

## Design Modification in a Multi-stage Deep Drawing Process

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### **Abstract:**

In this research an analysis of multi-stage deep drawing process is carried out for process design of cylindrical cup drawing with large drawing ratio ( $\beta = 3.416$ ). A three stage deep drawing tooling was designed and constructed to carry out the experimental work required to produce a cylindrical cup of (25mm outer diameter) formed from a circular flat blank (82 mm diameter) comprised of mild steel of (0.15%) carbon content, without any intermediate annealing. The difference in the drawing ratio between the neighboring stages was reduced so as to achieve more uniform deformation in the cross-section. The study confirms the real deformation mechanism and inspects the contact conditions at the tool-blank interface. In the second and third stage of drawing, three direct re-drawing methods were used to re-draw the cup produced from the first stage (By using internal blank holder, with out blank holder, and by using centering block method).

The analysis reveals that the difference in the drawing ratio, and the irregular contact condition between the blank and die (which occur when using second and third method of re-drawing), induces non-uniform metal flow, which cause wrinkling, tearing, and severe extension of metal during the re-drawing process. for There the first method (By using internal blank holder) was chosen for detailed analysis because it ensures reduction in wrinkling and tearing of the cup wall.

From the comparison between the results of the three stages of drawing, it has been found that the drawing force decrease for each successive stage of drawing process, increasing the value of effective strain distribution over the cup wall with die nose radius, the radial and hoop strain increases remarkably for each successive stage of drawing, while the thickness strain increases slightly, which lead to produce a uniform wall thickness of the re-draw cup. It was found that, the use of internal blank holder in re-drawing process, increases cup formability, extends tool life by eliminating wrinkling and tearing, reduces the possibility of failures, improves part quality and increase production speed.

### **الخلاصة:**

في هذا البحث، تمت دراسة عملية السحب العميق ولعدة مراحل ولنسبة سحب عالية مقدارها ( $\beta = 3.416$ ) وقد تم تصميم قالب سحب لثلاث مراحل لتنفيذ الجزء العملي اللازم لإنتاج قذح أسطواني بقطر خارجي (25mm) من صفيحة دائرية مستوية قطرها (82mm) من مادة الصلب الكربوني ذو نسبة كربون (0.15%) وبدون إجراء عملية تخمير بين المراحل الثلاث. وقد تم تقليل الفرق بين نسب السحب للمراحل الثلاث لغرض الحصول على تشكيل متجانس للجزء المنتج.

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ويشمل البحث دراسة ميكانيكية التشويه الحاصل واكتشاف ظروف التماس بين العدة والصفحة. في المرحلتين الثانية والثالثة من السحب، تم استخدام ثلاث طرائق لإعادة السحب المباشر هي (باستخدام وسادة ضغط داخلية، وبدون وسادة ضغط، وباستخدام قالب لمركزة الشغلة). وقد ظهر من الدراسة إن الاختلاف في نسب السحب وظروف التماس غير المنتظم ما بين الصفحة والقالب (التي تحدث عند استخدام الطريقة الثانية والثالثة من إعادة السحب)، ينتج منها انسياب غير منتظم للمعدن مما يتسبب في إحداث تجعد وتمزق وتمدد كبير في المعدن خلال عملية إعادة السحب. لذلك فقد اعتمدت الطريقة الأولى (استخدام وسادة ضغط داخلية) في إجراء عملية التحليل لأنها تضمن تقليل التجعد والتمزق في جدار القدر المنتج. بمقارنة نتائج المراحل الثلاث، وجد حدوث انخفاض في قوة السحب مع توالي المراحل المتعاقبة على جدار القدر مع زيادة قيمة نصف (effective strain) مع زيادة في قيمة الانفعال الفاعل. يزداد مقدار الانفعال القطري والانفعال (die nose radius) قطر تقوس مقدمة القالب الأنثى (المحيطي بشدة في كل مرحلة من مراحل السحب، في حين يزداد مقدار انفعال السمك بصورة قليلة مما ينتج جدار متجانس للقدر المنتج. وقد وجد إن استخدام وسادة الضغط الداخلية لمرحلة إعادة السحب يزيد من قابلية المعدن للسحب كما يزيد من عمر القالب بسبب منعه حدوث التجعد والتمزق، ويحسن نوعية المنتج وبالتالي يزداد الإنتاج ويقلل من احتمال الفشل (failure).

### **Introduction:**

Process of the blank material experiences additional complex deformation in each stage compared to the conventional drawing process. The process generally involves additional bending, unbending, stretching, compression and shear by different drawing ratios during the subsequent drawing stage. Since the deformation mechanism is very complicated and the final mechanical properties are difficult to predict, the process design is not easy for the manufacture of a product of desired shape and material properties. The deformation inherently proceeds with the irregular shapes of the cross-section and conditions that the cause failure such as tearing and wrinkling. Success or failure of the forming process is influenced by many process parameters such as the drawing ratio in each stage, the difference of the drawing ratio within the cross-section, the shape of the die, the strain-hardening coefficient, formability, the lubrication conditions, the degree of ironing and so forth.

Many researches on the multi-stage

In the multi-stage deep drawing deep drawing process have been carried out with trial and error experimental work in the factory without fundamental understanding of the complicated deformation mechanism and plasticity theory. Recently, the finite element method has been introduced to the analysis of the forming process and has provided useful information for manufacturing process design [1].

In (1994), Danckert [2], proposed a finite element simulation of two stage deep drawing process followed by ironing of the cup wall to analyze the residual stresses in the cup wall after the drawing stages and after ironing of steel blank. The results show that the ironing process causes a drastic change in the residual stress and causes a favorable distribution with regard to fatigue strength, stress corrosion resistance and stress cracking.

