EFFECT OF SPRINGBACK IN DP980 ADVANCED HIGH STRENGTH STEEL ON PRODUCT PRECISION IN BENDING PROCESS

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Abstract
Springback is a common phenomenon in sheet metal forming, in which the material undergoes an elastic recovery as applied loads are removed. Springback causes the forming shape to deviate from the intended design geometry. This phenomenon, which can be influenced by several factors, effects on both bending angle and bending curvature. The aim of this study is to determine the influence of different tool radius and the gap between punch and die on springback in bending of DP980 Advanced High-Strength Steels (AHSS) sheet. Experimental studies are combined with FEM method in commercial ABAQUS software to determine the bending angle after springback. To predict springback in bending process, the material properties are defined by Ludwik - Hollomon law, combined with the Hill'48 criterion. Experimental results are in good agreement with numerical simulations in case of bending in the rolling direction.

Keywords: Springback, advanced high strength steel (AHSS), DP980

1 Introduction

AHSS is gradually replacing conventional steel grades in the automotive industry because of their advanced properties such as improved formability, crash worthiness, low-mass, affordable cost and many environmental advantages [1, 2]. However, a wide application of AHSS in many potential auto body and structural parts is still limited due to challenges in formability [3]. In AHSS sheet forming, the most sensitive feature is the elastic recovery during unloading, i.e., springback, which has been widely researched since the 1990s. Many studies have analyzed and investigated the effect of parameters on the springback effect on various grades of AHSS [4-10]. The amount of springback is influenced by various process parameters, such as gap between punch and die, material thickness [4], forming force, tool radius [5-6], ratio between die radius and thickness [7], blank holder force [8], and material properties including sheet anisotropy, Young's modulus, strength coefficient, and strain hardening exponent [9]. Nowadays, the prediction of such forming defects using numerical simulation becomes a critical step and popular in modern industry, which allow reduction of traditional costly trial-and-error experiments. However, an accurate prediction of springback from numerical simulation is still challenging since the springback are affected by many factors including the boundary conditions [11-16]. Previous studies have primarily focused on springback effects in AHSS grades with tensile strength less than 800MPa [17, 18]. For AHSS grades with a tensile strength of more than

800 MPa, however, a few research has been conducted regarding composition, characteristics, and especially formability, although such material has been used to manufacture details such as body and frame in the automobile industry. In the present study, the focus is put on springback effect in bending process of DP980 steel, which possesses tensile strength more than 1000MPa. By applying simulations to practical problems, ABAQUS software predicts the amount of springback of DP980 sheet steel in bending when changing the process parameters: tool radius, $R = 5$mm and the gap between punch and die, $c = 1.1t \div 1.2t$, where t is thickness of the sheet. Steel sample exhibits work-hardening described by Ludwik – Hollomon law combined with Hill'48 anisotropic yield criteria. For general stress states, the Hill'48 criterion is the most widely used criterion since it is relatively simple, and its parameters can be determined easily using standard tensile tests in laboratory conditions. After obtaining simulation results, a measurement of the springback angle is performed using the graphics method. Experimental process is carried out to compare with simulation results in case of $R = 5$ mm, $c = 1.2t$, and bending in the rolling direction to find out their compatible.

2   Experimental procedure
Material
DP980 is dual-phase steel, which consists of a ferritic matrix containing a hard martensitic second phase in the form of islands. Chemical composition in percentage of DP980 steel is shown in **Table 1** [19].

Table 1 Chemical composition of DP980 steel

Alloying element (%)	C	Mn	Cr	Al	P	Mo	Ni	Si	Fe
DP980	0.107	2.59	0.975	0.0314	0.0148	0.0099	0.0111	0.0911	96

Mechanical properties of DP980 steel sheet are provided as [19]: Young's modulus $E = 210$ GPa; Yield stress $\sigma_0 = 677$ MPa; Ultimate tensile strength $= 1026$MPa, Strength coefficient $K = 1542$ MPa; Strain hardening exponent $n = 0.1409$.

FEM simulation of springback effect models
In this study, the commercial software ABAQUS is used to simulate the bending process and predict the amount of springback in DP980 steel.
Fig. 1 shows the geometry models for the bending process of a DP980 sheet in case of $R = 5$ mm and $c = 1.2t$. These geometry models consist of punch, die, and blank.
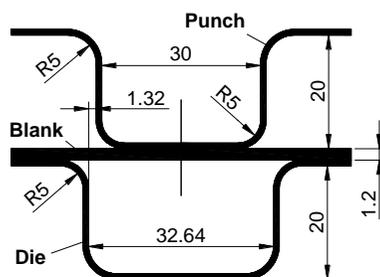

Fig. 1   Geometry model for forming simulation

To simulate the experiments, only one half of the specimen is modeled. The die and punch are modeled using the R3D4 rigid surface-elements, while the CPS4R elements are used for the blank. Throughout this study, the sizes of the blank are 90 mm (length) × 20 mm (width) × 1.2 mm (thickness).

