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STUDY THE SYMMETRIC- PLASTIC DEFORMATION MECHANISM OF CIRCULAR SHEETS IN CYLINDRICAL DIE

Sameer Dawood Ali
Assit.Lecturer
Engineering College / Diyala University
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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 11) simplified 2-D ax symmetric model of conical cup are been developed. This research thoroughly investigates the axsymmetric deformation mechanism to evaluating the formability of sheet metals and to study the effect of some parameters which influence the drawing process such as: Die geometries, friction coefficient, It reveals how plastic regions in a work piece appear and spread and how they vary with punch diameter and also shows the distributions of strains , internal forces and proposes approximate model for engineers than analyses the deformation of such work pieces and evaluate the formability of metal materials. The prediction of the plastic wrinkling of a sheet during forming operation in the experimental study is a good agreement with the present numerical analyses are carried out for work pieces of thicknesses 1.5 mm and 2 mm with diameters 120 mm and 150 mm respectively, The diameters of cylindrical punches are 45 mm and 65 mm respectively, using Ansys 11 program which was recently developed and has good prospects for engineering applications.

1. NOTATION

b initial radius of work piece
E Young's modulus
G shear modulus
h thickness of sheet
h^* work hardening modulus
q external load
R residual vector
Y initial yield stress
ε strain
θ semi angle of conical die
μ friction coefficient
γ poisons ratio σ stress

2. INTRODUCTION

It is important for production engineers carrying out sheet metal forming processes to select sheet materials appropriately and to design forming tools successfully, assuring both the required final shapes and the claimed service properties of their work pieces .However, it is not easy to do so because many factors such as material behavior of the sheet metal forming conditions, formability criterion adopted, etc, need to be considered. Moreover such factors often affect each other, so that one needs to have a comprehensive view for controlling an optimal process from design to operation, obviously, it presupposes an exact understanding of the action of each factor for instance. The effects of punch and die geometries, springback, wrinkling, lubrication and so on .However, there exist many difficulties in investigating these problems, owing to their complicated characters in coupling non- linear ties of geometry and material behavior .In recent years although there have been many advances in the applications of numerical techniques to analyzing the forming processes, very large computation time is required. Reference [1] pointed out that according to their experimental analysis the spring back using a hemispherical punch increased as the radius of the plate decreased , their experiments also showed that a central gap appeared between the plate and the punch at small deflection and disappeared as the plate deflection increased beyond ascertain point .

In references [2,3] investigated experimentally and analytically they gave the experimental relationship between punch travel and force are derived formulae for calculating spring back and wrinkling load on the basis of the assumption that the plate was either elastic or rigid perfectly plastic and that action of the punch was considered as a ring load even in analysis of wrinkling. Study [4, 5] provided the distributions of the surface strains in soft and hard aluminum plates and gave the relationship between punch load and displacement. They also studied the forming load using an approximate but simple analytical method. Their experiments showed that the wrinkling loads of thinner or herded plates were evidently lower than those of thicker or softer ones. In addition, they discussed the strain distribution using the principle of minimum internal work.

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 [6, 7].

Analysis based on Continuum Damage Mechanics (CDM) was carried out to check the necessary conditions for crack initiation ,three damage models were used to verity the experimental results of failure of the processes [8].

The process of forming in the present study can be divided in to three stages. The first is one in which the plate contacts the die only on the plate periphery. Elastic –plastic bending is the main reason for deformation in this stage, but wrinkling may often occur too. The second is the stage when the plate is in contact with the punch and with whole die. The work piece is ironed by the punch and die. The extent of identification of the work pieces with die depends significantly on the shape and number of the wrinkling waves which appear in the first stage, the third is the stage of spring back as the punch is removed. In fact analytical studies carried out in papers mentioned above were limited to the deformation of the first stage because the most representative phenomena of the mechanics of such a forming process as stated above appear in this stage. It's therefore necessary to understand fully the deformation mechanism.

The present study investigates the first stage of deformation of work pieces experimentally and theoretically, as a work pieces in this stage is in contact with the die only on its periphery, some new features of the problems which have not been found by the previous researchers.

3. THEORETICAL CONSIDERATION

Deformation analysis of work pieces in conical cup

Figure (1) show a work pieces in conical cup can be idealized by the model shown, the action of the cylindrical punch is considered as a ring load **P** acting at a radius equal to that of the punch $\mathbf{r}_p$, it is assumed that the friction between the work piece and the conical die is determined by the formula

Friction force = (friction coefficient **μ**) (normal force on die cone)

For an isotropic material the principal stresses for plane radial drawing are the radial drawing stress (σ_1) , the stress (σ_2) normal to the blank and the circumferential stress (σ_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 [9].

$$\frac{d}{dr}(t\sigma_1)+\frac{1}{r}(\sigma_1-\sigma_2)-2\mu=0 \qquad \text{----------------------1}$$

The physical conditions show that (σ_1) will be tensile and (σ_2), (σ_3) compressive, corner radius of the punch (R), final thickness of blank (t), original thickness of blank (t_o).

