Diyala Journal of Engineering Sciences

ISSN 1999-8716

Printed in Iraq

Vol. 02 , No. ٠١ , pp. 80-95 , June 2009

STUDY OF THE STRESS AND STRAIN DISTRIBUTION DURING DEEP DRAWING AND IRONING PROCESS OF METALS WITH A CIRCULAR PROFILED DIE.

Saad Theyyab Faris

Mech. Eng. Dept., College of Eng., University of diyala

(Received:9/9/2008 ; Accepted:22/3/2009)

ABSTRACT - In this study a numerical procedure was proposed for the design of deep drawing process using finite element method (F.E.M) through program code (ANSYS 5.4) simplified 2-D ax symmetric model of cylindrical cup are been developed. This work aims to study the effect of some parameters which influence the drawing process such as: Die geometries, friction coefficient, slight tilt and to predict the tearing failure in drawn part. The combined deep drawing and ironing process analyzed in the manufacturing of thin walled cans; the subsequent stages are pure ironing stages. In the production it was found that it is extremely important that the cup produced in the deep drawing and ironing stage has an even height. The die used was made with a cylindrical die land and detailed FEM-simulations show that an uneven cup height can be caused by a slight tilt of the die and or punch. The result showed that , the increasing the value of friction coefficient from (0.1) leading to increasing the cup height about (3) mm and this leading to predict the tearing failure in drawn part , so Instead of using a die with a cylindrical die land it is suggested to make the die land with a circular profile. FEM-simulations show that if the die made with a circular profiled die land the cup produced is nearly unaffected by a slight tilt of the punch and or die. The FEM-simulations thus strongly indicate that the combined deep drawing and ironing process becomes significantly more robust when the die is made with a circular profiled die land compared with experiment result and when a conventional die design with a cylindrical die land is used.

SYMBOLS DESCRPITION

Ri radius of inlet circular section

Ro radius of outlet

H cup height

Ao area ratio

~ die semi angle

J^* the actual externally supplied power

Vx,Vy,Vz Velocity components in the Cartesian Coordinate system

WI power due to plastic deformation

WE Power due to velocity discontinuity at the die entry shear plane

WF Power due to velocity discontinuity at the die exit shear plane

WS power due to the die surface friction

J Jacobean of the coordinate transformation equation

L length of die which is the distance between the entries and the exit shear planes of die

Pave average pressure on ram

Am friction factor

1. INTRODUCTION

Sheet metal forming is a significant manufacturing process for producing a large variety of automotive parts and aerospace parts as well as consumer products. Deep drawing is a compression-tension forming process involving wide spectrum of operations and flow conditions. With the developments in the technology the design of deep drawing is an art than science still today .It depends on the knowledge and experience of the design engineer only. The selection of various parameters is still based on trial and error methods .In the paper(1) the authors presents a new approach to optimize the geometry parameters of circular components, process parameters such as blank holder pressure and coefficient of friction etc. A finite element analysis simulation software fast form advanced is used for the validations of the results after optimization. Design in sheet metal forming, even after many years of practice, still remains more an art than science. This is due to the large number of parameters involved in deep drawing and their interdependence. These are material properties, machine parameters such as tool and die geometry, work piece geometry and working conditions. Research and development in sheet metal forming processes requires lengthy and expensive prototype testing and experimentation in arriving at a competitive product. The overall quality and performance of the object formed depends on the distribution of strains in the sheet material. Material properties, geometry parameters, machine parameters and process parameters affect the accurate response of the sheet material to mechanical forming of the component. The stretching primarily depends on the limit strains. The limit strains are sensitive to strain distribution.(2,3). The limit strains are described by the concept of forming limit curve. The forming limit represents the onset-localized necking over all possible combinations of strains in the plane of the sheet. Characteristic of process sequence in elliptical deep drawing products was scientifically investigated. The cross-section of the product body, drawing coefficient, punch radius (Rp), and die radius (Rd) considered as main design parameters(4,5).

Production rules that are distinguished from those of rotationally symmetric deep drawing products are given here. Rule, If the cross-section of deep drawing products is constituted a round in the major axis and a straight line in the minor axis, then the product is defined as elliptical deep drawing. The process dealt with in this work is a combined deep drawing and ironing process as shown in Figure (1.) The process is the second stage in an industrial production of thin wall cans in a transfer press. The first stage is a cutting process in which the circular blank is cut from a strip and the subsequent stages are pure ironing processes.; the cans produced in this stage had an uneven can height. The purpose of the investigation was to investigate why the production problems occurred and suggest measures to eliminate the problems. The experience from the production is that it is extremely important that the can produced in the deep drawing and ironing stage has a very even height. If the height varies too much it is not possible to produce a thin wall can successfully. the problems were solved on a trial and error basis. The die was dismounted from the press, polished and remounted and this procedure was repeated until the cup produced had a sufficiently even height. It can then be concluded that the deep drawing and ironing process is extremely sensitive to very small variations in tool geometry and/or finish: the only changes made to the die were accomplished by polishing. Two deep drawn and ironed cups were compared, so the height variation observed on the two cans was below the critical limit. The can height and the wall thickness of the two cans were measured on a coordinate measuring machine.

