Diyala Journal
of Engineering
Sciences

ISSN 1999-8716
Printed in Iraq

Vol. 05, No. 01, pp.103-116, June 2012

NUMERICAL PROCEDURE TO DESIGN A DIE AND STUDY ITS RELATIONSHIP WITH SOME PARAMETERS INFLUENCING ON THE BENDING PROCESS OF SHELLS

Sami Ali Nawi ALazzawi
Assistant Lecture
College of Engineering / Diyala University
E-mail: Samialazawi64@yahoo.com
(Received:7/2/2011 ; Accepted:3/10/2011)

ABSTRACT:- In this study a numerical procedure was proposed for the design a die bending to study the effect of springback which influences the bending process and its relationship with other parameters such as friction coefficient, bending load, die geometry, sheet thickness, Young modules, and stress level. Using available finite element program code(ANSYS .11) 3- Dimension ax symmetric model of semi conical shells was used to solve problems with material and geometric nonlinearities including large elastic- plastic strains and obeying bilinear isotropic hardening law. The result compared with analytical solution and showed that the best bending variables for producing completely product without failure are found as initial bending force = 12 KN, coefficient of friction = 0.1, the cone angle = 30 deg. So the springback increases inversely with young modulus and is normally compensated for by over bending the part also can bend at elevated temps to minimize springback A high value of stress and strain appears to be a good indicator to assess whether forming operation will be successful or not. The theories results were compared with Numerical solution and showed that a good agreement was compared with old research
KEYWORDS: Springback .Die bending . Bending Process of Shells.

NOMENCLATURE

E	Young´s (elastic) modulus	Mpa
Et	Tangent modulus	Gpa
Y	Yield stress	Mpa
Bf	Bending force	KN
M	Bending moment	N.m
n	Strain hardening exponent	
Ri.	Internal radius of the bemd	mm
Rm.	Mid-surface radius	mm
Rf	Final Punch (Die) Radius	mm
t	Sheet thickness	mm
θ	Bend angle	deg
Ø	Cone angle	deg
mf	Friction coefficient	
υ	Poisson´s ratio	
σ	True stress	Mpa
ri	Inner plate radius	mm

ro	Outer plate radius	mm
$\sigma_x, \sigma_y, \sigma_z$	Normal stress in x,y,z-direction	N/mm²
K	Springback percentage	

1- INTRODUCTION

In metal forming, a piece of material is plastically deformed between tools to obtain the desired product. A special class of metal forming concerns the case where the thickness of the piece of the material is small as compared to the other dimensions, i.e. sheet metal forming which is widely used in production process [1]. In spite of the Great developments achieved in plate die -bending it's to be noticed that this process is not satisfactorily studied [2, 3]. In the analysis to bending in U-shaped die showed that especially from the theoretical point of view, because of the mathematical difficulties, empirical and formulas, ignoring many of the influencing parameters are still in use. Development has been made in the field of finite element types, mesh adaptively, material laws failure, wrinkling and surface defects. Springback, contact, friction, currently, the accuracy & reliability of numerical simulations of sheet metal forming do not yet satisfy the industrial requirements. One of the limitations is still the high computational time for complex forming. Despite this development of iterative solver another limitation is the lack of detailed knowledge of material physics such as material behavior at high deformations and contact behavior. Therefore extensive research in the field of sheet metal forming is necessary to forming simulations [4, 5]. Numerical analysis can provide accurate prediction of the initial blank size and the strain distributions for steel material; this approach is more accurate by using finite element code (ABAQUS) [6, 7]. Has verified that (F.E.M) could predict the defects that occurred in various forming stages of bending operation. The (F.E.M) showed excessive compressive stresses occur in the flange area, the effect of varying die radii and die friction assemble pan for super plastic material (AL 7475 alloy) has been simulation [8, 9], with different friction coefficient was plotted the result show the parts are found to form faster with higher pressure in lower die friction stress was not affected by reduction ratio.

In this work conical part can be produced by die-bending , the process of die-bending is to be investigated in sectoral plates, each to a semi conical form ,the elastic-plastic phases of deformation will be studied as shown in figure (2), the elastic phase is ended when yielding is reached at any point in the plate correspondingly, the bending load at which yielding starts is calculated, generally , the knowledge of this yielding force as well as the force required to complete the bending is essential for the design of forming tool and for the selection of bending machines . In the plastic phase a developed die-bending apparatus will be described , the main feature of this apparatus is that it allows a line contact between the conical tool and a sectoral plate at the bending of loading and as a deformation continues by tool rotation about cone apex , the plate envelopes the conical loading tool at the end of the operation , the specimen completely surrounds the tool forming half of a cone , the relation between load and angle of rotation of tool was established in the elastic range of deformation

1-2 Theoretical Analysis

1-2-1 Analytical Solution

The equilibrium of a differential element gives the following differential equation for the deflected surface of the plate [10, 11]

$$\nabla^2 W = \left[\frac{\partial}{\partial r^2} + \frac{\partial}{r\partial r} + \frac{\partial}{r^2 \partial\theta^2}\right]^2 W \ = \ 0 \qquad \text{........(1)}$$

$$W = g(\theta)\cdot f(r) \qquad \text{........(2)}$$

$$f = r\sin\psi \quad \text{........... (3)}$$

$$\frac{d^4 g}{d\theta^4} + \frac{2\,d^2 g}{d\theta^2} + g = 0 \quad \text{……..... (4)}$$

$$\mathrm{w} = r\sin\psi\ (\cos\theta - \frac{\cos\phi}{\phi\sin\phi}\cdot\theta\sin\theta) \quad \text{............. (5)}$$

$$\mathrm{Q}_\theta = \frac{-K}{r}\ \frac{\partial}{\partial\theta}\left(\frac{\partial^2 \mathrm{W}}{\partial r^2} + \frac{\partial \mathrm{W}}{r\,\partial r} + \frac{\partial^2 \mathrm{W}}{r^2\,\partial\theta^2}\right) \quad \text{............. (6)}$$