Lee & Cao (2001)[3], developed an axisymmetric shell element for the multi-step inverse analysis for more accurate prediction of design variables

such as the initial blank shape, strain distribution, and intermediate shapes. , this approach is more accurate and the punch increment per step is much larger than that in the conventional incremental analysis.

Huh & Kim (2001)[4], have applied inverse FE analysis to estimate the initial blank shape, intermediate deform shape, thickness distributions and failure during multistage deep drawing operation of elliptic cup. The results show that the localized deformation occurs along the major axis of the elliptic cup and the wrinkling occurs along the minor axis, the modified design improved the quality of drawn part and reduces the possibility of failure occurrence.

Kim et al. (2001)[5], analyzed the three-stage deep drawing process of rectangular cup using an elasto-plastic finite element method. They have revealed that the non-uniform drawing ratio in the cross-section causes non-uniform metal flow, to produce failures such as wrinkling and tearing.

Cao et al. (2001)[6], have developed a new forming process that can reduce forming steps of an axisymmetric thick metal drawing problem. The results show that a measurement of tearing potential is about 5% lower than that in the original one, while the press loads are almost identical. The 10-step drawing is reduced to 6-step drawing.

Predicting the onset of the wrinkling in aluminum square cup forming, was investigated by Xi Wang & Cao (2000)[7]. It was found that the stress distribution is not uniform and the hoop stress is even not completely compressive in the side wall region (frustum). Those cases demonstrated that the presented analysis provides a simple and

The results show that as the number of analysis step is increased effective way to predict the onset of side-wall wrinkling.

FE modeling proposed by Altan (2000)[8], for the Limiting Dome Height test, shows that this test is very sensitive to friction. The results show that, the presence of friction, however hinders the free thinning at the apex of the punch. Therefore, the position of maximum strain, which corresponds to the location of maximum thinning point and moves away from the apex. The larger is the friction, the larger the distance between the apex and the point of maximum thinning.

Yao et al. (2000)[9], proposed a modified axisymmetric model with a center offset to predict tearing failure in the corner section of 3D parts. The proposed offset was found to be a function of the failure height, process parameters, including tooling geometry, material properties, friction coefficient, and restraining force provided by the blank holder.

Huh & Kim (2001)[10], introduced an optimum design procedure to seek the optimum process parameters in sheet metal forming process. Conditions of the blank holding force, the die shape, and the bead force were optimized to obtain a specific quality of products. The results show that the optimum design of process parameters has been well performed to decrease the amount of strain that prevents fracture by tearing.

Abedrabbo & Zampaloni (2005)[11]. investigated the wrinkling behavior of aluminum alloys during hydroforming process, when using square and round blank. It was found, that in the case of square blank, wrinkles do not form underneath the

blank holder, as rigid corners prevent drawing and cause the sheet to stretch. On the other hand, wrinkling is prevalent in the case of round blank, as the metal is drawn easily into the die cavity creating large compressive stress in the flange region.

Sing and Kumar (2005)[12], investigated the hydromechanical deep drawing process for producing cup shape part with assistance of pressurized fluid. It was found that, higher drawability and more uniform thickness distribution could be obtained when compared to conventional deep drawing.

#### **Experimental Work:**

In this work, a deep drawing tooling was designed and constructed to carry out the experimental work required to produce a cylindrical cup of (25mm outer diameter) formed from a flat blank by a three-stage deep drawing process without intermediate annealing as shown in Table (1) and Fig. (1-A & 1-B). The difference of the drawing ratio between the neighboring stages was reduced so as to achieve more uniform deformation in the cross-section.

The blank from which it is formed has a diameter of (82mm), (0.5mm) thickness and is comprised of mild steel of the following chemical composition (C 0.15% , Mn 0.5%, Cu 0.15%, S 0.04%, V 0.01%, P 0.035%).

The mechanical properties of the sheet material were determined by tensile testing ((200MPa)yield stress, (200GPa) Modulus of elasticity, and (0.3) Poisson ratio). The blank holding force ranging from (10-15) KN, was applied in the first drawing-stage during the full stroke (to

produce a cylindrical cup of (44mm) outer diameter) in order to control metal flow and prevent wrinkle formation removed thereafter. Three types of punches of (43,30&24 mm) diameter with fixed punch nose radius (4mm) have been used. Variable die nose radii (R=4,8,12 mm) for all the three stage have been chosen to investigate the effect of die nose radius on drawing force, cup wall thickness and the strain distribution over the cup wall of completely drawn and redrawn part.

Three direct re-drawing methods were used to re-draw the cup produced from the first stage as follows :

1-By using internal blank holder (cup holder), where the part is drawn completely without any defect. (The blank holding force ranging from 100-300 N )

2- By using centering block, where the part is drawn with wrinkling at the cup edge.

3- Without using blank holder or centering block, where the part is drawn with tearing of the cup edge as shown in Fig. (1-B).

Since the use of blank holder (method1) ensures reduction of wrinkling and tearing of the cup wall, this means that the possibility of failure is reduced, for there this research will be concerned with this method only.

The experiments were carried out using the Instron testing machine which has a capacity of 100KN and cross head speed of (300mm/min), with punch stroke reaching to (40mm) for the first stage (first draw), (50mm) for the second stage, and (70mm) for the third stage.

