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Numerical Investigation of Spring Back on Sheet Metal Bending Process

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Abstract- Spring back is the main defect in sheet metal bending process. The spring back of sheet metal bending, which is defined as elastic recovery of the part during un loading conditions. It should be taken in to considerations so as to produce bent sheet metal parts within acceptable quality. Spring back is affected by the factors such as; sheet thickness, tooling geometry, friction condition; material property and processing parameters. In this research the numerical investigation of Spring back on edge bending die process is done.. The numerical Analysis is done using ANSYS™ LS-DYNA™. The influence of sheet metal thickness, sheet metal type, friction, tool radius and tool shape on spring back for Aluminium, copper, mild steel and High strength steels, sheet metal have been considered for investigations.

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NUMERICALINVESTIGATIONOFSPRINGBACKONSHEETMETALBENDINGPROCESS

Strictly as per the compliance and regulations of:

Numerical Investigation of Spring Back on Sheet Metal Bending Process

Alie Wube Dametew [α] & Tafesse Gebresenbet [σ]

Abstract- Spring back is the main defect in sheet metal bending process. The spring back of sheet metal bending, which is defined as elastic recovery of the part during un loading conditions. It should be taken in to considerations so as to produce bent sheet metal parts within acceptable quality. Spring back is affected by the factors such as; sheet thickness, tooling geometry, friction condition; material property and processing parameters. In this research the numerical investigation of Spring back on edge bending die process is done.. The numerical Analysis is done using ANSYS™ LS-DYNA™. The influence of sheet metal thickness, sheet metal type, friction, tool radius and tool shape on spring back for Aluminium, copper, mild steel and High strength steels, sheet metal have been considered for investigations.

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I. Introduction and Background of the Study

Many sheet metal components are produced in different size and accuracy using various sheet metal forming processes. In order to obtain consistent and accurate product dimensions is crucial in manufacturing industry. In sheet metal forming process, a major factor preventing accurate final product dimensions is spring back in the part. Spring back is shape deviation from the design intended geometry which is due to the elastic recovery that occurs after the elastic plastic forming process. Factors that affect the amount of spring back for sheet metal forming process, including both process and material parameters such as; tooling geometry, friction condition; forming speed, die temperature, mechanical properties of materials, sheet metal type and sheet metal thickness. To obtain the desired geometry of the part; spring back prediction and optimizing is a considerable issue in sheet metal bending because tooling design primarily relies on accurate prediction of spring back.

a) *Statement of the problem*

The Bending process needs repeated experiments to reach the final accurate product. Some sheet metal products are produced still with defects and poor product quality. One of the main accuracy problems is due to elastic spring back effects. In this thesis investigation will be conducted to identify spring back effect of wiping die bending process and analysis will be yield the spring back reduction.

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b) *Objectives*

i. General Objectives

The main objective of this study is to investigate the factors influencing spring back formation in sheet metal forming for optimizing the sheet deformation process.

ii. Specific Objectives

- To investigate factors that influence spring back during wiping die bending.
- To analyze and simulate bending variables using analytical and finite element methods.
- To validate variables obtained from analytical and numerical modeling.
- Predict spring back and.
- To optimize sheet bending operation.

c) *Metrology of the research*

The research methodologies adopted in this study to achieve the stated objectives are presented as following: Initially a detailed survey of published literature review was conducted, This study was conducted to study spring back formation in sheet bending and predict factors affecting this phenomenon, using Numerical Analysis is done. A simple 2D and 3D bending process were investigated through numerical simulations for four sheet metal types i.e. aluminum, copper, mild steel and high strength steel, The parameters investigated in this study include; die geometry, sheet metal thickness, sheet metal type and friction condition. For the prediction and analysis of these factors done using Ansys10™ and LS-DYNA™. The analytical results were spring back for further numerical simulation analysis, since it was found that there are a number of issues which requires further study. Comparison of analytical and numerical results was also conducted, and lastly Conclusion and recommendations for a future work was provided.

II. Literature Review

A great deal of research has been conducted in order to reduce spring back, which would optimize the sheet forming process by reducing geometrical and material variables in the formed part. Finite element technique has played a major role in carrying out sheet metal forming and spring back analysis in order to gain accurate results. This chapter tries to summarize some key background references and their contributions to the problem of spring back. [Fahd Fathi Ahmed Abdi, 2000] presented the work which was concerned with the spring back experienced by the deformed sheet following the punch release stroke. He used several numerical techniques which enabled to define and determination of spring back.

A 3D hybrid membrane/shell method [Jeong-Whan, 2002] was developed in order to perform spring back analysis from the membrane mid-plane solution and also to reduce computational cost for sheet metal forming simulations. In the hybrid method, the bending strain and stresses were numerically calculated as post-processing considering incremental shape changes of the sheet obtained from the membrane finite element analysis beforehand. The stress and strain were passed on to a shell model to calculate spring back. With regard to verification purpose, the hybrid method was applied to predict the spring back of a 2036-T4 Aluminum alloy square blank is formed into a cylindrical cup. The spring back prediction was in good situation with the experimentally measured data and also with the results obtained using a shell model to simulate both loading and unloading conditions. For a bending-dominant problem, the method was also applied for the unconstrained cylindrical bending of a 6111-T4 aluminum alloy sheet, which exposes large spring back. According to W.P. Carden (2002) was the Measurement of spring back in Draw-bend have been carried out and analysed to investigate the role of typical process variables on spring back. The investigation leads to conclude that friction in the normal range encountered in sheet metal forming has little effect on spring back, This conclusion departs for fact of friction effect , most likely due to the fact that in many experiments the sheet tension cannot be controlled independently of friction. Ridha Hambli (2003) develops the effects of the die radius on the spring back angle obtained by simulation with and without the influence of damage. It can be observed that with the damage influence the spring back is lower as a consequence of the material parameters variation especially, the Young's modulus and the strain within the fibers. The difference between the curves decreases with increasing die radius. The decrease is attributed to the damage reduction within the sheet for higher die radius values. To estimate and reduce spring back of ax-symmetric part manufactured by Flex forming process was developed by [Hariharasudhan Palaniswamy, 2004] using combined optimization and FEM technique. Finite element simulations were performed in order to study the interrelationship of the blank dimensions and interface conditions on the spring back for an Axisymmetric conical part manufactured by flex forming. Sensitivity analysis are done using the finite element method (FEM) demonstrated that the magnitude of spring back and the overall dimensional quality are highly influenced by the initial dimensions of the blank. A conventional optimization method combined with FEM was used to obtain optimum blank dimensions that can reduce spring back. Finite element simulations of the forming process were conducted by Taylan Altan (2004) to study the influence of interface conditions on spring back. In the simulations, the Coulomb friction coefficient between the blank and die was varied from $\mu = 0.05$ to 0.15, within constant dimensions. FE results on the influence of friction are shows that a very small increase in spring back with increase in interface friction is observed, it implying that friction has a negligible effect on spring back formed part. They conclude that Interface friction to have negligible effect on spring back for flex forming process of the conical part considered in study.

[Buranathiti and Jian Cao, 2004] develops an effective analytical model to predict spring back for a straight flanging process to effectively predict spring back for a potential application in determining optimal tooling shapes and process parameters, understanding the mechanics of spring back, a mainly elastic recovery process, is essential. Spring back optimization of bending processes was proposed by [Daniel Lapidate, 2005] using the concept of experimental design and response surface methodology .this work described a sheet metal bending process optimization method for spring back minimization by combined finite element analysis, response surface method and gradient optimization techniques. Several work-hardening models were evaluated by [M.C. Oliveira a, 2006] in order to determine their influence on the numerical prediction of the spring back phenomenon. Variation simulation analysis method [Peng Chen b,2007] was developed for the effects of variations in material (mechanical properties) and process (blank holder force and friction) on the spring back were investigated for an open-channel shaped part. [T. Meindersa, I.A. Burchett, 2007] Proposed in the product design of spring back prediction, spring back compensation and optimization by Finite Element (FE) Analysis. The accuracy of the spring back prediction is improved; the FE simulation can be used to adapt the geometry of the forming tools and the process parameters to compensate for spring back.

III. Results and Discussions

This section is developed for the discussion and analysis of the results obtained in the Conducted numerical investigations.The developed model is used prior to implementation by utilizing different analyses to examine the effect of each parameter in the sheet metal bending process. The analysis conducted to examine the effect on the process is using the following ways

1. Conducting analysis in the developed numerical and analytical model to analyze and investigate the effect of each parameter.
2. Analytical predictions is compared with the previous studies, and then, we discuss the result and the recommendations are done.

a) Numerical predictions of spring back

Finite element analysis of wiping bending process was conducted using two types of element types such as; Plane element 182 and shell element 163. Spring back of sheet should be bent depends on the yield strength of the material. As the materials yield strength increases the spring back after unloading also increase. The spring back will occur where the yield stresses of the material is greater than the stress after un-loading condition. If the yield stress is equal the stress after deformation, there is no spring back. For stress- strain diagram the materials beyond yield stress it deforms plastically. The spring back is determined from numerical results using the following formulas

Energy Dissipation Method

Consider elastic stretching of sheet metal up to a strain of ε. The energy required in this stretching operation can be expressed as

$W_{min} = \int_0^{\varepsilon min} dW = \int_0^{\varepsilon min} FdI = \int_0^{\varepsilon min} \sigma x A dI = V \int_0^{\varepsilon min} \frac{\sigma min dI}{l} = V \int_0^{\varepsilon min} \sigma min * d\varepsilon min)$

$W_{max} = \int_0^{\varepsilon max} dW = \int_0^{\varepsilon max} FdI = \int_0^{\varepsilon max} \sigma max A dI = V \int_0^{\varepsilon max} \frac{\sigma max dI}{l} = V \int_0^{\varepsilon max} \sigma max * d\varepsilon max$

W spring back=W max-W min

When the loads are removed from this specimen, this elastic energy will be released again. The *energy dissipation*, i.e., the applied energy per unit of volume of material, hence can be expressed as

$Umin = \frac{W}{V} = \int_0^{\varepsilon min} \sigma min d\varepsilon min$ And $Umax = \frac{W}{V} = \int_0^{\varepsilon max} \sigma max * d\varepsilon max$

U spring back=U max-U min

For in the case of elastic deformations only, this energy dissipation can alternatively expressed as

$$U = \int_0^{\varepsilon min} E\varepsilon min d\varepsilon min = \frac{1}{2}(E\varepsilon^2)min = \frac{1}{2}(\sigma * \varepsilon)min$$

$$U = \int_0^{\varepsilon max} E\varepsilon max d\varepsilon max = \frac{1}{2}(E\varepsilon^2)max = \frac{1}{2}(\sigma * \varepsilon)max$$

$U_{spring\ back} = U_{max} - U_{min}$

The above formula predict that the amount of spring back in different conditions. The variation between maximum deformation stress and un-loading stress in different region are large the spring back increase. If the maximum and un-loading stress/strain variation is small and close to the maximum deformation stress, the spring back will be reduced. The amount of spring back is equal to the amount of these stress variations. Hence, using these information the amount of spring back are predicted from numerical results in the following way.

i. *Effect of sheet metal thickness*

$$U = \int_0^{\varepsilon min} E\varepsilon min d\varepsilon min = \frac{1}{2}(E\varepsilon^2)min = \frac{1}{2}(\sigma * \varepsilon)min$$

$$U = \int_0^{\varepsilon max} E\varepsilon max d\varepsilon max = \frac{1}{2}(E\varepsilon^2)max = \frac{1}{2}(\sigma * \varepsilon)max$$

$U_{spring\ back} = U_{max} - U_{min}$

- *At 0.8mm of aluminium sheet metal energy dissipation is*

$U_{min} = \frac{1}{2}[\sigma min x \varepsilon min = \frac{1}{2}[-0.699948 * (-0.702)] = 0.24$

