Comprehensive Theoretical, Experimental, and Numerical Analysis of Springback in Mild Steel Sheets during Free V-Bending, with Prediction Using an ANN-Based Model

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Book of Abstracts

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Comprehensive Theoretical, Experimental, and Numerical Analysis of Springback in Mild Steel Sheets during Free V-Bending, with Prediction Using an ANN-Based Model

Thursday, 31st October - 10:15 – 12:00 – Room 1 - Oral

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Keywords: Free V-bending, Spring-back, Artificial Neural Networks, Cold Forming, Finite Element Analysis

In order to design the mold in a short time and accurately and to achieve the desired measurement accuracy, it is vital to know the amount of springback in advance. In this study, the theoretical and experimental examination of springback in free bending molds was carried out, analyses were performed using the finite element method using experimental data, and then a prediction model was developed using artificial neural networks. A modular free V bending mold was designed to determine the springback amounts. Low Carbon Plate (DKP) steel material was used as the sample material in the experiments. The samples were obtained by bending them at 1, 2, 3 and 4 mm thicknesses, at angles of 15, 30, 45, 60, 75, 90, 105 and 120 degrees for each thickness and at 3 different nose radius values at each angle. At least 5 bending operations were performed for each sample in the experiments. The measurement accuracy and springback of the samples obtained from the bending operations were measured using an optical projection device. These measured elasticity values were compared comprehensively with the solutions made in the MSC Marc-Mentat® software used in computer-aided finite element analyses and with some theoretical models. In addition, an artificial neural network (ANN) model was established using experimental data, and with the help of the developed model, the results of intermediate values without experiments were tried to be estimated. It was observed that the established ANN estimation model produced values very close to the experimental data.

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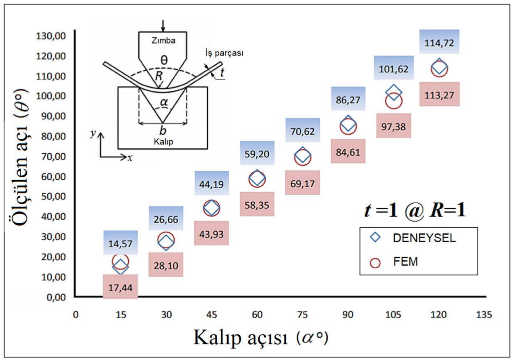