[Thickness strain]  $E_t = \ln ( t / t_0)$

Table (1): punch diameter & percentage reduction of the three stages of drawing

Blank diameter 82 mm	First draw	Second draw	Third draw
punch diameter (mm)	43	30	24
% Reduction	47	30	20
Clearance between punch & die	1.1 t	1.1 t	1.1 t

Where , t = Initial blank thickness (0.5 mm)  
 Maximum drawing ratio=Blank diameter/ Final punch diameter=82/24 = 3.416  
 Maximum percentage reduction for the three stage =  $(1-24/82) \times 100 = 70.7 \%$

In order to study the strain distribution within the cup during drawing operation, a grid pattern of (5,10,15,20,25,30,35& 40) mm radius circles, was chosen and printed (along 12 intersecting lines, 30 degree apart) on the original blanks, by using mechanical grid marker. In order to measure the cup wall thickness; the drawn cup was divided in to two parts by using a diamond saw . Digital thickness micrometer and tool microscope was used to measure the cup wall thickness and the changes in the grid circles during the deformation. Cup thickness and the average length of distorted grid radius were measured along the 12 intersecting lines as shown in Fig.(2).

Experimentally, the radial strain ( $E_r$ ) was obtained by measuring the changes in circle grid pattern printed on the original blank. The thickness strain ( $E_t$ ) was obtained by measuring the wall thickness of the completely drawn part at the deformed grid circle. Slab method was used to calculate these strains as follow

[Radial strain]  $E_r = \ln ( L / L_0 )$

[Hoop strain]  $E_h = - (E_r + E_t)$   
 [Effective strain (Equivalent strain)]  
 $E_{eff} = \{ 2 / 3 (E_r^2 + E_t^2 + E_h^2) \}^{0.5}$   
 where :  
 ( $E_r + E_t + E_h = 0$ ).  
 ( $t_0$ ) is the initial thickness of the blank (mm).  
 ( $t$ ) is the final thickness of produced cup wall (mm).  
 ( $L_0$ ) is the initial radius of the grid circle printed on the blank (mm).  
 ( $L$ ) is the final radius of the distorted grid circle after deformation (mm)

**Results and Discussion:**

In order to predict the failures such as tearing , wrinkling and sever extension during the re-drawing process, three methods of re-drawing die was were constructed as shown in figure (1-A & 1-B). The Fig.indicates that the deformation is performed successfully and the part is drawn completely with out any defect when using internal blank holder (method 1), sever wrinkling at the cup wall was observed when using centering-block (method 2), while wrinkling and cup edge tearing was observed when the drawing was performed without

blank holder (method 3). This difference in cup shapes can be explained as follows:

When methods (2&3), are used the tool contact condition between blank and die, does not impose sufficient holding force, which results in the stretch-dominated deformation of the blank. This irregular contact condition and different drawing ratios in cross section, induce non-uniform metal flow, which causes failure such as wrinkling and tearing to be observed as shown in the figure.

Since the die and the blank shape are not in favor of smooth contact, the original design requires the tool modification to improve the uniform contact and metal flow. This modification has been achieved by using internal blank holder (method 1) which overcomes the wrinkling and tearing defects. It was found that the use of blank holder is not so much to exert pressure (small blank holding force is between 100-300 N), but rather to give support to the cup wall during redrawing processes and control the metal flow, so that the blank can deform with bending and unbending deformation. It was found that the use of internal blank holder (method 1), increases cup formability, controls the metal flow and reduces the differing in drawing ratios, minimizes wall thinning, extends tool life by eliminating wrinkling and tearing, reduces the possibility of failures, improves part quality and increases production speed. Therefore the exposition here will focus only on the results concerning the use of internal blank holder in re-drawing process, because it ensures reduction of wrinkling and tearing of the cup wall.

The variations in the drawing force (punch load) with the punch

stroke under different drawing stages and at different die nose radii are shown in Fig. (2). For the first stage of drawing, it is shown that necking was considered to occur as the punch force reached its maximum value and started to drop. Following necking, splitting occurred at the point of the large drop in the punch force. It is shown that the drawing force for large die nose radius is slightly lower than that for small nose radius. This can be explained by more severe bending effect on small nose radius.

The figure shows that the punch load is remarkably reduced in the second and third stages of drawing, this can be explained as follows:

Due to reducing the drawing ratio between the subsequent stages of drawing, and because the amount of metal drawn in each subsequent draw is always less than the previous one, the deformation mechanism plays to reduce the contact conditions between the shell (Cup produced from the previous stage) and die, therefore it reduces the drawing force. This means that the drawing force decreases with each subsequent drawing stage. In the second and third stages of re-drawing, and after reaching the stability condition, the bending and unbending operations occur at constant cross-section, which makes the drawing force to approximately constant as shown in the stroke from (20 - 70 mm) in Fig. (2). It is seen that the optimal die corner radius at which the required drawing force is minimized is equal to ( $R=12\text{mm}$ ) for all stages, this means that, in order to minimize the drawing force, the die radius should be large enough to certain limit.

For the three stages of drawing, thickness along the grid circles at the produced cup wall was measured, the

percentage change of thickness was calculated and drawn as shown in Fig. (3). It is clear from the figure that initial blank thickness (0.5mm) at the region of a flat bottom face of the punch does not change and remains almost constant, this is because the flat face of the punch is in contact with blank, and due to the drawing force, friction comes into play which prevents any deformation of the metal under the punch head. Hence there is no thickness change observed at this region. However, the necessary deformation is provided by other portions of the cup, resulting in an increase in thickness in the wall and edge regions, this can be explained as follows ; The material lying at the punch nose region deforms more than the other portion of the cup wall and produces more thinning (tension) leading to high stress concentration at the punch nose radius (cup corner radius) as a result of excessive bending and stretching of metal at this region. Afterward the stress becomes compression which causes the cup rim (edge of the produced cup) undergo the most severe shrinking during the process, and hence becomes the thickest part of the wall. This can be shown obviously by maximum thickening of the cup wall at the cup rim to about (7 % for the first stage), (13 % for the second stage), and (22 % for the third stage).