$U_{max} = \frac{1}{2}[\sigma max \varepsilon max = \frac{1}{2}[0.865889 * (0.0327)] = 0.0141$

$U_{spring\ back} = U_{max} - U_{min} = 0.0141 - 0.24 = -0.22$

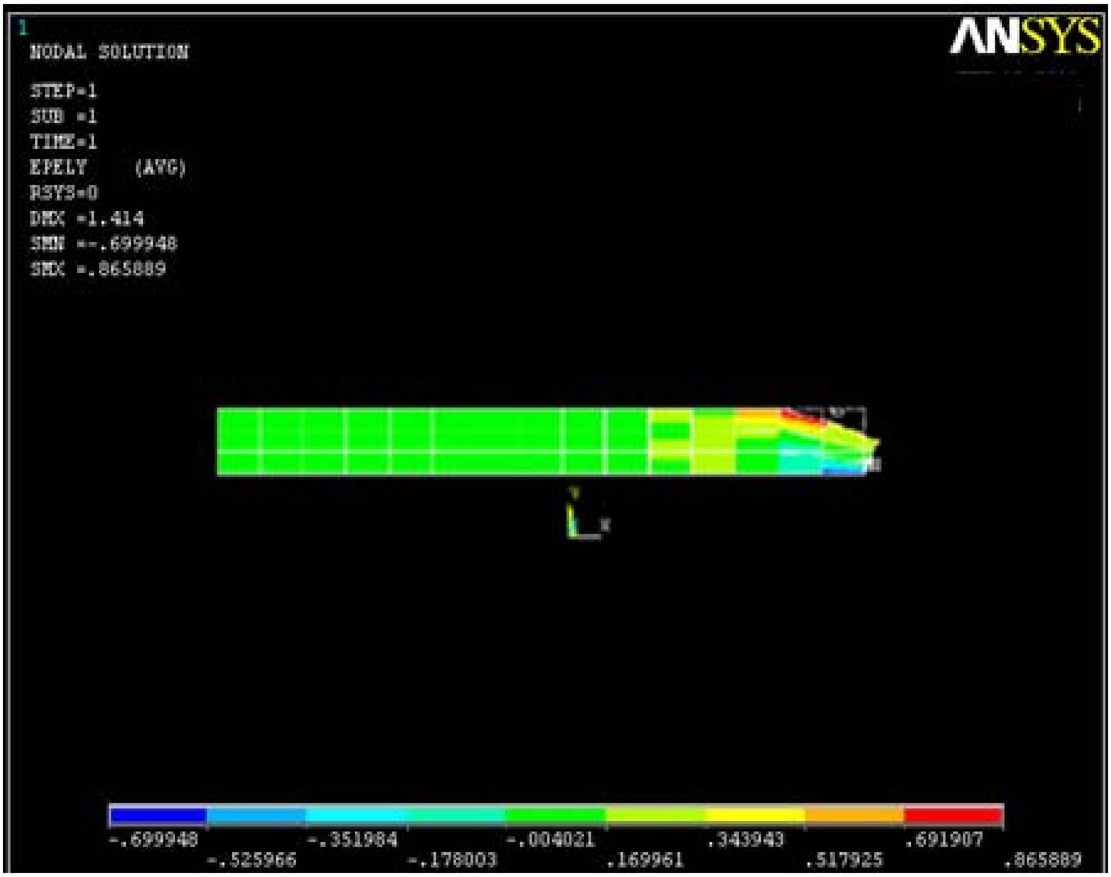
- *At 4.5mm of aluminium sheet metal energy dissipation is*

$U_{min} = \frac{1}{2}[\sigma min x \varepsilon min = \frac{1}{2}[-0.303525 * (0.851 * 10^{-3})] = -0.1291 * 10^{-3}$

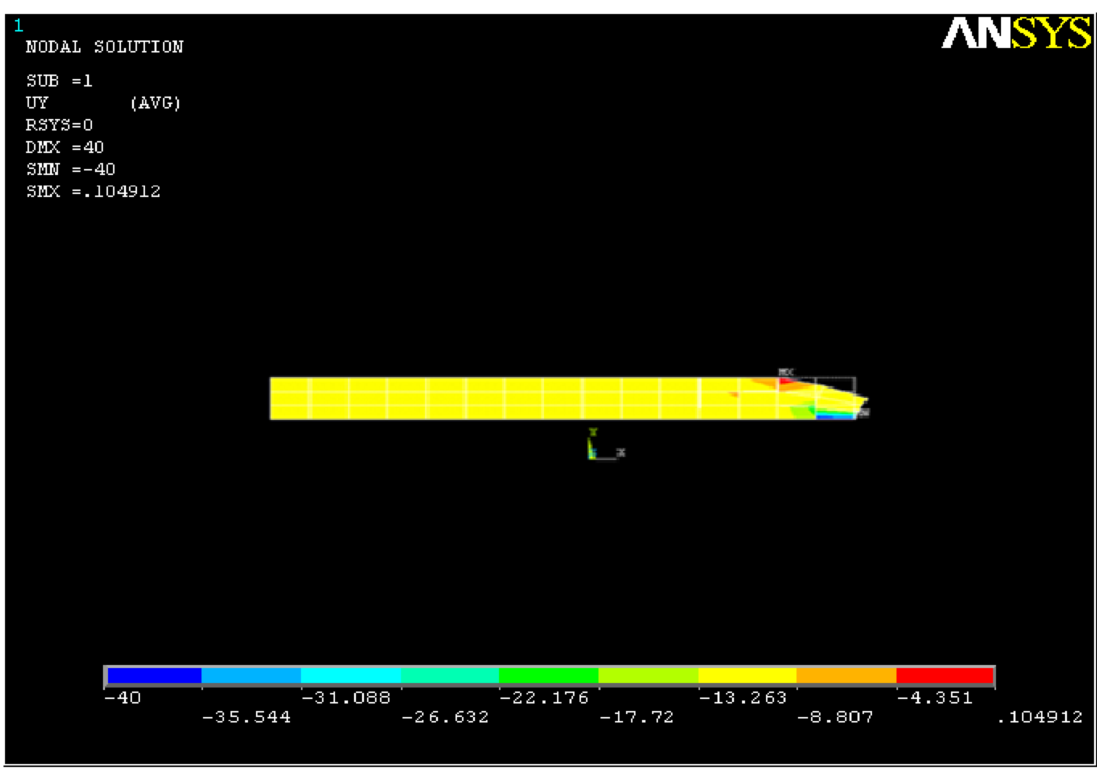
$U_{max} = \frac{1}{2}[\sigma max \varepsilon max = \frac{1}{2}[0.123278 * (0.206)] = 0.01602$

$U_{spring\ back} = U_{max} - U_{min} = [0.01602 - (-0.1291 * 10^{-3})] = 0.016149$

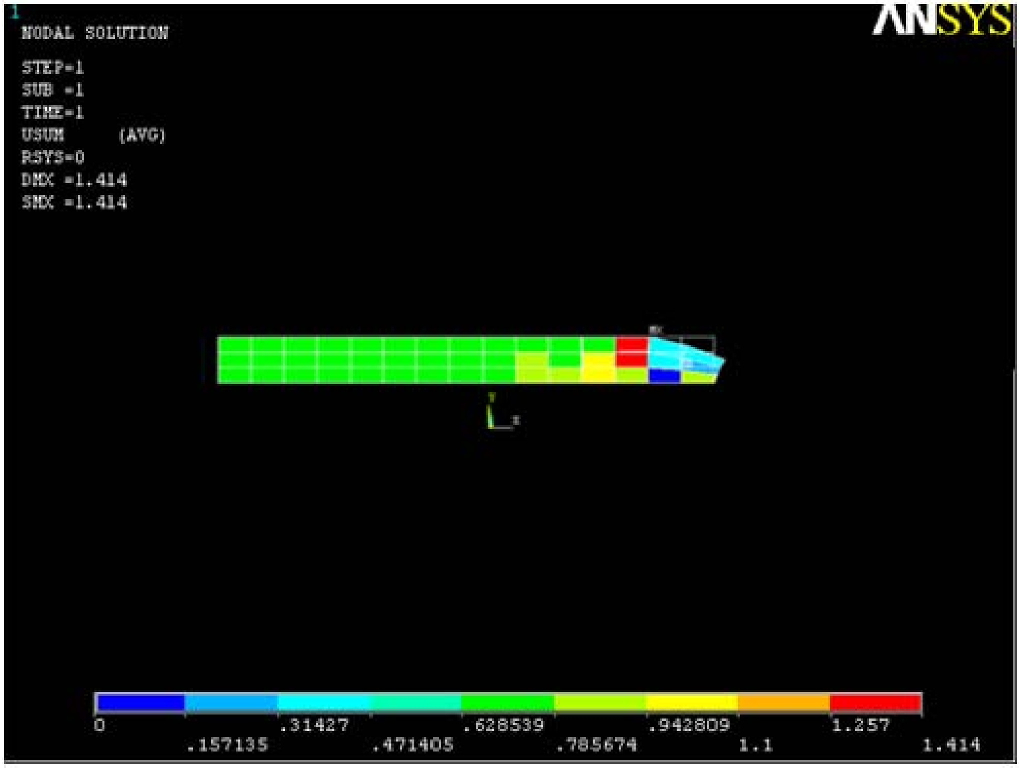
From the numerical result the minimum (SMN), and maximum stresses/ strain (SMX), in different coordinate system the results are display. On the result shown Figure 6.6 (a-h) indicates that, with the smaller sheet metal thickness the energy dissipation due to elastic deformation_is large. But when increasing of sheet thickness from (0.8 mm to 4.5mm) the energy dissipation due to stress/strain variation is reduced from -0.22 to 0.01615, this implies that maximum energy dissipation_is close to the minimum energy dissipation value. When the minimum energy dissipation approach to the maximum value the material is deform plastically. Hence, the spring back is reduced while increasing of sheet metal thickness. Hence, increasing of the thickness from 0.8mm 4.5mm within this range the spring back is reduced 20.35%



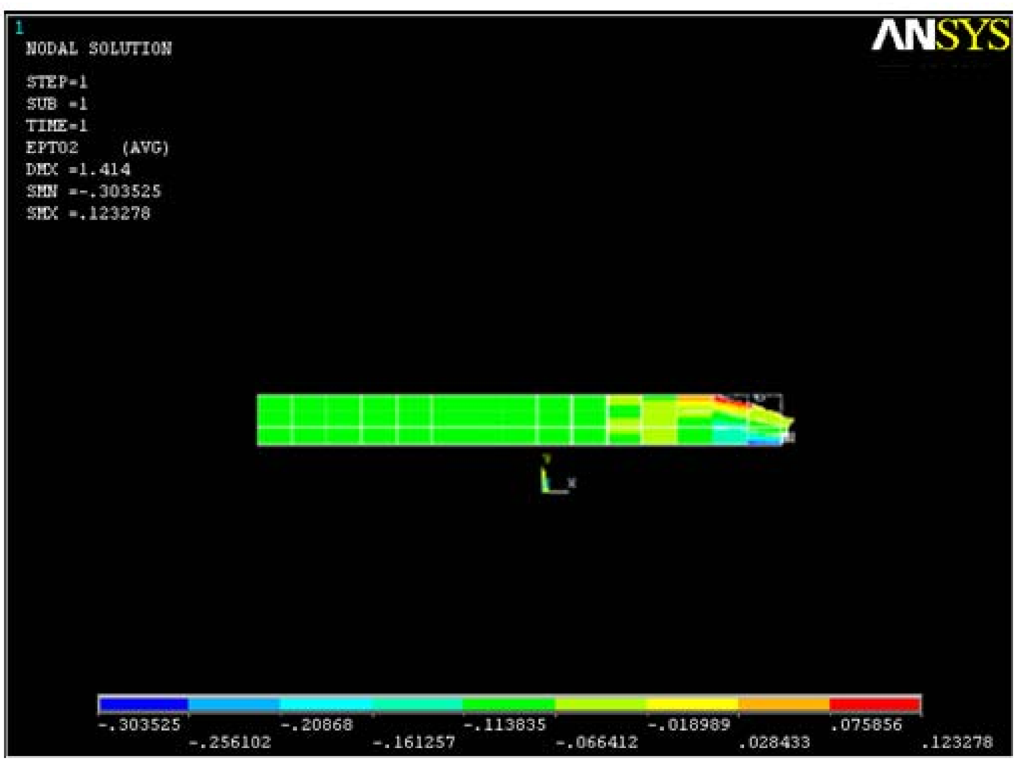
a) Nodal solution x-component (0.8 mm thickness)



b) Nodal solution y-component (0.8 mm thickness)



c) Nodal solution z-component (0.8 mm thickness)



d) Nodal solution x- component (4.5 mm thickness)