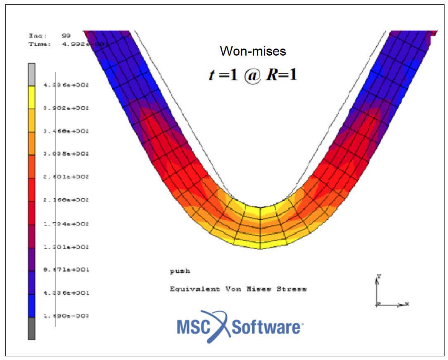

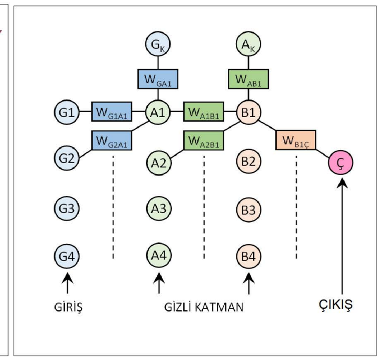

Introduction

The cold forming process is widely used in the production of various components, particularly in industries such as automotive, home appliances, and electronics, where steel sheet materials are common due to their wide range of applications. The products in these fields must meet precise dimensional tolerances. During the production of bending dies, several operations are carried out to achieve the desired product, often leading to time, cost, and labor losses. Common methods in sheet metal forming include V-bending, U-bending, edge bending, and free bending. Several experimental and theoretical studies have been conducted to examine springback behavior, including work by Inamdar et al. [3], who investigated springback in air V-bending operations with five different materials, showing that springback varies depending on the die opening-to-sheet thickness ratio and the bending angle. In addition to experimental research, theoretical work, such as that by Leu and Zhang [4], has contributed to the literature. They developed an empirical solution to predict springback for high-strength steels based on Hill's theory of plastic anisotropy, taking into account thickness ratio, normal anisotropy, and strain hardening exponent. Hai et al. [5] explored the relationship between bending angle and springback at high bending radii using SS400 stainless steel. Their findings demonstrated an increase in springback with increasing bending angles. More recent studies, such as Sharma et al. [6], developed a theoretical model for predicting springback in free V-bending of AA1050 and SS430 layered sheets using Hill’s anisotropic yield criterion and a power law for stress hardening. Experimental results showed a 15% deviation in some cases compared to theoretical predictions. Similarly, Asnafi [7] studied springback in stainless steel sheets of varying thicknesses, creating an analytical model that showed good agreement with experimental findings despite ignoring neutral axis shift and thinning. Other research has focused on improving prediction accuracy, such as Badr et al. [16], who found that springback in rolled Ti-6Al-4V alloy was significantly reduced compared to unrolled material. The effects of rolling direction on springback were also highlighted. In another study [17], high-strength steel SCGADUB1180 was tested at various bending angles and punch radii, with results showing that smaller punch radii and larger bending angles minimized springback. In this study, experimental data were compared with FEM analysis to investigate the springback behavior. The results were found to be very close to each other.

Material and Method

In the bending tests, the specimens were prepared in rectangular shapes with dimensions of 60x20 mm. The reason for selecting smaller material dimensions was based on the assumption that springback could be more accurately detected in a narrow area. The experiments for DKP steel included thicknesses of 1 mm, 2 mm, and 3 mm, with bending angles of 15, 30, 45, 60, 90, and 120 degrees. For each angle, bending was carried out using three different bending radius types according to the thicknesses of 1, 2, and 3 mm. The tensile test specimens were produced from the actual material, which had the same batch and serial number as the sheet material, and the tensile tests were conducted according to ASTM E8-M standard using a Tinius Olsen H300KU model tensile testing machine. The tensile test identified the material's physical properties, such as stiffness (elastic modulus), yield, and tensile strength. The stress-strain graph obtained from the tensile test is shown in Figure 1a.

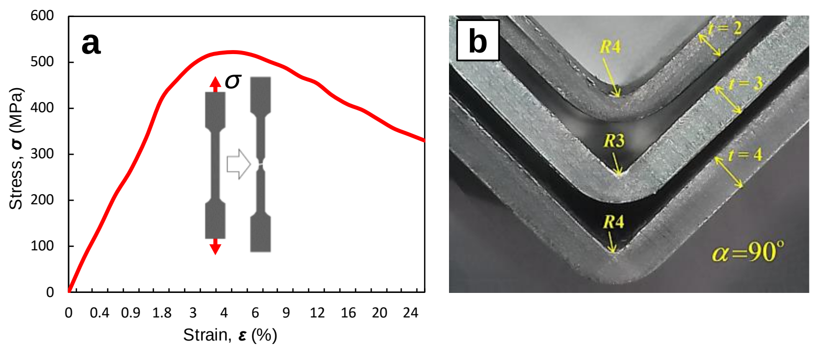

Fig. 1. (a) Stress (MPa)- (%) elongation relationship of DKP sheet and (b) free V-bent samples with different thickness and radius at 90° bending angle

The bending process was performed numerically using the MSC Marc Mentat® analysis software. To characterize the material, three standard tensile tests were conducted on the samples, and the stress-strain curve for soft steel (DKP) sheet material was obtained based on the average values. The samples had an average modulus of elasticity of 200 GPa and a Poisson's ratio of 0.3. Experimental approaches and assumptions from previous studies were adopted when determining the die dimensions. A double-acting hydraulic press was used in the bending process, and the springback angles occurring in the samples after bending were measured using an optical projection device. Figure 1b shows the post-bending images of three samples bent at a 90-degree angle with different thicknesses (t) and bending radii (R). These samples have values of t=2 mm and R=4 mm, t=3 mm and R=3 mm, and t=4 mm and R=4 mm.

Results and Discussion

The numerically analyzed and experimentally measured springback values are presented comparatively in Fig. 2. When comparing the springback values for sheet material with a thickness of 1 mm, it is observed that the bending results obtained experimentally and through FEM show close agreement in most cases. In general, as the bending angle increases, the amount of springback also tends to increase. In the graphs, square markers represent experimental results, while circular markers indicate numerical analysis (FEM) results. To avoid expanding the text volume in this section, only the FEM results at 30, 60, and 90 degrees and for thicknesses of t=1, 2, and 3 mm are shown Fig. 2. When examining the results in Fig. 3a-Fig. 3c, it is clearly observed from the changes in the red region that as the bending angle increases, the amount of plastic deformation elongation decreases.