$$\mathrm{K} = \frac{\mathrm{E\,t}^3}{12(1-\nu^2)} \quad \text{…............ (7)}$$

$$\mathrm{Q}_\theta = 2\,\mathrm{K}\ \sin\psi\ \frac{\cos\varphi}{\varphi\sin\varphi}\ \frac{1}{\mathrm{r}^2}\ (-\sin\theta) \quad \text{.............. (8)}$$

$$P = 2\int_{r_i}^{r_o} (\mathrm{Q}_\theta)_{\theta=\phi}\ dr \quad \text{…........... (9)}$$

$$P = 4K\ \sin\psi\ \frac{\cos\phi}{\phi}\left(\frac{1}{r_i} - \frac{1}{r_o}\right) \quad \text{…............ (10)}$$

$$\sigma_\theta = 2\,\frac{\mathrm{E}\sin\psi}{(1-\nu^2)} \quad \text{............ (11)}$$

$$\sin\psi = \frac{(1-\nu^2)}{2E}\ \frac{r_i}{t/2}\ \frac{\phi\sin\phi}{\cos\phi}\ \sigma_y \quad \text{........... (12)}$$

$$P = \frac{1}{3}\ \sin\phi\ \sigma_y\ t^2\,(1 - \frac{r_i}{r_o}) \quad \text{........... (13)}$$

$$p_0 = 2\,U_0 \int_{r_i}^{r_o} \frac{M}{r}\ dr \quad \text{........... (14)}$$

$$p_f = 2\,\mu U_f \int_{r_i}^{r_o} \frac{M}{r}\ dr \quad \text{........... (15)}$$

$$p = p_o + p_f \quad \text{........... (16)}$$

$$p = 2(U + \mu U_f) \int_{r_i}^{r_o} \frac{M}{r}\ dr \quad \text{........... (17)}$$

$$M = \frac{t^2}{2\varepsilon^2}\ \sigma_y \int_0^{\varepsilon} \theta\, d\theta\ = \frac{t^2}{4}\ \sigma_y \quad \text{........... (18)}$$

$$P = \frac{1}{2}\ t^2\ \sigma_y\,(U + \mu U_f)\ \ln\frac{r_o}{r_i} \quad \text{........... (19)}$$

$$\sigma_x = \frac{\mathrm{E}}{1-\nu^2}\left(\frac{1}{\mathrm{R}_x} + \frac{\nu}{\mathrm{R}_y}\right).\mathrm{Z} \quad \text{........... (20)}$$

$$\sigma_y = \frac{\mathrm{E}}{1-\nu^2}\left(\frac{1}{\mathrm{R}_y} + \frac{\nu}{\mathrm{R}_x}\right).\mathrm{Z} \quad \text{........... (21)}$$

$$Mx = My = M \qquad \text{........... (22)}$$

$$\frac{1}{R_x} = \frac{1}{R_Y} = \frac{1}{R} \qquad \text{........... (23)}$$

The equations (21& 23) become

$$\sigma_x = \sigma_y = \frac{E.Z}{(1-\nu)R_x} \quad \text{For elastic zone} \qquad \text{........... (24)}$$

$$e = \frac{Z}{R} = \frac{\sigma}{E}(1-\nu) \qquad \text{........... (25)}$$

Since $\sigma = \sigma_y$, $e = e_y$

$$\sigma_y = \frac{E.e}{(1-\nu)R} \qquad \text{........... (26)}$$

$$K_s = \frac{1}{R} = \frac{(1-\nu).\sigma_y}{Ee} \qquad \text{........... (27)}$$

1-3-2 Numerical Solution

The prime objective of an analysis is to assist in the design of a product to design or select the tools; such design essentially consists of predicting the material flow during process, determining whether it is possible to form the part without internal defects, predicting the force & the stresses necessary to execute the forming process. By using the (ANSYS.11) program which has many finite element analysis capabilities, complex, non linear, transient, dynamic analysis, elastic -plastic, creep, large deformation and buckling [(12)].

1-3-3 Performing a Typical (ANSYS. 11) Analysis

The (F.E.M) model of the sheet material and bending die is shown in figure (1 .a).

The Geometry of Die and Punch (F.E.M) Mesh Model with Cone Angle 30^o Typical (ANSYS .11) analysis has three distant steps which are built the model, apply Load and obtain the solution, Review the result.

.

1-3-4 Build the Model

The ultimate purpose of a finite element analysis is to re-create mathematically the behavior of an actual engineering system. In other words, the analysis must be an accurate mathematical model of a physical prototype. In the broadest sense, the model comprises all nodes, elements material properties, real constant, boundary conditions, and other features that are used to represent physical system, with solid modeling so describe the geometric boundaries of model over the size and desired a shape of element automatically, by contrast, with direct generation method can determine the location of every node and the size, shape and connectivity of every element prior to defining these entities in model. Solid modeling is usually more powerful and versatile than direct generation and is commonly the preferred method for generating models alternative to creating, solid models can create them in cad systems and then import them in program (ANSYS. 11) for analysis. Building a finite element model requires more of user's time than any other part of the analysis, first, we specify a job name and analysis title, and then we define the element types, element real constants, material properties and geometry.

1-3-5 Defining Element Types

In this work four types of elements were used for analysis:

1-3-5-1 Solid 45 3-D Structural Solid

By eight nodes having three degrees of freedom at each node, translations in the nodal x, y & z directions, and the element has plasticity it is used for the three dimensional.

1-3-5-2 Shell 181 Finite Strain Shell

It is suitable for analyzing thin to moderately thick shell structures , it is a four nodded element with six degrees of freedom at each node , translation in the x ,y &z directions and rotations about the x, y &z axes.

1-3-5-3 Link 3-D spar

The three- dimensional spar element is a uniaxial tension – compression element with three degrees of freedom at each node, it is used to join the die and modify the contact between the sheet and die, punch.