2. POSSIBLE REASONS FOR THE PRODUCTION PROBLEMS

An ironing process cup be unstable resulting in uneven can height and uneven wall thickness, if the thickness reduction is close to the critical reduction ratio (1,2,3,4,5). The ironing process can also become unstable if the die land is slightly tilted, and it was judged that the most likely reason for the variation in can height in this case could be attributed to a tilt of the die land[6]. The die was, made with a cylindrical die land as shown in Figure (1). If the die land is slightly tilted in relation to the punch contact between cup wall and die land is lost on one side; on the opposite side, a slight tilt will only give rise to minor changes in the contact conditions. The loss of contact between cup wall and die land on one side will reduce horizontal contact force here to zero; on opposite side the contact force remains nearly unaffected. A slight tilt will thus give rise to a net horizontal force on the die, which will try to deflect. The die (or the punch), increasing the reduction ratio where contact is lost and decreasing the reduction ratio on the opposite side. A slight tilt of the die land in relation to the punch may be cause by inaccurate machining, inaccurate mounting and/or alignment of the tools in the press, inaccurate guide ways in the press and/or elastic deformation of the press.

3. THEORETICAL CONSIDERATION

For an isotropic material the principal stresses for plane radial drawing are the radial drawing stress ($\pm_1$) , the stress ($\pm_2$) normal to the blank and the circumferential stress ($\pm_3$) .The stresses will be regarded as positive when tensile , the stress acting on an element in the flange , at current radius (r) and the equation of radial equilibrium is [7,8,9].

$$\frac{d}{dr}(t\pm_1)+\frac{1}{r}(\pm_1-\pm_2)-2\text{«}=0 \qquad \text{----------------------1}$$

The physical conditions show that ($\pm_1$) will be tensile and ($\pm_2$), ($\pm_3$) compressive, corner radius of the punch (R), final thickness of blank (t), original thickness of blank (t_o).

$$\frac{d}{dr}(t\pm)=\frac{t}{r}(\pm_3-\pm) \qquad \text{----------------------2}$$

$$\pm-\pm_3=m\bar{\pm} \qquad \text{----------------------3}$$

$$d\pm=-m\bar{\pm}\frac{dr}{r}-\pm\frac{dt}{t} \qquad \text{----------------------4}$$

$$d\pm=-m\bar{\pm}\frac{dr}{t} \qquad \text{----------------------5}$$

$$\bar{\pm}=\bar{\pm}_o+B(\ln\frac{R}{r})^n \qquad \text{----------------------6}$$

$$\text{®}(R_o^2-R^2)t_o=\text{®}(r_o^2-r^2)tm \qquad \text{----------------------7}$$

$$\left(\frac{R}{r}\right)^2\left(\frac{to}{tm}\right)-1=\left(Ro^2.\frac{to}{tm}-r^2\right)\frac{1}{r^2}=\frac{c}{r^2} \qquad \text{----------------------8}$$

$$\ln\frac{R}{r}=\frac{1}{2}\ln\left\{\frac{tm}{to}\left(1+\frac{c}{r^2}\right)\right\} \qquad \text{----------------------9}$$

$$d\pm=-m\bar{\pm}_o\frac{dr}{r}-mB\left[\frac{1}{2}\ln\left\{\frac{tm}{to}\left(1+\frac{c}{r^2}\right)\right\}\right]^n\frac{dr}{r} \qquad \text{---------------------10}$$

$$\pm=-m\bar{\pm}\ln\frac{r}{ro}-mB\int_{ro}^{r}\left[\frac{1}{2}\ln\left\{\frac{tm}{to}\left(1+\frac{c}{r^2}\right)\right\}\right]^n\frac{dr}{r} \qquad \text{---------------------11}$$

If values of (± &±̇) are substituted in to equation (11) it is possible to trace the thickness changes of any particular element of metal at initial (R) By numerical integration, provided that the relation between (r) and (r_o) is known .

This relation may be derived from the equation of incompressibility

$$\left(r_o^{\,2} - r^2\right)\frac{tm}{to} = (R_o^2 - R^2) = cons\tan t = C \qquad \text{---------------------12}$$

$$r = \left(r_o^2 - C.\frac{to}{tm}\right)^{1/2} \qquad \text{---------------------13}$$

Where (tm) is the current mean thickness of metal between the rim radius (ro) and any radius (r)