Fig. (4,5,6) show the strain distribution of fully drawn part at each forming stage. It is seen from the figures that the deformation of the blank consists of radial strain (tension  $E_r$ ) and circumferential compression (Hoop strain  $E_h$ ), and change in thickness (Thickness strain  $E_t$ ). It is clear that a considerable change of the strain distribution is observed in the flat as well as radius areas of the

drawn part. It is seen that the strain at each forming stage is more than that for the previous one, because the cup in the new drawing stage maintains the strain of the previous one. The distributions of the thickness strain explain thickening at the cup wall and thinning at the punch corner region as a result of excessive bending and stretching of metal. It is obvious that the strain distributions for all drawing stages, are similar in shape, and have the same trend with different values, where high strain concentrations are present at the large die nose radius as a result of excessive stretching of metal over the die nose due to increasing the contact area between the blank and die (leads to increase in friction force which causes increase in strain). From the strain curves, one can conclude that the radial and hoop strains increase remarkably for each successive stage of drawing while the thickness strain increases slightly, resulting a uniform wall thickness of the redrawing cup.

Fig. (7) represents the distribution of effective strains (equivalent strain) over the cup wall at each forming stage for different values of die nose radius of completely drawn part. It is seen that the strain distribution over the cup wall increases with increasing the die nose radius for the three stages of drawing and the value of strain increases for each successive drawing stage, and reaches its maximum value at the cup edge.

### **Conclusions:**

For all drawing stages, the distributions of the thickness, explain thickening at the cup wall and thinning at the cup corner radius as a result of excessive

bending and stretching of metal over the die nose. The thickening can produce wrinkling along the cup wall while the thinning can produce tearing of the cup during the forming process.

The radial and hoop strain increase remarkably for each successive stage of drawing while the thickness strain increases slightly, which leads to produce a uniform wall thickness of the re-draw cup.

The drawing force decreases for each successive stage of drawing.

Frictional force is applied to the metal largely by the edge of the punch and not by its flat section.

Failure such as wrinkling and tearing occurs by non-uniform metal flow because of the irregular contact conditions due to the different drawing ratios in the cross-section, and the absence of blank holder during re-drawing process.

The use of blank holder is not so much to exert pressure in re-drawing process, but to support the cup wall and modify the contact conditions during re-drawing processes, It is necessary to produce a complete re-drawn part out with defects.

It was found that the use of internal blank holder (method 1), increases cup formability, controls the metal flow and reduces the difference in drawing ratios, minimizes wall thinning, extends tool life by eliminating wrinkling and tearing, reduces the possibility of failures, improves part quality and increases production speed.

Essential points to be considered for the die design are ; uniform change in the drawing ratio between the neighboring stages, uniform contact between the tool and the blank, accurate bottom shape of the cup, and suppression of wrinkle generation.

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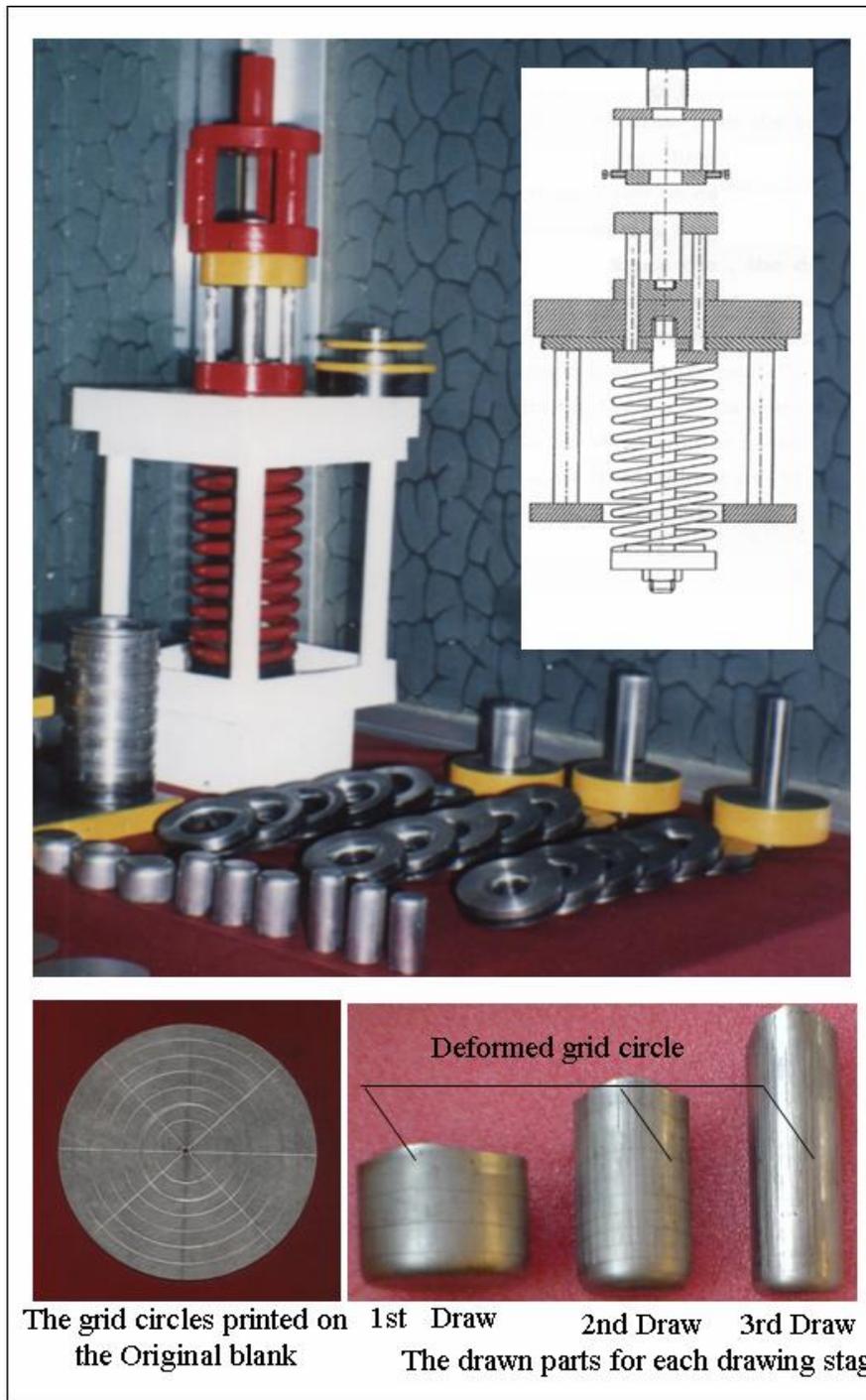