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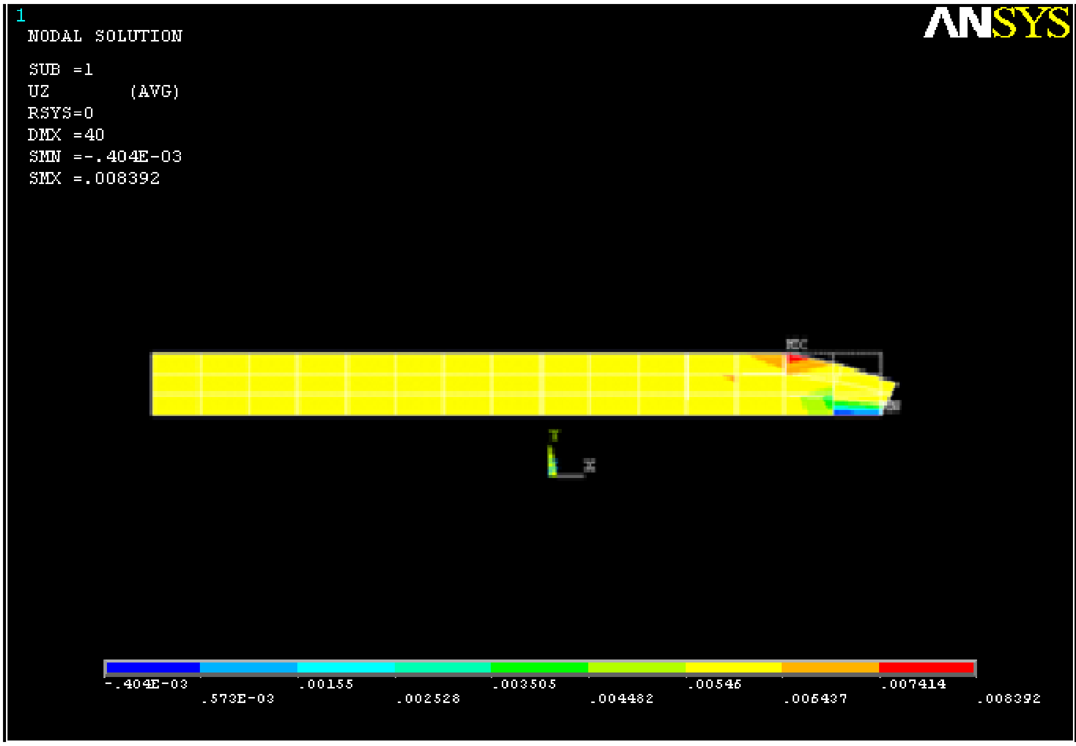
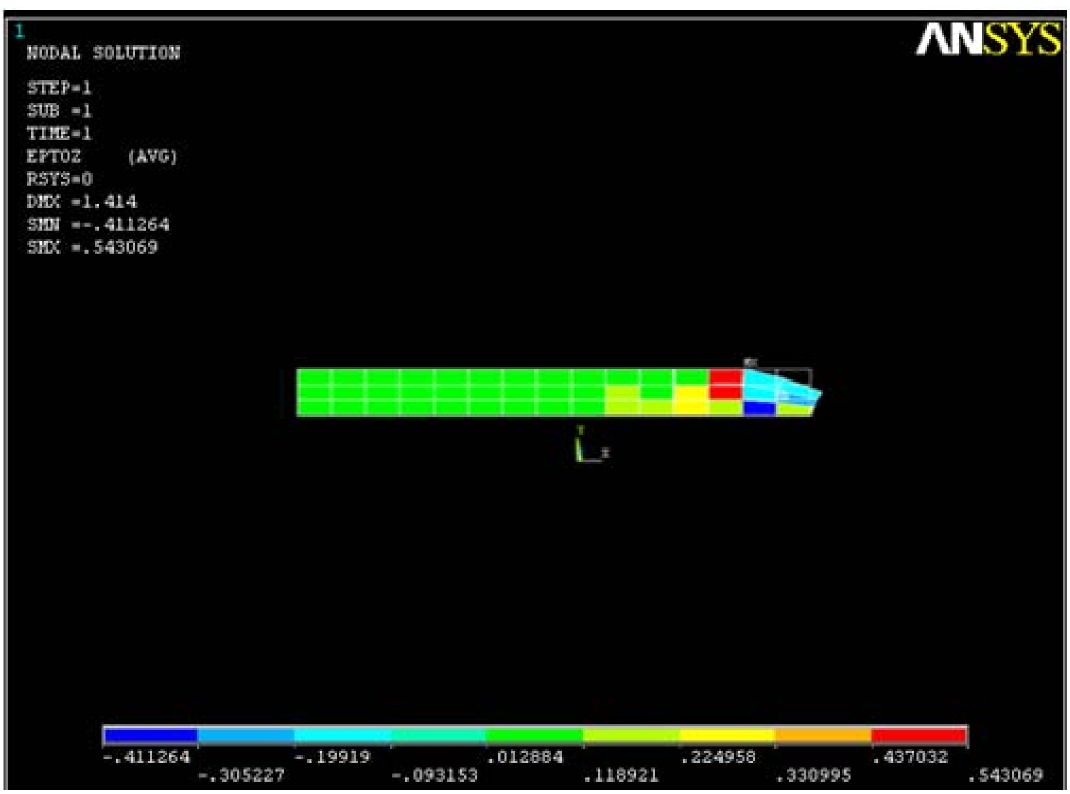
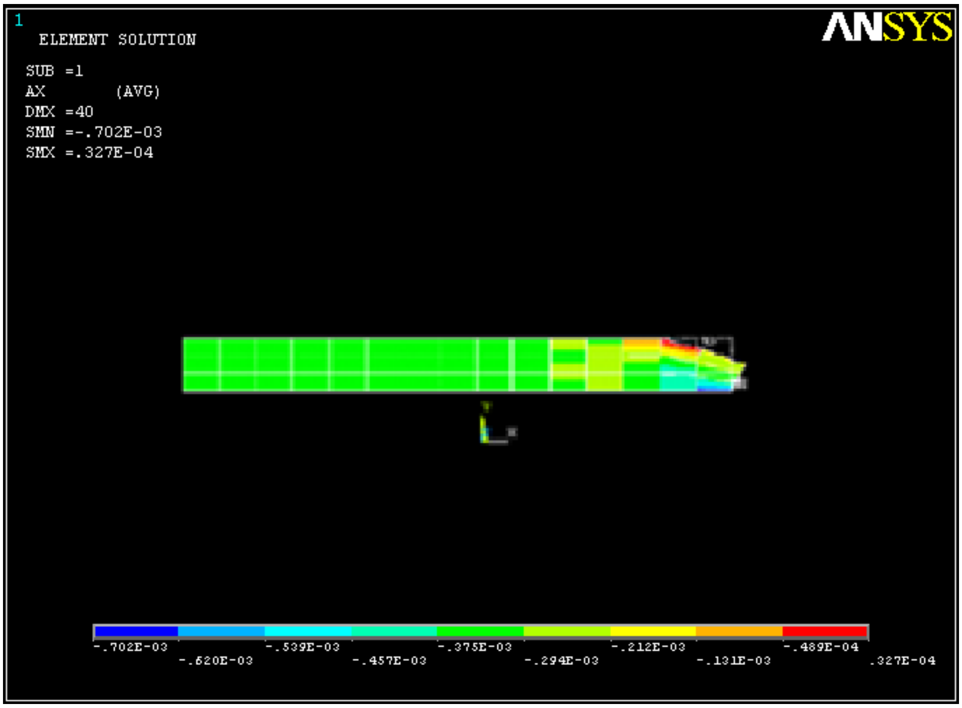


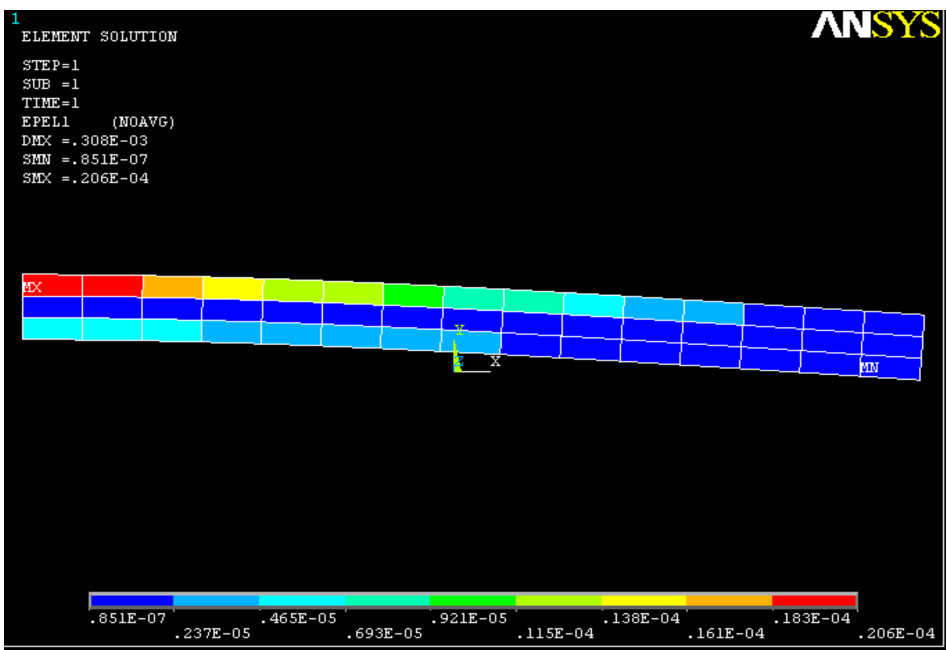
e) Nodal solution y-component (4.5 mm thickness)



f) Nodal solution z-component (4.5 mm thickness



g) Elastic Strain and Element solution for Aluminum sheet metal (at 0.8mm)



h) Elastic Strain and element solution for Aluminum sheet metal (at 4.5mm)

