stage, The resulted part has an inside diameter of 32.725 mm. In reverse redrawing the material flows in the opposite direction to the punch stroke and the outside of the part during the first stage becomes the inside part in the second stage. In the third stage the cylindrical blank cup2 is placed over a die (external diameter of hollow punch in second stage) the another punch which diameter 27.489 mm will deform the cup2 to the final product which have 27.489 mm. The drawing reduction for three stages is shown in table 2. In figure (3) showed that the thickness distribution to the three steps of the process from bottom of cup to the top of cup, there are not change in the thickness in the base of cup because there are not excessive deformation in this region, and in the punch profile region the more thinning occur because of stretching produced from excessive bending in this region and then begins to rise until reaching maximum value in the cup rim. In the end of cup wall, final thickness is bigger than initial thickness, it happens due to compressive efforts that appear to reduce the sheet diameter. Different stages of material deformation during simulation in multistage deep drawing are shown in figure (4).

In figure (5) ,(6), (7) explain the strain distribution over cup wall from cup bottom for direct, reverse and revere redrawing, the explanation of behavior of the strain in all figures as follows. Radial strain of the produced cup wall is found by simulation. It is seen from these figures, that the value of radial strain under cup bottom is zero, where very small deformation occurs in this area which cannot be observed, then it increases suddenly at punch corner continuously until the rim of the flange reaches a maximum value at the cup edge, due to tension in this direction. While thickness strain obtained by simulation It is evident from the figures that the value of thickness strain at the cup bottom is approximately equal to zero, due to friction which prevents any deformation of the metal under the punch face, and hence there is no thickness change observed, afterward at a cup corner, the value of thickness strain becomes negative reduce in thickness as a result from tension stress in this area, then becomes a positive at the cup wall increase in thickness because of compressive stress in this direction, and then continues to increase to reach maximum value at the cup edge. Hoop strain for the three step of drawing. The result shows, that the value of hoop strain is approximately equal to zero at the cup bottom, where very small deformation occur, afterward it become positive at the cup corner expand in circumference due to tension stress in this area, then begins to decrease towards cup wall to have negative value shrinkage in circumference, because of the compression applied in this direction, and it continue to decrease to reach a maximum value at cup rim.

CONCLUSIONS

The multi stages reverse deep drawing was simulated using finite element method with implicit formulation and using von miss yield criteria. It is founded when considering multi-stage drawing, the task is even more difficult because the strain and thickness distribution resulting from the first stage will influence the subsequent results, more thinning appear in region under the punch profile radius due to excessive stretch in this region in the first stage while increase in thinning in the wall cup will appear in the second and third stages because this region which severe from more stretch in first stage will be wall cup in the next stages. Finally this work aim to produce circular cup in with high drawing ratio in single stroke by using multi reverse redrawing without the need to annealing operation and eliminate the time required to setup the tools among the stages as in direct redrawing which means reducing the cost, time, efforts, error shape and enhancing cup production.