Fig.(1-A) The tooling used at each drawing stage and the fully drawn parts

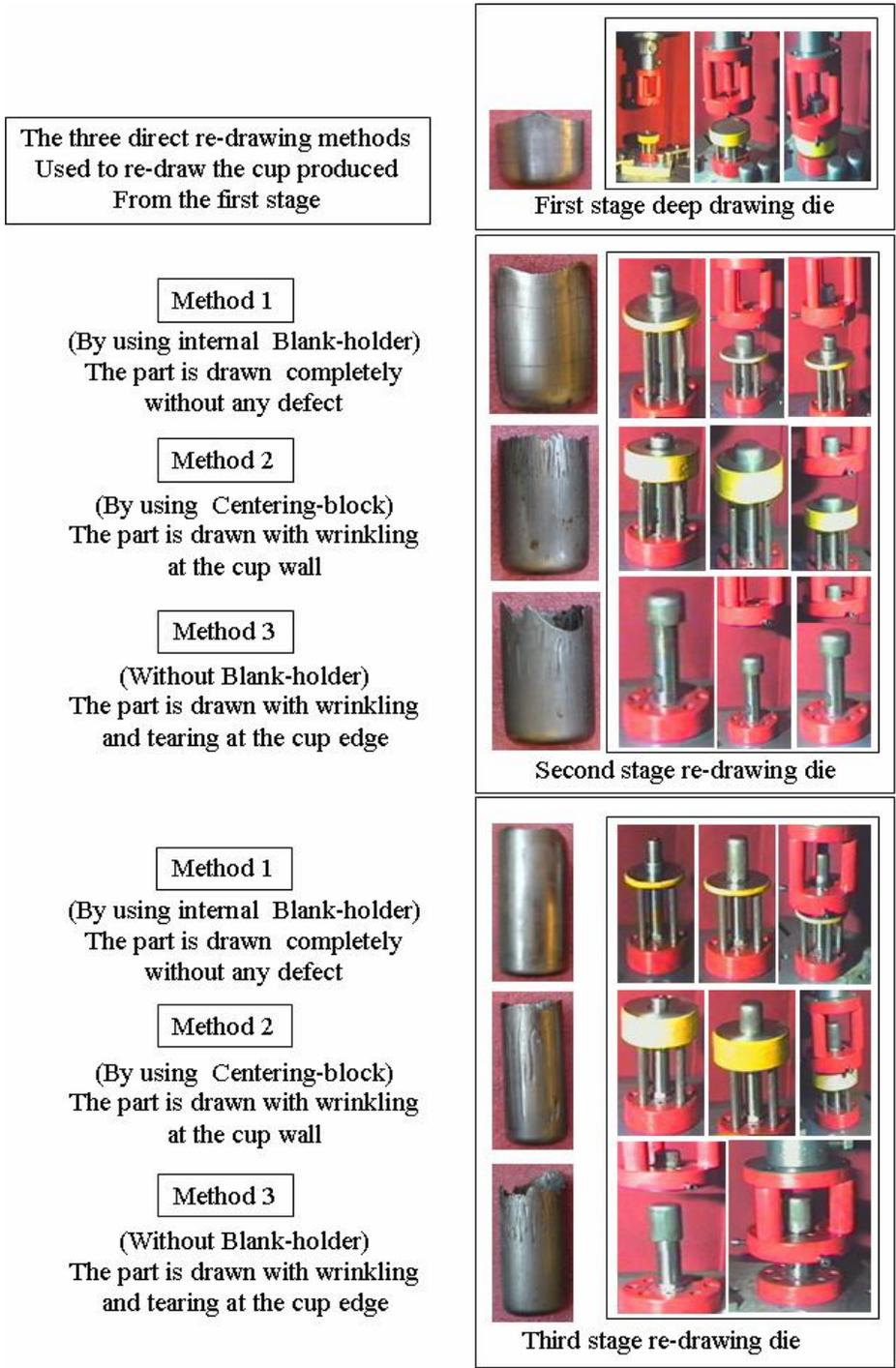


Fig.(1-B) The tooling used at each drawing stage and the fully drawn part .

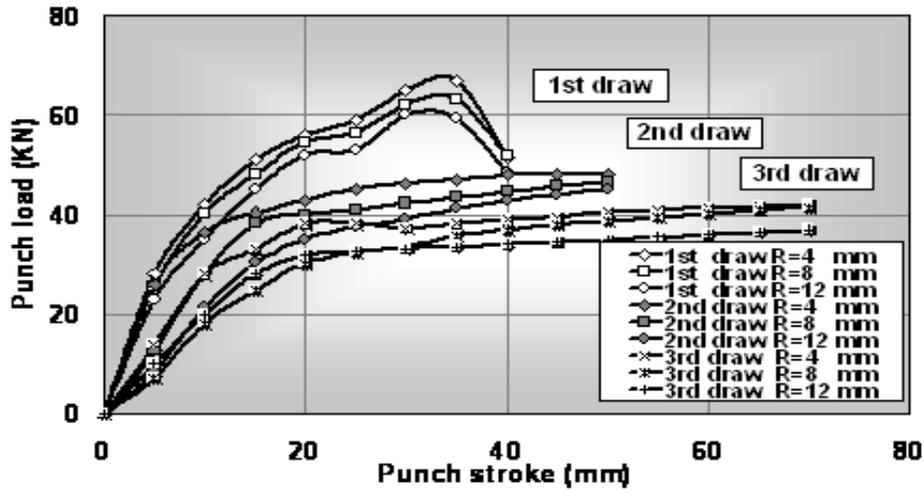


FIG (2 ): The effect of die nose radius on drawing force for the three stages (draw) of drawing.