1-3-5-4 Contact 49 3-D Point – to – Surface Contact

It is used to represent contact and sliding between a node and a surface in three dimensions, the elements have five nodes with degrees of freedom at each node. Translations in the nodal x,y &z directions , contact occurs when the contact node penetrates the target base , elastic coulomb friction and rigid coulomb friction are allowed where sliding is along the target base.

1-3-6 Defining Element Real Constant:

In this work, it needed it is required to select the correct real constant set, the real constant set for each contact surface must be the same as the one used for the corresponding target surface for each contact pair, and each contact pair must reference its own real constant number as shown in figure (1.b).

2- CASE STUDY

Nonlinear material properties are usually tabular data, such as plasticity data, data tables are always associated with a material number and most often used to define non-linear material properties. An isotropic elastic-plastic constitutive model with isotropic strain hardening was used to simulate the response , the elastic behavior was taken to be linear and the plastic response was modeled using the von misses yield criterion , with the material properties of a Nickel Chrome Steel listed below (9, 12) .

Young's Modules of Elasticity	E = 208 GN/M²
Shear Modulus	G = 82 GN/M²
Elastic limit	σ_y = 1200 MN/M²
Tensile Strength	Ts = 1700 MN/M²
Density	ρ = 7800 Kg/M³
Shear Yield Strength	τ_y = 650 MN/M²
Poisson's Ratio	υ = 0.34

3- RESULT & DISCUSSION

3-1. Effect of Thickness on the Bending Process

Thickness of produced semi-conical shell was measured and compared with the thickness obtained by simulation as shown in figure (3) which shows that the yielding forces Increases almost with thickness of sheet , but the thickness measurement before and after bending showed that it remains practically unchanged , Also no appreciable hardness change was registered in the test carried out .The results obtained by finite element method (ANSYS 11 program) are very close to those predicated by analytical solution when the coefficient of friction are chosen (Mf = 0.1 , 0.15) [14].

3-2. Effect of bending load on The Springback

In order to check this effect with consider three different values of the Bending force (BF) (5,10,and 20 KN) during the experiments, Punch force was recorded along with punch displacement (stroke) as shown in figure (4) in which the values predicted by simulation are compared with experimental values, The figure shows that the bending force increases as the blank holding force increases for BF = 5 KN the blank gradually loses the contact of the die. The best bending parameters without failure is found as Initial force =10 kN.

3-3. Effect of Young modules on The Spring back

Because the materials has a finite modulus of elasticity plastic deformation is followed by springback upon removal the load .So the springback increases inversely with young modulus (Modules of elasticity) as shown in figure (5) which was compared with different thickness .

3-4. Effect of Friction on Bending Process

Forming a process is important; furthermore, precise coefficient of friction values can greatly improve process design and analyzing numerical process simulation, validation and control of forming processes. In this work, the effect of friction on the bending of semi-conical shells is investigated, four values (Mf = 0.05, 0.1, 0.15) were implemented for the simulation. (Displacement) under different conditions, figure (6) reveals that the force increases with increased friction at the blank -die punch interface. In the case where friction coefficient (Mf = 0.1) the maximum force is (12 kN) while for the case (Mf = 0.2) is (25 kN) these results show that the model is robust to friction, indicating that change in (Mf) will greatly alter the predictions, this concluded that the higher friction restrains the movement of material, producing more localized strain profiles and more punch force. Figure (6) (The results clearly show that for lower value of friction coefficient the stress is expected to be more uniformly for the value of (Mf = 0.1) than (Mf = 0.15) in which the stress value is much more than reasonable values . The simulation result provides large stress equivalent.

3-5. The Effect of Radials Distance and Angle of Tool Rotation

Figure (7,8) shows that the pressure between tool and specimen varies almost inversely with the radial distance & angle of tool rotation. Measurements before and after bending showed that it remains practically unchanged; also no appreciable hardness changes were registered in the test carried out.

To investigate the effect of die and punch profile radius on operation four models of die and punch in order to apply the load as shown in figure The maximum forming depth was set (40) mm to ensure that the parts are completely bending and removed from the die for all the dies and punches Figure (8,9) The Value of the stresses in Y ,X axis' in the thickness = 6 mm the bending force for large die radius and large punch radius is lower than that for small radius in both theories it is clear that the effect of punch radius on bending fore is less than the effect of die radius because the bending effect is concentrated at the region of die corner of radius at which the required bending force is minimized is equal to (L/2R = 0.4) this means that in order to minimize the bending force ,The die radius should be as large as possible (inversely with the radial distance) & angle of tool rotation

Figure (10) Shows Value of plastic Stress Equivelent Elements near die surface in zone of applying load are subjected to high longitudinal compression in the die, which changes to a tensile stress peak as the material emerges from the die and its evident that the die length has a little influence on the distribution of effective strain and effective stress also the effective strain is concentrated at die noses. Figure (11) shows Stress in Y direction when Mf=0, 1 in a good agreement within [13]. Figures (12, 13) show the value of Elastic Plastic Strain Equivalent and Elastic Plastic Strain Equivalent (F.E.M) after Springback.

4- CONCLUSIONS

The ability to perform a successful bending operation depends on many parameters for the adopted data have been studied using numerical analysis and compared with analytical solution and it shows that:

1. The best bending parameters without failure is found as follow, Initial force =12 KN, coefficient of friction = 0.1, die punch length = 150 mm, , Sheet thickness = 3 mm , L / 2R = 0.4 ,Precise Coefficient of friction values can greatly improve process design and analysis , Numerical process simulation , Validation & control of forming processes .
2. The work presented indicates that the finite element rate – independent Elastic – Plastic approach offers the feasibility of making rational assessment for prediction the springback in bending problems and to assessment of the maximum longitudinal residual stress.
3. The die length has a little influence on the distribution of effective strain and effective stress also the effective strain is concentrated at die noses. As the bending increases keeping stretching constant through stretch bending process, curvature, Final curvature and springback ratio increase and available maximum curvature increases.
4. Because all materials have a finite modulus of elasticity plastic deformation is followed by springback upon removal the load. So the springback increases inversely with young modulus and is normally compensated for by over bending the part also can bend at elevated temps to minimize springback .Expressed in terms of the ratio of initial to final bend radii. The Study presented indicates that the finite element rate independent Elastic-Plastic approach offers the feasibility of making rational assessment for prediction of stress and deformation in bending problems involving a very complicated interaction of geometrical , material and contact- nonlinearities and to assessment of the maximum longitudinal residual stress in formed product .

