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Impact of Geometric Parameters on Spring-Back Deformation in Double-Layer Metal Sheet Bending with an L-Shaped Die

Pham Hoang-Vuong

University of Transport and Communications (UTC), No. 3 CauGiay Street, Lang Thuong Ward, Dong Da District, Hanoi, Vietnam

Abstract: This study delves into the intricate dynamics of the return deformation process in double-layer metal sheet stamping on an L-shaped die, focusing on the pivotal influence of punch and die size parameters. The specific parameters under scrutiny include die radius, die clearance, and plate length. Employing a comprehensive methodology, this research conducts finite element simulations using Abaqus software, ensuring both data collection requirements and implementation feasibility are met. The simulation results are rigorously compared with the published data from a seminal comparative study [1], providing a critical point of reference for analysis. The findings of this investigation illuminate a profound similarity in the impact of three critical parameters, namely die radius, degree of mold opening, and plate length, on the degree of spring-back deformation in the L-bending of SPCC double-layer materials. This outcome not only substantiates and extends the existing body of knowledge but also offers novel insights into the interplay of these parameters in the double-layer metal sheet stamping process, thus contributing significantly to the field of manufacturing and process optimization.

Keywords: *The Spring-Back Deformation; Double-Layer Metal Sheet Stamping; Die Size Parameters; Finite Element Simulations; Manufacturing Process Optimization*

1. Introduction

Bilayer metals represent a valuable solution for addressing the demands of specialized materials, offering a unique amalgamation of engineering properties that are unattainable with single-metal configurations. These exceptional properties include but are not limited to enhanced abrasion resistance, elevated strength, corrosion resilience, and specific weight and elasticity requirements. As a result, bilayer metals find diverse applications across various industrial sectors such as automotive, chemical, and electrical engineering. The manufacturing of these materials encompasses various methods, ranging from the compaction of two distinct layers through rolling to the lamination of two materials in a heated state followed by further rolling to achieve the desired thickness. Other techniques involve processes like explosion welding, followed by rolling, among others [2].

Within the realm of bilayer metal fabrication, the stamping process presents a unique challenge – the occurrence of spring-back deformation following the shaping operation. This issue not only complicates simulation efforts but also poses a considerable obstacle to accurate design calculations. Extensive research has been conducted in this domain, resulting in a plethora of published works. However, this article focuses on a specific research document [1] as a foundational basis for comparison and contrast of findings. In the referenced study, the author explored the influence of punch and die parameters on the extent of spring-back deformation after stamping materials using an L-shaped mold. The outcomes were validated through finite element simulations and substantiated by actual experimental data.

Abaqus, a comprehensive software suite rooted in the finite element method, offers a wide range of problem-solving capabilities, spanning from relatively straightforward linear analyses to complex non-linear simulations. Notably, Abaqus boasts a rich library of elements that can faithfully replicate virtually any geometric configuration. Leveraging these attributes, the authors of this study opted to employ Abaqus software to conduct simulations and extract crucial parameters. The material chosen for simulation in this research is the SPCC steel plate, a cold-rolled steel sheet that adheres to the Japanese standard JIS G-3141. The 'C' in SPCC denotes 'Cold Rolled,' denoting its exceptionally smooth and aesthetically appealing surface finish. Categorized as mild carbon steel, SPCC steel commands relatively higher prices in the market [3].

Upon executing simulations, the results revealed disparities when compared with the reference article. However, it is noteworthy that the influence graphs of mold radius, mold gap, and plate length parameters exhibited remarkable similarity. This observation lays the foundation for a more in-depth exploration and analysis, which is the core objective of this research endeavor.

2. Materials and Simulation

The material under investigation is the SPCC double-layer metal sheet, characterized by the following technical specifications [4]:

Specific gravity: 7.8e-6

Elastic modulus: 210,142 MPa

Poisson's coefficient: 0.3

The relationship between equivalent stress and equivalent strain is described by the equation:

