Spring back behaviour of hole expansion with various punch movement and positions.

Author Balina Kranthi Kumar
Spring back behaviour of hole expansion with various punch movement and positions.

Summary

A methodology for making a spring back behaviour of hole expansion in gas tank. Work is initiated for SAAb automobile and the geometry of model is created by using the software’s called Unigraphics and hyper mesh and secondly the simulation of the model is done in Ls-dyna to know the spring back behaviour of hole with various depth and positions of the punch. The yield strength of the element and stress, strain distribution and different radius of the blank are used to reduce the cracks at the lower edge of the blank. Steel material is used and the thickness of the material (0.229mm). The simulation of the work includes loading of punch and its displacement. This study demonstrates the efficiency of the model to simulate the hole expansion and better understanding of the expansion of radius and spring back angle.

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List of symbols and abbreviations

\%

* 

Do – initial diameter
Df – final diameter

\sigma_m \quad - \quad \text{maximum stress}

\sigma_y \quad - \quad \text{yield stress}
1 Introduction

Spring back causes a major problem in sheet metal stamping. It measures the difference between the shape of final part and the shape of forming die. Therefore it requires a more number of operations for improving the production time and reduction of cost in industry.

Sheet metal forming is the process of converting from the sheet metal to the required shape without fracture. It is used to make smaller parts to the complex shapes in the industry. The manufacturing of large stampings required sheet metal which is fixed at the edges by blank holder and it is deformed by means of punch and the die.

Sheet metal forming operations are so different in executing to the numerical simulations. To obtain accurate indications on the formability rate is not so high in the industry. It is made trial and error basis to get the desired shape. Finite element codes can predict the stress, strain element thickness etc accurately. While coming to the spring back analysis the accurate is low.

To get the accuracy of the spring back of Ls-dyna and to get in-depth study of spring back. Different shape factors are added into this like variation in section width, flange angle change and radii to study the effects on spring back.

Experimental studies prove the dependence of spring back on material, die radii, plastic deformation, shell thickness and friction.

Spring back: Metal forming process spring back plays a major role. When the load is applied on the blank material sheet is deformed and the contour of the sheet section takes the die shape, on the release of the load the elastic deformation disappears due to release of the elastic strain energy and the final contour of the deformed sheet takes place the shape which is different from the die. This elastic recovery of deformation is known as spring back.

Spring back is effected by the parameters called distribution of elements, number of integration points for the thickness of material, contact parameter and hourglass control.

In this study the simulation tests are performed on the high strength steel to get higher accuracy.
2 Background

2.1 Hole expansion test:

In hole expansion test the flat sheet specimen with a circular hole in the centre between annular die plates and deformed by a punch which expands the material and the cracks are formed on the edges of the hole. The punch should be well lubricated and should have larger profile radius. The test is stopped when the visibility of cracks are appeared. The cracks formed on the edge of the blank may be due to the mechanical properties of the material, microstructure, geometry of the model, or application of load, etc. [1, 2]

Hole expansion (%): \( \frac{(D_f-D_o)}{D_o} \times 100 \)

\( D_f \) = final diameter
\( D_o \) = initial diameter

2.2 Previous works:

DP600, DP800 materials are used to study the behaviour of the mechanical properties and microstructure characteristics for stretch flangeability. [17]
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3 Material model

Barlat_YLD2000 is used in this study to overcome the Barlat_YLD96 in Ls-dyna.

3.1 Explicit time integration:

Explicit time integration is used for high dynamic process for crash analysis. It uses small inexpensive time steps for short duration. Computation of dependent variables can be made interms of known quantities. Unknown appears only on one side of the equation and known’s on the other side of the equation.[3,4]

\[ x(t+h) = x(t) + hf(x(t)) \]

Internal and external forces are summed at each node point and a node acceleration is computed by diving the node mass.

\[ [M][X]n = [F_{external}]n - [F_{internal}]n \]

3.2 Number of integration points:

The number of integration points for material thickness used is 7. Because the by using at least 5 number of integrations points we get acceptable result and by using 7 number of integration points we get accurate results.[5]

3.3 Contact theory:

ONE_WAY_SURFACE_TO_SURFACE is used in this study. Because the specified slave nodes are checked for penetration of master segments. If not, the nodes are projected back to the contact surface during the initialization phase.[6]

3.4 Element theory:

Fully integrated elements are used because material thickness is small as compared to the stress and dimensions in plane. By using these shell elements we get better results for spring back. [7]
3.5 Implicit time integration:

Implicit time integration is used for static and Quasi-static process and low rate dynamic analyses. It requires a few bigger time steps and suitable for long duration problems. Unknown appears on both sides of the equation.