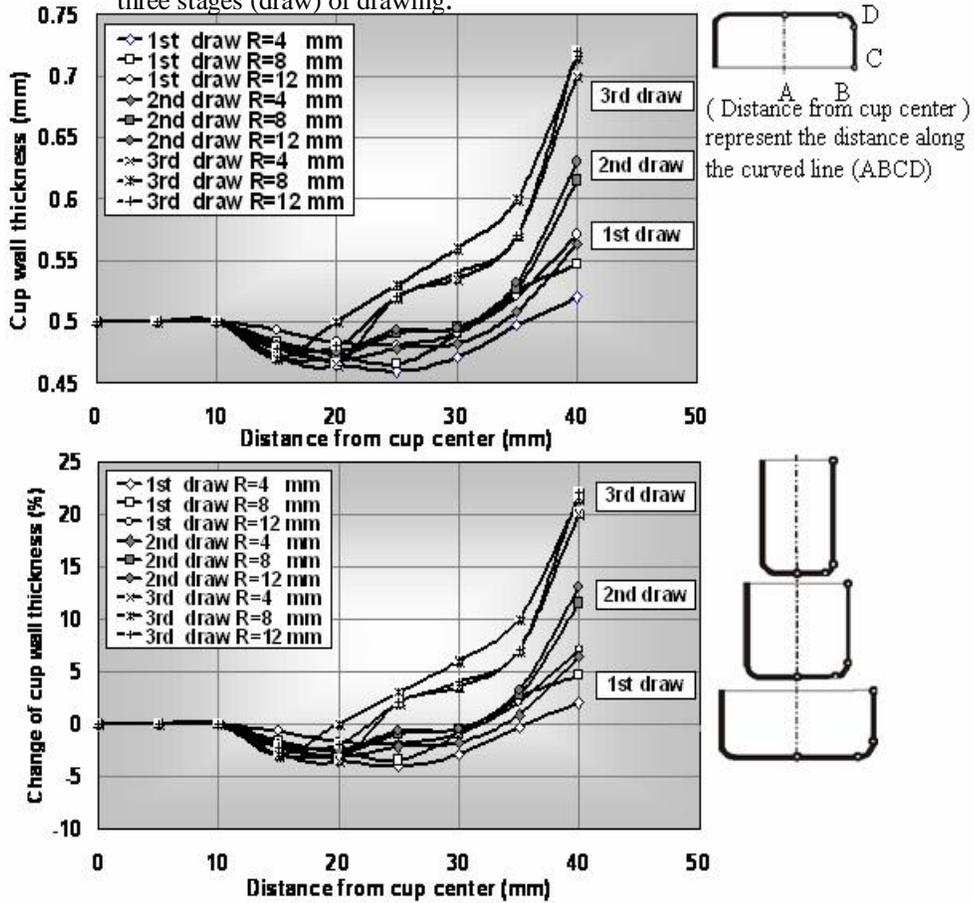


FIG (3 ): The effect of die nose radius on cup wall thickness for the three stages of drawing

