Investigation of Process Parameters Affecting on Spring-Back in V-Bending Process for Deep Draw Steel using FEA and Taguchi Technique

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Abstract— In this study, process parameters like punch angle, die opening, grain direction and pre bend condition of the strip for deep draw steel are investigated. The finite element method (FEM) in association with the Taguchi and the analysis of variance (ANOVA) techniques are carried out to investigate the degree of importance of process parameters in V-bending process. From results it is observed that punch angle had major influence on the spring-back. Die opening also showed very significant role on springback. On other hand, it is revealed that grain direction had least impact on springback however if strip from flat sheet is taken then it is less prone to springback as compared to the strip from sheet metal coil. Hyper Form software is used for FEM simulation and experiments are designed using Taguchi method. Percentage contribution of the parameters is obtained through the ANOVA technique.

Keywords— Bending, FEM, Spring-back, Taguchi,

I. INTRODUCTION

Manufacturing industries are very much concerned about the manufacturing of high-precision sheet metal. Sheet metals are used in automotive industries, housing-utensil industries and electronics industries. Every industry is trying to reduce the trial time to deliver the good quality product on time. Sheet metal bending is the most widely used process in sheet metal industries. Spring-back is a very common and critical phenomenon in sheet metal forming operations, which is caused by the elastic redistribution of the internal stresses after the removal of deforming forces. Spring-back compensation is absolutely essential for the accurate geometry of sheet metal components.

However, the spring-back is studied in most of these researches. For examples, H K Yi, [1] studied a model based on differential strains after relief from the maximum bending stress , derived for six different deformation patterns in order to predict spring back analytically. Thaweepat Buranathiti and Jian Cao [2] studied an effective analytical model for spring back prediction in straight flanging processes. The effect of punch height on V bending angle is examined by Sutasn Thipprakmas [3] using finite element model and results are validated through experiments. Effects of process variables on V-die bending process of steel sheet are discussed by You-Min Huang [4]. The investigation deals with a model which predicts the correct punch load for bending and the precise final shape of products after unloading, in relation to the tensile properties of the material and the geometry of tools. Ján SLOTA and Miroslav JURČIŠIN [5] analyzed TRIP, AHSS and mild steel considering normal anisotropic behavior of the materials for prediction of Springback in v-bending for automotive industry using experimental and numerical approaches. Himanshu V. Gajjar [6] focused on application of Hyperform, LS-DYNA for Finite Element Analysis of Sheet Metal Air – bending. Wang et al. [7] studied the spring-back control of sheet metal air bending process. W.M. Chan [8] also focused on Finite element analysis of spring-back of V-bending sheet metal forming processes where he investigated spring-back in the V-bending metal forming process with one clamped end and one free end. Different die punch parameters such as punch radius, punch angle and die-lip radius are varied to study their effect on spring-back. High-accuracy V-bending system by real time identifying material property is examined in by Kazunari Maia [9] in which a bending system is proposed in order to realize high precision V-bending. Leu and Hsieh [10] investigated the influence of the coining force on spring-back reduction in V-die bending process the simulation model of the V bending process of sheet metals is elaborated by Florica Miocara Groze [11] where ABACUS is used for finite element simulation for springback prediction of the v bending process. Sutasn Thipprakmas and Wiriyakorn Phanitwong [12] used Taguchi technique for Process parameter design of spring-back and spring-go in V-bending process where three process parameters of bending angle, material thickness and punch radius are investigated.

Although many researches have been conducted the study for various factors affecting on spring-back but the study of factors affecting on springback such as punch angle, die opening, grain direction of sheet metal and pre bend condition of strip for sheet metal V bending for deep draw steel have not been researched yet. The aim of the presented work is to examine the degree of importance of process parameters such as punch angle, die opening, grain direction of sheet metal and pre bend condition of strip for sheet metal V bending for deep draw steel, using Finite Element Simulation, Design of Experiments (Taguchi Method) and the analysis of variance (ANOVA). The commercial software Hyper-Form is used to carry out the prediction of spring-back. The FEM simulation results are verified by the experiments. The percentage contribution of each affecting factor on springback is estimated with help of ANOVA technique. The characteristics “Smaller is better” for signal-to-noise ratio is considered for process response.

Analysis of variance is a method of partitioning variability into identifiable sources of variation and the associated degrees of freedom in an experiment. The percentage contribution of each affecting parameter on springback is estimated with the help of ANOVA technique.