Fig. 6.6: The effect of sheet metal thickness

ii. *Effect of sheet metal Type*

❖ *At 0.8mm of aluminium sheet metal energy dissipation is*

$$U_{min=}\frac{1}{2}[\sigma min x \varepsilon min = \frac{1}{2}[-0.699948 * (-0.702)] = 0.24$$

$$U_{max=}\frac{1}{2}[\sigma max \varepsilon max = \frac{1}{2}[0.865889 * (0.0327)] = 0.0141$$

$$U_{spring\ back}=U_{max}-U_{min=}\ 0.0141 - 0.24 = -0.22$$

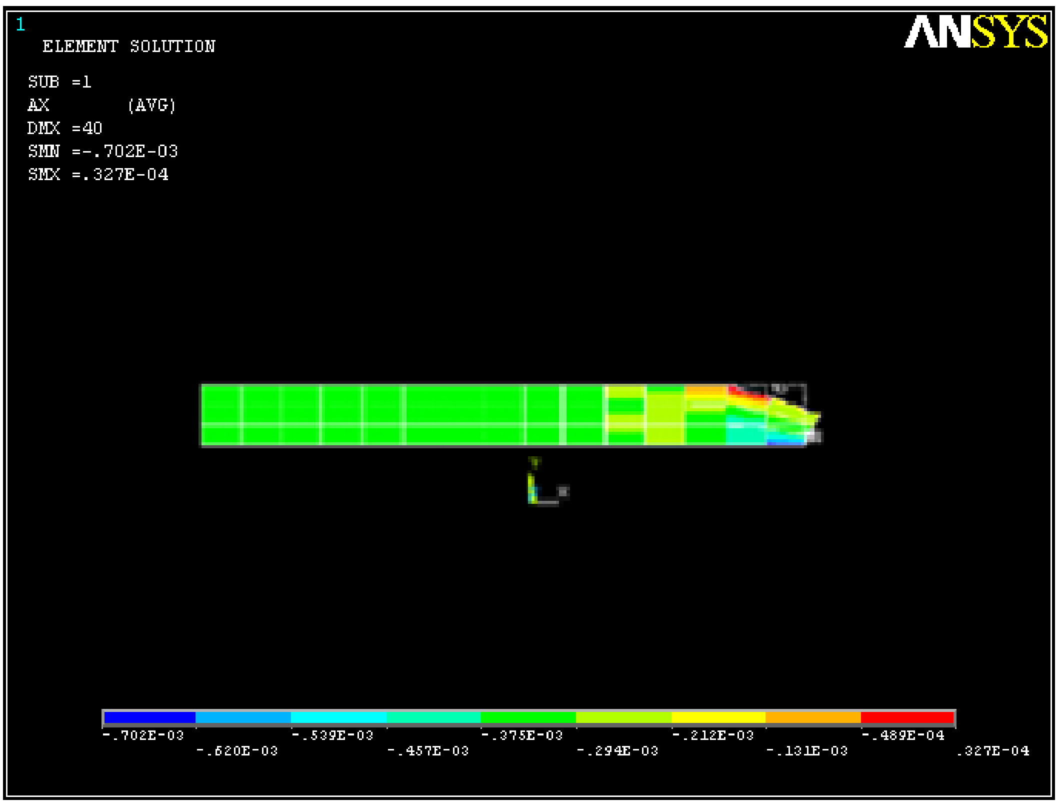
- *At 0.8mm of high strength steel sheet metal energy dissipation is*

$$U_{min=}\frac{1}{2}[\sigma min x \varepsilon min = \frac{1}{2}[0.202x10^{-3} * (-0.201x10^{-3})] = -0.0203x10^{-6}$$

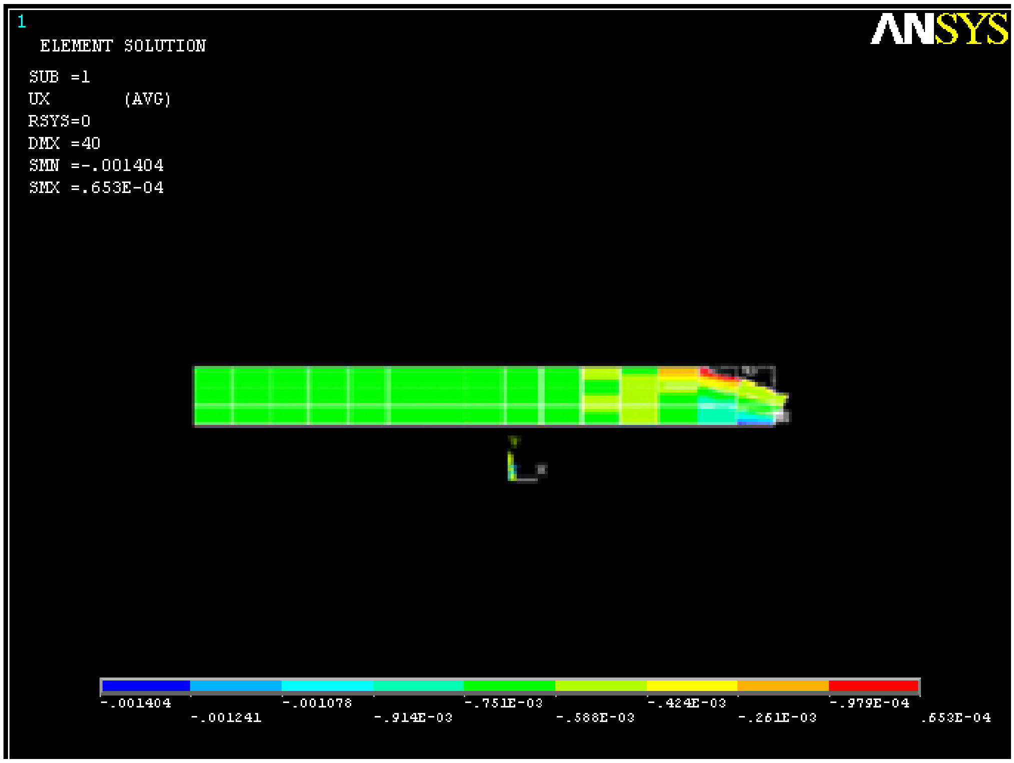
$$U_{max=}\frac{1}{2}[\sigma max x \varepsilon max = \frac{1}{2}[0.433x10^{7} * (0.004196)] = 0.908x10^{4}$$

$$U_{spring\ back} = U_{max} - U_{min=}\ 0.908x10^{4} - (-0.0203x10^{-6}) = 0.91$$

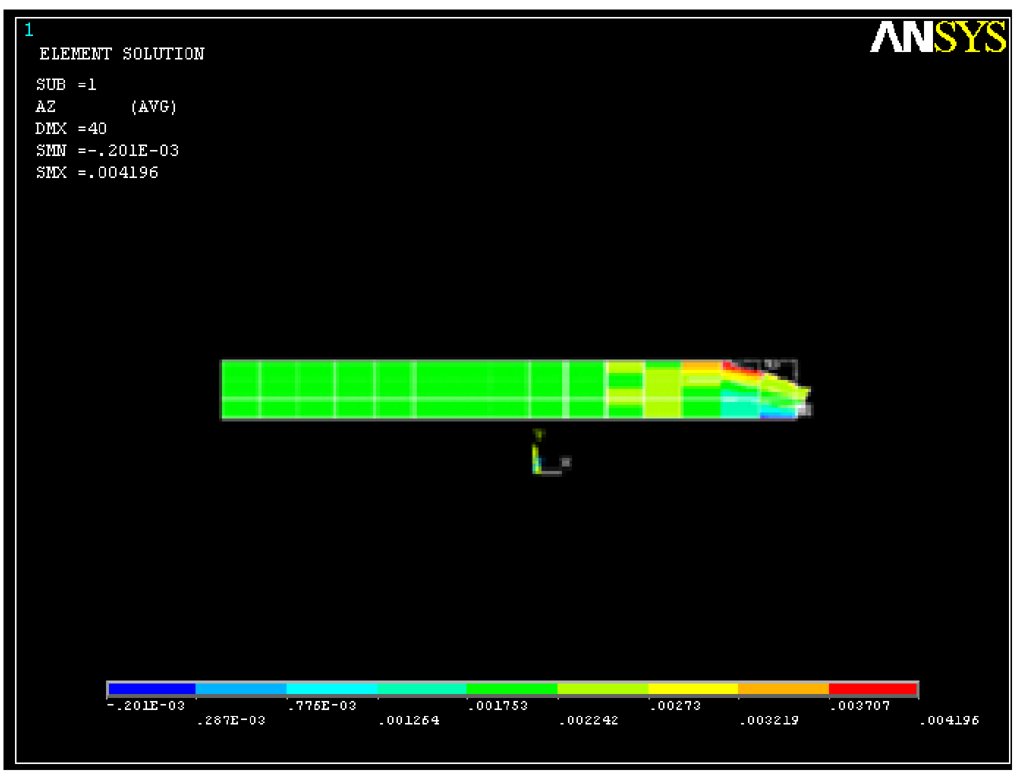
The numerical results of Aluminium, copper, mild steel and high strength steel sheet metal figure.6.6.and figure .6.7 (a-d) shows that for constant sheet metal thickness (0.8mm), the energy dissipation variation is range from -0.22 to 0.91 .Result clearly show that increasing the sheet metal strength (Aluminium to High strength steel) the variation increases. High strength steel needs a considerable higher amount of maximum punch load than the aluminium sheet metal. As we know increasing of sheet metal ultimate strength the punch load is increase. Due to this higher strength, the material is not easily deformed plastically. As a result, the material returns to the original shape and spring back occurs. Hence, the spring back increases from Aluminium to High strength sheet metal.



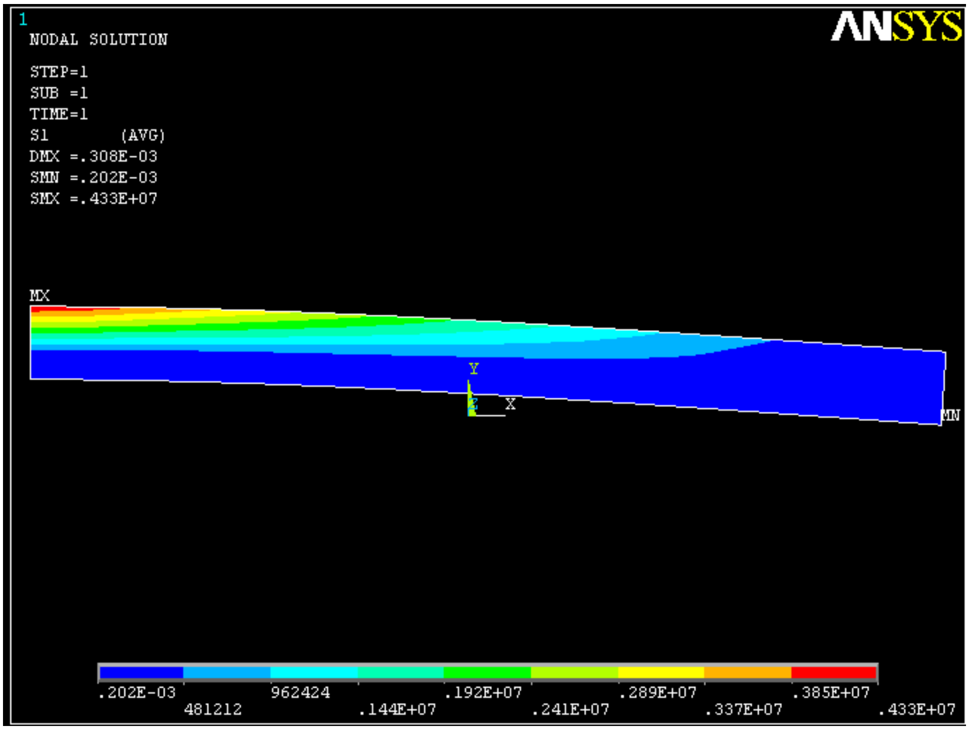
a) Element solution for Aluminum sheet metal (at 0.8mm)



b) Element solution for Copper sheet metal (at 0.8mm)



C) Element solution for High strength steel sheet metal (at 0.8mm)