\[
x(t+h) = x(t) + hf(x(t+h))
\]

A global stiffness matrix is computed, inverted and applied to the nodal out of balance force to obtain a displacement increment.

\[
[M] \{X\}_{n+1} + [K] \{x\}_{n+1} = [F_{external}]_{n+1} - [F_{internal}]_{n} - [M] \ddot{\{X\}}_{n}
\]

At first explicit forming analysis is carried out which includes the dynain file and properties of material. Secondly the input file from forming is taken input for coarsening where coarse mesh is obtained. Similarly the dynain file from coarsening is used input for spring back simulation. [3,4]

3.6 Hardening model:

Spring back depends on the hardening law used in numerical simulation. It shows the initial yield surface to the final yield surface by plastic deformation. It consists of two hardening laws (a) isotropic hardening (b) kinematic hardening. Where the change in surface can be depend on size, shape or position. The pictures are taken from the net non-linear/von-mises-material properties. [14, 15, 16]

3.6.1 Isotropic hardening:

When a material is loaded there will be change in yield surface where it reaches the point A and while removal of load it takes pointed line. When we apply the load once again it does not reach the point A, but increase elastically. By applying the load inversely the plastic deformation occur in the material. So the shape and position does not change, but change in its size occurs with increase of yield stress.

In isotropic hardening model the size and shape does not change the yield surface but size changes by increasing the yield stress. [14, 15, 16]
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3.6.2 Kinematic hardening:

Kinematic hardening model is preferred for cyclical loading by considering the Bauschinger effect.

Bauschinger effect refers to material property of plastic deformation. When the material undergoes deformation plastically its compression strength decreases (or) increase of tensile strength occurs which effects the shift of yield surface to the yield direction. It is described by two ways (a) local stress in the material may decrease the yield strength by assisting the movement of dislocation in inverse direction. (b) Dislocations in the opposite direction use the same source which used to produce dislocation in the initial direction. [14, 15, 16]
4 Scope of work:

4.1 Factors that effect the sheet metal stamping process for hole expansion. [8]

- Mechanical properties of material
- Uniaxial tensile test & biaxial tensile stress
- Ductility
- Residual stress
- Stress distribution
- Radial tensile strain
- Plastic strain
- Microstructure
- Fracture mechanism
- Stretch bending fracture
- Radius to the thickness ratio
- Geometry of the model
- Friction
- Lubrication
- Mesh size
- Die and punch design
- Press speed
- Load application
- Spring back

4.2 Factors that studied for the spring back behaviour of hole expansion with various punch movement and positions are:

- Mechanical properties of the material (Mild steel)
  Density, young’s modulus, friction coefficient, thickness, yield stress, punch velocity, dimensions of geometry…………………Fig.1

- Geometry of the model
  Geometry is created by using the Unigraphics and meshing is done in hyper mesh software provided by university west. Dimensions are in mm, geometry created is Punch, die, blank holder, and blank…………………………….Fig.2, 3.

- Stress distribution
  Von mises stress: where the material tends to yield when it reaches the maximum yield criteria. It is used for prediction of deformation of material when different types of loads are applied…………………………………..Fig.5

- Plastic strain: When the load applied and removed on the material it deforms elastically and when the continuous loading is applied for further the plastic deformation is occur on the material. The study shows to minimize the plastic strain deformation………………………………………………………Fig.26

- Mesh size used 0.5mm to get good accuracy and time factor.
Spring back behaviour of hole expansion with various punch movement and positions.

- Punch design with different radii to minimize cracks on the blank ……Fig.3
- Load application blank holder force 8900 N of punch velocity 5000
  In order to prevention of cracks, wrinkles, spring back measurement …Fig.1.
- Trimming the surface at different depths of 20, 22, 24 in mm
  For measuring the spring back angles and stress strain factors that occur in the
different position of blank surface………………Fig.15,16, 17, 18.
- Coarsening the model
  Is to reduce the model size, to get faster calculation, and implicit spring back,
  improve the convergence of nonlinear implicit equilibrium iterations…Fig.19
- Spring back measurement of angles
  Measures the shape of final part to the shape of forming die……Fig.21 to 25.
- Figures which was shown in the study are taken from ls-prepost 2.4 version.

