ANALYTICAL AND EXPERIMENTAL EVALUATION OF SPRING BACK EFFECTS IN A TYPICAL COLD ROLLED SHEET

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ABSTRACT
Prediction of spring back for forming of a typical shape of Cold Rolled steel sheet has been carried out using FEM. The objective of this work is to predict the spring back in the form of a typical shape of cold rolled steel sheet and compare that with the actual spring back as occurs in experiment. A typical shape is designed using AutoCAD and Solidworks. Die and punch to form the shape has been designed using 2d and 3d modelling tools. The Finite element simulation is done considering the material and geometric nonlinearity. Non-linear material properties are obtained from the tensile testing of the standard test specimen made from the same material and of same thickness. Geometric nonlinearity is considered by selecting appropriate option in the FEM package. Die, punch and sheet are considered in the finite element analysis. Final deformed shape after occurrence of spring back has been obtained in the finite element analysis. Die, punch and sheet is made for model blade and forming operation is carried out using hydraulic press. Spring back obtained in the actual forming of the sheet is measured and compared with the FE analysis results which are in line with each other.

Key words: Die, Experiment, Finite Element Analysis, Forming, Nonlinear, Punch, Sheet, Solid Model, Spring Back

1. INTRODUCTION: SPRING BACK

As sheet bending is an important manufacturing process, it is prudent to be able to predict many of the causes and effects of spring back. The phenomena of unbending of a metal strip after a forming operation is called spring back. Control of spring back for the bending processes applied in practice is difficult for a number of reasons, especially in mass production. Sheet metal forming processes, such as bending, stretching and drawing are widely applied industrially, but design of tools and selection of sheet material remain almost invariably dependent on trial and error. The main reason is that the manufacturing process is influenced by various factors like shape of tools, characteristics of material, process variables and the geometric configuration of the work piece, which are difficult to formulate into a precise mathematical model. Literature is available in the fields of sheet metal bending like pure bending, V-die bending, simple flanging and other processes. Most materials can be bent to quite a small radius, but the problem is to control the shape of the bent work piece. In general, a bent work piece will recover elasticity i.e. spring back on unloading, so that the bend quality is heavily dependent on the spring back, which is a function of material properties and process parameters such as Young’s modulus, yield stress, strain hardening abilities, plastic anisotropy, thickness and die geometry.

The evaluation of elastic spring back effects is a fundamental aspect in the practice of sheet forming operations. Spring back, in fact, introduces deviations from the desired final shape - consequently, the stamped sheet does not conform to the design specifications and could make it unsuitable for the application. Since almost all the sheet forming processes are characterised by a significant amount of deformation introduced by a bending mechanics, the distribution of strain along the sheet thickness is strongly inhomogeneous. Such a distribution, together with the elastic-plastic behaviour of the work piece determines the occurrence of spring back after removal of the forming tools. It is well known from the tensile test that the elastic part of the total strain, which is recovered if the load is released, is equal to the ratio of the stress before unloading to the Young modulus. The tendency to elastic spring back increases by increasing the strain hardening coefficient and by decreasing the elastic stiffness. A complete knowledge of the spring back phenomenon and its dependence on material and process variables is strongly required in order to develop effective real time process control systems.

It is a difficult task to undertake numerical simulation of sheet bending process precisely. In the last two decades some mathematical models were proposed to predict spring back effects for simple geometries. As far as bending is concerned, most analytical approaches were based on simple beam or plate bending theories, that made it possible to analyse the influence of material parameters on spring back.

1.1. Factors affecting spring back

Elastic recovery of formed part in unloading known as spring back causes shape error in final product of sheet metal forming processes. Several approaches have been proposed for analysis of spring back and compensating its error. The spring back
occur at the last step of process and the final geometry of work piece can be obtained at the end of direct process modelling. For prediction of spring following factor has to be considered.

**Material Non-linearity:** As all materials have a finite modulus of elasticity, plastic deformation is followed by elastic recovery upon removal of the load; in bending, this recovery is known as *spring back*.

**Geometric non-linearity**
When there is a large deformation the shape of the structure changes which is responsible for change in stiffness of the structure. That is called geometric nonlinearity. Hence, stiffness changes due to deformation and change of the shape of the geometry has to be considered to get the final deformation of geometry and for prediction of spring back.

**Contact non-linearity**
In the forming operation of sheet metal there is contact between sheet and punch and also between sheet and die. So the contact forces and sliding have to be considered for the forming simulation. The friction forces between all the surfaces between the die, sheet and punch determine the bending force and determine the spring back.

To establish the methodology for prediction of spring back in cold forming/bending of sheet metal, a preliminary study was carried out on a typical blade profile.