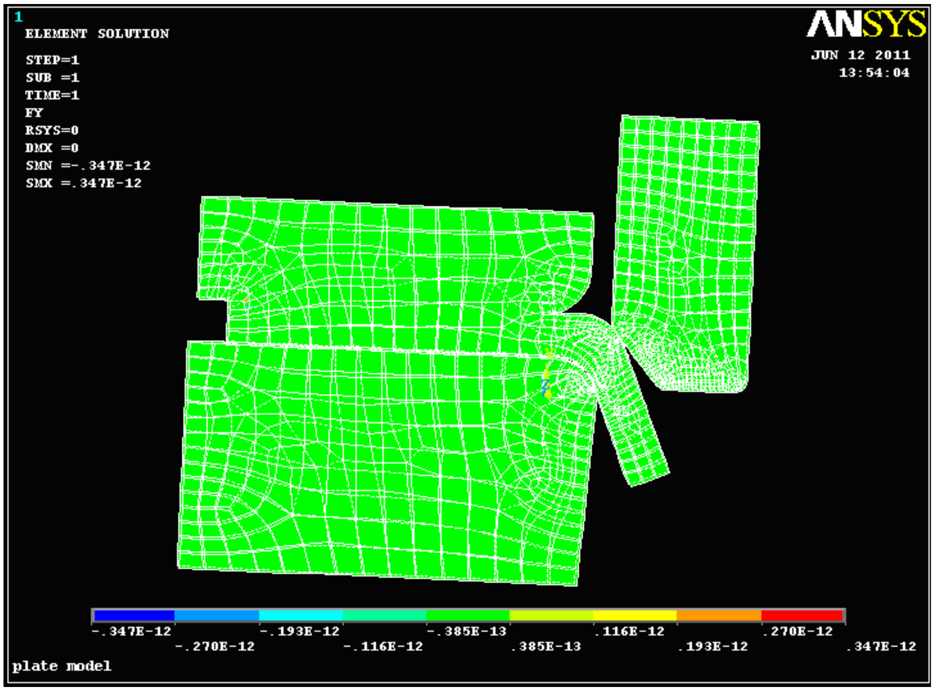
Stress and Nodal solution for High strength steel sheet metal (at 0.8mm)

Fig. 6.7: The effect of sheet metal Type

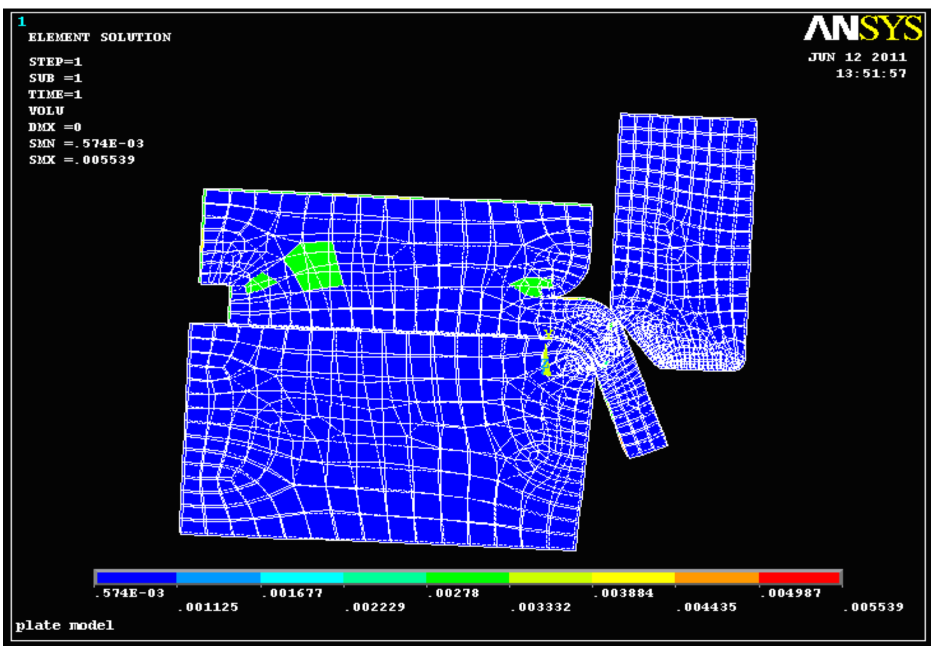
b) The effect of Tool geometry

i. *Tool radius (Rp)*

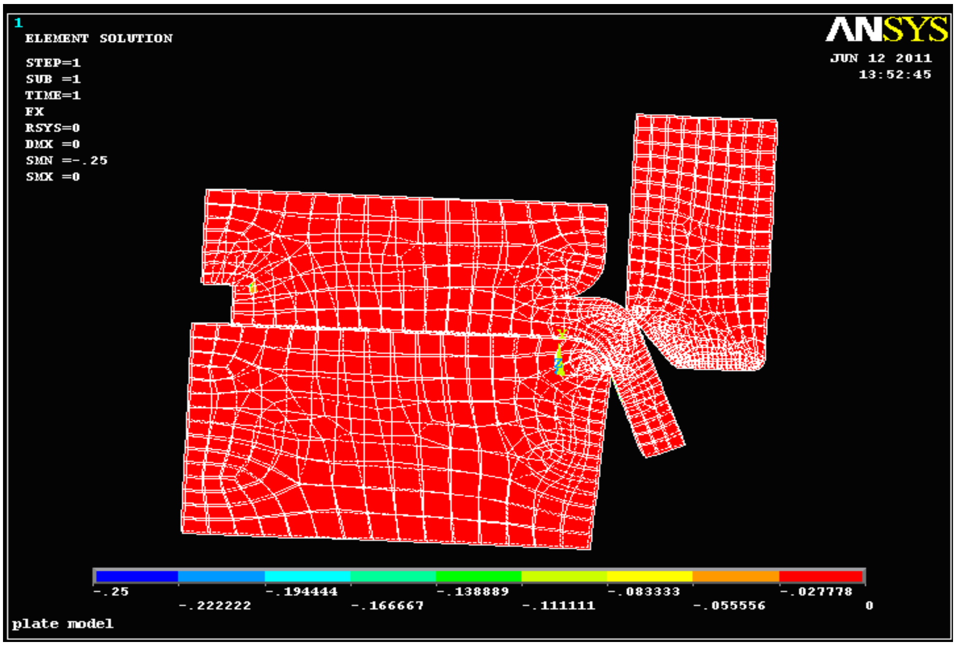
The analysis is to examine the effect of varying the punch radius on spring back. For this purpose the punch is having a different radius Rp, = 10mm, 16mm and 23mm are utilized. The spring back results obtained from numerical analysis in figure6.8 (a-c) shows that Smaller values of the punch radius (Rp=10mm), for the same blank thickness result in smaller spring back values in the deformed sheet metal. From the figure clearly indicates that for reducing of tool radius from23 mm to 10mm the spring back is reduced.



a) Element solution for punch radius (Rp) =10mm



b) Element solution for punch radius (Rp) =16mm

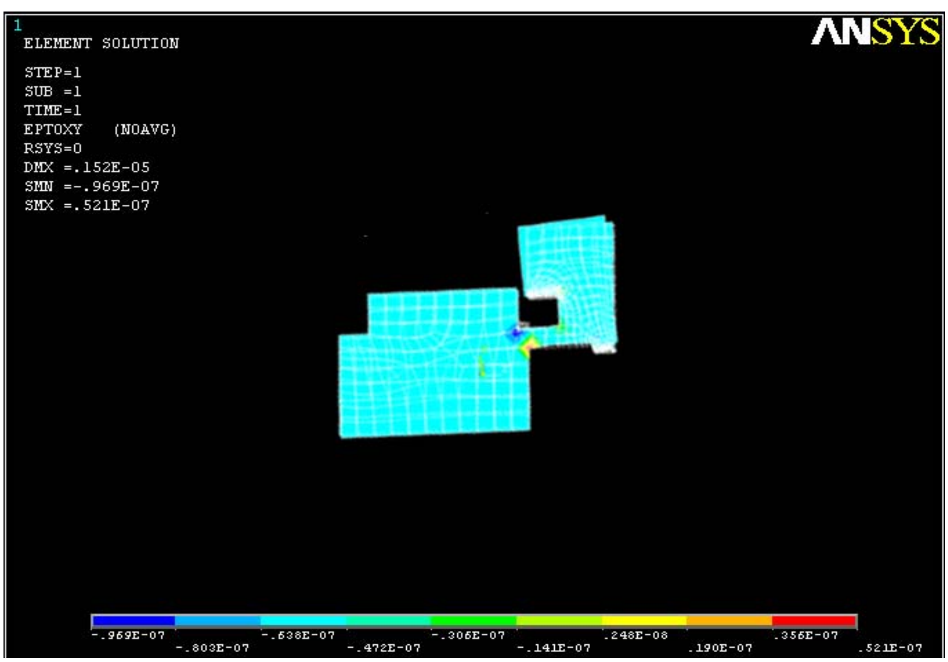


c) Element solution for punch radius (Rp) =23mm

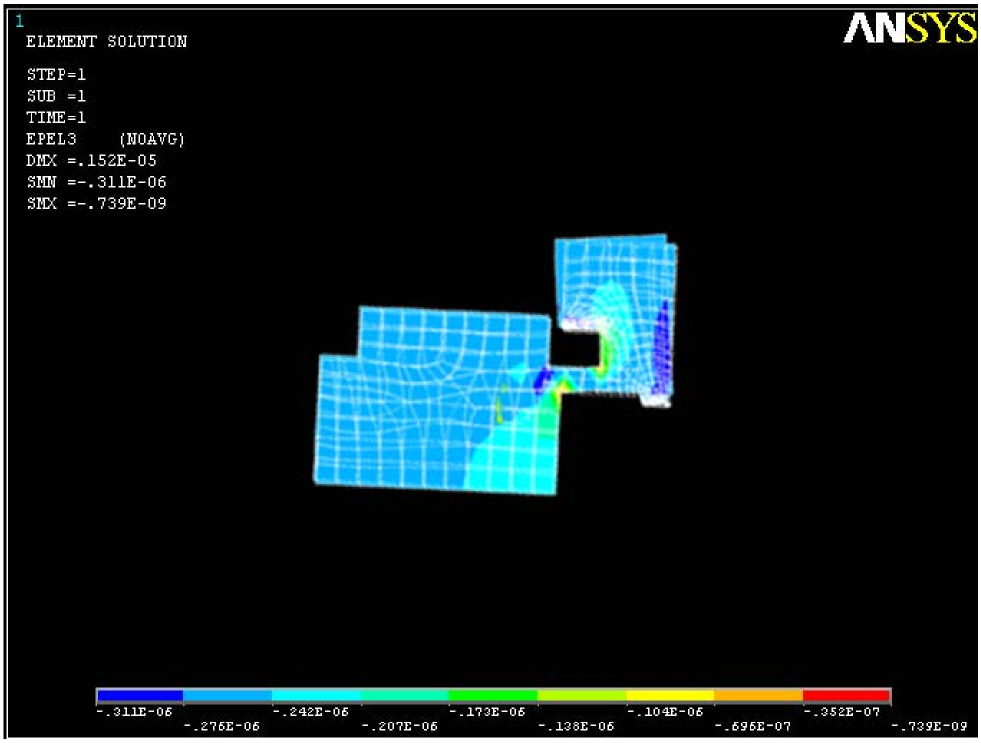
Fig. 6.8: The effect of tool radius (Rp)

ii. *Effect of Tool Shape*

In the case of edge bending die observed in fig 6.8 variation of the result range from -0.25to 0.0739 and in the case of differential die the variation ranges from 0.16 to 0.23 .these result shows that in the case deferential die the result close to the maximum value. The reason is in deferential die the pressure is applied in different cross sections of the blank. Due to this the material is deformed plastically. Hence, tool Shape is a significant factor for spring back formation and spring back is highly reduced in the case of differential die bending.