### TABLE I

<table>
<thead>
<tr>
<th>Process Parameter</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Punch Angle</td>
<td>860</td>
<td>880</td>
<td>900</td>
</tr>
<tr>
<td>B Die Opening</td>
<td>12t</td>
<td>16t</td>
<td>20t</td>
</tr>
<tr>
<td>C Grain Direction</td>
<td>00</td>
<td>450</td>
<td>900</td>
</tr>
<tr>
<td>D Pre Bend Condition of Strip</td>
<td>Tension</td>
<td>Compression</td>
<td>Flat</td>
</tr>
</tbody>
</table>

![Main Effects Plot for SN ratios](image)

**Fig. 1. Main effects plot for S/N ratios**

Figure 1 shows the main plot effect for S/N ratios for four process parameters i.e. punch angle (A), die opening (B), pre bend condition of the strip (C) and grain direction of sheet metal(D).

II. METHODOLOGY

**Taguchi method**

In the given study experiments are designed using Taguchi method with L18 orthogonal array. Four process parameters with three levels, including punch angle, die opening, grain directions of sheet metal and pre bend condition of strip are applied. Process parameters along with their levels selected for the study are shown in Table I. The spring-back angle is taken as process response.
From the graphs obtained through Taguchi technique shows that S/N ratio is highest for parameter punch angle (A) and then for parameter die opening (B). It is also seen that S/N is lower for process parameter pre bend condition of the strip (C) and it is lowest for process parameter grain direction of sheet metal (D).

**FEM simulation procedure**

In the presented work FEA simulation of V bending of sheet metal is performed using Hyper Form. Solid elements are used for meshing the sheet metal. Punch and die are meshed with rigid mesh which means there will not be any effect on punch and die during analysis. Type of mesh and number of elements are kept constant during all simulations. Fig. 2 shows the FEA simulation model in Hyper Form. The sizes of strip used for FEA simulation and actual experimentation are 80 mm in length, 40 mm in width and 2.5 mm in thickness. Hyper-Form is used as the FEM simulation tool. A punch angle of 860°, 880° and 900°, a material thickness (t) of 2.5mm, and die opening of 12t, 16t and 20t, grain direction of sheet metal 0°, 45° and 90° and pre bend condition of strip i.e. sample is taken from sheet metal coil and studied from both sides. Another sample is taken from flat sheet and investigated.

**Experimental procedure**

For experimental procedure three V-bending dies with die opening 12t, 16t and 20t are used keeping die angle and die radius constant where ‘t’ is the thickness of sheet metal. Three punches with 860, 880 and 900 punch angles are used keeping punch radius constant as shown in fig.3. Experiments are performed on universal tensile testing machine in the laboratory with the same FEM simulation conditions. The laboratory experiments are carried out to validate the FEM simulation results. Fig. (4a) and (4b) show the actual experimental set up used. The bending angle of the component is examined using the profile projector.
III. RESULTS AND DISCUSSION

Application of ANOVA

The process parameters and their levels investigated in springback and are listed in Table I. To investigate the degree of importance of the process parameters, therefore, the ANOVA technique is carried out in this case. The ‘‘Smaller is better (S/N)’’ characteristics are considered for the springback. The SS, MS, F, P and percentage contributions calculated for each process parameters in the case of springback are illustrated in Table II. In the case of springback, the percentage contributions of the punch angle, die opening, pre bend strip condition and grain direction are 47.45%, 38.52%, 3.57% and 1.37% respectively. Based on these statistical analysis results, it is found that the degree of importance of process parameters in V-bending process depended on punch angle (A), die opening (B), pre bend condition of the strip (C) and grain direction of sheet metal (D).

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
<th>% Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>27.6701</td>
<td>13.8351</td>
<td>20.4000</td>
<td>0.0000</td>
<td>47.45%</td>
</tr>
<tr>
<td>B</td>
<td>22.4640</td>
<td>11.2320</td>
<td>16.9600</td>
<td>0.0010</td>
<td>38.52%</td>
</tr>
<tr>
<td>C</td>
<td>0.7985</td>
<td>0.3993</td>
<td>0.6000</td>
<td>0.5680</td>
<td>1.37%</td>
</tr>
<tr>
<td>D</td>
<td>2.0804</td>
<td>1.0402</td>
<td>1.5700</td>
<td>0.2600</td>
<td>3.57%</td>
</tr>
<tr>
<td>Error</td>
<td>5.3042</td>
<td>0.5894</td>
<td></td>
<td></td>
<td>9.10%</td>
</tr>
<tr>
<td>Total</td>
<td>58.3172</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As shown in the results, for the given case of springback the process parameters of the punch angle had the most influence, followed by similar influence of die opening and the small influence of the pre bend strip condition and the grain direction

Effects of process parameters on the spring-back

In the presented work, the effects of punch angle, die opening, grain direction and pre bend condition of strip are clearly investigated and identified based on the tensile and compressive stress distribution analysis using Hyper Form. The results showed that as punch angle is changing from $86^\circ$ to $90^\circ$ tensile and compressive stresses are also increasing. It is also observed that percent strain is higher for $86^\circ$ and lower for $90^\circ$ after removal of punch causing lower springback. It is also observed that as the die opening is increased, the amount of springback is reduced.