4. APPLICATION, RESULTS AND DISCUSSION

4.1. FEM Simulations of the Deep Drawing and Ironing Process

In order to investigate if a slight tilt of the die land cup give rise to a cup height variation), the deep drawing and ironing process was simulated using the FEM through program code (ANSYS 5.4) . In Figure (3) is shown the FEM model. The model was due to symmetry made as a half model. All tool elements were modeled using rigid shell elements, and the blank was modeled with solid elements (four elements in the thickness direction, total number of solid elements: 30656).The blank material was modeled as elastic-plastic. Coulomb friction was assumed in all contact interfaces with the friction coefficient (μ = 0.1). The die and the blank holder were completely constrained. The punch, which was slightly tilted in relation to the die (tilt angle 0.4 degree), was prescribed a displacement in vertical direction and was free to move in the horizontal direction. The sheet material used in experimental work was annealed mild steel of 0.5 % carbon with sheet thickness of (to = 0.5 mm) , in order to select the optimum tool geometries , three types of punches with (p = 3,6,9 mm) corner radius and six types of dies with (d = 2,3,4,6,8,10 mm) corner radius have been chosen to study their effects on the drawing process . punch speed of (300 mm / min), the maximum punch displacement was set at (40 mm) In order to be able to simulate the effect of a slight tilt of the punch it is extremely important to have very little node penetration in the cup wall-die land interface. Most of the Contact (48 2D) Node -to-Surface Contact Element are penalty based. With a penalty based contact algorithm it is impossible to avoid node penetration if there is contact. The amount of node penetration can be limited by adjusting the penalty stiffness. However it was not possible to obtain reliably results using a penalty based contact algorithm. Instead a constraint based contact algorithm was used, and with this algorithm node penetration was nearly completely avoided. In Figure (4,5) are shown the equivalent strain distribution in the deep drawn and ironed cup with the cylindrical die land from this Figure it can be seen that a slight tilt of the punch does give rise to an uneven cup height and an uneven strain distribution. Figure (6,7) are shown the equivalent plastic strain distribution in the deep drawn and ironed cup with the circular die land ,its clear that initial blank thickness at the region of a flat bottom face of the punch does not change , This is because the flat face of the punch is in contact with blank and with drawing force , friction comes in to play which prevents any deformation of the metal under the punch hence, In Figure (8) is shown the cup wall thickness as function of the angle to the rolling direction and with the distance from the inside bottom as parameter. In (2 mm) can height the wall thickness is largest in a direction close to the rolling direction, whereas from (4 to 12 mm) the thickness is smallest in this direction. The thickness distributions shown in Figure (8) could indicate that the punch initially had been displaced slightly off centre and that during the deep drawing and ironing, the punch had been pushed in the opposite direction. According to the craftsmen on the shop floor it was sometimes possible to improve the can height distribution by slightly offsetting the punch. It can thus be concluded that it may be possible to produce a can with an even height but without having an even wall thickness and it is thus questionable if evenness of the cup height can be used as a quality measure. This because, in the opinion of the author, it is more important for the subsequent ironing stages to have an even can wall thickness in the circumferential direction than to have an even can height.

There is no thickness change observed at region . At the punch corner there is a small tension which causes thinning of thickness and afterward it become compression in which causes thickening of the cup wail . the measured values of the thickness are close to the theoretical values obtained by simulation and direct comparison between figure (9) and Figure (11) the effect of the circular profiled die land radius on can wall thickness is gives the best results for design than effect of the cylindrical profiled die land radius on can wall thickness when the tilt angle between die and punch: 0.4 degree and coefficient of friction = 0.1 .Direct comparison between the FEM results in previous research[(10)] and the experimentally measured height distribution and, is not possible because the FEM simulation was carried out with rigid tools, but quantitatively the agreement is good. The FEM simulation clearly shows that the uneven can height can be caused by a slight tilt of the die land in relation to the punch.

4.2. Results & Measures to the Instability

A very simple way to reduce the effect, which a slight tilt of the die land in relation to the punch has on the contact conditions between die lands and cup wall, is to make the geometry of the die land in such a way that a slight tilt only gives rise to minor changes in the contact conditions. This can be accomplished by making the die land circular profiled instead of cylindrical (which is the common practice). FEM simulations of the deep drawing and ironing carried out with a circular profiled die land were carried out. Besides from the geometry of the die land, the FEM-model used was identical to the FEM model used to simulate the deep drawing and ironing carried out with the conventional die with the cylindrical die land. Figure (6) is shown the equivalent strain distribution in the deep drawn and ironed cup. Also it can be seen that the cup has a nearly even cup height and that the strain distribution is nearly even in the circumferential direction. By comparing the equivalent strain distributions and the cup height shown in Figure(4) and (6) it is obvious that the can quality is improved significantly when the deep drawing and ironing is carried out with the circular profiled die land compared to when carried out with the cylindrical die land. With the circular profiled die land is employed the cup quality (thickness of cup wall and cup height) is nearly unaffected by a slight tilt of the die land in relation to the punch.

Figure (11,12) The simulation result provides large stress and strain values at the center of the cup, because it does not have bending resistance at the punch shoulder .The effect of punch stroke on the effective stress and effective strain distribution over the cup wall it seen that the more uniform distribution the more reasonable values of stress and strain are for the value of friction = 0.1

5. CONCLUSIONS

1. The FEM simulations show that when the deep drawing and ironing is carried out with a conventional cylindrical die land, a slight tilt of the die land in relation to the punch can give rise to variations in the can wall thickness and in the cup height.
2. The FEM results are in good qualitative agreement with the experimental findings. To improve the robustness of the deep drawing and ironing process it is suggested to make the die with a circular profiled die land in place of the cylindrical die land,

because by making the die land circular profiled, a slight tilt of the die will only give rise to minor changes in the contact conditions in the die land – can wall interface.