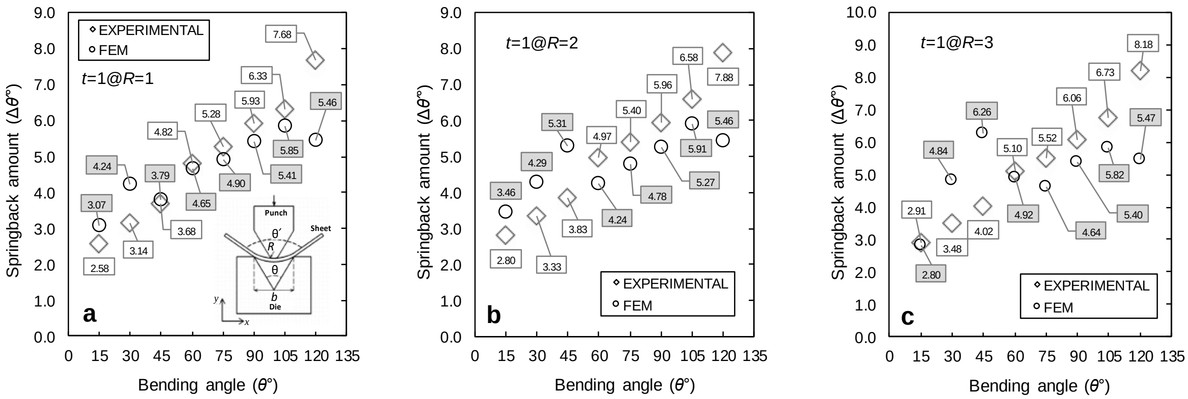

Fig. 2. Experimental and FEM comparison of air V bending process for 1 mm thick DKP sheet and 1 mm punch radius

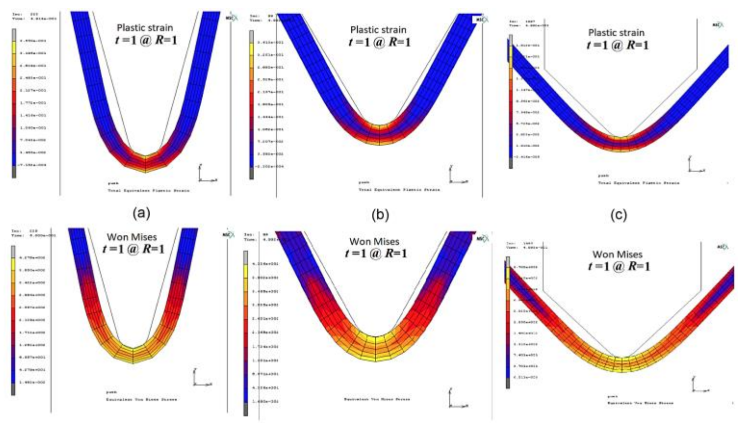

Fig. 3. Springback FEM results for 1 mm thick DKP sheet bent at (a) 30°, (b) 60° and (c) 90° die angle and 1 mm punch radius (up→plastic strain & down→won-mises stress)

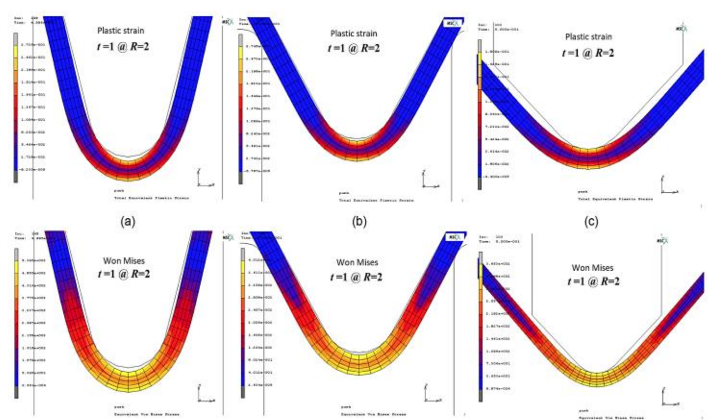

Fig. 4. Springback FEM results for 1 mm thick DKP sheet bent at (a) 30°, (b) 60° and (c) 90° die angle and 2 mm punch radius (up→plastic strain & down→won-mises stress)

