Springback Prediction Analytical Model for V-Bend Process

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Abstract—The deviation from desired dimensions due to elastic driven change in shape during unloading of the forming part is known as spring back phenomenon. This springback causes increase in time, cost & trials to develop the acceptable part. To eliminate these cost effective factors the springback prediction analytical model is developed and applied to V-bend forming process. The analytical model is developed by calculation of the bending stress & bending strain induced in blank in loading conditions, followed by the yield moment and elastic plastic moment conditions, and then the springback is evaluated by the geometrical analysis for the completely loaded component in V-bend forming process. The proposed model is validated using FEA software HyperForm.

Keywords- Spring back Prediction, Sheet metal, Bends angle, Analytical model, HyperForm

I. INTRODUCTION

Various research works has been carried out for effective understanding of forming process in experimental, analytical & computational studies. Elastic unloading process causes change in shape of forming part i.e. springback. However springback is majorly affected by the complexity in combination of bending-unbending, loading-unloading & stretching during forming process. As per the consideration of the manufacturing industrial practices this springback is the one of parameter affects to design tool for the forming part. As the change in dimensions after unloading due to springback leads to increase in trials, time & cost to achieve acceptable dimensions of forming part. Hence the understanding the effect of the design parameters along with component material properties on springback, Springback prediction model is effectively helps to design forming tool.

The research work of springback prediction analytical model were developed for flange bending by Nan Song & et.al.[2] & Thaweepat Buranathiti, et.al.[3], Jenn-Terng Gau, et.al for aluminum sheet forming[4], Tian-xiaZou, et.al. for thin plate forming[10]. The simple tool description is assumed in this analytical methodology to evaluate springback angle. Bending stress & strain, bending moment applied for the deformation of blank & the elastic property of the sheet metal causes the change in shape while unloading of part from V-bend tool. This research activity is purely based on analytical model and is focused on the V-bend process of the sheet metal with different three materials & bend angles. Validation of proposed model is carried out using FEA software Hyper Form.

II. V-BEND PROCESS DEFINITION

This paper used a straight V-Bending process to develop the model for springback prediction for the sheet metal with different bend angle and sheet material. V-bend process consists of punch, die, and blank. The setup of tool is shown in figure 1 with following characters:

- A: The touching point between the deformed sheet and the punch
- B: The separation point between the deformed sheet and the die
• C: Part width
• L: Length of die shoulder
• O: The die root position
• t: Thickness of sheet
• \( \theta_0 \): Fully loaded configuration
• \( \theta_l \): Fully unloaded configuration, the springback angle is defined by,

\[
\Delta \theta = \theta_l - \theta_0 \quad \ldots \ (a)
\]

![V-bend tool design parameters](image)

**III. ANALYTICAL MODEL**

In this paper the analytical springback prediction model for V-bending process is proposed based on
the earlier model in Reference [3]. The proposed analytical model is verified using FEA software
HyperForm. In this model the springback is predicted by assuming linear distribution of moment from
point B to point O. For most of the analytical models following assumptions are used [3]:

• For the sheet metal of blank, along width of blank the plain strain conditions and along thickness
direction plane stress conditions are considered
• The blank sheet metal is isotropic and homogeneous in nature
• The blank sheet metal follow the power hardening law and Von-Mises yield criterion
• During the deformation process the normal planes to the sheet surface remain planes
• Bauschinger effect is neglected.
• Bending-strain-free conditions are considered for the blank sheet middle layer
• Conservation of volume is assumed- variation of volume due to elastic deformation is negligible.
• Along the straight and curved parts bending moment distributions are linear.
• During unloading stage only the elastic deformation occurs.

3.1. Strain & Stress expressions

The curvature \( \kappa \) of the deformed sheet with thickness \( t \) is defined as

\[
\kappa = \frac{1}{R_d + t/2} = \frac{1}{R} \quad \ldots \ (b)
\]

Where \( R_d \) is the die corner radius and \( R \) is the effective bending radius.

Using Von Mises law, Young's Modulus \( E' \), Yield Stress \( Y' \) & Strength Coefficient \( K' \) for plane
strain calculation using Poisson’s ratio \( (\nu) \) are,

\[
E' = \frac{E}{1-\nu^2} \quad , \quad Y' = \frac{2Y}{\sqrt{3}} \quad \& \quad K' = \frac{2K}{\sqrt{3}} \quad \ldots \ (c)
\]
Yield strain using hook’s law is \( \varepsilon_{y1} \) & using power law is \( \varepsilon_{y2} \) given as,

\[
\varepsilon_{y1} = \frac{Y}{E} \quad \& \quad \varepsilon_{y2} = \max \left[ \varepsilon_{y1}, \left( \frac{Y}{Y'} \right)^n \right]
\]  \( \ldots (d) \)

Hence, the bending fiber position at \( \varepsilon_{y1} \) & \( \varepsilon_{y2} \) are given as,

\[
t_{y1} = \frac{\varepsilon_{y1}}{k} \quad \& \quad t_{y2} = \frac{\varepsilon_{y2}}{k}
\]  \( \ldots (e) \)

Yield moment \( M_y \) can be given as,

\[
M_y = \frac{2}{3} Y' \left( \frac{t}{2} \right)^2
\]  \( \ldots (f) \)