3. FEM simulations show that the cup quality (cup wall thickness and can height) is nearly unaffected by a slight tilt of the die in relation to the punch when the die is made with a circular profiled die land in place of the cylindrical die land.
4. The FEM simulations thus strongly indicate that the deep drawing and ironing process becomes significantly more robust when carried out with a circular profiled die land.
5. The industrial experience and the FEM simulations show that the deep drawing and ironing process is extremely sensitive to small changes in the geometry of the die land when the die is made with a cylindrical die land. A likely explanation why a die with a cylindrical die land can be made to work just by polishing is that the polishing unintentionally makes the die land slightly profiled.

REFERENCES

1. J.Danckert, Ironing of thin walled cans, Annalsof theCIRP,Vol.50/1 (2001) pp165-168
2. Date P.P."Sheet Metal Formability" Proceedings of the training program of sheet metal forming research association at Indian Institute of Technology, Mumbai, 2005.
3. J. Danckert, the Influence from the Die Land on the Stability of the Ironing Process,In: Proc.NUMISHEET. Kim, (2002) pp115-120
4. S. A. Majlessi and D. Lee. "Deep Drawing of Square-Shaped Sheet Metal, Part 2 :experimental study," J. Eng. for Industry, Vol. 115, pp. 110-117, (1993).
5. M. M. Moshksar and A. Zamanian, "Optimization of the tool geometry in the deep Drawing of Aluminum," J. Mats. Proc. Tech., Vol. 72, pp.363-370, (1997).
6. J. Danckert, Ironing of thin walled cans: The use of FEM to Identify and Solve Production Problems, In: Proc.Complas VII, D.R.J. E Onate, B.Suarez (2003) p.136.
7. W.Johnson & P.B.Mellor "Engineering Plasticity" Van Nostrand Rinhold Company Ltd .London (1980), pp, (292-315).
8. John Bird "Higher Engineering Mathematics "fifth edition (2006)published by Elsevier Ltd , Great Britain .
9. T.Z.Blazynski "Plasticity and Modern Metal Frming Technology" Elsevier Applied Sience , London andNew York (1989) pp(208-240).

10. N.Iwata & M.Goth " Finite Element Simulation of Deformation and Breakage in Sheet Metal Forming an Elastic-Plastic Analysis of Square –Cup Drawing Process " JSME International Journal series A , Vol 38 , No.2 .1998 p p, 289 -295.

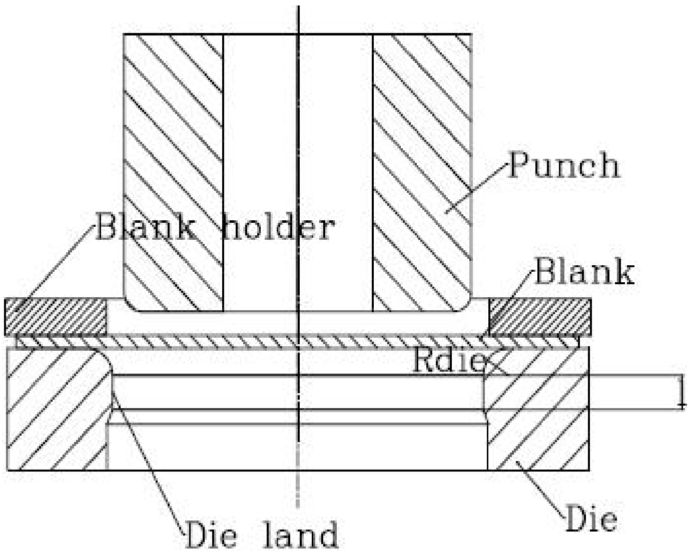

Fig. (1): Sketch 0f the deep drawing and ironing process.