5- REFERENCES

1. Timo Meinders “Simulation of Sheet metals forming processes” PhD Thesis Applied Mechanics, University of Twente, AE. Eng. The Nether Land, Canada 1999 A: aaa htm.
2. B.Zuenkler “Theoretical determination of forming for plates in U-Shaped dies” Baender, Blech, Rohr, 1999.
3. G. Oehler “Bending of Plate” Hanser Verlay1989.
4. S.Kobayashi & T. Altan “Metal forming and the Finite Element Method” Oxford University Press, New York 1998.
5. N. Langerak & S.P, Kragtwigk “The use of Finite Element in the development of alight weight steel and aluminum car body” Proceeding of the second Esaform Conference on Material Forming J.A Covased Guimarases. 1999.
6. P.P .Date "Sheet metal Formability" Proceeding of the Training Program of Sheet Metal Forming Research Association at Indian Institute of Technology .2007.
7. T.Altan “Forming improving progressive die design by Simulation” Stamping Journal 2005.
8. N, Chandra & S.C.Rama “Application of Finite Element Method to the design of super plastic forming processes” Translation of the ASME .Vol 144/ 1997.
9. A.H.ALHilli " Springback due to Bending and Stretch Bending of Sheet metal”MSc

Thesis .AlNahrain University. Mech Eng College 1999.
10. S.Timoshenko & W .Krieger "Theory of plate & Shell" MacGHill NewYork, London1997.
11. Alan.Jeffrey "Advanced Engineering Mathematic" Uni of New Catle-upon-Tyne San Diego SanFrancis com. New York, 2007.
12. .Wanson "ANSYS 11 Manual" Swanson Analysis Systems Co America / 2007.
13. L.Zhang & R.W. "Investigation of Sheet Metal Forming by Bending & Wrinkling of circular sheet" pressed by a hemispherical punch international Mechanical science. Vol. 31. 1998.
14. Nicholas Zabaras "Sheet Metal Forming Processes Elastic plane strain Bending" Cornell University MA E212 -2001.

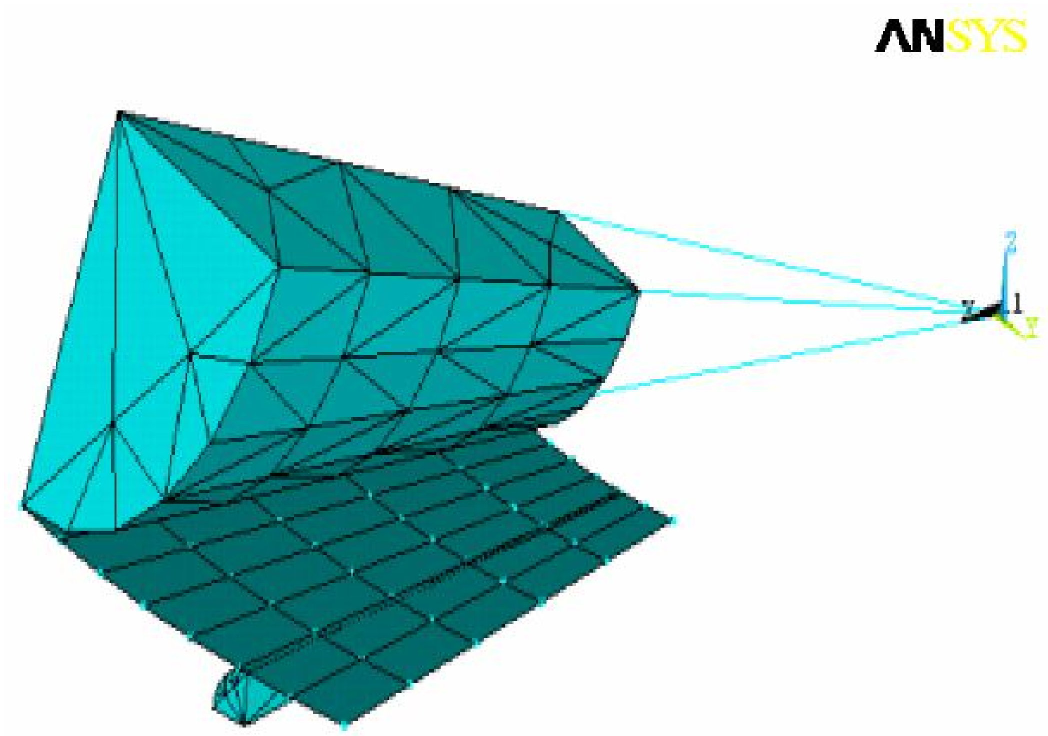

Fig.(1.a): the Geometry of Die and Punch (F.E.M) Mesh Model with Cone Angle 30.