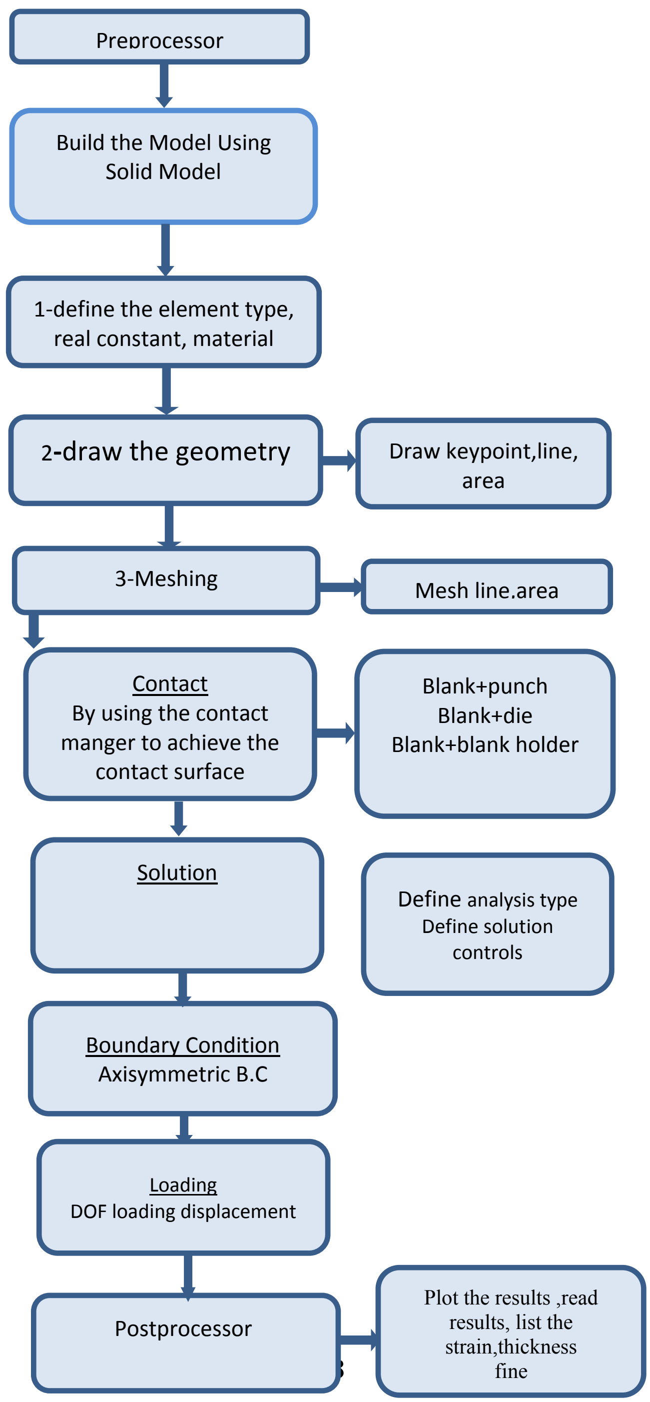


Figure (1) The flow chart of the methodology.

Table (1) The material properties.

material	Young's modulus, E(GPa)	Tangent modulus, Et (GPa)	Yield stress, бy (MPa)	Poisson's ratio, ν
L.C.St	200	0.5	203	0.3

Table (2) The drawing reduction for three stages(D◦=blank diameter ,dp= cup diameter).

Drawing reduction (r)	First stage (direct deep drawing), $D_\circ$ =85mm	Second stage (reverse redrawing), $D_\circ$ = 47.85mm	Third stage (reverse redrawing), $D_\circ$ =32.725mm
$r = (D_\circ - d_p)/D_\circ$	0.45	0.3	0.16

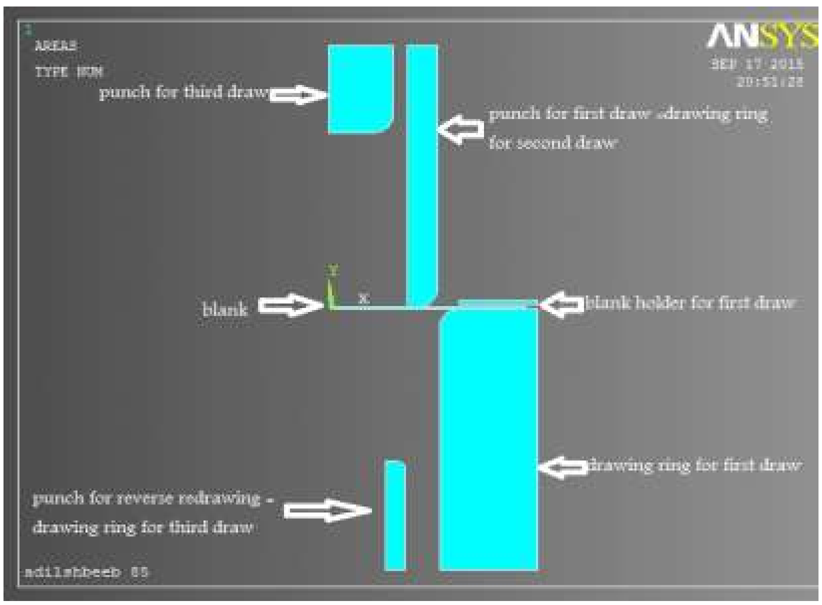


Figure (2) The finite element model of the multi reverse deep drawing.