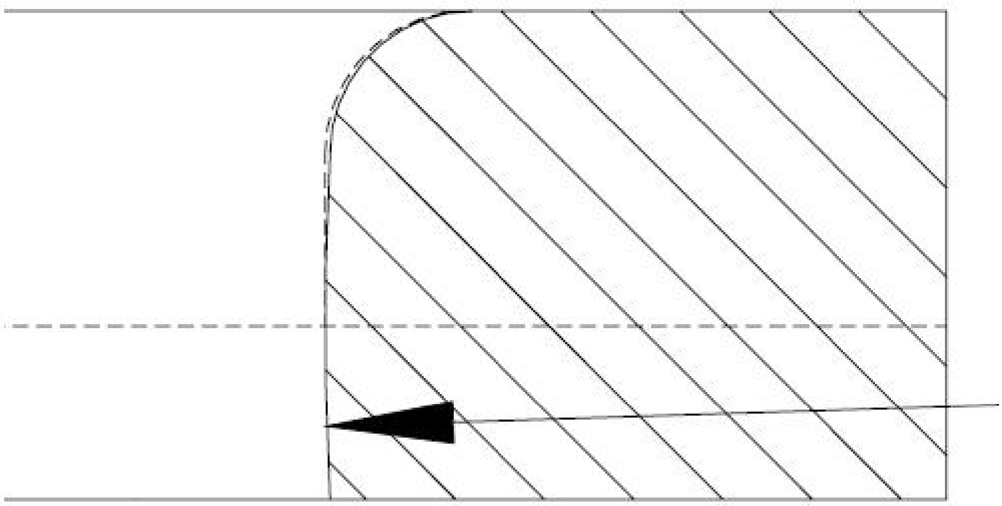

Fig. (2):the circular profiled die land (full line) shown together with the cylindrical die land (dashed line)

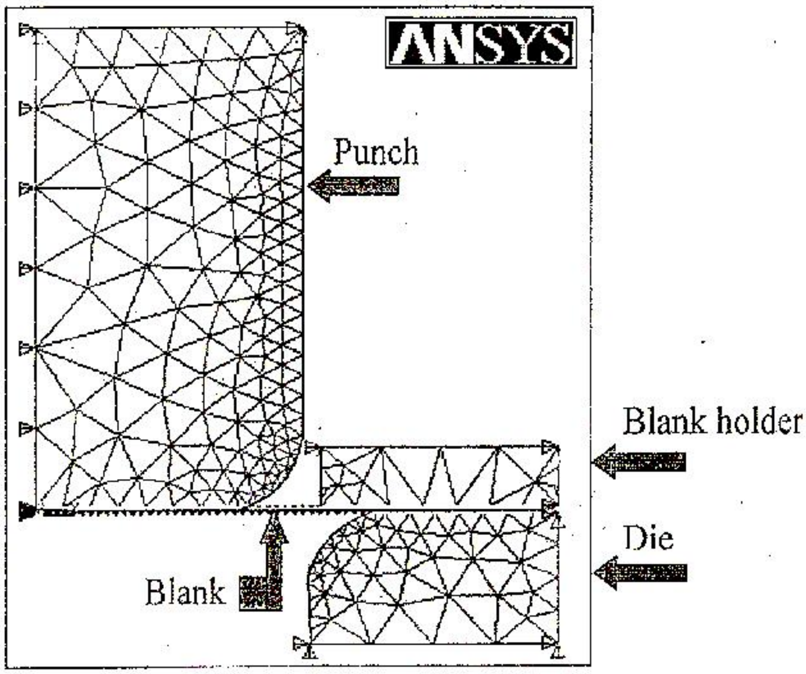

Fig. (3): FEM model of the deep drawing and ironing process. (MESH)

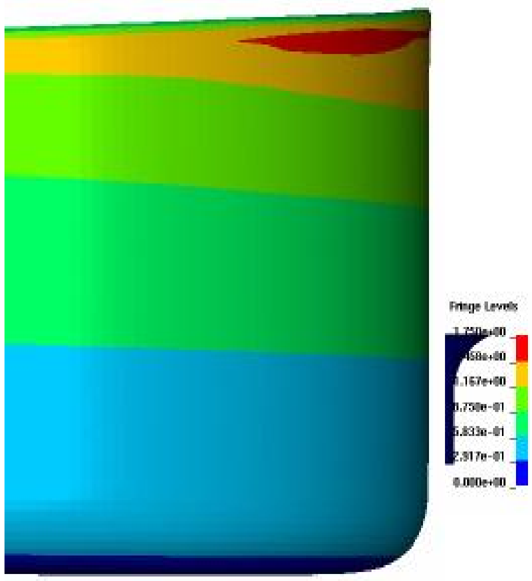

Fig. (4): Right half cup with the cylindrical die land. The contours show the equivalent plastic strain distribution. Tilt angle between die and punch: 0.4 degree

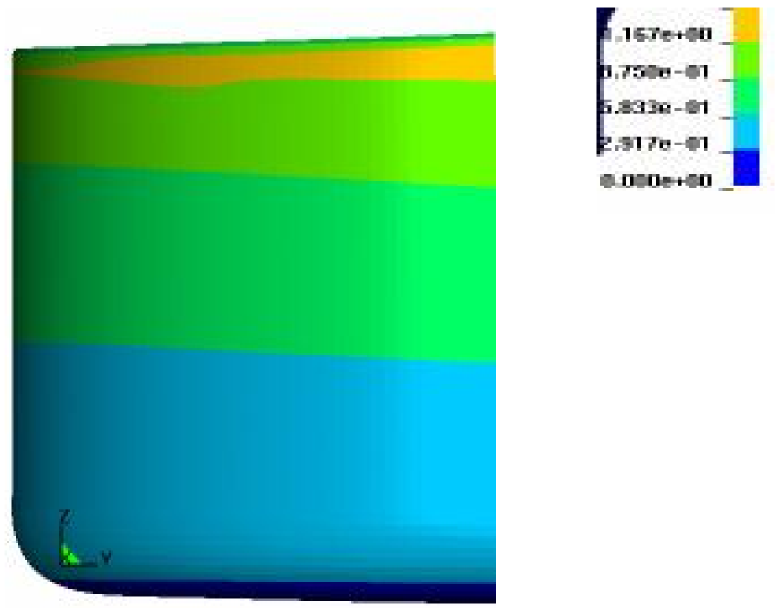

Fig. (5): Left half cup with the cylindrical die land. The contours show the Equivalent plastic strain distribution. Tilt angle between die and punch: 0.4 degree