a) Element solution x -component (with 0.8mm thickness Al sheet metal)



b) Element solution y-component (with 0.8mm thickness Al sheet metal)

Fig. 6.9: The effect of tool shape

iii. *The effect of friction*

❖ *At 0.01 friction coefficient the energy dissipation is*

$$U_{min=}\frac{1}{2}[\sigma min x \varepsilon min = \frac{1}{2}[61211 * (0.181x10^{-8})] = 0.26$$

$$U_{max=}\frac{1}{2}[\sigma max \varepsilon max = \frac{1}{2}[0.433x10^{7} * (0.311x10^{-6})] = 0.67$$

$$U_{spring\ back}=U_{max}-U_{min=}\ 0.67 - 0.26 = 0.19$$

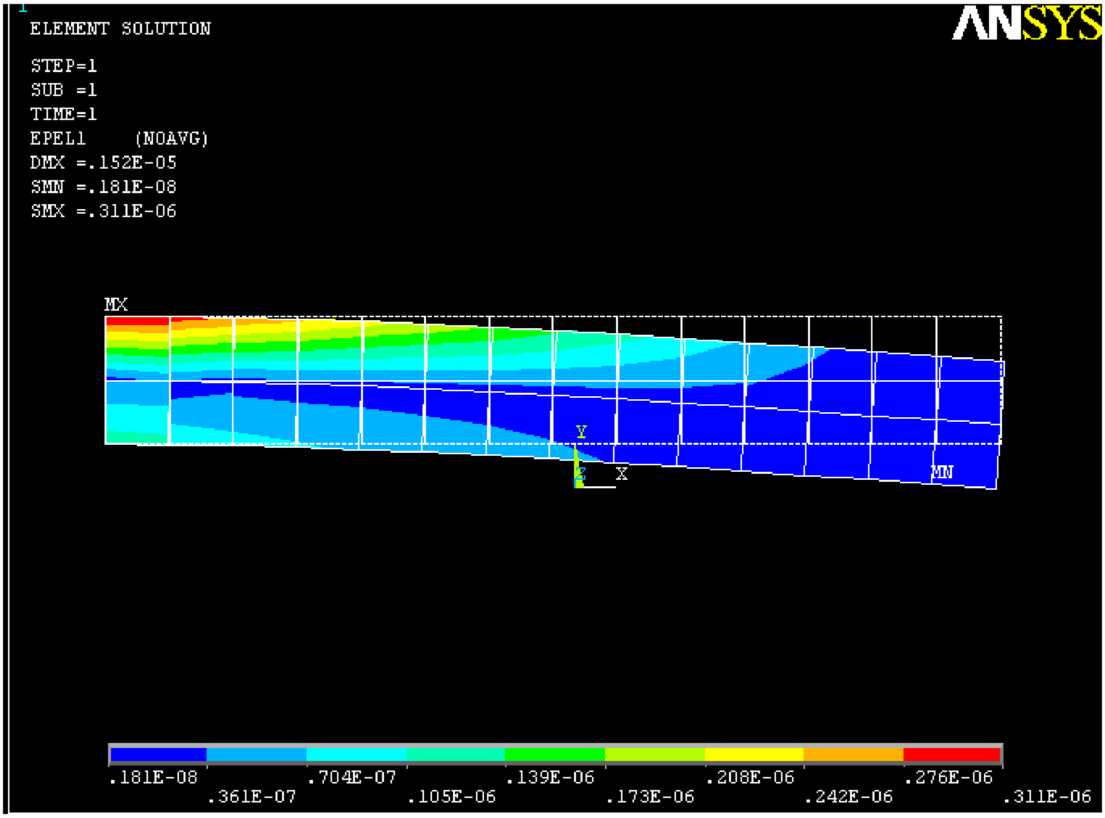
At 0.50 friction coefficient the energy dissipation is

$$U_{min=}\frac{1}{2}[\sigma max \varepsilon max = \frac{1}{2}[-0.433x10^{7} * (-0.122x10^{-6})] = 0.524$$

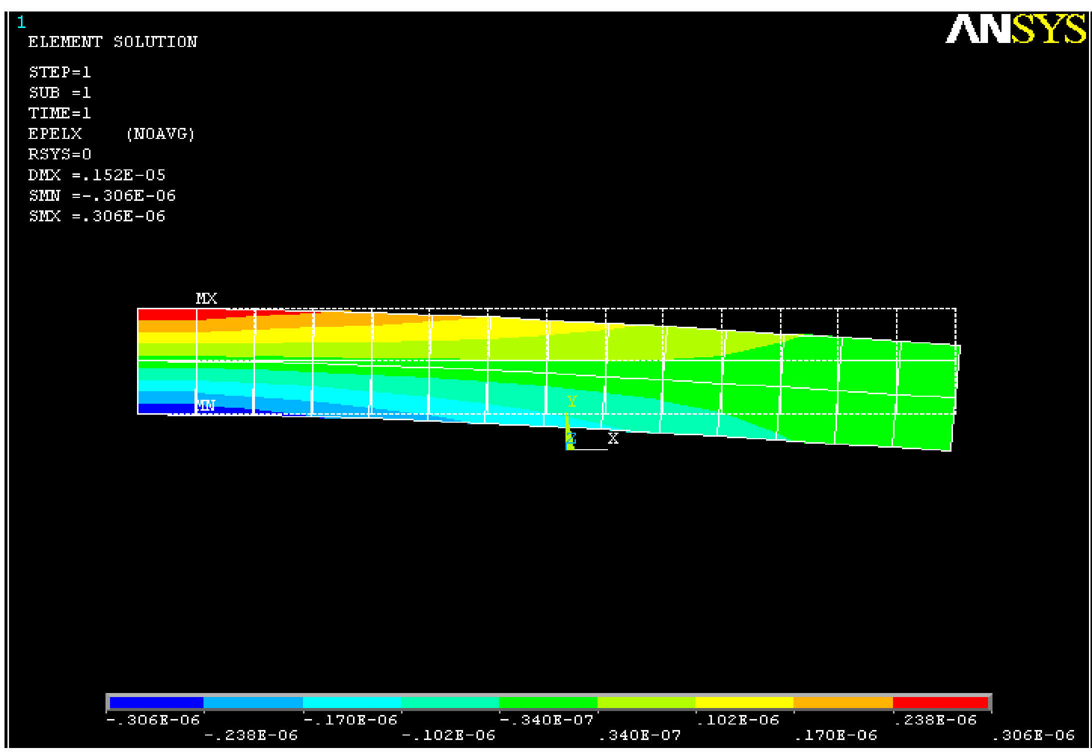
$$U_{max=}\frac{1}{2}[\sigma max \varepsilon max = \frac{1}{2}[-821.995 * (0.122x10^{-6})] = -0.05x10^{-3}$$

$$U_{spring\ back}=U_{max}-U_{min=}\ -0.05x10^{-3} - (0.524) = -0.5205$$

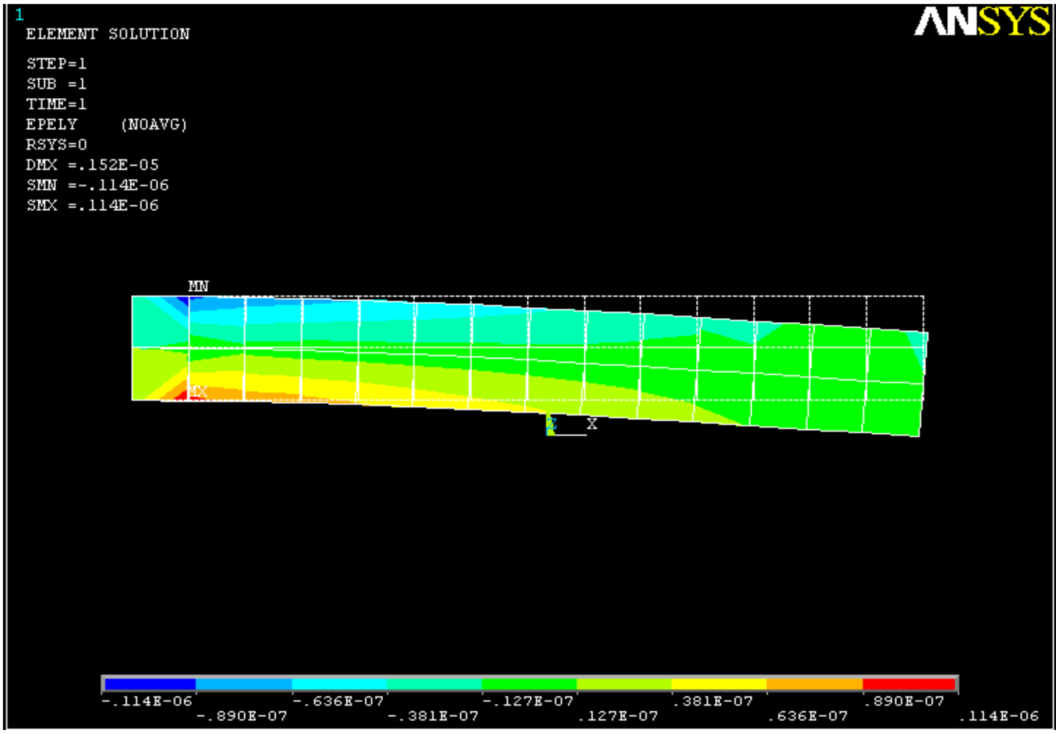
Numerical result conducts that, the coefficient friction varies from μ = 0.01 to 0.50, with constant dimension and the same sheet metal type. The result increases from 0.19 to 0.52 these needs for maximum bending force. During increasing of the bending force the material will be deformed plastically. But this higher amount force is removing from the material it is highly returned to the original position. Due to this fact the spring back is increased by increasing of friction coefficient for certain limit.



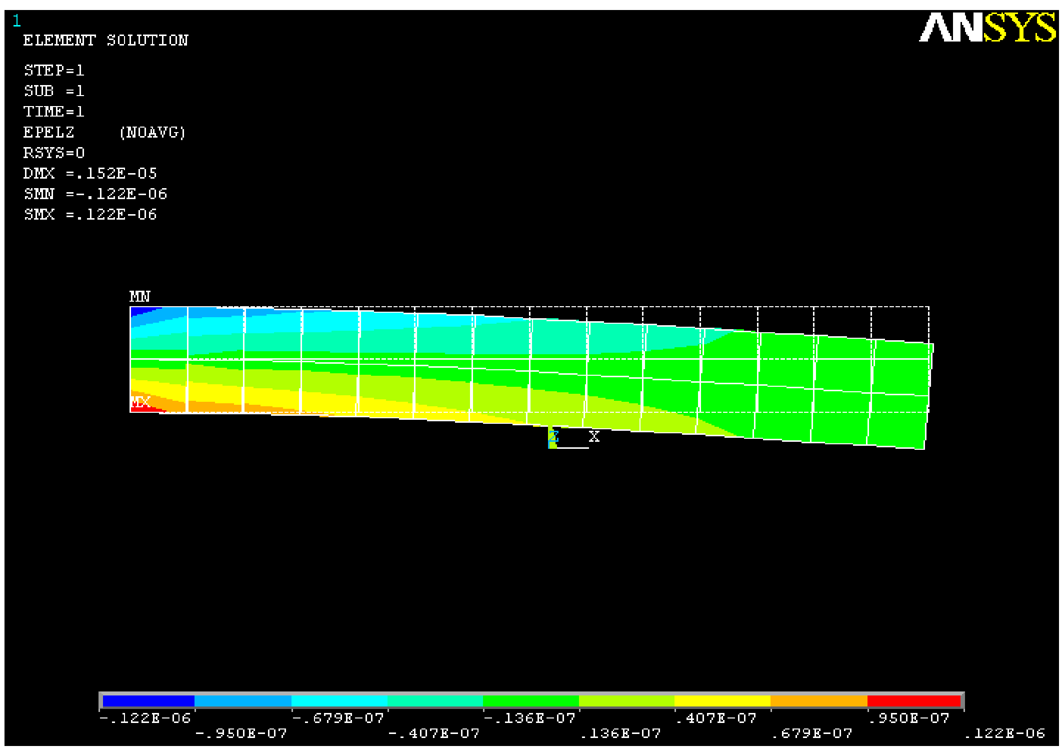
a) Element solution y-component (at μ =0.01)



