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Research Article

Optimization Of Bending Process Parameters For HSLA420 Material Sheet: Experimental Analysis And Stress Evaluation

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ARTICLE INFO **ABSTRACT**

In the dynamic landscape of the engineering industry, there is a persistent emphasis on achieving precision and intricacy in the bending of components. This study delves into an exhaustive examination of parameters governing the bending process, including the bending angle of the punch, die opening, deformation stress, and elasticity, specifically in the context of bending V-shaped bars utilizing alloy steel HSLA420. Employing advanced computational tools like ABAQUS SIMULIA software, simulations are conducted using the finite element method (FEM) in conjunction with Taguchi and analysis of variance (ANOVA) techniques. The investigation unravels crucial insights into aspects like tensile stress, compression, and the intricate phenomenon of reverse-forward elasticity during the simulation of V-bar bending. Remarkably, comparisons with prior research findings elucidate the consistency between simulation outcomes and experimental observations, underscoring the reliability and validity of the proposed methodology.

Keywords: V-bending, Finite Element Method (FEM), spring-back, Taguchi, HSLA420 materials

1. INTRODUCTION

The mechanical engineering landscape is witnessing a surge in interest and investment, particularly in the domain of high-precision sheet metal fabrication. Sheet metal, owing to its versatility and efficiency, finds extensive applications across diverse industries such as automotive, shipbuilding, electronics, and aerospace. Among the myriad methods employed for sheet metal fabrication, bending emerges as a preeminent technique, enabling the rapid production of components with minimal manufacturing errors. Noteworthy advancements in bending technology have been chronicled in seminal scientific publications, including pioneering research by scholars at the University of Wisconsin-Madison and other notable contributions [1-5]. Thipprakmas's [6] exploration of the influence of punching height on V-bending angle using FEM, substantiated by empirical validation. Buranathiti and Cao's [7] development of effective analytical models for prognosticating reverse elasticity in straight flange processes. Slota and Jurčišin's [8] in-depth analysis of TRIP, AHSS, and mild steel to prognosticate reverse elasticity in V-bending pertinent to automotive applications.Wang et al. [9] and Chan et al.'s [10] exhaustive investigations into inverse elastic control in sheet metal bending processes. Yi et al.'s formulation [11] of a model predicated on post-maximum bending friction relaxation to analytically predict reverse elasticity. Thipprakmas and Phanitwong's [12] adept utilization of the Taguchi technique to optimize process parameters for reverse and forward elasticity in V-bending processes.

While considerable strides have been made in elucidating forward and backward stress and elasticity parameters in sheet metal bending experiments, comprehensive investigations into bending metal sheets under varied V-shaped die conditions remain scarce. Consequently, this study endeavors to shed light on the intricacies of metal sheet bending in V-shaped molds, with a particular emphasis on elucidating the influence of die shoulder width and radius on stress and elasticity responses. Furthermore, the research aims to enhance comprehension of forward and reverse elastic processes during bending operations.

The study employs a robust modeling approach and leverages advanced computational tools such as ABAQUS CAE 2017 software to obtain results, facilitating predictions through the variance method (ANOVA). Through this comprehensive approach, the research aims to contribute novel insights into the bending process, fostering advancements in high-precision sheet metal fabrication.

2. RESEARCH METHODS

2.1. Experimental Procedures:

The research adopts a multifaceted approach, incorporating both experimental and computational techniques to comprehensively investigate the V-bending process of metal sheets using alloy steel HSLA420. The experimental procedures are meticulously designed and executed to explore the intricate interplay of process parameters, while computational simulations are employed to validate and augment the experimental findings.

Figure 1. Experimetal setup

2.2. Experimental Setup:

The experimental setup entails the utilization of three V-shaped bending molds with varying mold openings of 12t, 16t, and 20t (where 't' represents the thickness of the metal sheet) and punch angles of 86°, 88°, and 90°, respectively. Moreover, the system's friction coefficients are modulated across three levels: 0.1, 0.15, and 0.20. Notably, the material under investigation is HSLA 420 hard alloy steel, renowned for its robustness and resilience in engineering applications.