In addition, the pre bend strip condition is also simulated and it is found that for given case it also had impact on springback on lower scale. With FEM simulation as well as experimental validation it is observed that grain direction did not influence the springback significantly.

During past research it is observed that lots of work has been performed on the phenomenon of springback and parameters influencing it.

In the presented work the mechanism of springback related to process parameters punch angle (A), die opening (B), pre bend condition of the strip (C) and grain direction of sheet metal (D) is clearly identified based on the tensile and compressive stress distribution analysis. It found that as the die opening increased tensile and compressive stresses are also increased. It is investigated that the increase in punch angle also increased the tensile and compressive stresses.

Hence, with these characteristics, as the die opening increased, the amounts of springback decreased. However it is also observed that with tensile and compressive stresses are higher for flat condition of the strip. In FEM simulation for the grain directions no significant change is observed in tensile and compressive stresses and thereby in springback.

The results illustrated that the punch angle had a great influence on the tensile and compressive stresses whereas die opening is found to be the second most influencing parameter on tensile and compressive stresses. The grain direction and pre bend condition of strip had a less influence on tensile and compressive stresses and hence on springback. Figure 5 explains the effect of each process parameter on tensile stresses and compressive stresses. However figure 6 shows the effect of each process parameter on percent strain.

![Fig.5 Tensile stress & compressive stresses](image-url)
Fig. 7 a) and b) shows a tensile and compressive stresses generated during one experiment with 90° punch angle, 20 ton die opening, flat strip condition and 0° grain direction. Similarly results are obtained for all 18 experiments as per Taguchi Technique for percentage of strain after removal of bending force for all cases.

Based on the tensile and compressive stress distribution the effects of process parameters and degree of importance of process parameters are clearly analyzed by the ANOVA technique. It observed that the punch angle and die opening had a major influence on spring-back.

Comparing the FEM simulation and Experimental results

The accuracy of the FEM simulation results is validated by laboratory experiments. Commercial FEM software Hyper-Form showed good agreement with the experimental results. In this study, the experimentation is performed in which the errors in analyzed springback angle are approximately 5% compared with the experimental results. In this study, experiments are carried out to confirm the accuracy of FEM simulation results especially for the case of punch angle, die opening, pre bend strip condition and grain direction for deep draw steel. Fig. 8 shows the comparison between the FEM simulation and the experimental results.

IV. CONCLUSIONS

In the presented work four process parameters like punch angle, die opening, grain direction and pre bend condition of strip affecting on springback in V-bending process for deep draw steel IS 1079-1994 are analyzed and studied using FEM simulation, Taguchi and the ANOVA techniques. The results obtained through FEM simulation are validated by Laboratory experimentation. From the above study it is observed that two process parameters punch angle and die opening had major influence on springback with their approximately calculated percentage contribution of 47.45% and 38.52% respectively because as punch angle increased from 86° to 90° tensile and compressive stresses induced into the strip are also increasing from 335 MPa to 385 MPa and 392 MPa to 486 MPa respectively. The more stresses generated during the process yields the material to plastic state which results into the less straining after removal of the bending force.
The percentage straining after removal of bending force for the punch angle from $86^\circ$ to $90^\circ$ found to 7.05% to 1.23%. Same is the case for die opening as die opening is increasing from 12t to 20t tensile and compressive stresses induced into the strip are also increasing from 320 MPa to 380 MPa and 385 MPa to 485 MPa respectively. The more stresses generated during the process yields the material to plastic state which results into the less straining after removal of the bending force. The percentage straining after removal of bending force for the die opening from 12t to 20t found to 7.55% to 1.35%.

On other hand the unique parameter studied here i.e. pre bend condition of strip also had influence on springback with its approximately calculated percentage contribution of 3.57%. Grain direction is identified as the parameter with least influence on springback with its approximately calculated percentage contribution of 1.37%. The effects of above process parameters could be clearly identified through tensile stress and compressive stress distribution analysis using Hyper Form. It is presented that, the punch angle and die opening had a major effect on the tensile and compressive stresses. Hence to find the optimum value of springback the designer has to concentrate on punch angle and die opening.

REFERENCES


[9] KazunariImaiia, Junichi Koyama, Yingjin Jin, High-accuracy V-bending system by realtime identifying material property, journal of materials processing technology 2 0 1 ( 2 0 0 8 ) 193–197