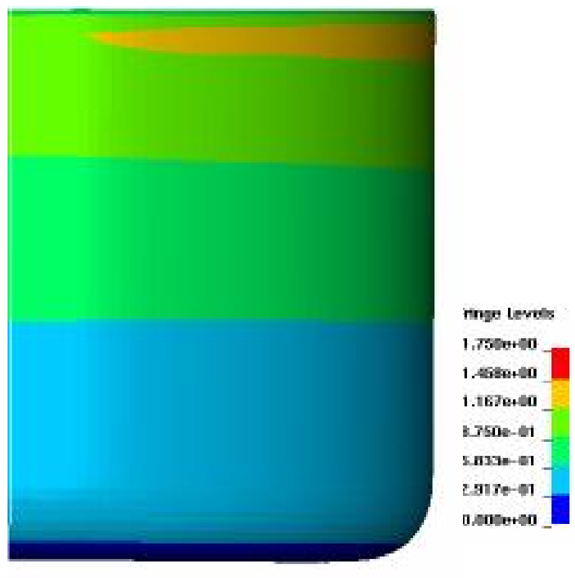

Fig. (6): Right half cup with the circular profiled die land, show the equivalent plastic strain distribution. Tilt angle between die and punch: 0.4 degree

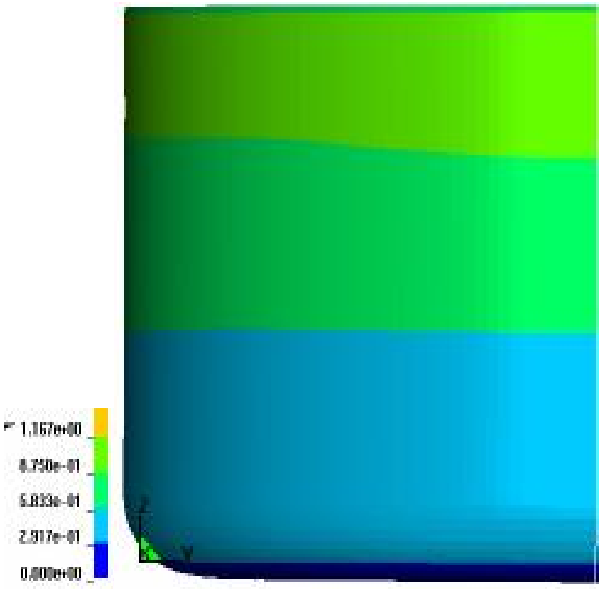

Fig. (7): Left half cup with the circular profiled die land, show the equivalent plastic strain distribution. Tilt angle between die and punch: 0.4 degree

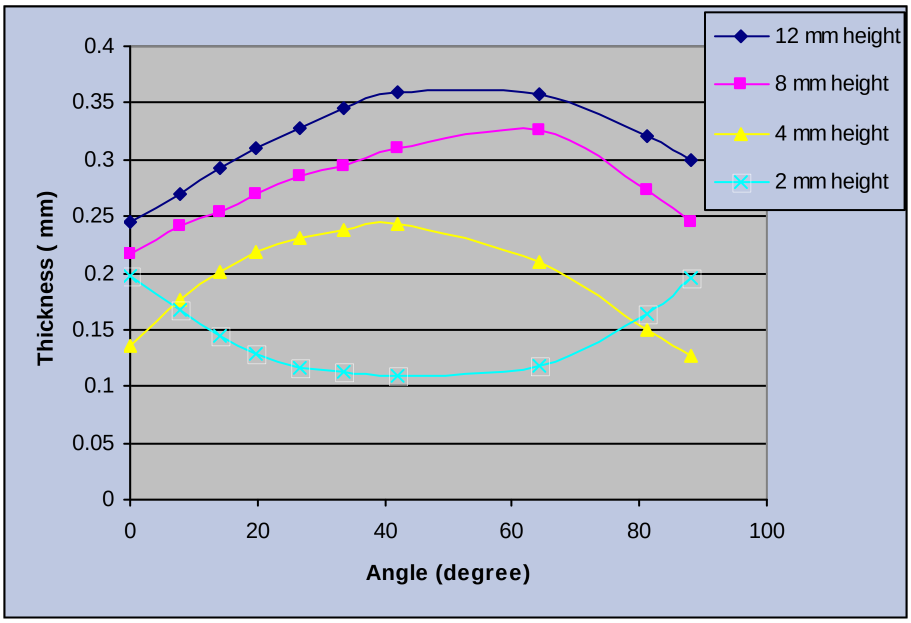

Fig. (8): Cup wall thickness as function of the angle and with the distance from the inside bottom as parameter.