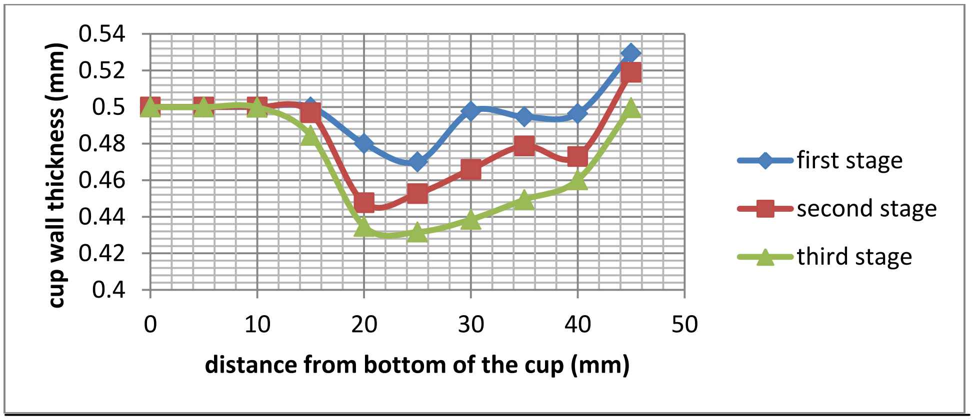
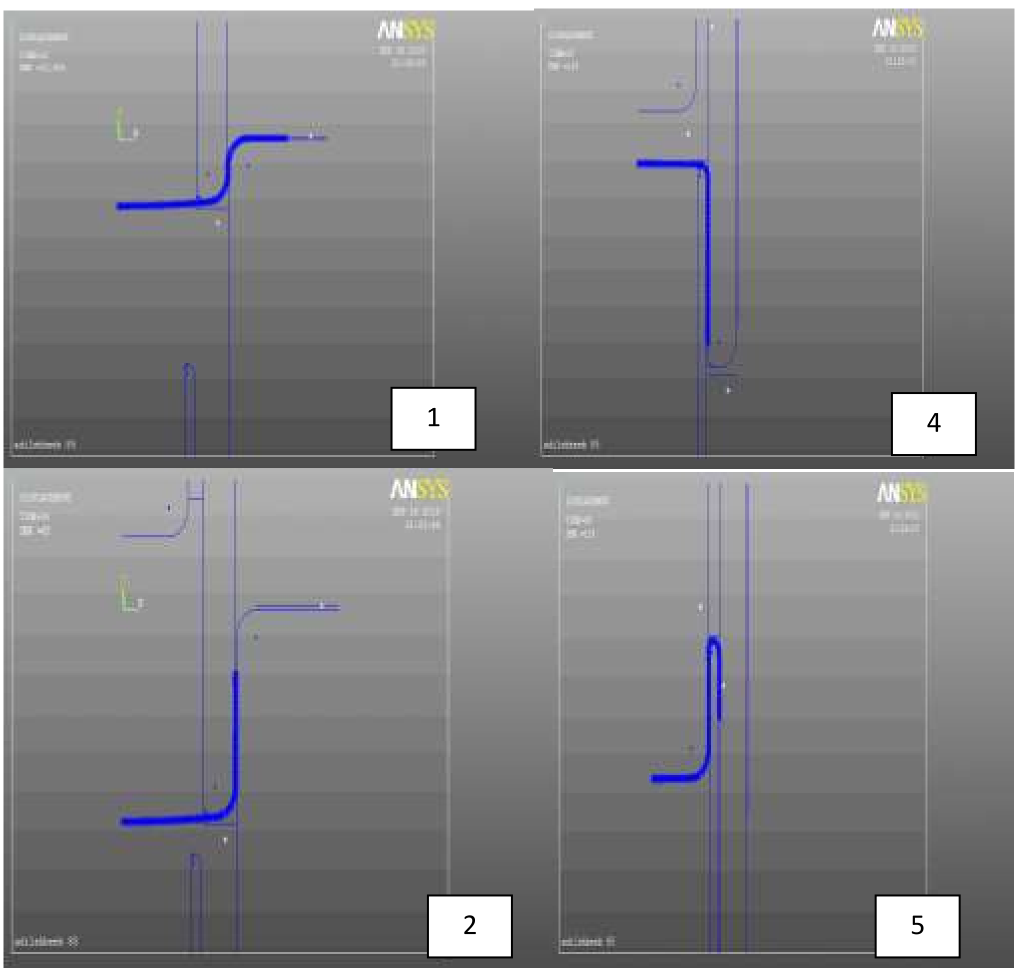