When the Von Mises stress values are examined under constant thickness and bending radius (Fig. 4), the resistance level of the 1 mm sample to the applied load decreases as the angle increases, and the stress distribution spreads over a larger area with a lower intensity. In other words, as the bending angle increases, the sample undergoes less plastic deformation, resulting in an increase in springback. When examining the bending results of samples with a sheet thickness of 1 mm and a punch radius of 2 mm, it is observed that springback values increase as the punch radius increases compared to bending results with a punch radius of 1 mm. Additionally, an increase in springback values is observed as the bending angle increases (Fig. 5).

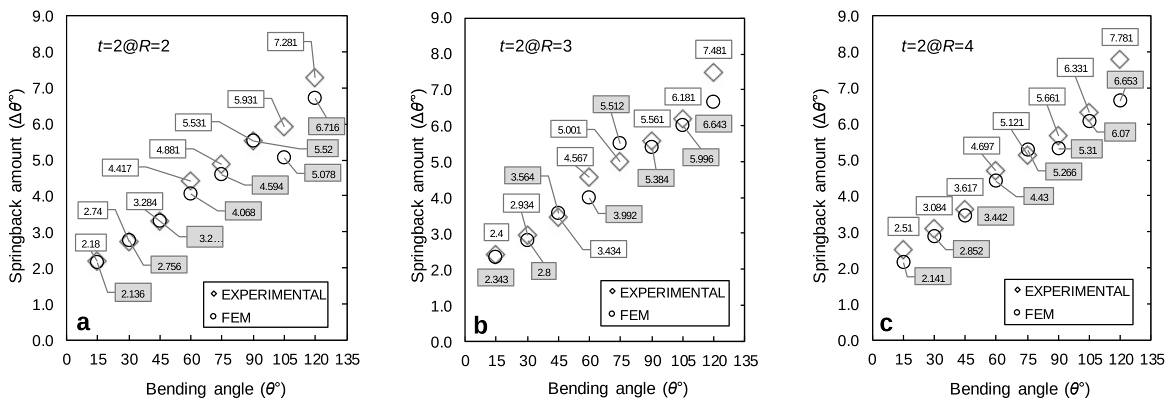

Fig. 5. Experimental and FEM comparison of air V bending process for (a) *R*=2, (b) *R*=3 and (c) *R*=4 radius @ *t*=2 mm thick DKP sheet

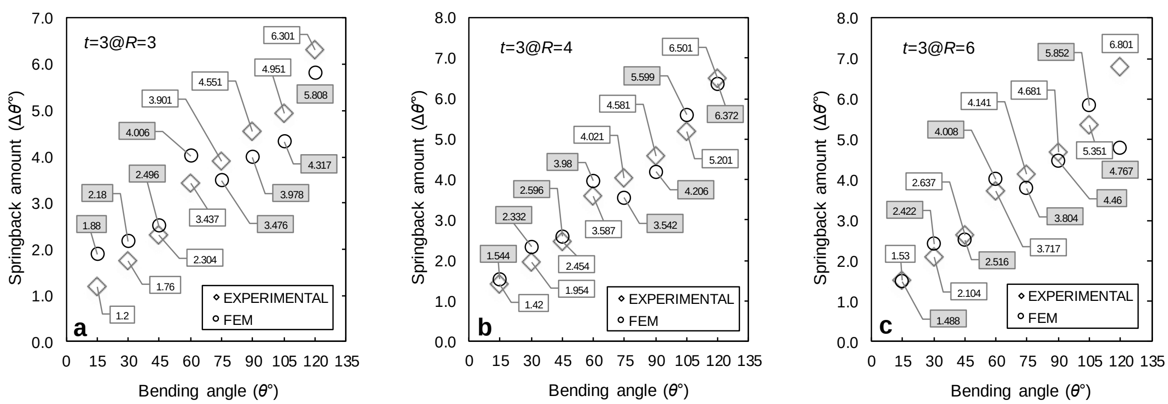

Fig. 6. (a) Experimental and FEM comparison of air V bending process for (a) *R*=3, (b) *R*=4 and (c) *R*=6 radius @ *t*=3 mm thick DKP sheet

When Fig. 5 and Fig. 6 are examined together, it is seen that springback generally increases as the bending angle increases. Similarly, springback increases as the punch radius increases. However, springback values decrease significantly as the sample thickness increases. For example, when the sheet thickness increases from 2 mm to 3 mm with a constant *R*=3 mm punch radius, the angle values measured in the 30-degree bending case decrease from 32.94° to 32.18°, respectively.