$$\frac{d}{dr}(t\sigma)=\frac{t}{r}(\sigma_3-\sigma) \qquad \text{--------------------2}$$

$$\sigma-\sigma_3=m\bar{\sigma} \qquad \text{-----------------3}$$

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

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

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

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

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

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

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

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

If values of (σ & $\vec{\sigma}$) 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) ,Where μ was measured experimentally with no lubrication applied, the boundary forces can be expressed as:

$$N_b = -\frac{P r_p(\cos\theta - \mu \sin\theta)}{(b+u_b)(\sin\theta + \mu\cos\theta)} \qquad \text{------------------ (14)}$$

$$M_b = \frac{1}{2} h N_b \qquad \text{-------------------- (15)}$$

4. FINITE ELEMENT ANALYSIS

Using ANSYS-11 the finite –element analysis was simulated by building a model with same as the assumed model in theoretical analysis fig. (1), Both the current experimental study and numerical calculation were carried out for work pieces of the external load (p) and punch displacement (Wp) curves : model 1 for work piece of initial diameter 150 mm , thickness 2 mm ,punch diameter 45 mm and model 2 the sheet thickness 1.5 mm and punch diameter 65mm. The work pieces were made of medium carbon low alloy steel sheet which is considered to be an isotropic material and the average curve is used through the calculation.

To have an environmental effect similar to that of reality and theoretical assumption the model has to be meshed to a specific shape of element according to the chosen element which is solid (plane-82)with 8-node element defined by eight nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The element may be used as a plane element or as an ax symmetric element. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. The sharp directional change of metal flow at the corner of the roll entry is not easily represented by means of small number elements. Because of symmetry one half of the model was first solved later the results showed by symmetry expansion of results. The loading process in ANSYS-11 is employed by applying a horizontal displacement to a work piece at time step according to the flow velocity at different load step option.

The deep drawing process was simulated using the FEM through program code (ANSYS 11). 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 (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. 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.

Table 1 show the chemical composition of medium carbon low Alloy Steel 4130 which is used in the study [10].

Applying the material properties according to given data in table (2) was the most important step before meshing the model to enable the program to apply the equation of finite element which the program built based on it fig.(2).

5. RESULT AND DISCUSSION

Figure(3) is shown the external load (p) and punch displacement (Wp) curves : model 1 for work piece of initial diameter 150 mm , thickness 2 mm ,punch diameter 45 mm and model 2 the sheet thickness 1.5 mm and punch diameter 65mm. It is show the whole processes of loading and un loading of the workpieces, also show that the spring back are slight compared to the case of plate bent to a shape of single curvature.

Figures (4a and 4b) reveal the spread of the plastic regions in the radial section of work pieces. It's found that the plastic regions of two identical work pieces behave differently if subjected to punches with different diameters. For the model 1 the upper plastic region first appears at the central part of the sheet, and then spreads to periphery with unloading at the original part inside the circle of the ring load. However for model 2 the spread and unloading occur before the upper plastic region reaches the central axis. It should be noted that only the sheet elements inside the circle of the ring load undergo a complicated loading and un loading process, while the elements outside the circle are always in a loading state. The distributions of circumferential membrane force $N\theta$ of model 1, model 2 and their variations with external load are shown in figure (4 parts a and b) respectively. The figure indicates that the variation of $N\theta$ in the neighborhood of the circle of the ring load is sharp , and a band of negative value of $N\theta$ exists outside the load circle . This band is the essential factor which causes circumferential wrinkling. It should be noted that the position of maximum negative value of $N\theta$ bend near the periphery. Figure (5) The simulation result provides large stress 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 are for the value of friction = 0.1 ,Figure (6) exhibits the curves of the distribution of radial strain εr and circumferential strain $\varepsilon\theta$ on surfaces confirms that the deformation process can be regarded as one that deforms with large displacements but small strains, because the strains are small except in the very narrow region around the load circle. It is to be expected that the radial strain on z= h/2 positive. However, the fact that positive εr appears on part of the surface z=-h/2 is unexpected .Nonetheless, if one has noted that a work piece in the conical cup test is supported on the periphery of z=h/2 and hence there exists a negative bending moment applied to the boundary, then εr near the periphery on z= -h/2 must indeed be positive. It is easy to imagine that there would be a region of high curvature around the circle of ring load.

According to systematic numerical analyses find that the peak of the latter moves slightly to the periphery as the punch advances. It is very much related to the variation of the radial bending moment Mr .The external load increases to a certain extent, a peak in Mr appears at the position corresponding to that of the later high curvature area. In figure (7) is shown that 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 this figure could indicate that the punch initially had been displaced slightly off centre and that during the deep drawing, the punch had been pushed in the opposite direction. It can thus be concluded that it may be possible to produce a can with an even height but without 110 having an even wall thickness and it is thus questionable if evenness of the cup height can be used as a quality measure.