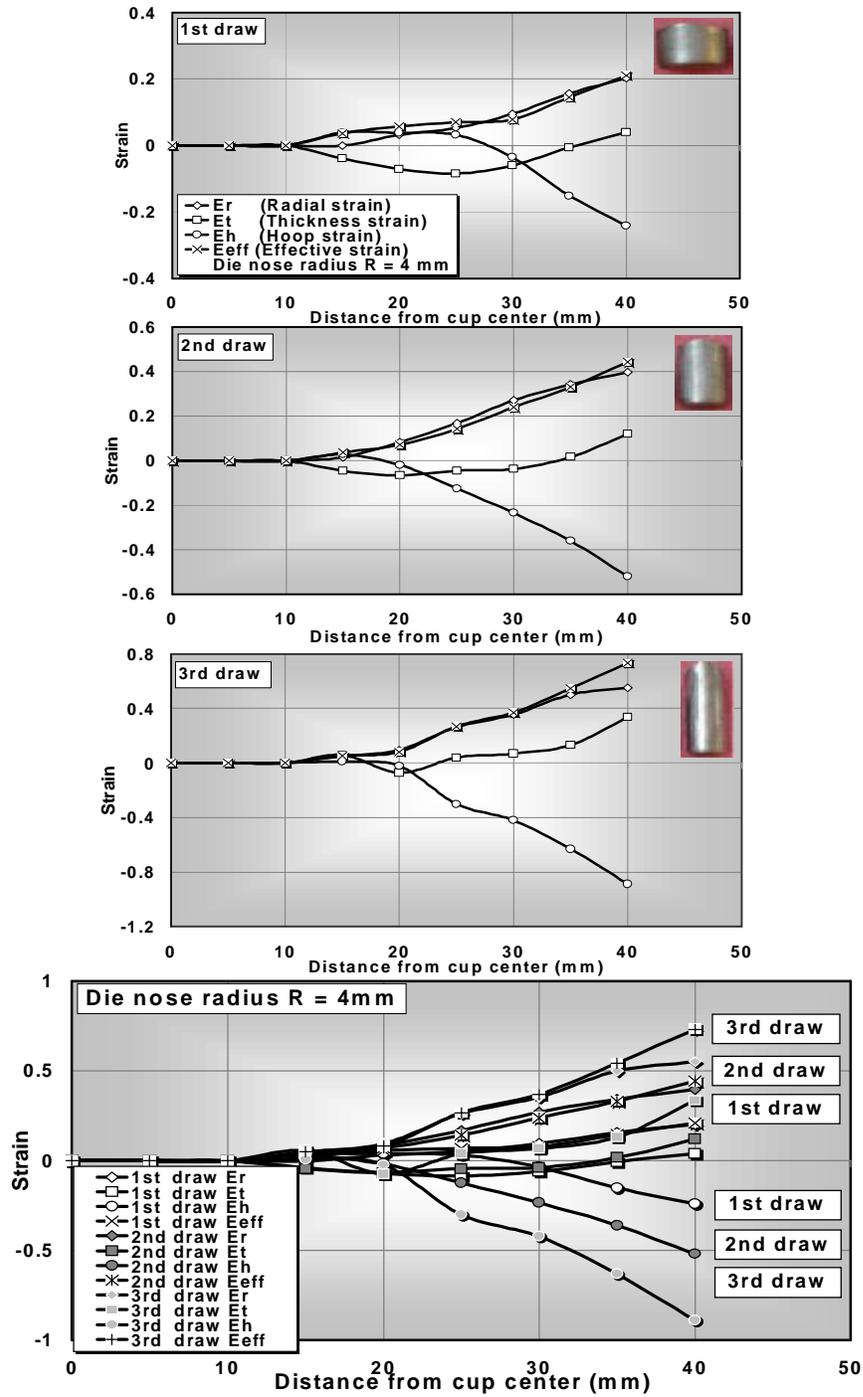


FIG (4) : The effect of drawing stages on strain distribution over the cup wall for various die nose radii

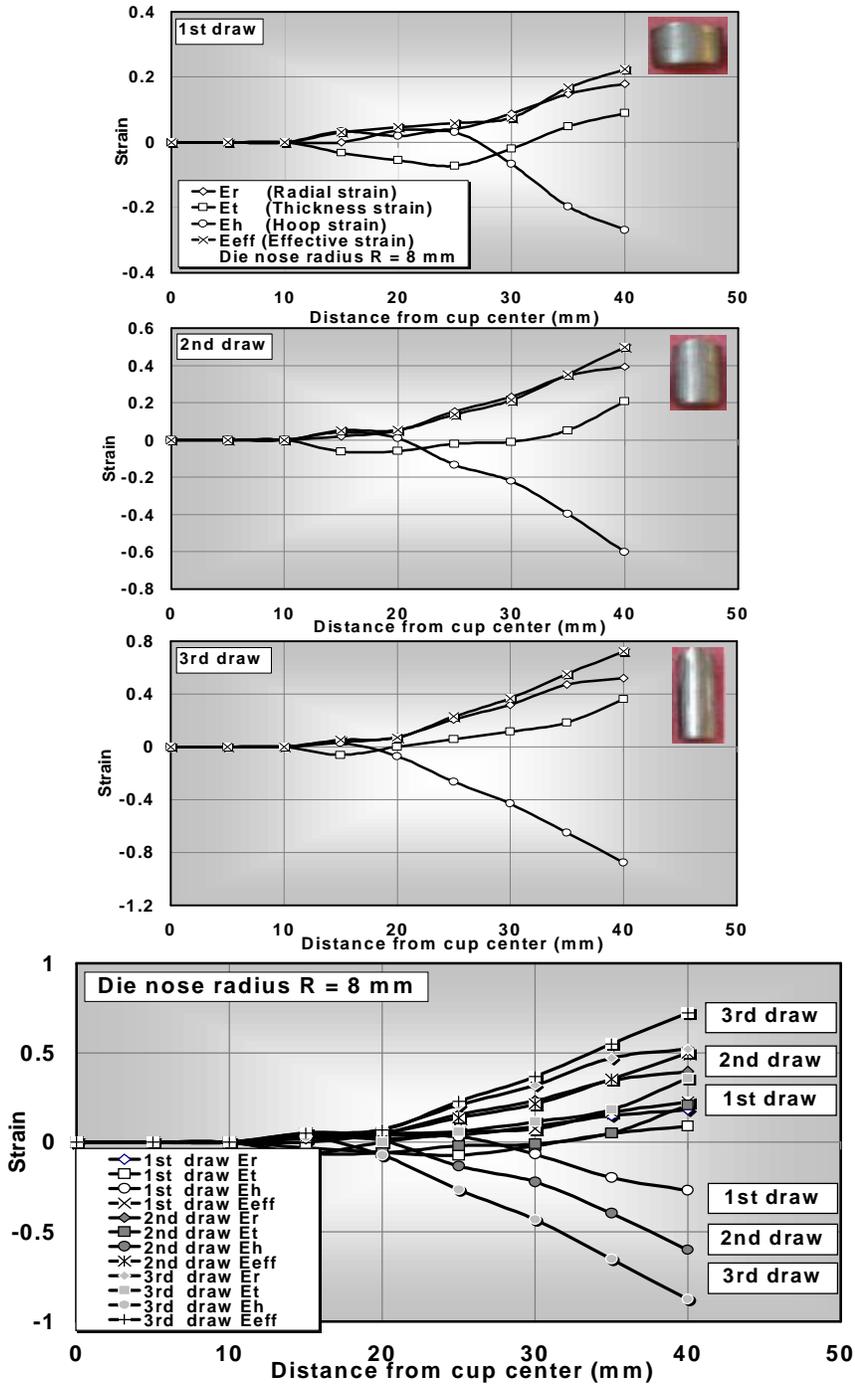


FIG (5): The effect of drawing stages on strain distribution over the cup wall for various die nose radius