It is seen that experimental and numerical springback increases in parallel for the same bending angle. As the bending angle increases, the springback behavior of the material increases. In other words, as the bending angle increases, the internal stress level on the material also changes. As the bending angle increases, external factors causing material deformation decrease; therefore, the elastic properties of the material become more apparent. This provides a significant advantage in terms of durability and longevity, especially in the design phase of large structures. The effects of factors such as punch radius, bending angle, and material thickness on the mechanical properties of sheet material are critical to the success of manufacturing processes. When optimizing such process parameters, researchers need to consider not only the initial results but also the long-term performance of the material.

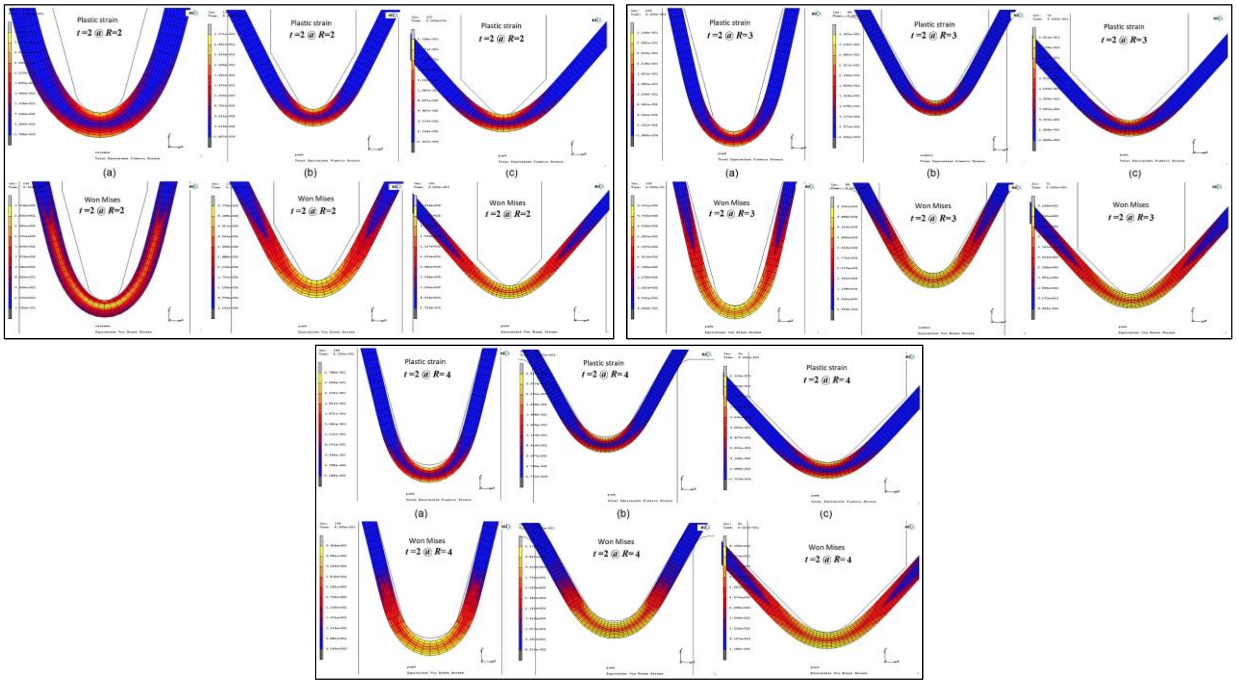

Fig. 7. (a) Springback FEM results for 2 mm thick DKP sheet bent at 30°, 60° and 90° die angle and 2 mm punch radius (up→plastic strain & down→won-mises stress), (b) for *R*=3 mm radii and (c) for *R*=3 mm radii of sample