There is no thickness change observed at region. Figure (8) is shown elastic strain at max displacement 0.4 with the min value = 0.948e-03 and max value = 0.04117 .Figure (9) Non linear stress at min value 28436 and max value 0.124 E+7 . Figure (10) Non linear Plastic Strain with min value = 0.001052 and max value 0.031584 .

Figure (11) stresses in x direction when Mf = 0.1 with min value=-0.504E+09 and max value = 0.504E+09.Figure (12) shows the value of stresses in y direction when Mf = 0.1 with min value=-0.238E+09 and max value = 0.244E+09 .Figure (13) present the value of plastic stress equivalent with min value=3.013 Mps and max value = 630.579 Mps .

Figure (14) Non linear stress at min value 194.274 Mps and max value 0.149E+09 when the Mf = 0.15

6. CONCLUSIONS

1. The FEM through program code (ANSYS 11) is very efficient for solving the highly non – linear problems of sheet metal forming .
2. The evolution of plastic regions in a work piece is closely related to the variation of punch diameter .
3. The movement of the position of maximum negative value of Nθ may affect the plastic wrinkling of the work piece .
4. The deformation process of a work piece can be considered as one that undergoes large displacement with small strains .
5. The approximate analytical model proposed here may prove useful for production engineers.
6. According to systematic numerical analyses find that the peak of the latter moves slightly to the periphery as the punch advances. It is very much related to the variation of the radial bending moment Mr .

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Table(1): Chemical Composition of Medium Carbon Low Alloy Steel 4130.

C	Cr	Mo	Other	
			Mn	Si
0.28 - 0.33	0.8 - 1.1	0.15 - 0.25	0.4 - 0.6	0.2 - 0.35

Table (2): Material Properties Data used in ANSYS 11 Program [11].

E GN /m^2	G GN /M^2	σ_y MN/m^2	τ MN/m^2	Tensile Strength MN/m^2	Ultimate Shear Strength MN/m^2	Density
207	80	280	175	480	350	7800

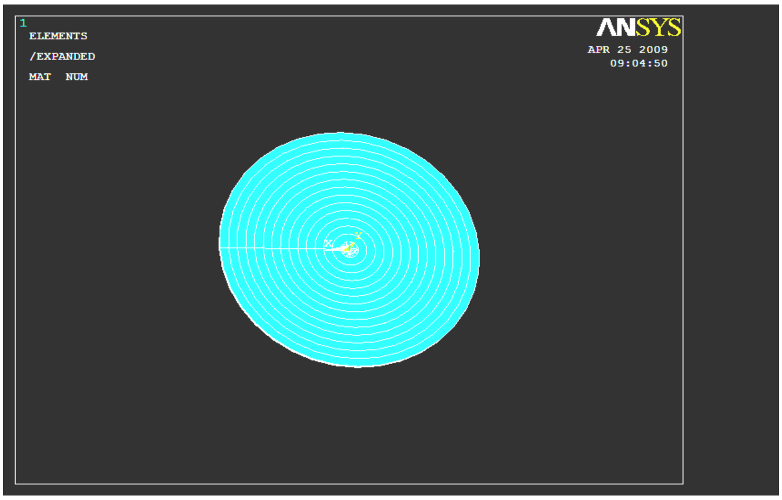

Fig.(1): the geometry of sheet material (mesh).

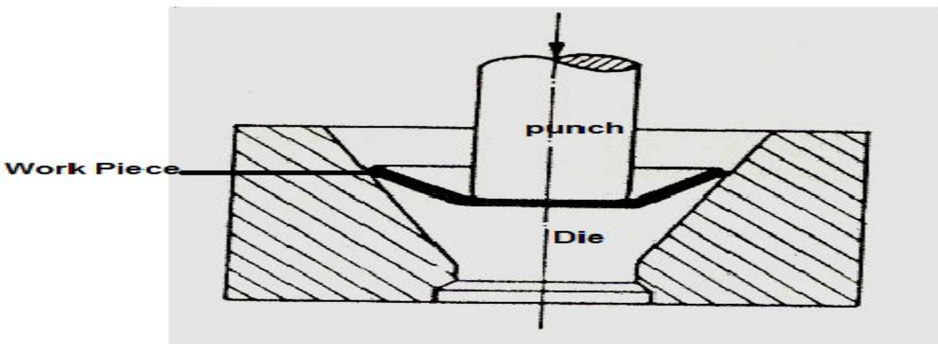

Fig.(2): Schematic diagram of the conical cup .