4.3 Defining the problem:
In order to reduce the cracks which appeared on the material?

Following steps are performed
- Applying different radius of the blank size
  a) 20 mm inner radius & 55 mm outer radius…………(Fig.6,7)
- Making punch of radii (40mm)………………………..(Fig.3)
- Punch displacement for 20mm, 22mm, 24mm…………….(Fig.21,22,23)
- Applying the punch velocity (5000N)………………………..(Fig.2)
- Displacement of punch by .7mm by x-direction…………(Fig.9)
- Inclination of punch by 1 to the axis of symmetry………..(Fig.10)
- Element size used 7………………………………………..(Fig.24, 25)
- Forming……………………………………………………(Fig.4).
- Trimming the surfaces at 20, 22, 24 in mm……………..(Fig.15to18)
- Applying different mesh size……………………………..(Fig.19, 20)
- Measuring the spring back angles………………………..(Fig.24,to 25)

4.3 Limitations:
- The work will only consider simulation.
- No validation of the model will be performed
- Checking the radii of the curvature
- High work hardening rates
5 Geometry/ material properties:

5.1 Collection of data:

<table>
<thead>
<tr>
<th>Material</th>
<th>High strength steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>7.8g/cm³</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>210 Gpa</td>
</tr>
<tr>
<td>Friction coefficient</td>
<td>0.3</td>
</tr>
<tr>
<td>Blank holder force</td>
<td>8900 N</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.229mm</td>
</tr>
<tr>
<td>Yield stress (Mpa) &amp;Ro</td>
<td></td>
</tr>
<tr>
<td>0º</td>
<td>315.68</td>
</tr>
<tr>
<td>45º</td>
<td>309.82</td>
</tr>
<tr>
<td>90º</td>
<td>306.96</td>
</tr>
<tr>
<td>Punch velocity</td>
<td>5000</td>
</tr>
</tbody>
</table>

Fig.1 Mechanical properties of material and dimensions of model. [9]

5.2 Creating a model:

Geometry of the model is created in Unigraphics and the meshing of the model is done in hyper mesh software’s

<table>
<thead>
<tr>
<th>model</th>
<th>Radius in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>punch</td>
<td>40</td>
</tr>
<tr>
<td>Die</td>
<td>41</td>
</tr>
<tr>
<td>Blank holder</td>
<td>41.5</td>
</tr>
<tr>
<td>Blank</td>
<td>Inner 20&amp;25 outer 55&amp;50</td>
</tr>
<tr>
<td>Radius of curvature</td>
<td>R6</td>
</tr>
</tbody>
</table>

Fig .2 Geometry of the model.
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Lay out of the model punch, die, blank holder, blank.

Fig. 3 Layout of the model.

5.3 Procedure of executing the model in Ls-dyna:

- Creating the model in Unigraphics
- Meshing the geometry in Hyper mesh
- Output the model to Ls-dyna format
- Applying the material, density, poison’s ratio, friction coefficient, blank holder force thickness of blank, yield stress, radius for model
- Sheet stamping process
- Gravity loading process
- Building mesh
- Time step control
- Dynamics
- Termination time
- Output of dynain result
- Trimming
- Coarsening
- Spring back simulation
6 Simulation of design:

6.1 Forming

- Displacement of the punch 20mm.

Fig. 4 Punch depth of 20 mm.

Fig. 5 Von-misses stress.
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- Minimizing the cracks on the blank by maximize the radius of the blank to 25 mm

Fig. 6 Formation of cracks on blank edge.

Fig. 7 50 mm diameter of blank.
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Fig. 8 Elimination of cracks on the blank.

- Displacement of the punch by .7mm

Fig. 9 Displacement of punch by .7mm.
Spring back behaviour of hole expansion with various punch movement and positions.

- Inclination of the punch by 1° rise

![Fig. 10 making inclination by 1° rise.](image)

6.2 **Trimming**

The operation is done to eliminate the part from the original part.

- **Before trimming:**

![Fig. 11 Blank before trimming from forming process.](image)
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- **After trimming:**

![Trimmed part and results in good formability on the edges.](image1)

Fig. 12 Trimmed part and results in good formability on the edges.

- **Eliminated part from the original geometry.**

![Trimmed part from the forming.](image2)

Fig. 13 Trimmed part from the forming.

- **Front view of the trimmed geometry model**

![Front view of the final trimmed surface.](image3)

Fig. 14 Front view of the final trimmed surface.
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- Trimming the surface at different depths 11.73 mm, 13.28 mm, and 14.9 mm.

- 11.73 mm

Fig. 15 Trimming the surface at 11.73 mm.

- 13.28 mm

Fig. 16 Trimming the surface at 13.28 mm.
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- 14.9mm

Fig. 17 Trimming the surface at 14.9 mm.

- Comparing the trim surface at 16 mm to the various depths of the punch displacement 20 mm, 22 mm, and 24 mm.