The die is fixed in all directions. The punch is allowed to move only in the vertical direction. The deformation of the blank is restricted in transverse direction. The friction coefficient (μ) between the punch and the die is assumed of 0.1. The tool radius is $R = 5$ mm. The gap between punch and die is c = 10%.t. Photo map method is used to measure the springback level of DP980 AHSS sheet during bending process.

DP980 steel exhibits work-hardening described by Ludwik – Hollomon law combined with Hill'48 anisotropic yield criteria. These models are widely used because it is relatively simple, and its parameters can be determined easily using standard tensile tests in laboratory conditions.

The Ludwik – Hollomon equation is expressed as:

$$\sigma = \sigma_0 + K\varepsilon^n \tag{1.}$$

where K is strength coefficient, n is strain hardening exponent, and ε is true strain.

Since sheet material is commonly produced by cold rolling, the mechanical properties of material are thus different in the rolling direction (RD~xx), transverse direction (TD~yy), and normal direction (ND~zz). Therefore, anisotropic material properties are taken into account in the present study to investigate springback effect. The model of Hill'48 yield criteria is applied to describe the anisotropy properties of DP980 material. The Hill'48 equation is given by:

$$\varphi = F\left(\sigma_{yy} - \sigma_{zz}\right)^2 + G\left(\sigma_{zz} - \sigma_{xx}\right)^2 + H\left(\sigma_{xx} - \sigma_{yy}\right)^2 + 2L\sigma_{yz}^2 + 2M\sigma_{xz}^2 + 2N\sigma_{xy}^2 = \bar{\sigma}^2 = Y_0^2 \tag{2.}$$

Where φ denotes the yield function, $\bar{\sigma}$ is the equivalent stress, and Y_0 a reference yield stress of the material. F, G, H, L, M and N are Hill's anisotropic parameters, which can be expressed by Lankford's coefficients with the condition $G + H = 1$ and plane stress condition $\sigma_{zz} = \sigma_{xz} = \sigma_{yz} = 0$. They are defined as

$$F = \frac{r_9}{r_{90}(r_0 + 1)}, N = \frac{(1 + 2r_{45})(r_0 + r_{45})}{2r_{90}(1 + r_0)}, L \text{ and } M \text{ are equal to } N. \tag{3.}$$

Where: r_0, r_{45}, r_{90} - Lankford's coefficients which represents anisotropy values measured in the 0°, 45° and 90° to the rolling direction, respectively, $r_0 = 0,8354$, $r_{45} = 1,0347$, $r_{90} = 0,9441$ [19] so $F = 0,482111$, $G = 0,544836$, $N = 1,656289$, $H = 0,455164$.

On the other hand, according to [20], they are also defined as

$$\begin{cases} F = \frac{1}{2R_{22}^2} + \frac{1}{2R_{33}^2} + \frac{1}{2R_{11}^2} \\ G = \frac{1}{2R_{11}^2} + \frac{1}{2R_{33}^2} + \frac{1}{2R_{22}^2} \\ H = \frac{1}{2R_{11}^2} + \frac{1}{2R_{22}^2} + \frac{1}{2R_{33}^2} \\ L = \frac{3}{2R_{23}^2}, M = \frac{3}{2R_{13}^2}, N = \frac{3}{2R_{12}^2} \end{cases} \tag{4.}$$

The anisotropic yield stress ratios R_{11}, R_{22}, R_{33}, R_{12}, R_{13} and R_{23} are obtained by above equation and given in **Table 2**.

Table 2 shows the anisotropic yield stress ratios

The anisotropic yield stress ratios	R_{11}	R_{22}	R_{33}	R_{12}	R_{13}	R_{23}
Values	1	1,067	0,974	0,952	1	1

Experimental conditions

DP980 sheet steels are cut under CNC K7745M machine with different directions compared to RD: 0°, 45°, and 90°, respectively. These specimens are then bent by MTS809 multifunctional machine (tensile testing machine) in case of $R = 5$ mm and $c = 1.2t$.

3   Results and discussion

Simulation results

Simulations that use the material model and the boundary conditions described in the previous section are performed by the means of ABAQUS software.