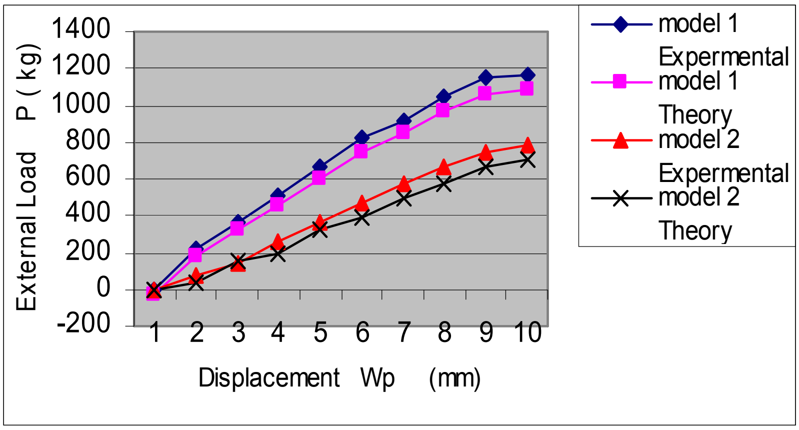

Fig.(3): External load (p) and punch displacement (Wp) curves : model 1 for work piece of initial diameter 150 mm , thickness 2 mm ,punch diameter 45 mm and model 2 the sheet thickness 1.5 mm and punch diameter 65mm.

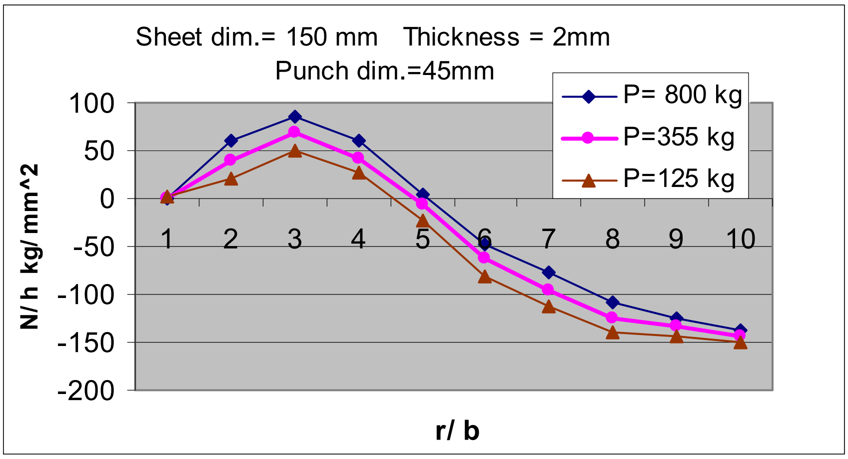

Fig.(4a): Distribution of circumferential membrane forces Nθ for model 1 (Sheet dim. =150mm, Thickness of sheet = 2mm. Punch dim= 45m).

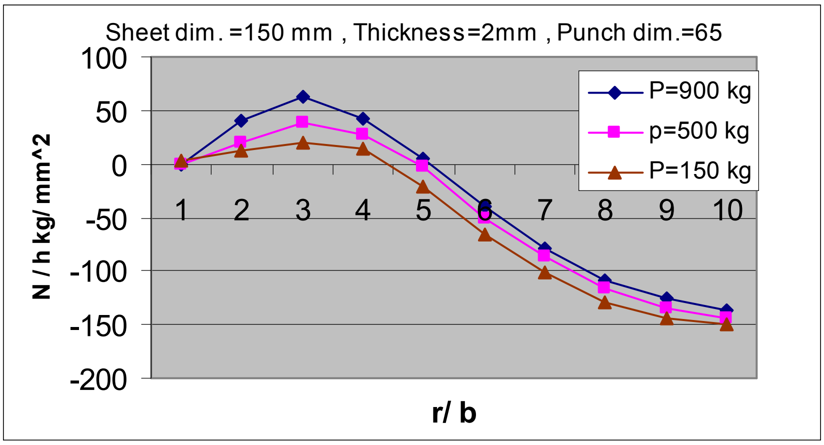

Fig.(4b): Distribution of circumferential membrane forces Nθ for model 2 (Sheet dim. =150mm, Thickness of sheet = 2mm. Punch dim= 65m).

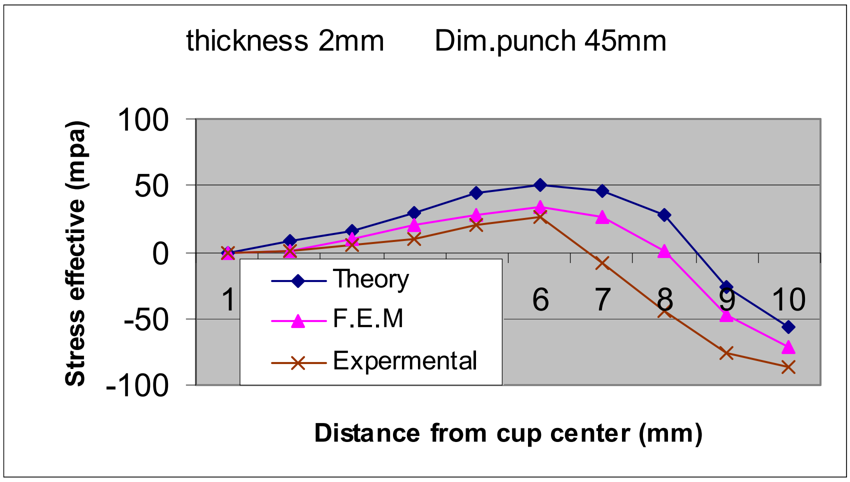

Fig.(5): the effect of punch stroke on effective stress distribution Comparison of theory result, F.E.M and Experiment.