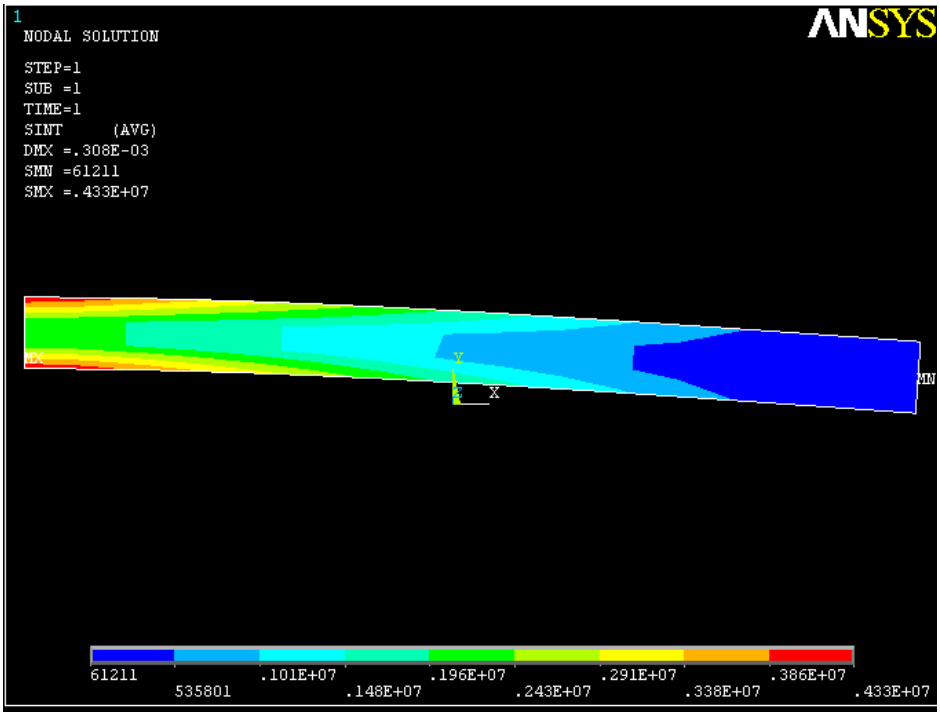
b) Element solution y-component (at μ =0.05)



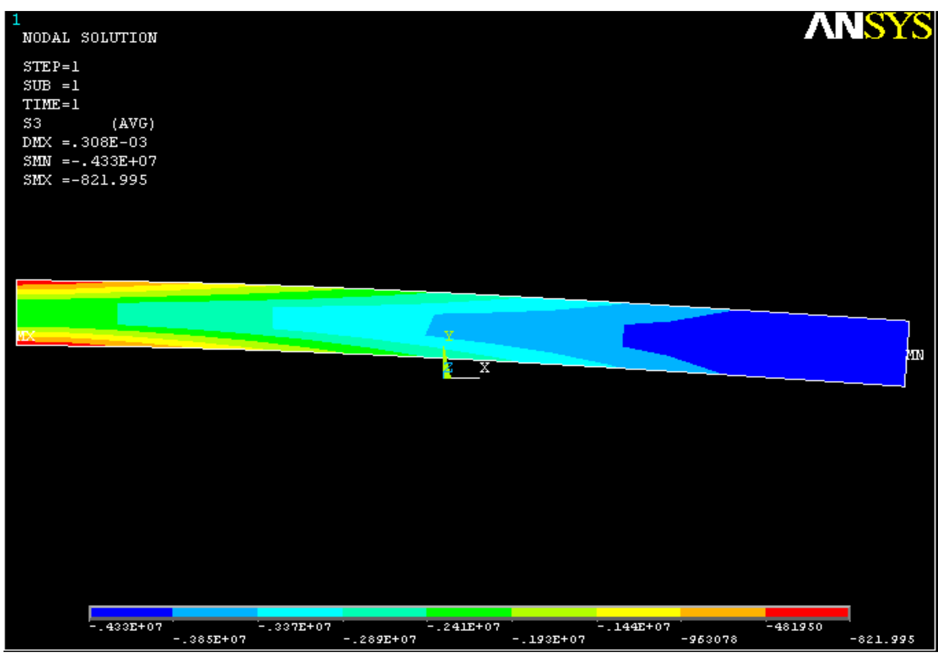
c) Element solution y-component (at μ =0.15)



d) Element solution y-component (at μ =0.50)



e) Stress and Nodal solution y-component (at μ =0.01)



f) Stress and Nodal solution y-component (at μ =0.5)

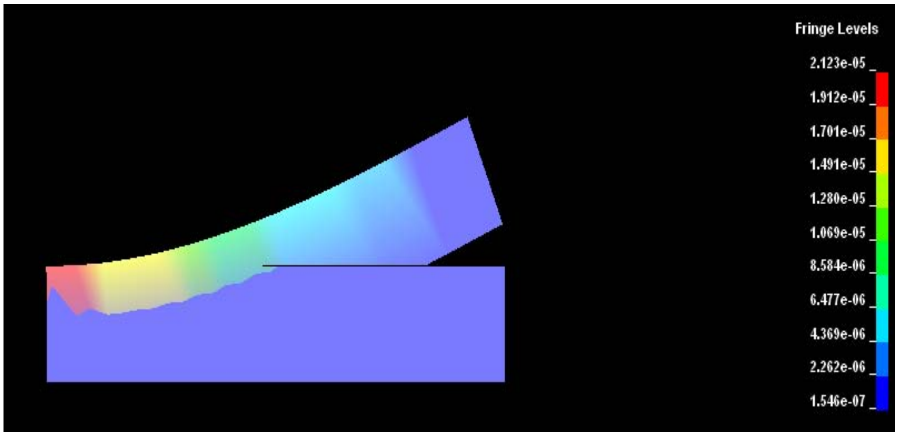
Fig. 6.10: The effect of friction

IV. Implicit Results

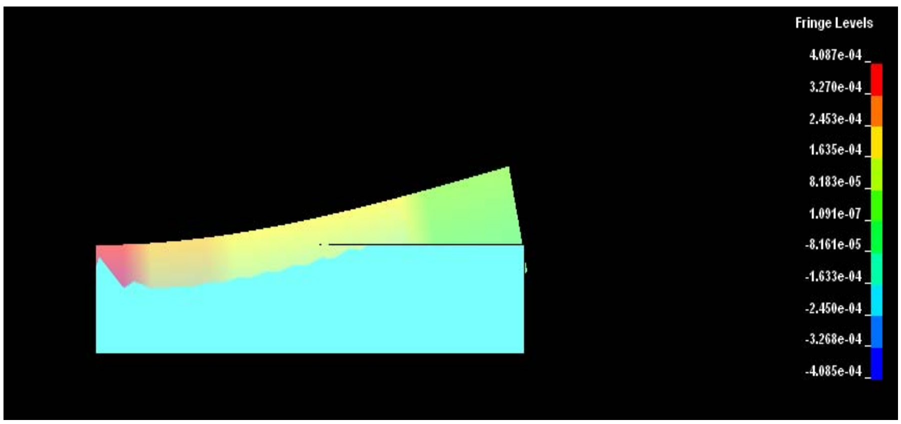
The implicit numerical results have the same effect with explicit result but the difference is the amount of values for the parameters.

a) The effect of sheet metal thickness

The implicit result shows in Figure 6.11 with the smaller sheet metal thickness the stress and strain variation are large. But when increasing of sheet thickness from (0.8 mm to 4.5mm) the stress variation is reduced from 2.12 to - 0.0154. This implies that increasing of the thickness from 0.8mm 4.5mm the spring back is reduced.



a) Mean strain at (0.8mm thickness)

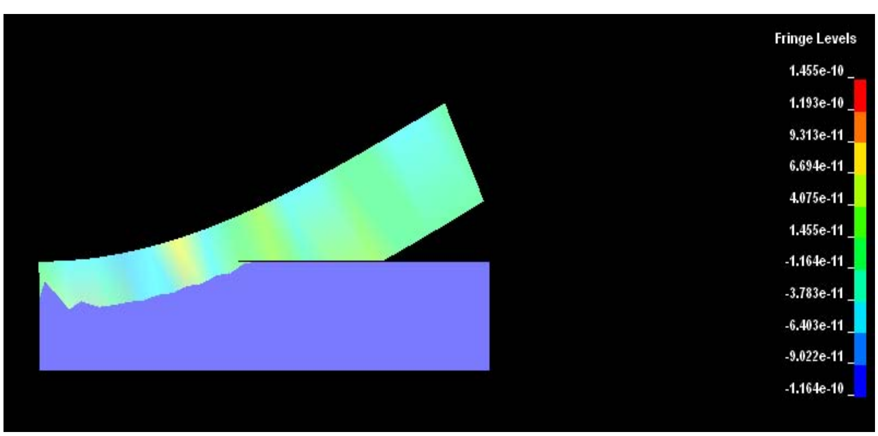


b) Mean strain (4.5 mm thickness)

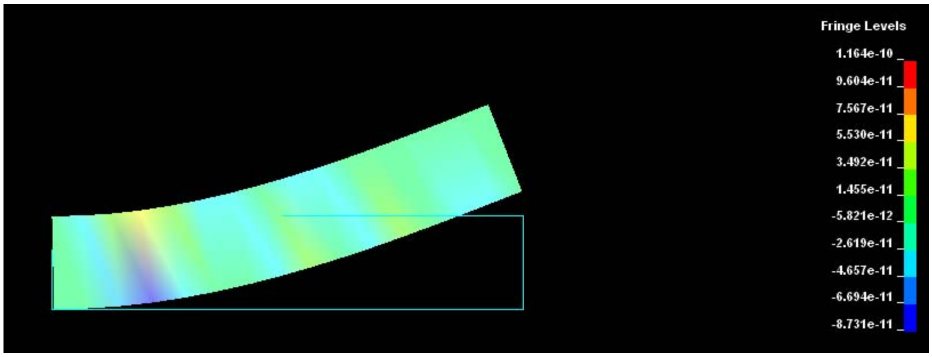
Fig. 6.11: the effect of thickness

b) Material type

The effect of sheet metal type shows that in figure 6.12 for constant sheet metal thickness, the stress variation is range from - 0.0154 to 0.212. The results clearly show that increasing the sheet metal strength (Aluminium to High strength steel sheet metal) the variation increases. This is due to the yield stress of the sheet metals that is spring back of sheet should be bent, depends on the yield strength of the material. As the materials yield strength increases the spring back after unloading also increases. The spring back will occur where the yield stresses of the material is grater than the stress after Un-loading condition. If the yield stress is equal the stress after deformation, there is no spring back .hence the spring back increases from Aluminium to High strength sheet metal.



a) Mean strain (Aluminum sheet metal)