Fig. 2a shows the results of the bending process simulation in case of $R = 5$ mm, $c = 1.2t$.
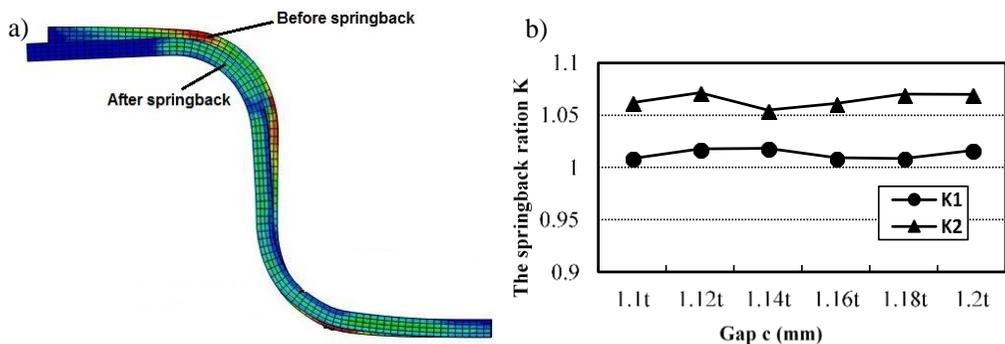

Fig. 2   a) The results of the bending process simulation in case of $R = 5$ mm, $c = 1.2t$; b) The springback ratio in various gap in case of $R = 5$ mm

To determine the springback amount, the angle after springback is firstly measured, then the springback ratio at the upper and bottom corners are calculated as $K_1 = \dfrac{\alpha_1}{\alpha}$ and $K_2 = \dfrac{\beta_1}{\beta}$, respectively. Where α, α_1 are upper corners before (expected $=90^0$) and after bending; β, β_1 are bottom corners before (expected $=90^0$) and after bending. The springback ratio in case of $R = 5$ mm is calculated at the upper corner K_1 and the bottom corner angle K_2. These calculation results are shown in **Fig. 2b.**

In case of $R = 5$ mm, both the upper and bottom corners are larger than 90 degrees. Thus, the smaller springback ratio is, the smaller the springback amount becomes. At the upper corner, the springback amount is the least in the case of $c = 1.1t$ and the highest in case of $c = 1.14t$. And at the bottom corner, the springback amount achieves the lowest and highest values at $c = 1.14t$ and $c = 1.12t$, respectively.

Based on the simulation results a few remarks may be given as follows: At the surveyed gap, different springback amounts are found at the upper and bottom corners.

To provide underlying mechanisms of occured springback effect, pairs of elements 1-2 and 3-4 are analyzed for stress-strain properties. These pairs of elements within the high stress region at the bending angle are symmetric across the neutral axis in the direction of the sheet thickness.
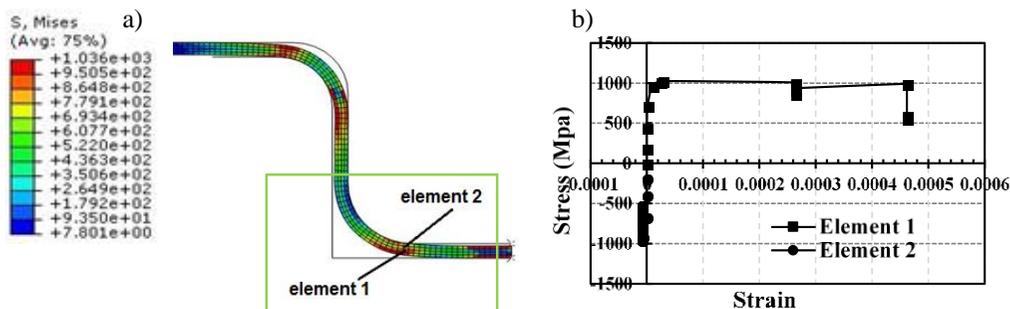
Pair of elements 1-2 are shown in **Fig. 3a**.

Fig. 3   a) Pair of elements 1-2; b) The principal stress-strain properties of elements 1 and 2

The principal stress-strain properties of elements 1 and 2 are shown in **Fig. 3b**.
The strain of element 2 is much smaller than that of element 1 along the bending process. Element 2 has a negative principal stress and strain while element 1 is positive. It proves that element 1 at the inner region of the bend is compressed while element 2 at the outer region is stretched and there is a difference in intensity of stress between these two elements.
The amount of principal stress and the principal stress and strain curve of elements 3 and 4 are shown in **Fig. 4a** and **Fig. 4b**.
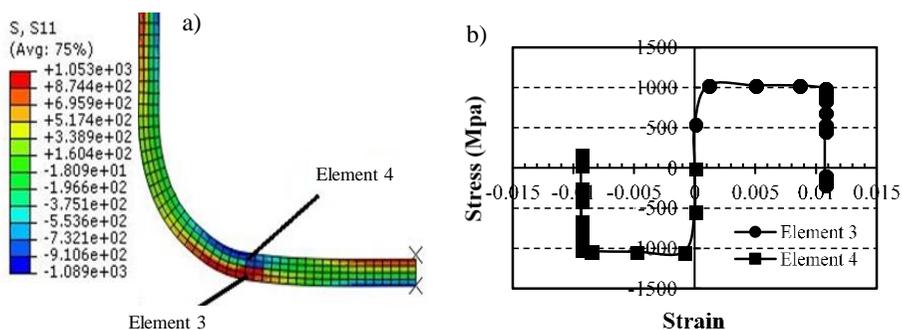