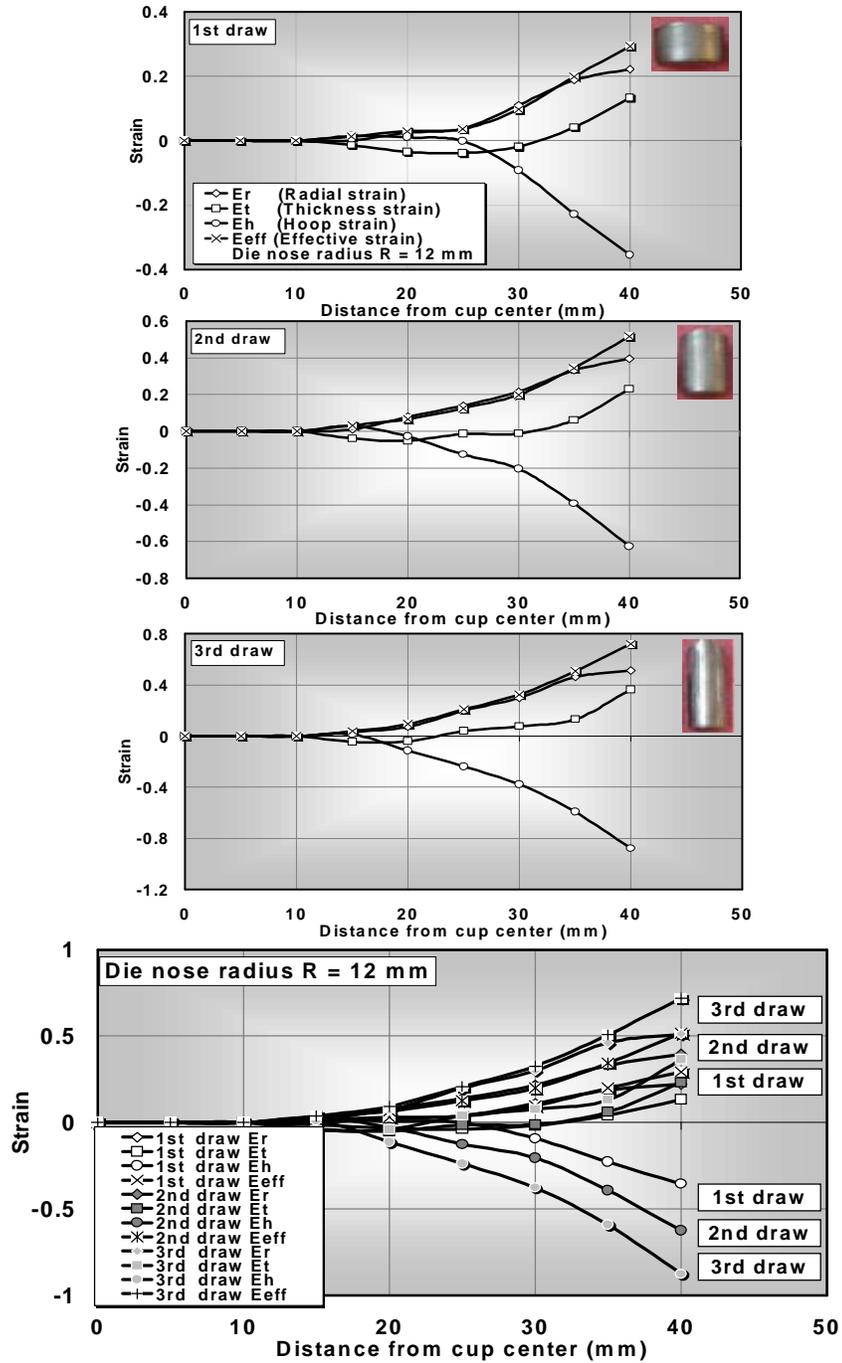


FIG (6): The effect of drawing stages on strain distribution over the cup wall for various die nose radius

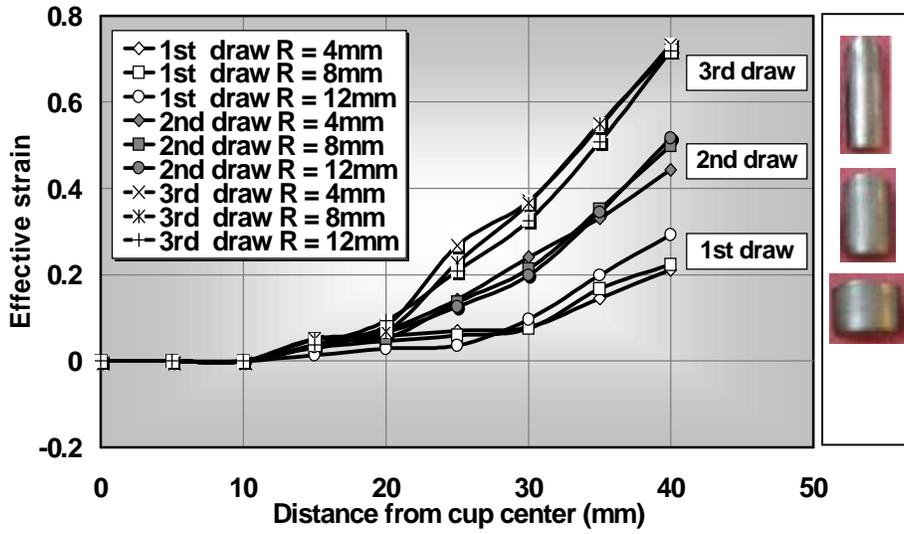


FIG ( 7 ): The effect of drawing stages on effective strain distribution over the cup wall for various die nose radius