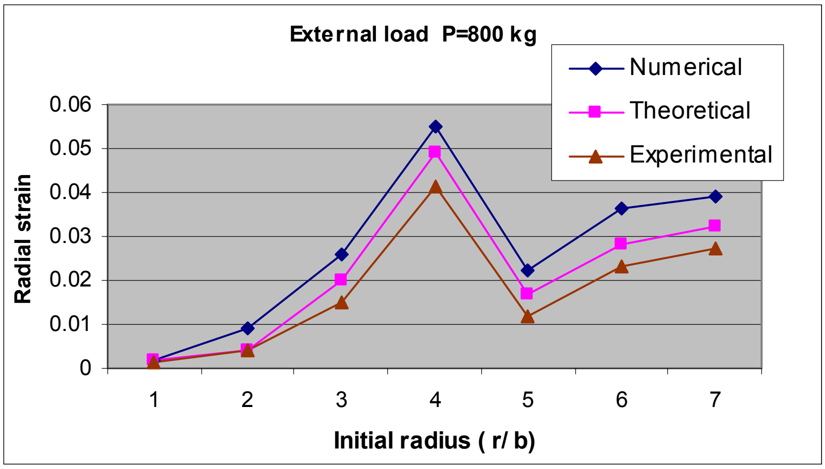

Fig.(6a): Distributions of radial strain on initial radius of sheet when the external load equal 800 kg comparison of theory result, F.E.M and Experiment.

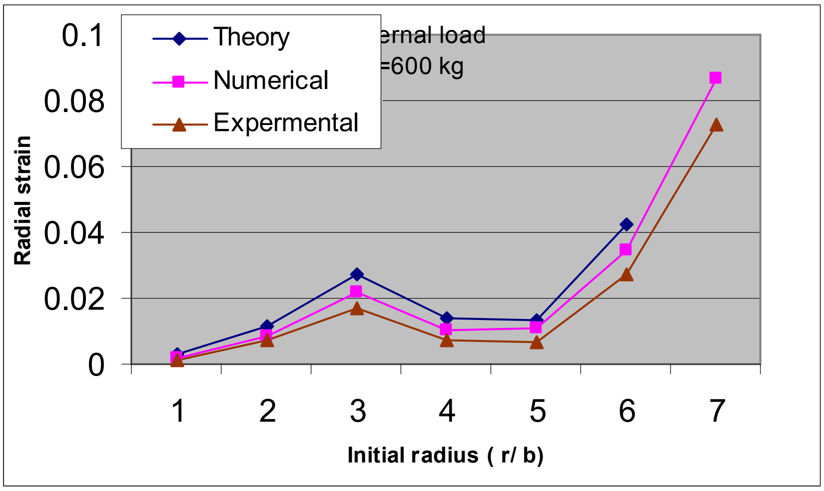

Fig.(6b): Distributions of radial strain on initial radius of sheet when the external load equal 600 kg comparison of theory result, F.E.M and Experiment.

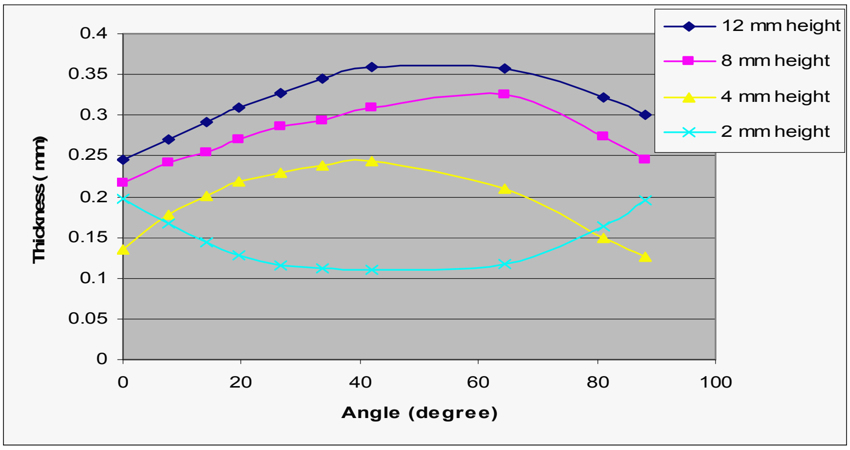

Fig.(7): Cup wall thickness as function of the angle and with the distance from the inside bottom as parameter.