$\sigma=166+210{,}142\times(1-\exp(-41.452\times\varepsilon))$

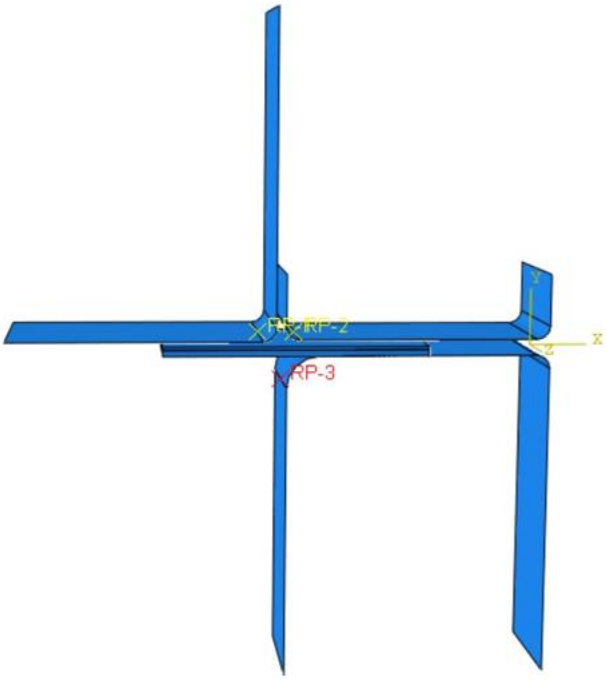

Fig. 1. FEM model

In the pursuit of understanding the influence of die radius, punch-die file distance, and sheet length on the extent of spring-back deformation following SPCC double-layer metal stamping, a finite element model (Fig.1) was meticulously constructed. This model serves to curtail design calculation expenses and streamline the simulation process. It features a scenario in which the punch, die, and stop plate are intricately interlinked through frictional interactions, while the test specimen comprises a double-layer SPCC steel plate.

The table below delineates the dimensional parameters of the punch, die, and stop plate within the model, accompanied by a selection of variable sizes:

Punch, Die, and Blank holder Parameters (Table 1):

Table 1: Punch, Die, and Blank holder Parameters

Component	Height (mm)	Length (mm)	Width (mm)	Curve Radius (mm)
Blank holder	10	40	20	2
Die	50	40	20	3;5;7
Punch	50	40	25	2
SPC blank	40;60;80	-	-	20

Moreover, the simulation accommodates variations in the punch-die gap dimensions, set to 0.1 mm, 0.2 mm, and 0.3 mm during the simulation process.

The simulation process unfolds in three distinct steps:

Step 1: The metal plate is propelled at a constant speed of 1 mm/s until it makes contact with the surface of the first metal plate.

Step 2: While under loading conditions, the punch descends, causing the metal plate to bend and contact the die surface.

Step 3: The punch retracts to its initial position.

This cycle is then repeated, with parameters such as mold radius, SPCC metal sheet length, and pestle-mortar distance being systematically altered during each iteration. The boundary condition parameters governing the simulation model across these steps are illustrated in the table below:

Boundary Condition Parameters (Table 2):

Table 2: Boundary Condition Parameters

	Step 1	Step 2	Step 3
Die	U1 = U2 = 0	U1 = U2 = 0	U1 = U2 = 0
Punch	U1 = 0	U1 = 0; U2 = -50	U1 = 0; U2 = 50
Blank holder	U1 = 0; U2 = 0	U1 = 0; U2 = 0	U1 = 0; U2 = 0

3. Results and Discussion

During this investigation, the manipulation of dimensional parameters such as metal plate length, punch-die distance, and curvature radius has led to noteworthy variations in the outcomes, offering valuable insights into their influence.

Investigating the Impact of Die Radius:

To delve into the ramifications of die radius on the spring-back outcomes following the plastic deformation of SPCC metal sheets, simulations were conducted under specific conditions: a constant sheet length (L) of 60 mm, a fixed punch-die distance (C) of 0.2 mm, and a dynamic die radius (R) of 3, 5, and 7 mm, respectively, as shown in Fig.2.

Assessing the Influence of Die - Punch Gap:

To evaluate the role of the gap between the die and punch, the parameters were set as follows: die radius (R) maintained at 5 mm, and metal plate length (L) at 60 mm. Investigations were initiated by altering the gap size (C) between the die and punch to 0.1 mm, 0.2 mm, and 0.3 mm, respectively, as shown in Fig.3.

Analyzing the Effect of Metal Sheet Length:

Inquiries into the impact of metal sheet length were conducted while keeping die radius and die-punch clearance parameters constant at R = 5 mm and C = 0.2 mm. The SPCC sheet length (L) was systematically varied, taking values of 40 mm, 60 mm, and 80 mm, as shown in Fig. 4.

The results of these inquiries are meticulously presented in the tables and figures, alongside comparisons with available experimental and analytical findings.