Fig. 18 making trim at 16 mm with comparison to the fig .15, 16, &17.
6.3 Coarsening

- Applying the coarsen for the trimmed parts
- Moderate coarse mesh and dense coarse mesh is studied by applying to the trimmed parts.
- Moderate coarse mesh

Fig. 19 moderate coarse mesh for depth of 20 mm.
- Dense coarse mesh

Fig. 20 dense coarse mesh at contact surface of punch and blank.
6.4 Spring back

- Spring back angle measurement for 20 mm deep punch movement

Fig. 21 spring back angle for reference node of 70052 for 20 mm deep punch move.

- Spring back angle measurement for 22 mm deep punch movement

Fig. 22 spring back angle measurement for 22mm.

- Spring back angle measurement for 24 mm deep punch movement
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Fig. 23 spring back angle measurement for 24mm.

Fig. 24 spring back measurement for inclination of punch.

...  
- Spring back measurement inclination of the punch by 1°:
Spring back behaviour of hole expansion with various punch movement and positions.

- Displacement of the punch by x direction .7mm

Fig. 25: Spring back measurement for displacement of punch in x-direction.

Fig. 26: Plastic strain in the blank.
Spring back behaviour of hole expansion with various punch movement and positions.

7 Results:

Comparison of spring back behaviour with different depths of the punch movement to its displacement and inclinations. The measured spring back angle is normal to the x direction to the plane.

<table>
<thead>
<tr>
<th>Punch move and inclination</th>
<th>Measured spring back angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 mm</td>
<td>121.623</td>
</tr>
<tr>
<td>22 mm</td>
<td>121.60</td>
</tr>
<tr>
<td>24 mm</td>
<td>121.619</td>
</tr>
<tr>
<td>Inclination by 1°</td>
<td>129.25</td>
</tr>
<tr>
<td>Move of .7mm</td>
<td>114.5</td>
</tr>
</tbody>
</table>

Fig. 26 Measured spring back angles. Measuring of spring back angles are done by taking normal to the x-direction with the node of 70052, where the position of X=0.000469208, Y=-0.000469208, and Z=-1.03842.

- Designing the geometry of model.

- The elimination of cracks on the edges of the blank is achieved by designing the geometry of the model by increasing its inner radius from 20mm to 25mm. (Fig. 6, 7)

- Trimming operations are performed for (20mm, 22mm, and 24mm) (Fig. 15 to 18)

- Measuring the spring back angle for maximum punch depths to the trimming position at 16mm. (Fig. 18)
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- Coarsening is done for the model in order to observe the changes by applying the coarse mesh and dense mesh. (Fig.19, 20).

- Measuring the spring back angles and its behaviour is obtained in the study.

- From the above measured spring back angles (121.623, 121.60, and 121.619) to the punch movement of (20mm, 22mm, and 24mm) shows very less deviation of angles to the punch movement. (Fig.21, 22, and 23).

- Inclination of the punch by 1º shows the spring back angle of 129.25 º. (Fig.10)

- Displacement of punch by .7mm shows the spring back angle of 114.5 º. (Fig.9)

- Measuring the spring back angles behavior and reduction of cracks is obtained in the study.

8. Conclusions:

- An approach to the simulation modeling increasing of the inner radius of the blank size to 50mm diameter from 40 mm is proposed for reduction of cracks on the blank edge surface and for measuring spring back angle behaviour.

- The results obtained from the simulation process are realistic for the designing the geometry of the model and capable of giving more accurate simulation results of stress distribution in the model.

- The simulated results such as stress distribution and the relationship between the punch load and its travelling time agree well with the results.

- Displacement of the punch by x-direction by .7mm. and inclination of the punch shows the spring back behavior of angles.

- Trimming the surface at the different radius of the blank surface to observe the formability and vice-versa by moving of punch for different depths.

- Behaviour of spring angles shows the approximately similar results for different punch depths.
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- Displacement and inclination of the punch results shows the spring back angle behaviour.

Further study:
Experimental and finite element analysis of tool wear and thickness reduction to the radii and its curvature. The residual stress on the edges of the blank, stretch bending fracture, design of punch and die, and friction coefficient during the practical implementation of stamping.

Limitations:
- The work will only consider simulation.
- No validation of the model will be performed
- Checking the radii of the curvature
- High work hardening rates
- Tensile test data
- Ductility
- Microstructure

The information that effects the stamping process in reduction of cracks and the spring back behaviour depends on the Mechanical properties of material uniaxial tensile test & biaxial tensile stress and etc.
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References


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