### 2. MODELING OF MODEL BLADE
In this paper non linear FE Analysis of a 2mm CR MS Sheet is carried out for prediction of spring back. The shape of the blade profile is taken as taper, as shown in the Fig.2.
The solid model of the blade profile is made and some views are shown in Fig.3.

2.1. Design of Die-punch set for the forming of model blade

Die and punch set are designed for the forming simulation of the model blade. The die is modeled exactly matching with the outer surface of the model blade profile where as punch is modeled matching exactly with the inner section of the model blade profile so that the Die and Punch profiles are offset to each other by thickness of the sheet. Four guides are provided to locate the sheet with respect to die and punch and not to move in axial and transverse directions. Model of die, punch, guide, sheet and their assembly is shown in the figures 4 to 6.
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2.2. Modeling of test specimen
Model of the test specimens for the sheet material of same thickness is also made for the tensile testing of the material to generate the stress strain diagram and to get the material properties data to be used for simulation. Fig.7. shows the model of the tensile test specimen

Figure 6 Die punch set assembly (3d model)

Figure 7 3D model of the Tensile test Specimen

2.3. Modeling of the Sheet
Model of the CR MS sheet of same Thickness which is used for forming of model blade is shown in Fig.8.

Figure 8 A 3D model of the Cr MS sheet
2.4. Tensile testing of the standard test specimen
Tensile test specimens are manufactured and tensile testing of those specimens are carried out in UTM prior to the analysis. The material property values obtained from the tensile testing are required to be used for the simulation.

2.5. F. E. Analysis for Prediction of spring back in a Cold forming operation
Cold forming is a large deformation phenomenon. In a forming operation a metal/non-metallic thin component is deformed beyond its elastic range so that permanent deformation remains after the operation. Component to be formed is placed on a rigid die and load is applied through punch to deform the component to a desired shape of the die. After the punch is removed, the component recovers some amount of deformation which is defined as elastic deformation and the rest is attributed to plastic deformation which remains as permanent deformation and that results in the final shape after forming.

To simulate the forming phenomenon and to check the spring back, the Die, Punch and 2mm thick sheet are modelled using FE tools.

Analysis of the forming operation is done considering material and geometric non-linearity. As the component is deformed beyond the elastic limit, consideration of material non-linearity is required for the analysis and as the deformation is large, effect of geometric non-linearity has to be considered.

2.6. Modeling of Die using FE tools
Die is modelled as Discrete Rigid Body-3d Shell. A reference point is created on the Die to specify constraints and boundary condition for the Die, which is meshed with 4-node 3-D bilinear rigid quadrilateral element.

![Figure 9](image)

Figure 9 3D model of the Die modelled as Discrete Rigid Body-3D Shell in FE tools

2.7. Modeling of Punch
Die is also modelled as Discrete Rigid Body-3d Shell. A reference point is created on the Die to specify constraints and boundary condition for the Die and Punch is modelled using 4-node 3-D bilinear rigid quadrilateral.
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Figure 10 3D model of the Punch modelled as Discrete Rigid Body-3D Shell

2.8. Modeling of Sheet
Sheet is modelled with 3D Deformable body with extruded shell-mid surface with a uniform shell thickness of 2mm. Sheet is meshed with shell element S4R. With a 4-node doubly curved thin or thick shell, reduced integration, hourglass control, finite membrane strains.

Figure 11 3D model of the 2mm thick Sheet modelled as 3D Deformable Extruded Shell-mid surface

2.9. Material properties definition
Material property definition for Discrete rigid bodies i.e. for die and punch is not required as they are considered as rigid.

Material property for Deformable sheet is defined as nonlinear material.

For finding the material properties, standard test specimens are made and specimens are tested in an UTM.

Material properties extracted from tensile testing of the test specimens and taken in FE tools are as follows

Young’s modulus of Elasticity (E) =2.1e5 N/mm², Poisson’s ratio=0.3

<table>
<thead>
<tr>
<th>Sl. no</th>
<th>Stress</th>
<th>Plastic strain</th>
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<tbody>
<tr>
<td>1</td>
<td>220</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>250</td>
<td>0.002</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>0.008</td>
</tr>
</tbody>
</table>
Corresponding stress strain curve is given in fig .12 below:

![Stress-strain curve](image)

**Figure 12** Assembly of the Die punch set in ABAQUS

### 2.10. Boundary conditions

**Interaction or contact definition**

Surface to surface contact with finite sliding conditions is defined between sheet and Die and also for die and punch. Initially the sheet is resting on the die i.e. they are just touching each other and also punch is in contact with the sheet.

**Displacement Boundary condition**

Die is kept fixed.