Figure (3) the thickness distribution for three stages of the process.



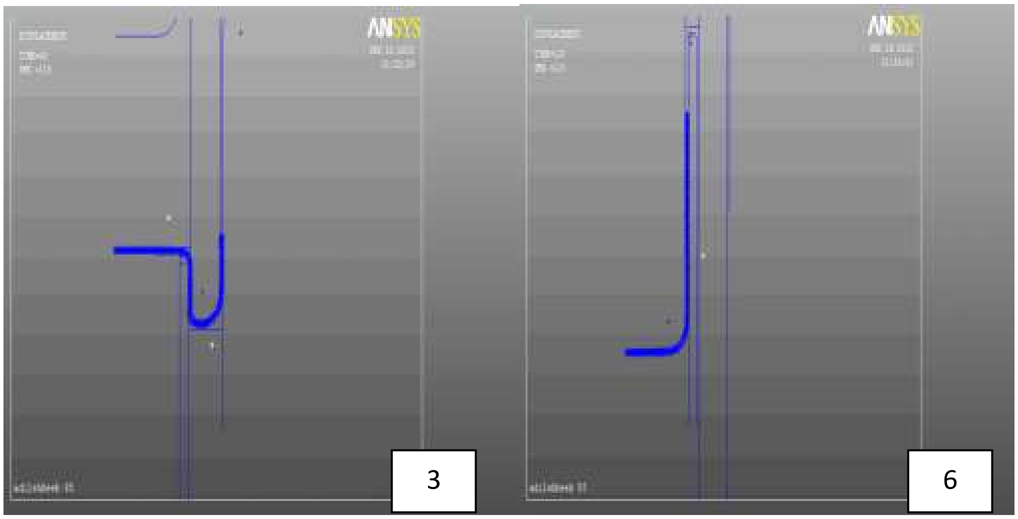


Figure (4) different stages of material deformation during simulation in multistage deep drawing.