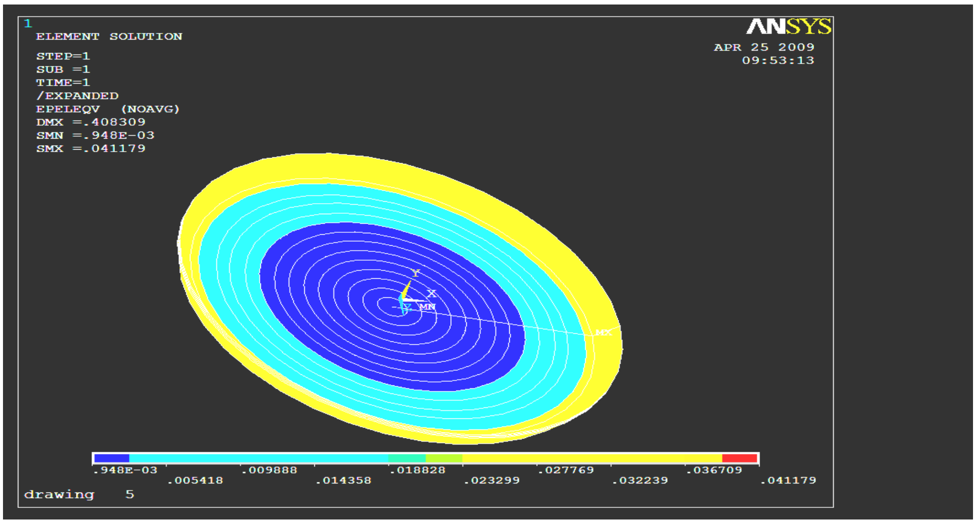

Fig.(8): Elastic Strain at max displacement 0.4 show the min value = 0.948e-03 and max value = 0.04117.

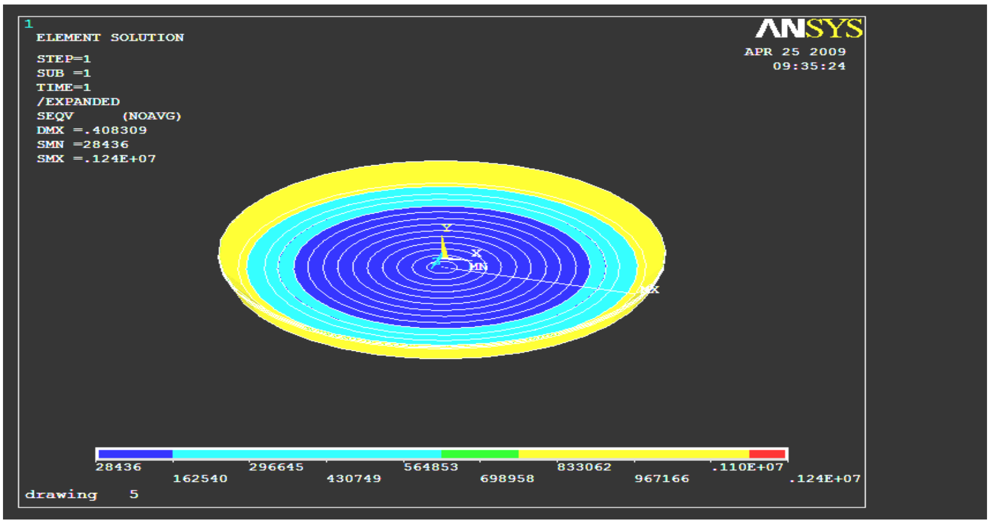

Fig.(9): Non linear stress at min value 28436 and max value 0.124 E+7 when Mf=0.1.

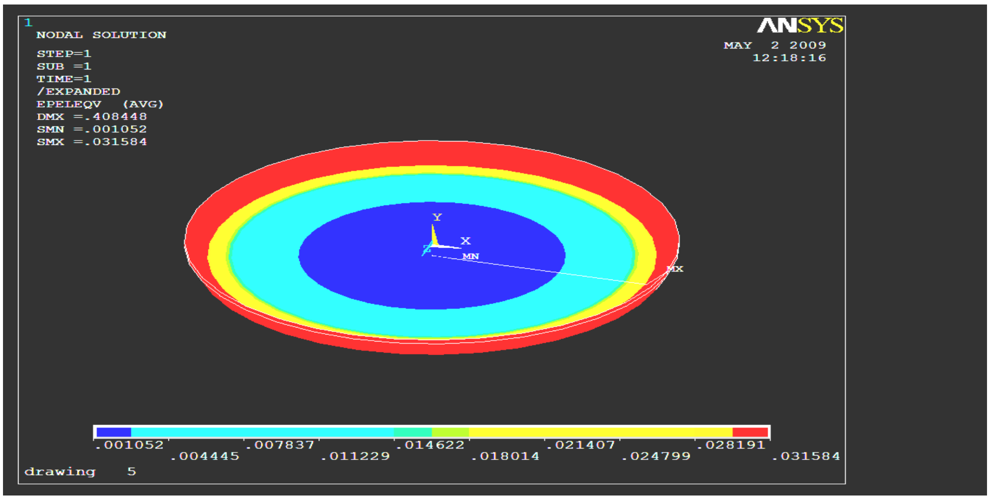

Fig.(10): Non linear plastic strain with min value = 0.001052 and max value 0.031584.