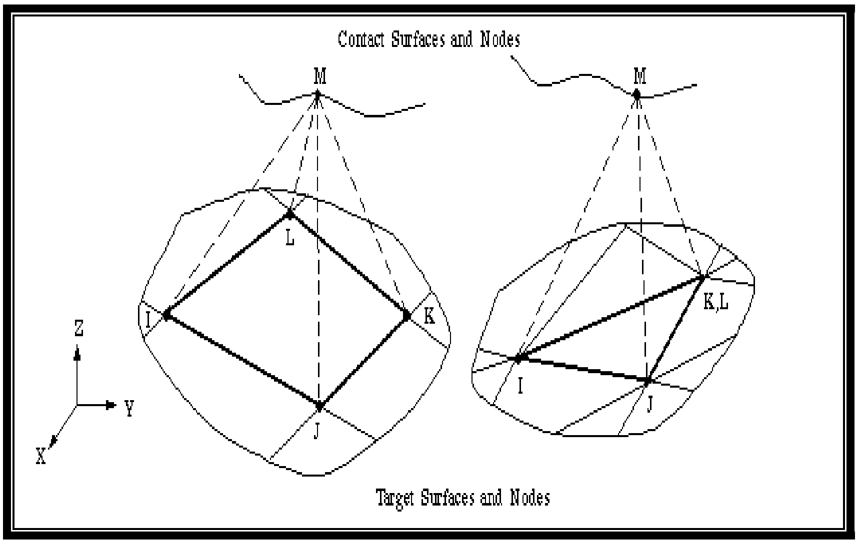

Fig.(1.b): the Geometry of Contact Surface & Contact between Target Surface Element and Nodes.

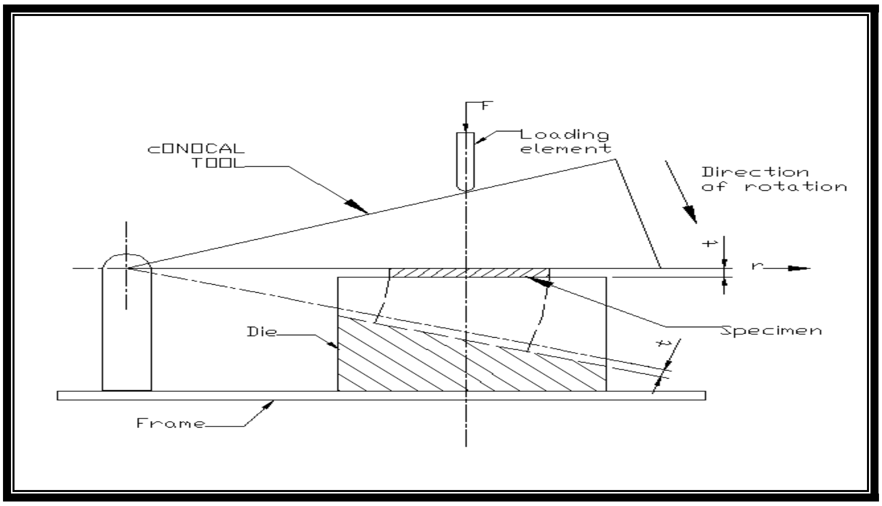

Fig.(2): described a developed Die-bending apparatus.

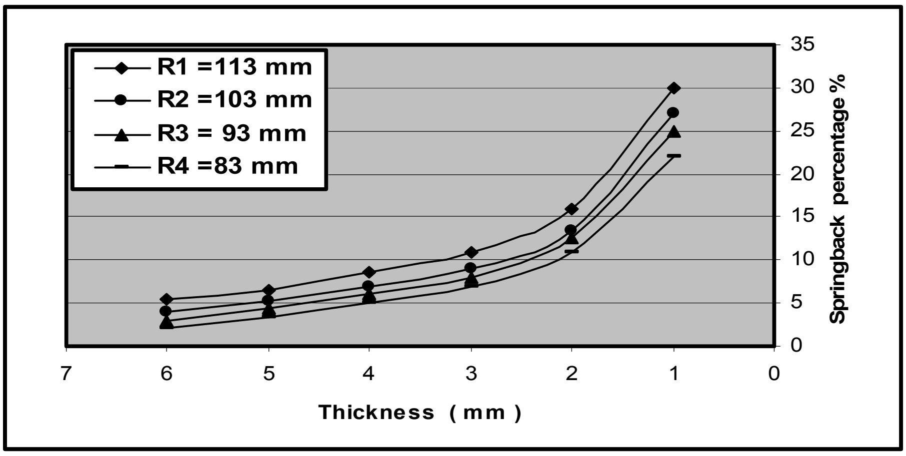

Fig.(3): The Springback % Varies with the Thickness due to the Locutions of Applied Load for Steel Shells.

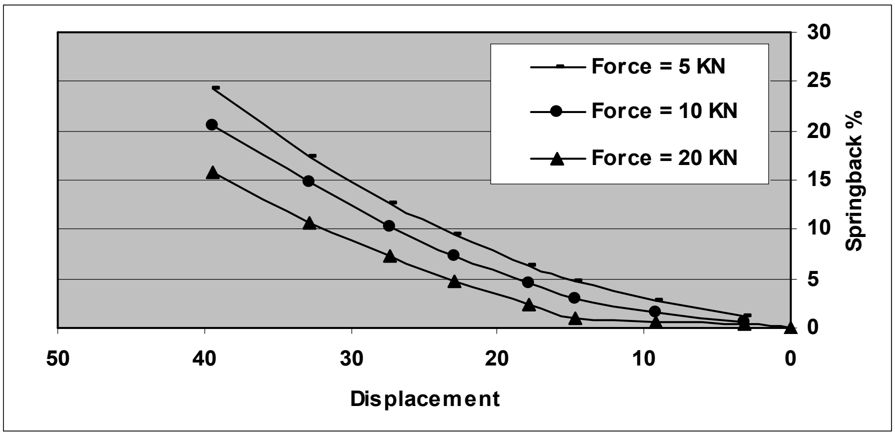

Fig.(4): the bending Force Varies Inversely With the Springback % .