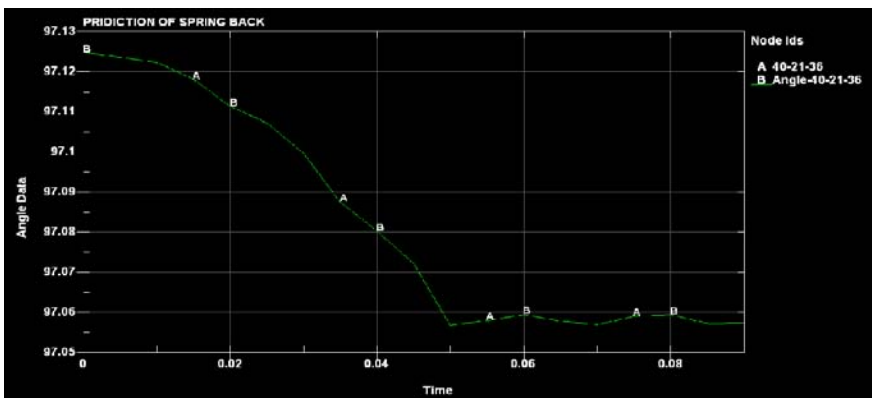


b) Mean strain (High strength steel sheet metal)

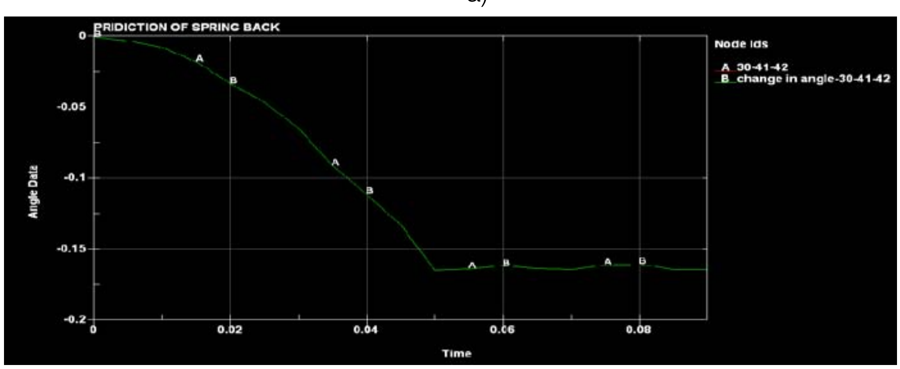
Fig. 6.12: the effect of thickness

c) The effect of angle

Fig 6.13 shows that the bending angle increases the variation will be reduced, when the variation of spring back angle decrease the spring back also decrees.



a)



b)

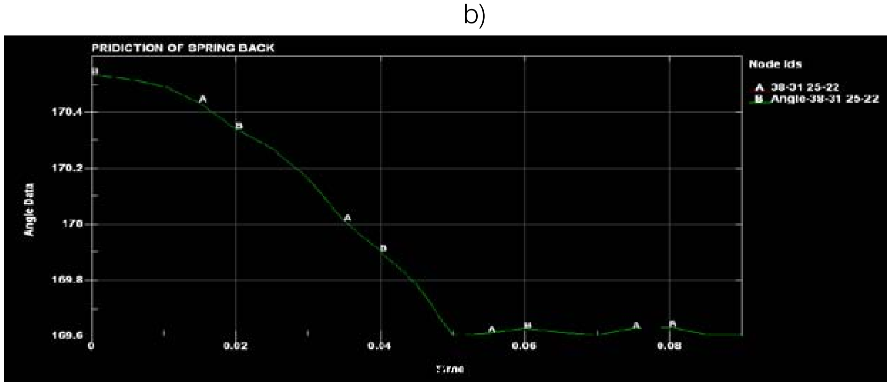
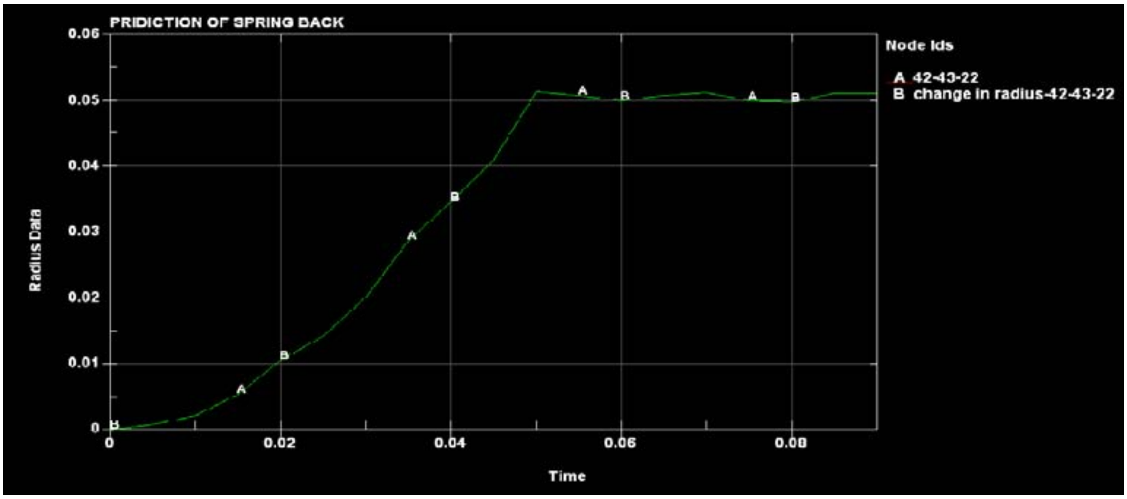


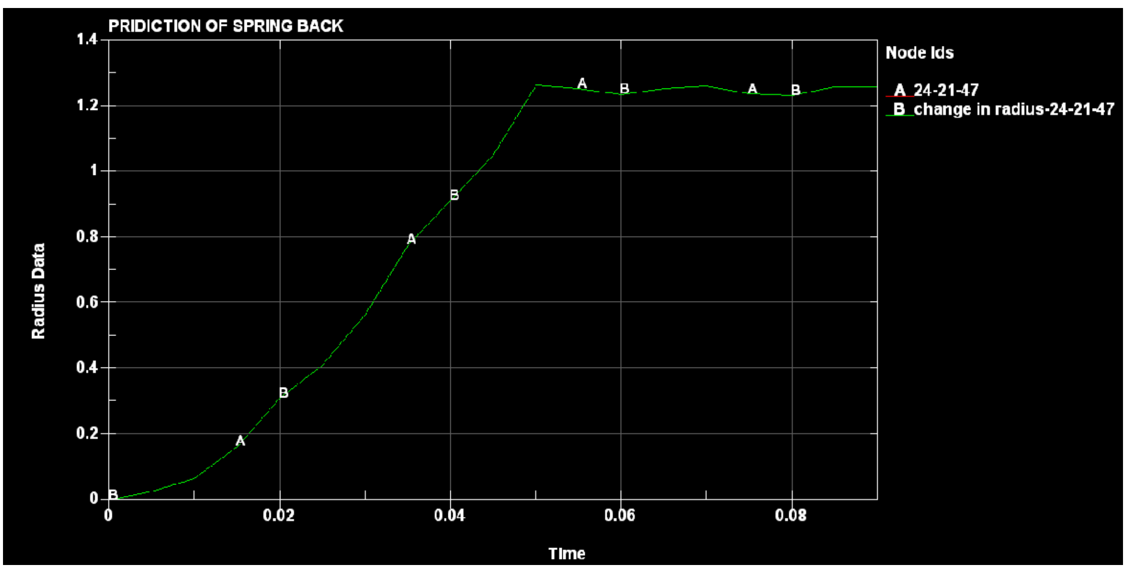
Fig. 6.13: Effect of bending angle

d) The Effect of tool Radius

The numerical results shows in figure 6.14, For Small punch radius the numerical result have smaller spring back values in the deformed sheet metal. From this result predicts that for increasing of tool radius from 21 to 47 mm the spring back is increase from 0.01 to 1.2.



a)



b)

Fig. 6.14: The effect of tool radius

V. Validation of the Mode

Under this topic Analytical predictions are compared with the previous studies. In the second method, we compare the Analytical investigations with the finite element predictions. It is an effective result in comparing for the validation of the attained results.

a) Comparison of our investigation with the previous studies

The Stepped Binder Force Trajectory and Neural Network Control proposed by Jian Cao and Brad Kinsey in order to predict and control spring back in forming process. Regarding the sheet thickness and binder force as possibly the most significant process parameter, the robustness of their control system was tested against variations in the friction coefficient, and excellent results were obtained. However, the effect of material type in the material properties and sheet thickness were not investigated in their work. Therefore, further closed-loop control simulations with these variations were conducted here in order to form a comparison with the neural network control system. The spring back angle values from these neural network control system have wider difference comparing to our result. The resulting spring back angle from the process was calculated within a range of 0.29° to 1.8°. For sheet metal thickness range from 0.8-4.5mm.but in the case of our result within the same thickness range the spring back angle values are 019-0.03. This indicates that the spring back angle of our analysis was considerably less and closer to the original angle. Though the method we have to use and developed are required producing accurate and sufficient results for predicting and controlling of spring back comparing with natural network control method. Recep Kazan (2008) was also conducted to predict spring back in wipe-bending process of sheet metal using artificial neural network (ANN). Here, several parameters were considered to predict spring back. The important parameters they considered for the analysis were sheet thickness and tooling geometry are used. In order to investigate the effect of die radius and blank thickness on the spring back angle of flanging process, models were done with the sheet metal thickness are taken as 0.7mm to 5.0mm and die radius also 0.7 to 5.0mm should considered. However the results with variations in sheet thickness (0.8-4.5mm) spring back angle by artificial neural network were investigated 1.763°. -1.24°.

For constant thickness with different sheet metal type the Variations of radius was investigated 1.2764.-1.89 but in our result the spring back is predicted with 0.08-0.49°.and 0.557-1.333 angle and tool radius respectively. From these analysis our parameter selection and prediction method (analytical and FEM) is better for prediction of spring back and optimization of bending process.

VI. Conclusions and Recommendation

a) *Conclusion*

In this research work a detailed study of the parameters that influencing on spring back was conducted. The conducted literature review revealed that, although similar studies were conducted in the previous developed models were unable to consider simultaneously all the parameters influencing spring back formation. Accordingly this work is an attempt to study spring back by including more parameters at a time in order to study spring back and predict the amount of spring back in sheet deformation process, thereby optimizing the sheet bending process. However a numerical investigation of spring back is conducted using ANSYS™ LS-DYNA™. The developed implicit and explicit numerical models are used for prediction of spring back formation by varying parameters such as: sheet metal material and thickness, coefficient of friction between the die and the material, and tool radius and tool shape .

The results were compared with the previous study results and, the following conclusions were drawn from this study;

- The result shows that increasing sheet metal thickness from 0.8mm to 4.5 mm the spring back is reduced by 20.35 %.
- When increasing of sheet metal strength spring back increases however, in these cases more maximum required punch loads are needed. Aluminium exhibits lower spring back than mild steel and high strength sheet metals. Using Aluminium sheet metal instead of High strength sheet metals spring back is reduced by 56. %
- For decreasing of the tool radius leads to spring back is reduced.
- Modifying tool shape also changes spring back. i.e. using deferential die instead of edge bending die the spring back is reduced by 12 %
- Increasing of friction coefficient from 0.01 to 0.50 the spring back is increase by 52%.
- Hence, an optimum value of sheet metal thickness, material type and tool radius should be chosen for reducing of spring back. Finally utilizing and compensation of tool geometry is considered for optimizing of bending process, when the spring back is reduced, this is also helps to obtain quality sheet metal product manufacturing.

b) *Recommendation and future works*

Some of the suggestions for further investigations are:

- To verify the spring back prediction through an experiments
- To compensate of spring back in the die design using FE simulations
- Development of spring back prediction is conducted in warm and cold sheet metal conditions are also considered.

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