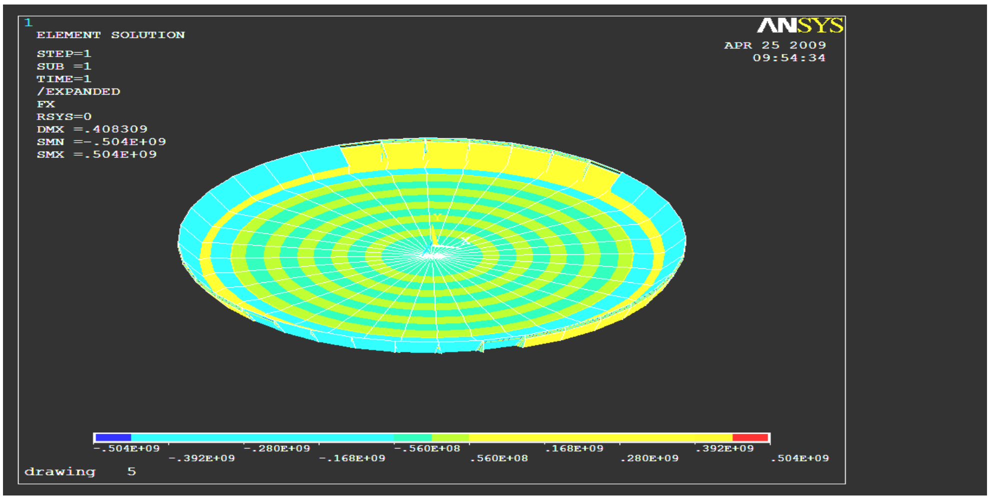

Fig.(11): the value of stresses in x direction when Mf = 0.1 with min value=-0.504E+09 and max value = 0.504E+09.

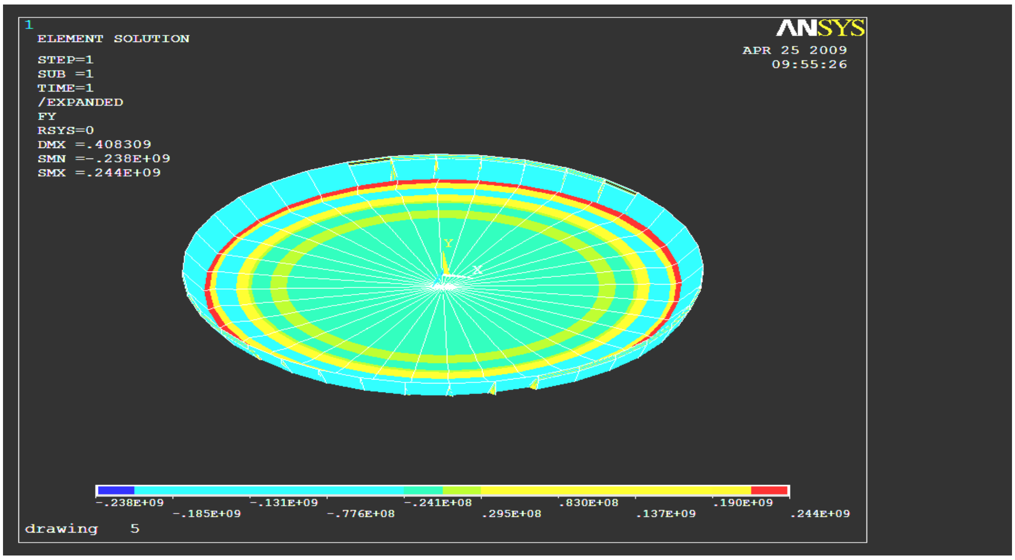

Fig.(12): the value of stresses in y direction when Mf = 0.1 with min value=-0.238E+09 and max value = 0.244E+09.