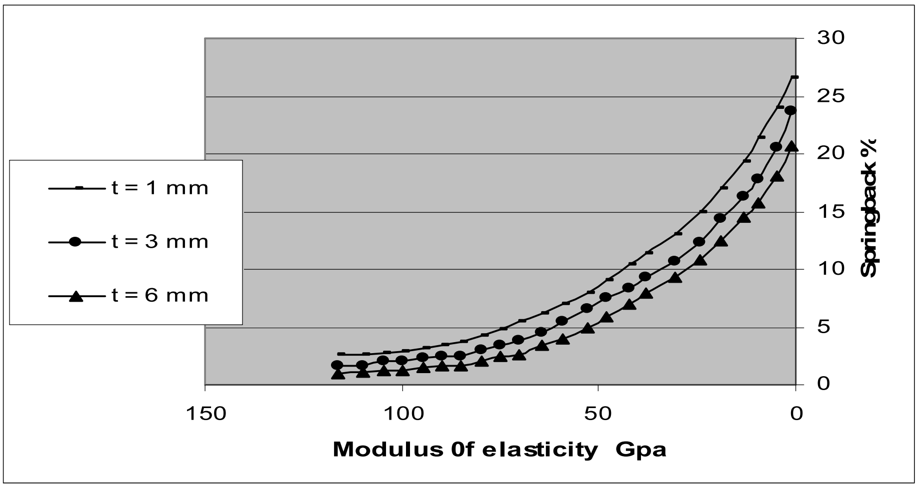

Fig.(5): the effect of Young's Modulus on The Springback Percentage.

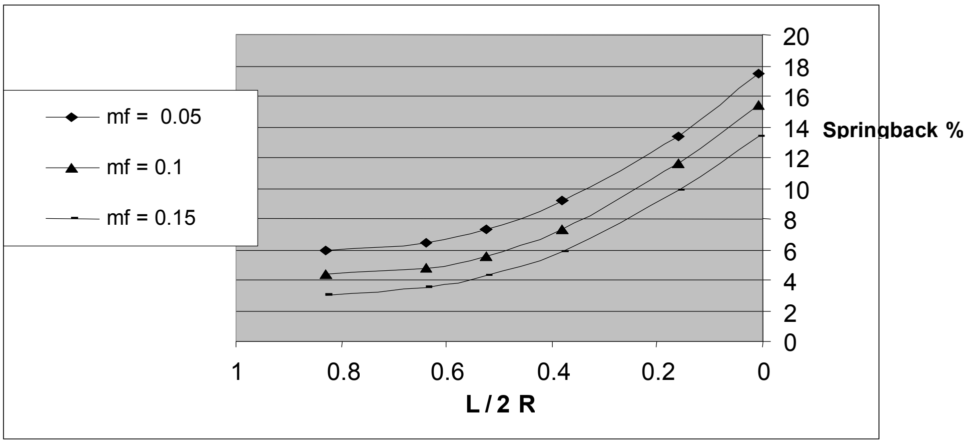

Fig.(6): the effect of Friction & Radials Distance on the Springback Percentage.

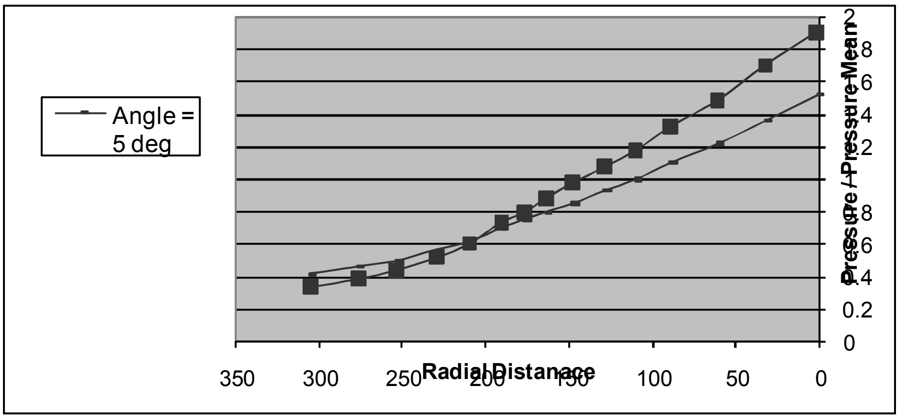

Fig.(7): the Pressure between Tool and Specimen Varies with the Radial Distance and Angle of Tool Rotation about (0).

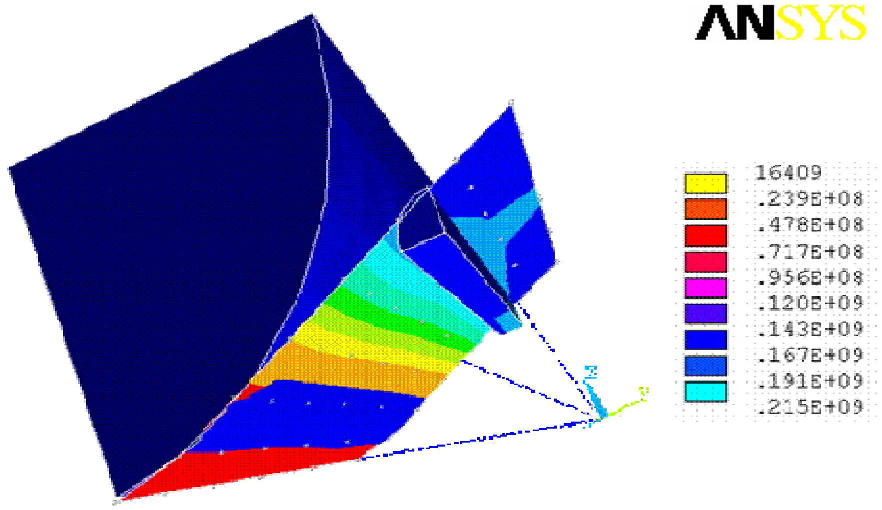

Fig.(8): The Value of the stresses in Y axis's in the Thickness = 6 mm.