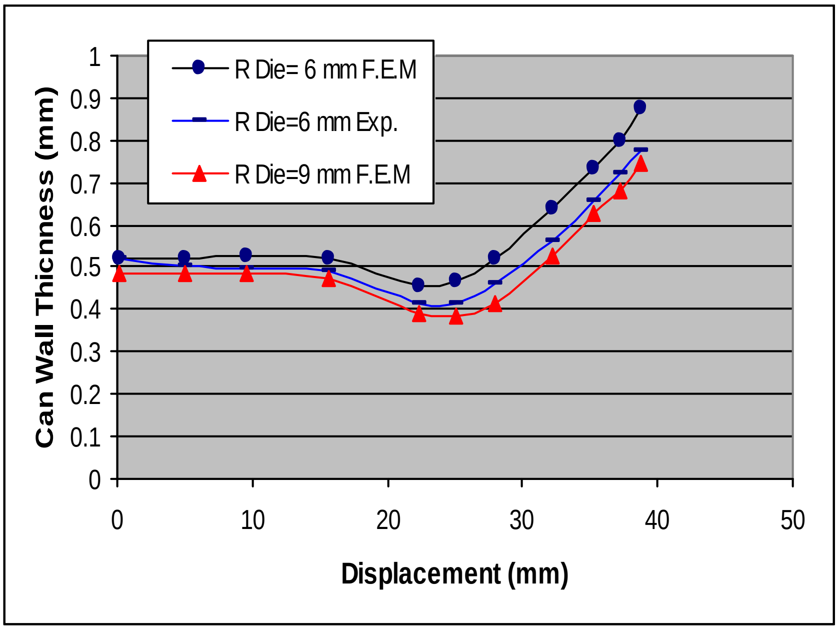

Fig. (9): the effect of the cylindrical profiled die land radius on cup wall thickness

Tilt angle between die and punch: 0.4 degree and coefficient of friction = 0.1

(Comparison of F.E.M & Experiment)

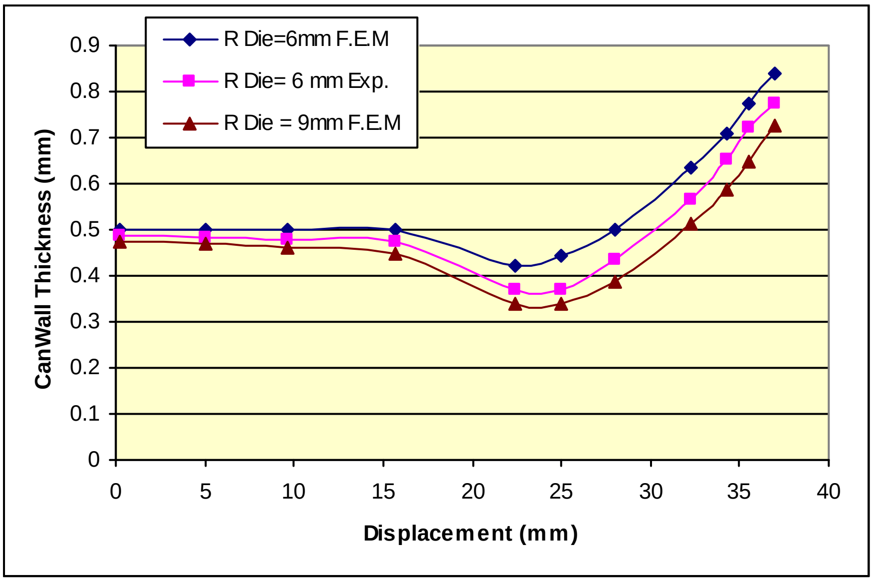

Fig. (10): the effect of the circular profiled die land radius on cup wall thickness.

Tilt angle between die and punch: 0.4 degree and coefficient of friction = 0.1

(Comparison of F.E.M & Experiment)