Impact of Dimensional Changes on Spring-back Parameters:

Notably, as dimensional parameters were altered, the spring-back parameters exhibited significant shifts following plastic deformation, thus highlighting the sensitivity of these parameters, including die radius, die clearance, and metal sheet length. The outcomes unveiled a degree of error, with the most substantial discrepancy observed when the material composition was modified, resulting in a 33.33% error. This error primarily stems from the difference between the simulated SPCC metal sample and the corresponding experimental sample.

R	FEM	EXP	SPCC	%
3	1.55	1.5	1	33.33
5	3.7	3.8	3.1	18.42
7	**4.7**	**5**	**4.5**	10.00

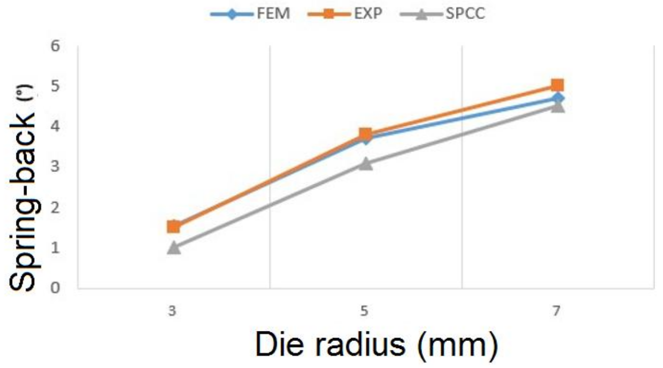

Fig. 2. Investigating the Impact of Die Radius

C	FEM	EXP	SPCC	%
0.1	**2.6**	**2.7**	**2.2**	18.52
0.2	3.7	3.8	3.1	18.42
0.3	4.53	4.8	4.2	12.50

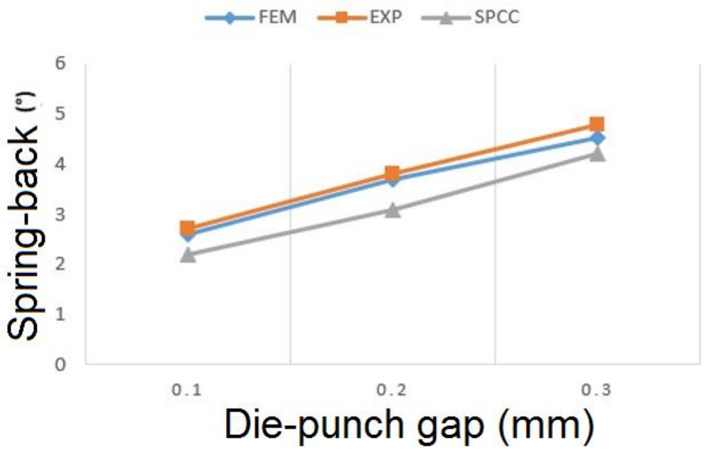

Fig. 3. Assessing the Influence of Die - Punch Gap

L	FEM	EXP	SPCC	%
40	4.7	4.3	4	6.98
60	**3.7**	**3.8**	**3.1**	18.42
80	3.6	3.7	2.8	24.32

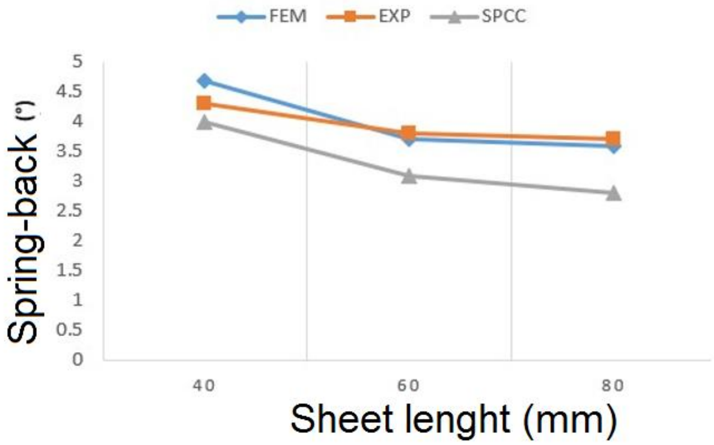

Fig. 4. Analyzing the Effect of Metal Sheet Length

The visual representation of the simulation results for the spring-back parameters after deformation further underscores the dynamic nature of these outcomes. Figures provide a comprehensive snapshot of the response to parameter changes, presenting a visual aid to the numerical data.

To facilitate a more direct understanding of the outcomes, the article includes comparisons between the simulation results presented herein and those obtained from previous experiments. The side-by-side comparison underscores the congruence and divergence of the findings, serving as a critical point of reference for analysis.