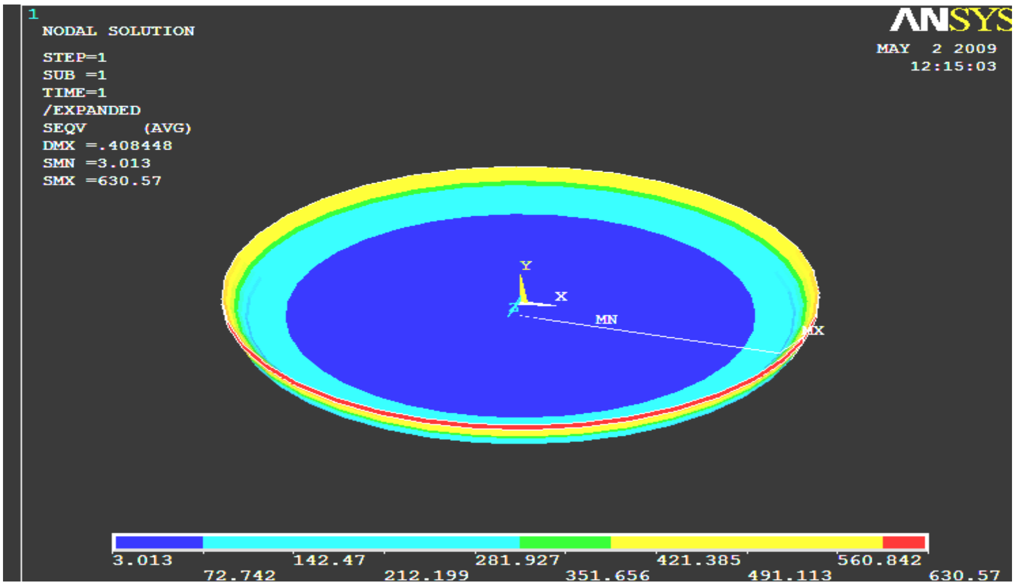

Fig.(13): The value of plastic stress equivalent with min value=3.013 and max value = 630.579.

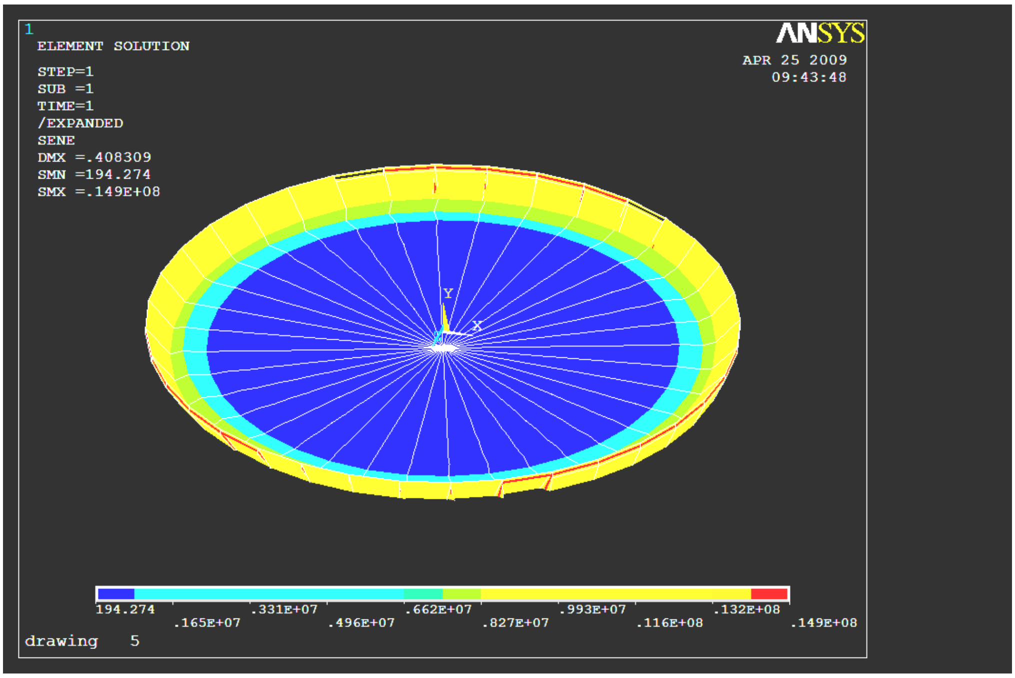

Fig.(14): Non linear stress at min value 194.274 and max value 0.149E+08 when the Mf = 0.15.

دراسة الية التشوة المرن اللدن المتماثل لصفيحة دائرية بقالب اسطواني

م.م. سمير داود علي
جامعة ديالى / كلية الهندسة

الخلاصــة

في هذه الدراسة وظفت اجراءات عددية لتصميم عملية السحب العميق باستخدام طريقة العناصر المحددة مـــن خلال برنامج (Ansys 11) ببناء نموذج متماثل ثنائي الابعاد متطور لانتاج وعاء مخروطي .
ومن خلال هذا البحث تم دراسة الية التشوه لحساب قابلية التشكيل لصفيحة معدنية تحت تاثير بعض المتغيــرات التـــي تؤثر على عملية السحب مثل الشكل الهندسي للقالب ، معامل للاحتكاك واشير الـــى كيفيـــة ظهـــور المنـــاطق اللدنـــة وتوزيعها مع تغيير قطر القالب وتوزيع الانفعالات ، القوى الداخلية وخصائصها تقرب نموذج عملية التحليل للمهندسين وتخمين قابلية التشكيل لمادة المعدن والتنبؤ لظهور التجاعيد اللدنة للصفيحة .
عملية التشكيل في الدراسة المختبرية كانت متوافقة لعملية التحليل العددي التي نفذت على قطعة عمل بسمك ١،٥ ملم و ٢ملم وبقطر ١٢٠ و ١٥٠ ملم على التوالي وكان قطر القالب الاسطواني ٤٥ ملـــم و ٦٥ ملـــم وباســـتخدام برنـــامج (Ansys 11) الذي طور مؤخرا وبخصائص عالية التطبيقات الهندسية .