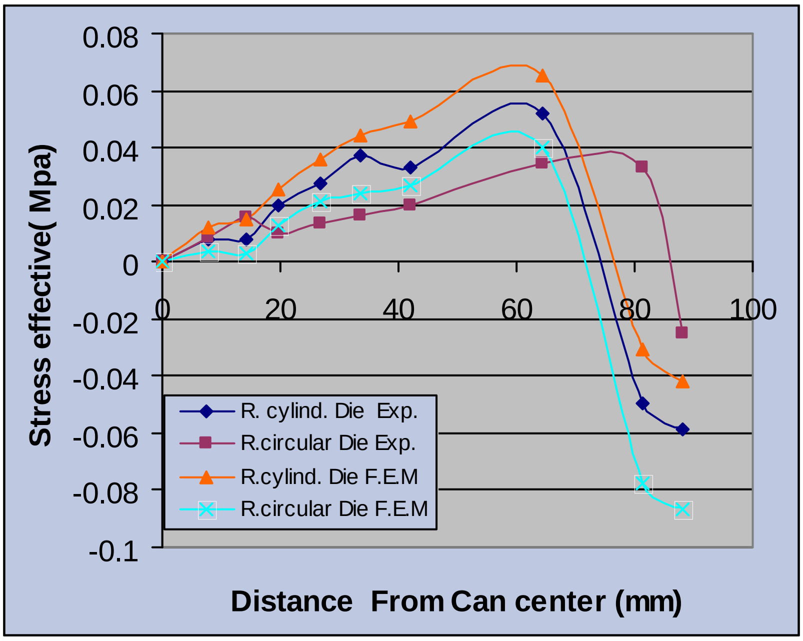

Fig. (11): the effect of punch stroke on effective stress distribution over the cup wall.

Coefficient of friction = 0.1 (Comparison of F.E.M & Experiment)

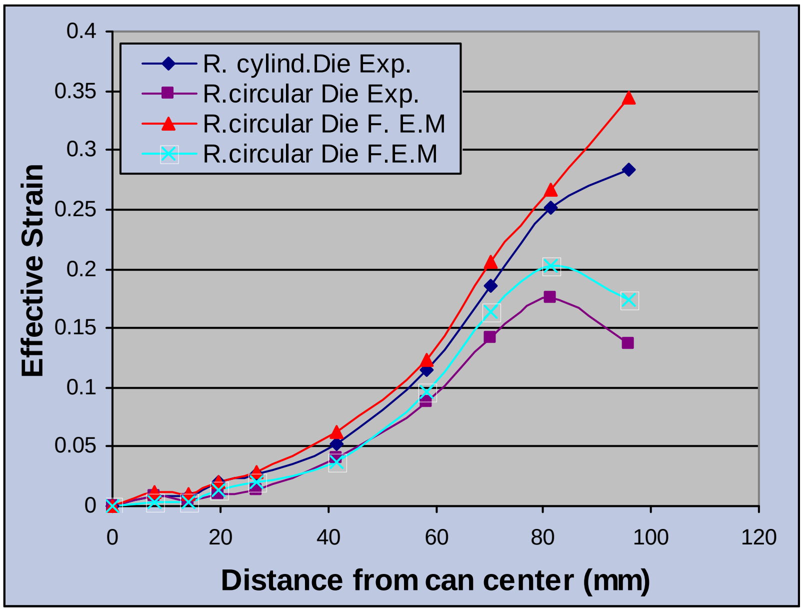

Fig. (12): the effect of punch stroke on effective strain distribution over the cup wall, Coefficient of friction = 0.1 (Comparison of F.E.M & Experiment)

دراسة توزيع الاجهادات والانفعالات خلال عملية السحب العميق والتسطيح للمعادن بقالب دائري المقطع

د. سعد ذياب فارس

مدرس

كلية الهندسة – جامعة ديالى

الخلاصة :

في هذه الدراسة تم افتراض إجراءات لتصميم عملية السحب العميق بطريقة العناصر المحددة (F.E.M) من خلال برنامج (Ansys5.4) وتطوير موديل متماثل ثنائي الأبعاد لوعاء اسطواني المقطع.والهدف من هذا العمل هو لدراسة تأثير بعض العوامل المهمة التي تؤثر بصورة مباشرة على عملية السحب العميق مثل الشكل الهندسي للقالب،معامل الاحتكاك ، الميل الخفيف في مقدار نصف قطر التقوس لحافة القالب والتنبؤ في فشل التمزق في جدار الجزء المسحوب.

تم تحليل المزج بين عملية السحب العميق والتسطيح أو العصر في تصنيع أوعية نحيفة الجدران والمرحلة اللاحقة هي تسطيح تام للجدار حيث انه وجد في الإنتاج إن الأهمية القصوى للوعاء المنتج بالسحب العميق والتسطيح هو

الارتفاع المتساوي لجدار القالب المستخدم والمصمم بنصف قطر التقوس لحافة القالب بشكل اسطواني و اسلوب المحاكاة بين إن الارتفاع غير المتساوي لجدار الوعاء بسبب الميل الخفيف للقالب والمخرم ، لذا بدلا من استخدام قالب بنصف قطر تقوس لحافة القالب بشكل اسطواني تم اقتراح صنع قالب بنصف قطر لحافة التقوس بشكل دائري والنتائج بينت ان زيادة قيمة معامل الاحتكاك عن 0.1 يقود إلى زيادة ارتفاع جدار الوعاء حوالي 3 ملم وبالتالي يؤدي إلى بداية الفشل بالتمزق للجزء المسحوب . المحاكاة أشرت وبتمييز بان المزج بين عملية السحب العميق والتسطيح أصبحت الأكثر أهمية ورصانة عندما يكون نصف قطر التقوس لحافة القالب بشكل دائري عند مقارنتها بنتائج القالب بشكل اسطواني .