Summary of Key Simulation Cases:

The results showcased in the article encapsulate several critical simulation scenarios, which are briefly summarized here:

Case 1: L = 60 mm, C = 0.2 mm, R = 7 mm (Fig. 5)

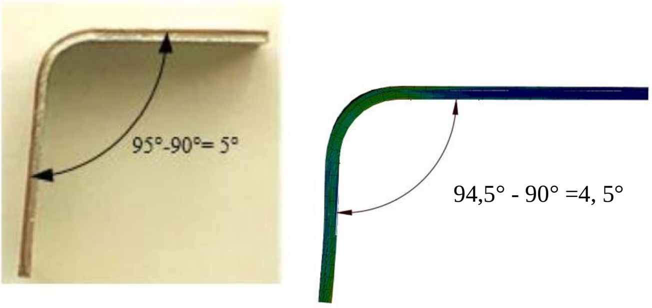

Fig. 5. Spring-back comparison for Case 1: L = 60 mm, C = 0.2 mm, R = 7 mm between simulation and experiment

Case 2: L = 60 mm, C = 0.1 mm, R = 5 mm (Fig. 6)

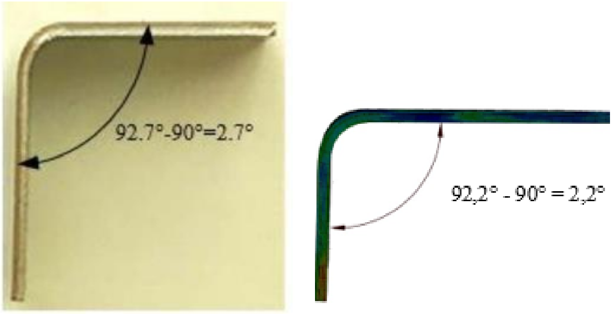

Fig. 6. Spring-back comparison for Case 2: L = 60 mm, C = 0.2 mm, R = 7 mm between simulation and experiment

Case 3: L = 60 mm, C = 0.2 mm, R = 5 mm (Fig.7)

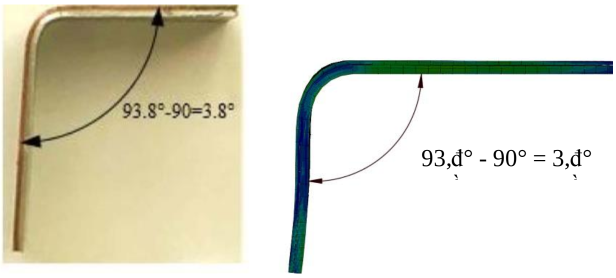

Fig. 7. Spring-back comparison for Case 3: L = 60 mm, C = 0.2 mm, R = 7 mm between simulation and experiment

These representative cases provide valuable insights into the influence of parameters on the elastic parameters and underscore the dynamic nature of the response in the SPCC double-layer metal sheet L-benidng process.

4. Conclusion

In this study, a comprehensive spring-back simulation test was conducted using Abaqus software on double-layer SPCC metal sheets. The outcomes of this research bring forth critical insights and implications for further understanding of the problem at hand.

The results of this investigation reveal a complex interplay between several pivotal parameters that govern the degree of spring-back in SPCC metal sheets after plastic deformation. In summary, the following key observations and conclusions can be made:

Die Radius and Die-puch gap Influence: The findings illuminate a notable reduction in elastic parameters following plastic deformation when the die radius is decreased, and the gap between the punch and die is reduced. This suggests a direct correlation between these parameters and the material's tendency to spring back or deform.

Impact of Metal Sheet Length: Contrary to the die radius and punch-die gap, the research demonstrates that the sping-back parameters increase as the length of the metal sheet is extended. This observation underscores the influence of metal sheet length on the degree of spring-back deformation, providing a valuable insight into the material's behavior during the stamping process.

These results not only provide a deeper understanding of the intricate dynamics involved in the stamping of double-layer metal sheets but also offer novel insights into the specific influence of die radius, punch-die gap, and metal sheet length on the degree of spring-back deformation. Such insights hold significant promise for advancing the field of manufacturing and process optimization, offering potential avenues for improving the precision and efficiency of L-bending processes in various industrial applications.

Moreover, this research contributes to the growing body of knowledge concerning the complex relationship between material properties and forming processes, thus serving as a valuable resource for future investigations in this domain. In conclusion, the outcomes of this study extend beyond the immediate context, with potential applications in diverse industries where the stamping of double-layer metal sheets is a common practice.

5. Reference

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