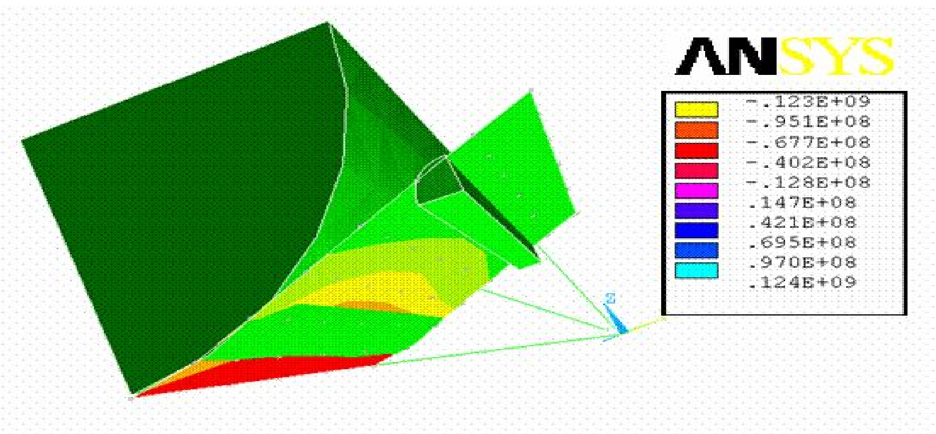

Fig.(9): The Value of the stresses in X axis's in the Thickness = 6 mm.

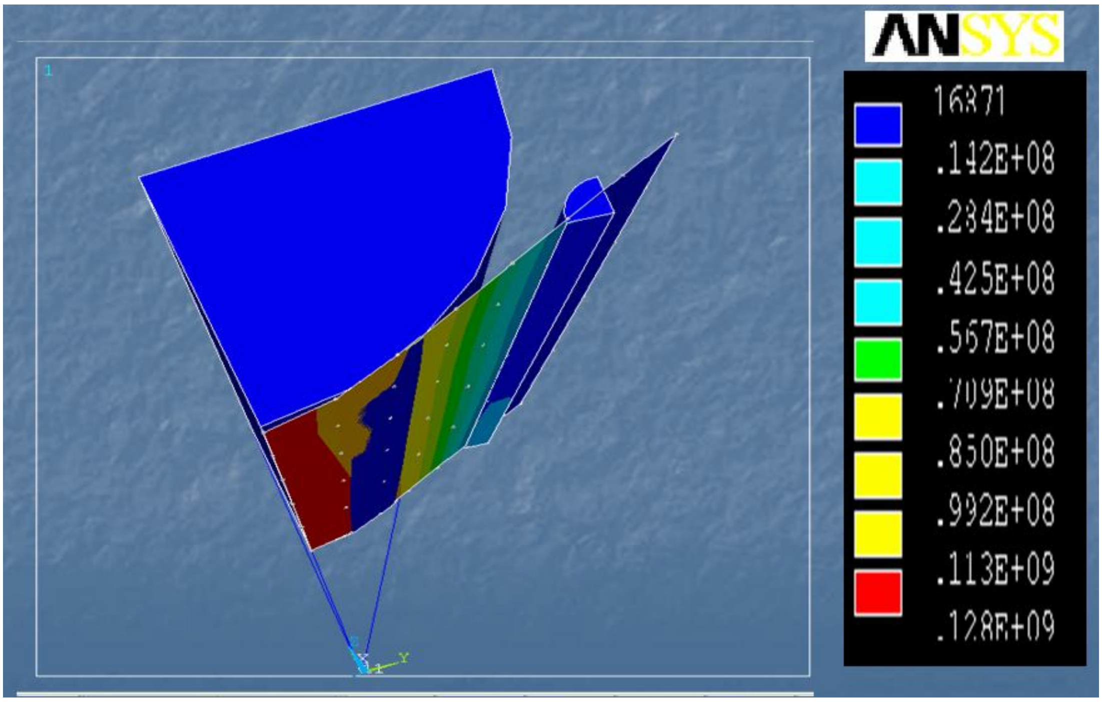

Fig.(10): the Value of plastic Stress Equivelent(F.E.M).

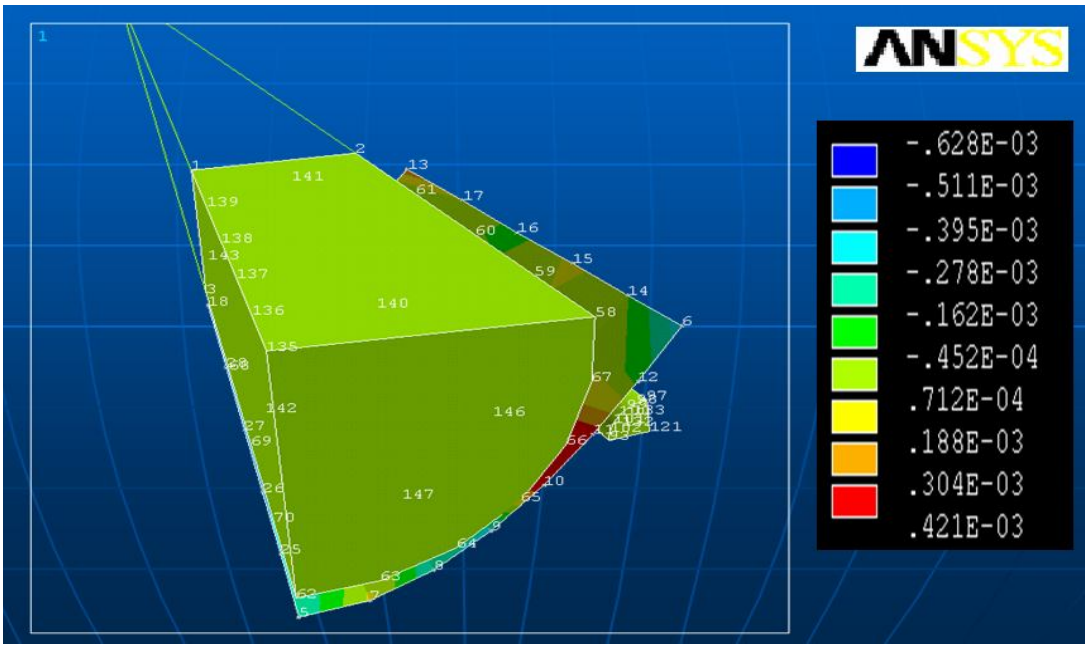

Fig.(11): Stress in Y-direction when (MF=0.1).