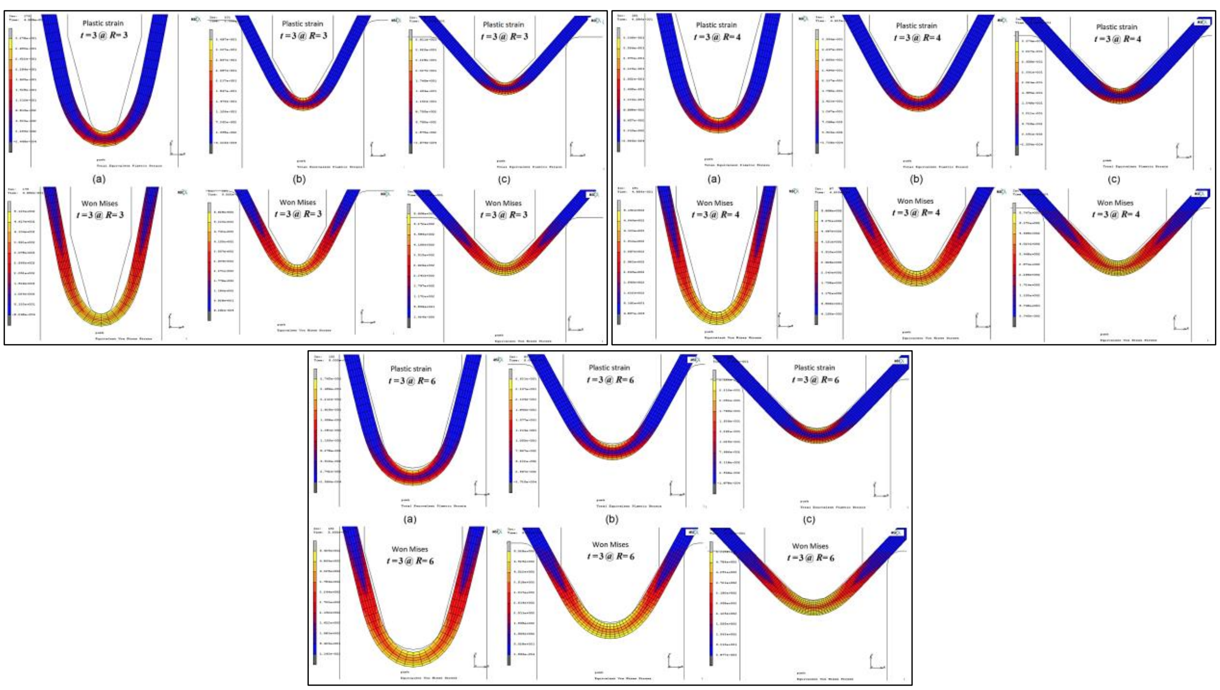

Fig. 8. (a) Springback FEM results for 3 mm thick DKP sheet bent at 30°, 60° and 90° die angle and 3 mm punch radius (up→plastic strain & down→won-mises stress), (b) for *R*=4 mm radii and (c) for *R*=6 mm radii of sample

The values obtained with FEM are shown in Fig. 7 as plastic strain and Von-Mises stresses from *R*=2 mm to *R*=4 mm for the test samples with *t*=2 mm thickness. When the results are examined, the maximum Von-Mises stress field is seen at the angle θ=30° for a fixed *t*=2 mm thickness, and this stress field decreases as the angle increases (See Fig. 7a-Fig. 7c). Similarly, the plastic strain values are read at the maximum at the smallest angle of 30 degrees. Under the fixed angle, it is seen that there is an increase in the internal stress regions in general as the thickness increases (See Fig. 7a-c and Fig. 8a-c).

Summary

In this study, the springback behavior of low carbon plate (DKP) samples with different thicknesses and punch radii was investigated during bending processes using a free V-bending die. Finite element analyses were performed with MSC Marc Mentat® software and springback simulations were obtained at various thicknesses. When the experimental results were compared with the numerical analyses, it was observed that the results were largely consistent. It was evaluated that small differences could be due to measurement errors in the experimental processes. In the study, it was determined that increasing the thickness decreased the springback, while increasing the bending angle and radius increased the springback. It is anticipated that this study will contribute to the prediction of springback in commonly used materials such as DKP.

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