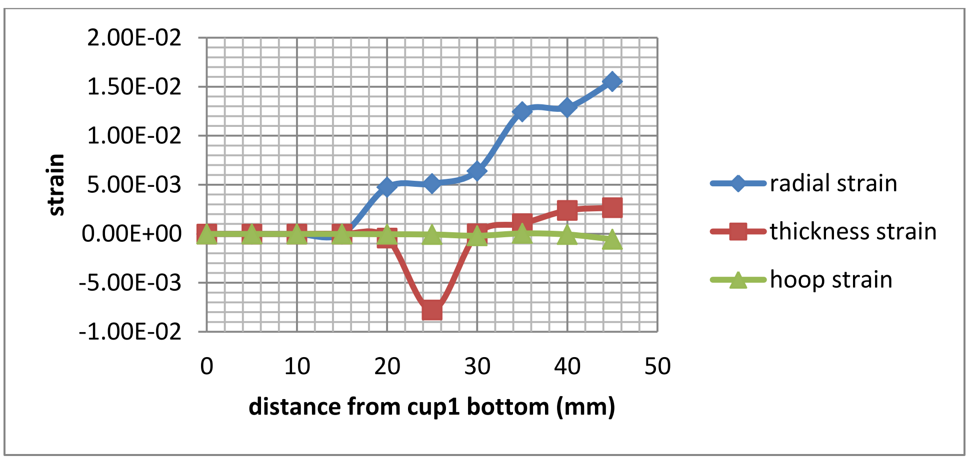


Figure (5) strain distribution over cup wall for first step of the process.

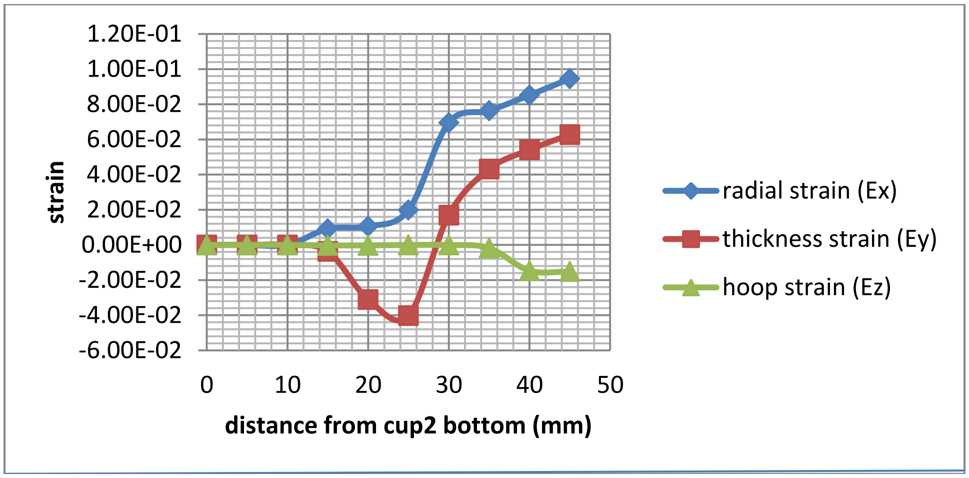


Figure (6) the strain distribution to second step of the process (reverse redrawing).

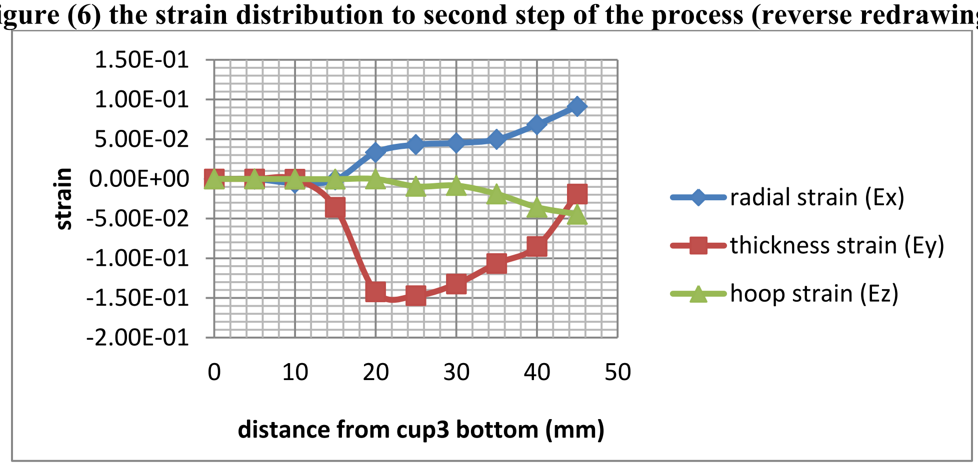


Figure (7) the strain distribution to third step of the process (reverse redrawing).

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