Displacement boundary conditions are given for the punch in number of steps. Punch moves gradually towards down and bend the sheet. Once the die comes to its lowest extreme position the sheet takes the outer shape of the punch/die. Immediately after that, the punch is displaced upward and final deformed shape of the sheet is obtained.

### 2.11. Assembly of Die Punch set and Sheet

Initially the die punch and sheet are assembled in a position as shown in the fig.13. Meshed model of the assembly is shown in Fig. 14.

![Assembly of the Die punch set](image)
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**Figure 14** FE model of Assembly of the Die punch Set in ABAQUS

### 2.12. Simulation Results and estimation of spring back

Displacement plot has been made for the Die punch set in assembly. Fig.15 and Fig.16 shows the displacement plot of the Punch and sheet when punch reaches its bottom most position i.e. when the deformation of the sheet is maximum and sheet takes the shape of the die and this is the shape before sping back. Fig.14. shows the smaller end of the profile and fig.15 shows the larger end of the blade profile before spring back.

**Figure 15** Deformed Shape of the sheet when the punch moves to the bottom most position i.e. before spring back (Showing smaller end)

**Figure 16** Deformed Shape of the sheet when the punch moves to the bottom most position i.e. before spring back (showing larger end).
Once the Punch is lifted from the Die (i.e. from its bottom most position), the sheet becomes free and some amount of deformation is recovered i.e. final deformed shape deviates from the Die shape which is the spring back. Fig.17 and Fig.18 show the displacement plot of the Punch and sheet when punch is lifted from the die (i.e. from its bottom most position). Fig.16. shows the smaller end of the profile and Fig.17. shows the larger end of the blade profile after spring back. Maximum amount of spring back as predicted for the smaller end profile is 0.58 linear units (for the bottom most node) and that for the larger end profile is 2.97 linear units (for the bottom most node).

![Deformed Shape of the sheet when the punch is lifted from its bottom most position (showing smaller end)](image1)

**Figure 17** Deformed Shape of the sheet when the punch is lifted from its bottom most position (showing smaller end) i.e. after spring back

![Deformed Shape of the sheet when the punch is lifted from its bottom most position (showing larger end)](image2)

**Figure 18** Deformed Shape of the sheet when the punch is lifted from its bottom most position (showing larger end) i.e. after spring back

3.0. MANUFACTURING AND ASSEMBLY OF THE DIE PUNCH SET IN THE HYDRAULIC PRESS, FORMING OF THE MODEL BLADE AND MEASUREMENT OF SPRING BACK

3.1. Manufacturing of the die punch set
Manufacturing drawings of the Die-Punch assembly, Die, Die Fixture, Punch, Punch Fixture, Sheet, Guide Strip and Test specimens are made for the manufacturing of these items and the same are manufactured as per the drawings.

3.2. Assembly of the die punch in the Hydraulic press
Die-Punch set is assembled in the Hydraulic press. Die is assembled to the bottom portion of the hydraulic press using the Die fixture and the punch is assembled to the upper portion of the hydraulic press using the Punch fixture and guide strips are attached.
3.3. Forming of the CR Sheet and measurement of spring back

After assembling the die punch in the hydraulic press, the forming/bending of the sheet is carried out as shown in Fig. 19. Cylinder of the hydraulic press is gradually moved and forming operation of the model blade is carried out. After forming the die is displaced downward gradually so that sheet is free on the die and punch is completely removed from the die so that there is no contact between die and punch. After the punch is lifted from the die the final deformed shape of the sheet is obtained as shown in Fig. 20 and this spring back is measured for the bottom most position of the die as shown in Fig. 21.

**Figure 19** The die punch set in the Hydraulic press and sheet forming/bending

**Fig 20** Final deformed shape after spring back

**Fig 21** Measurement of spring back
4.4. Comparison of simulation results and the experimental results and conclusions

Simulation results are compared with the experimental results to see the capability of the FEA software for non-linear analysis like forming simulation. Spring back results are compared in Table 2.

It is seen that finite element simulation results are in line with the experimental results. Also it is found that when there is significant amount of spring, the simulation results and experiment results are in close approximation with each other. Hence it is concluded that the finite element simulation can be used for prediction of spring back prior to the forming operation using FE tools. This can be useful for spring back prediction and die design for cold forming of banana type of hollow guide blades for steam turbine.

<table>
<thead>
<tr>
<th>Spring back at the bottom most node</th>
<th>Simulation in linear units</th>
<th>% difference between analysis and experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Larger end profile</td>
<td>3 (Approx.)</td>
<td>-5%</td>
</tr>
<tr>
<td>On smaller end profile</td>
<td>&lt; 1.0</td>
<td>-20%</td>
</tr>
</tbody>
</table>

REFERENCES

[2] Springback Phenomenon in Sheet metal
[3] V-die Air Bending-Experimental and Numerical Study