3.2 Computation of bending moments

Bending moment (\( M \)) of deformed sheet is represented by,

\[
M = \int_{-\frac{t}{2}}^\frac{t}{2} \xi \sigma(\xi) d\xi
\]  \( \ldots (g) \)

Bending moments of deformed sheet is decomposed in following bending moments [3]:

Bending moment \( M_{elas} \) is in elastic region, \( M_{plas1} \) is along in Luders Band, \( M_{plas2} \) is along plastic region under power law and they expressed as,

\[
M_{elas} = \frac{2}{3} E' \kappa (t_{y1})^3
\]  \( \ldots (h) \)

\[
M_{plas1} = \min \left[ Y' \left( \left( \frac{t}{2} \right)^2 - (t_{y1})^2 \right), \max \left\{ Y' \left( (t_{y2})^2 - (t_{y1})^2 \right), 0 \right\} \right]
\]  \( \ldots (i) \)

\[
M_{plas2} = \max \left[ \frac{K'}{n+2} \frac{2}{R^n} \left( \frac{t}{2} \right)^{n+2} - t_{y2}^n, 0 \right]
\]  \( \ldots (j) \)

Total bending moment = \( M_{elas} + M_{plas1} + M_{plas2} \)  \( \ldots (k) \)

The external force from punch \( P \) acting normally at \( A \) with the angle \( \theta_p \) with respect to the loading direction of punch is

\[
P = \frac{(1.2)C.T^2.TS}{L}
\]  \( \ldots (l) \)

T.S.: Ultimate Tensile strength of sheet material,

\[
\text{Figure 2. V-bend tool design parameters}
\]

The bending moment at die root position \( O \) is represented by \( M_0 \) and it is derived using the pressure distribution along the bend part \( S \) between point \( O \) and \( A \). \( M_0 \) is derived & expressed as,

\[
M_0 = P \left[ l \cos (\theta_h - \theta_p) + R \sin (\theta_h - \theta_p) \right]
\]  \( \ldots (m) \)

Here \( \theta_p \): Angle applied by die at point \( B \) is vertical to the plane of sheet hence = 90°

\[
\text{Figure 3. Bending moment diagram}
\]
3.3 Computation of bending moments

l, \( \theta_B \), \( \theta_P \), and S are geometrical based parameters used in the force/moment expressions are calculated from their geometry relations. Where l is length between applied load by punch and the support of blank at the die opening length-distance between A and B & expressed as, \( l = \sqrt{\frac{4Et}{LY}} \) and approximately \( l = \frac{L}{2} \), \( \theta_B = (\theta_P - \theta_l) \) & S = R. \( \theta_B \)

3.3 Prediction of springback angle

In this springback prediction model for V-bending, the springback is considered as a purely elastic recovery of the process. Hence to calculate the springback along the straight region between point A to B, along l is derived by assuming \( M_B = 0 \) & Bending moment at A (\( M_A \)) is \( M_A = M_{elasplas} \), hence it is expressed as \( \theta_l = \frac{1}{t} \varepsilon_{y1} Y_B l \) ... (n)

The springback angle for the curved part S along V-shape bend can be given by solving as

\[
\theta_S = \left( \frac{S}{M_{O-M_A} E t^2} \right) M_B M dM = \frac{S}{t} \varepsilon_{y1} Y_B (1+M')
\]

... (o)

The springback of complete V-bend is given as the summation of springback angle along straight part and the curved part and can be given as:

\[
\Delta \theta = \theta_s + 20_l
\]

... (p)

IV. RESULTS AND VALIDATION

Tooling & material parameters used for analytical model calculations are,

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<thead>
<tr>
<th>Table 1. Component dimensions</th>
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<tr>
<td>C</td>
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<th>Table 2. Blank material properties</th>
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<td>Exp. No.</td>
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<tr>
<td></td>
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<tr>
<td>1.</td>
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Figure 4. Meshing of punch, blank & die in FEA HyperForm software

Figure 5. Springback angle for one side is between fully loaded & unloaded condition for Exp. No.1

Figure 6. Springback angle for one side is between fully loaded & unloaded condition for Exp. No.2

Figure 7. Springback angle for one side is between fully loaded & unloaded condition for Exp. No.3
CONCLUSION

In the proposed analytical model the bending stress and bending strain are analytically calculated by considering the incremental change in the deformation in V-shape during loading. The yield moments and elastic-plastic moments are calculated followed by the geometrical analysis of the blank for the fully loaded conditions. Using these parameters the springback prediction is carried out with calculating the springback along straight and curved part of the blank after the unloading conditions. The proposed analytical model is applied for the materials SAE-CR-550R, SAE-CR-700R, SAE-CR-830R and the springback prediction is calculated. By analyzing the results it is seen that the springback prediction using analytical model is showing approximately similar results as compared to FEA springback prediction values. The results are showing avg. error of 1.2º error compared with FEA results, & hence they are acceptable. It is seen that this analytical model is effectively helps for the understanding of the springback angle after forming, so that it can be compensate by change in design parameters. This model helps to reduce the computational & experimental efforts for compensation of springback for this particular part. This model is really cost effective by reducing time & trials to develop the tool for acceptable part.

REFERENCES