Fig. 4   a) The amount of principal stress in the blank; b) The principal stress and strain curve of elements 3 and 4

Similarly, element 4 is compressed while element 3 is stretched and there is a slight difference in intensity of stress between the two elements 3 and 4.
As the material is bent, the inner region of the bend is compressed while the outer region is stretched, so the molecular density is greater on the inside of the bend than on the outer surface. The compressive forces are less than the tensile forces on the outside of the bend. In addition, there is a difference in intensity of stress between two tensile and compression regions within the material. As a result, the material tends to return to its flat position.

Experimental results
Experimental results shown in **Fig. 5a** with different directions compared to RD: 0°, 45°, and 90°, respectively. To calculate the springback amount, the bending angles are measured. The obtained results are shown in **Fig. 5b**.
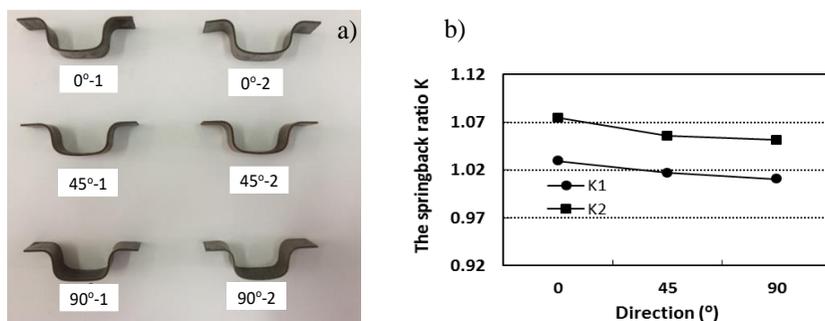
Fig. 5   a) Experimental results of specimens along 0°, 45°, 90° after forming in case of $R = 5$ mm and $c = 1.2t$; b) The sprinhback ratio of specimens along 0°, 45°, 90°
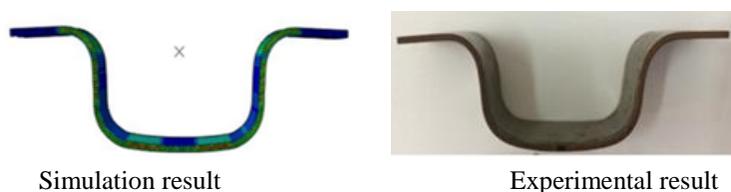

Simulation result   Experimental result

Fig. 6   Simulation and experiment results comparison after bending that following the 0° directions

On the whole, the springback ratios in both the upper and bottom corners are greater than 1. Therefore, the higher the springback ratio is, the greater the springback amount becomes. The springback amount gradually decrease in three different directions 0°, 45°, 90° along with the rolling direction. **Fig.6** shows a comparison between simulation and experimental results after bending that following the 0° directions.
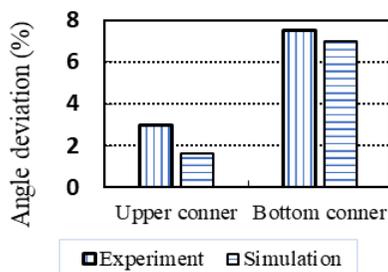

Fig. 7   Simulation and experiment angle deviation

Fig. 7 shows simulation and experiment angle deviation at the upper and bottom corners are less than 2.1%. This small value proves that the application of the hardening models is appropriate.

4   Conclusions

The simulation results shown that the springback amount of the DP980 steel varies in the upper and bottom corners according to the gaps. Where $R = 5$ mm, the largest springback percentage is 1.83 % in the upper corner and 7.14 % in the bottom corner.

Experimental results indicated that the springback amount gradually decreases in three different directions 0°, 45°, 90° along with the rolling direction. In the 0° direction, A comparison of simulation and experimental results showed that the springback amount of DP980 sheet steel at the bending angle after forming process is small. Therefore, the application of the hardening models for simulation is appropriate.

The results obtained from this study are the basis for calculating and selecting the solution when forming for DP980 AHSS.

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