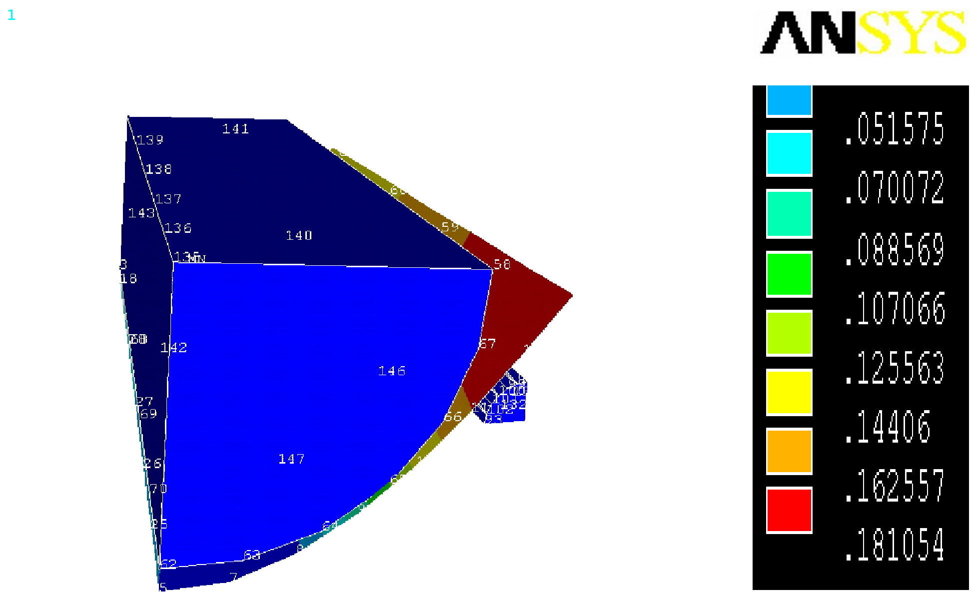

Fig.(12): the value of Elastic Plastic Strain Equivalent (F.E.M).

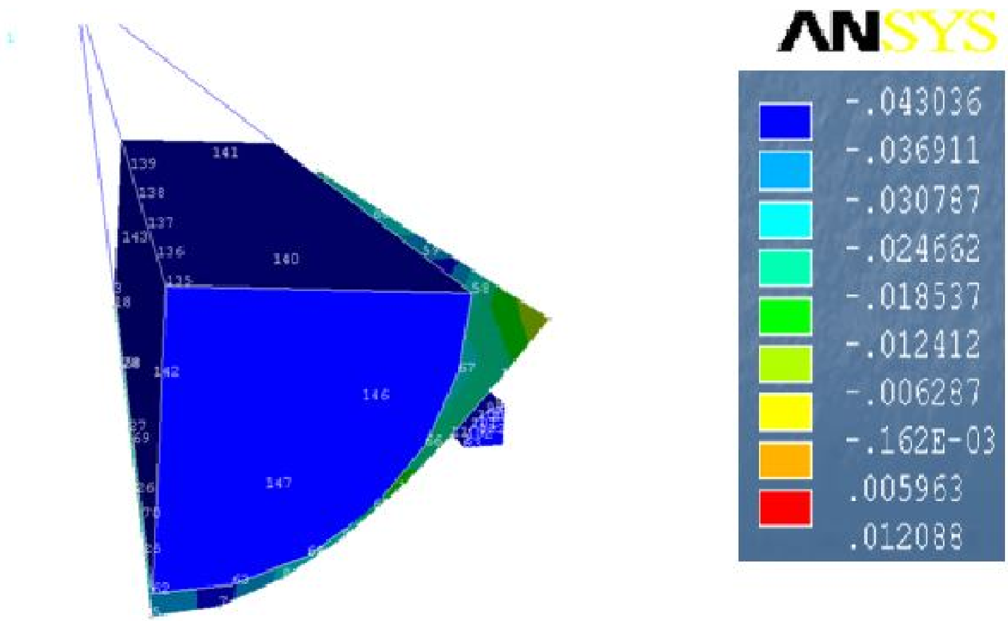

Fig.(13): Elastic Plastic Strain Equivalent (F.E.M) after Springback.

إجراءات عددية لتصميم قالب ودراسة علاقته مع بعض المتغيرات المؤثرة على عملية انحناء الرقائق المعدنية

م.م. سامي علي ناوي العزاوي
كلية الهندسة / جامعة ديالى

الخلاصة:

في هذه الدراسة تم توظيف إجراءات عددية وتصميم قالب لدراسة عملية انحناء الرقائق المعدنية نصف المخروطية وتأثير الارتداد المرن وعلاقته مع المتغيرات الأخرى مثل معامل الاحتكاك ، حمل الانحناء ، زاوية القالب ،سمك الصفيحة ،معامل يونك و مستوى الإجهاد باستخدام نظرية العناصر المتناهية (F.E.M) وبتقنية برنامج (ANSYS.11) وبناء موديل ثلاثي الأبعاد متماثل لرقائق معدنية نصف مخروطية لحل المسائل اللاخطية تتضمن الانفعالات المرنة اللدنة وتخضع لقانون التصليد الانفعالي.

النتائج العملية والنظرية قورنت مع الحلول العددية وبينت لأفضل متغيرات لعملية انحناء منتج كامل بدون فشل بقوة انحناء 12 كيلو نيوتن ومعامل احتكاك 0.1 مع زاوية مخروط 30 درجة وسمك الصفيحة 3 ملم ومقدار الارتداد المرن يتناسب عكسيا مع معامل يونك ولوحظ إن أعلى قيم للإجهاد والانفعال كانت مؤشر جيد لبيان أن عملية التشكيل كانت ناجحة أم لا . كذلك النتائج بينت توافق بشكل جيد مقارنة مع بحوث سابقه.

مفاتيح الكلمات: النابضية الارجاعية ، قوالب الانحناء ، عمليات انحناء الاغلفة