2.3. Simulation Process:

To complement the experimental investigations, computational simulations are conducted using the ABAQUS simulation software. The simulation model, meticulously crafted to mimic real-world conditions, features a metal plate with dimensions of 90mm (length), 30mm (width), and 2.4mm (thickness) (Fig. 2). The simulation encompasses nine distinct modules, each meticulously designed to simulate various aspects of the V-bending process with the Propertiles of HSLA420 sheet in Table 1.

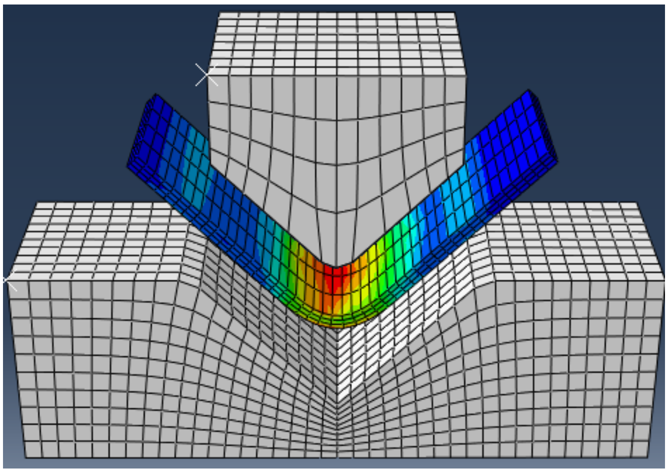

Figure 2. Simulation setup

Table 1 Propertiles of HSLA420 sheet

Propertiles	**HSLA420**
Young Modul (Gpa)	210
Poisson Coeficient	0.3
Yield Strength (Gpa)	432
Tensile Strength (Gpa)	488
Density	7800
Thickness	1.5

Through this integrated approach, encompassing both experimental and computational methodologies, the research aims to elucidate the nuanced dynamics of the V-bending process and pave the way for enhanced precision and efficiency in sheet metal fabrication.

2.4. Taguchi Method and ANOVA:

TABLE 2: PROCESS PARAMETERS AND THEIR LEVELS

Process Parameter	Level 1	Level 2	Level 3
Punch Angle	86°	88°	90°
Die Opening	12t	16t	20t
Coefficient of Friction	0.1	0.15	0.20

The Taguchi method, pioneered by Genichi Taguchi, stands as a cornerstone of this research endeavor. Renowned for its efficacy in enhancing product quality while minimizing costs, the Taguchi method has been extensively adopted in various industries, including engineering and biotechnology. By utilizing the orthogonal screen L18 design, the study incorporates three critical process parameters—punch bending angle, die opening, and coefficient of friction—each with three levels (Table2) . This strategic experimental design facilitates a systematic exploration of the factors influencing the V-bending process.

Additionally, Analysis of Variance (ANOVA) emerges as a pivotal statistical tool for partitioning variation and discerning the contribution of individual parameters to the forward-backward elastic behavior of the metal. Through ANOVA, the research aims to unravel the intricate relationships between process parameters and their impact on the bending characteristics of the material.

3. RESULTS AND DISCUSSION

The Taguchi method and ANOVA table (table 3) were employed to investigate the influence of various parameters on the deformation of HSLA420 material sheets, particularly focusing on the deformation angle. Utilizing Abaqus software, simulations were conducted to gather data on the deformation angle concerning variations in the punch angle (A), the V-opening of the die (B), and the friction coefficient (C). The analysis utilized the signal-to-noise ratio (S/N) with the criterion of "Smaller is better" [13-14].

The ANOVA table provided insights into the percentage influence of the three parameters: the bending angle of the punch (A), the opening of the V-shaped die (B), and the friction coefficient (C) on the deformation process. Results indicated that the V-opening of the die had a substantial impact on bending, exerting nearly total influence, while the angle of the punch and the friction coefficient exhibited negligible effects on the process.

Table 3: ANOVA

Parameter	**S/N Ratio for Each Level**			**Sum of Squares**	**Percentage of Effect**
	1	2	3		
A	-19.13	-19.18	-19.23	0.0131	0.0377
B	-18.92	-19.26	-19.36	0.328	0.9418
C	-19.18	-19.22	-19.15	0.007	0.0203
Total	-	-	-	0.348	-

Following the simulation process, tensile and compressive stresses were determined for various configurations of the bending angle of the punch, opening of the die, and friction coefficient. The relationship between these parameters and stress levels was visually represented through charts.

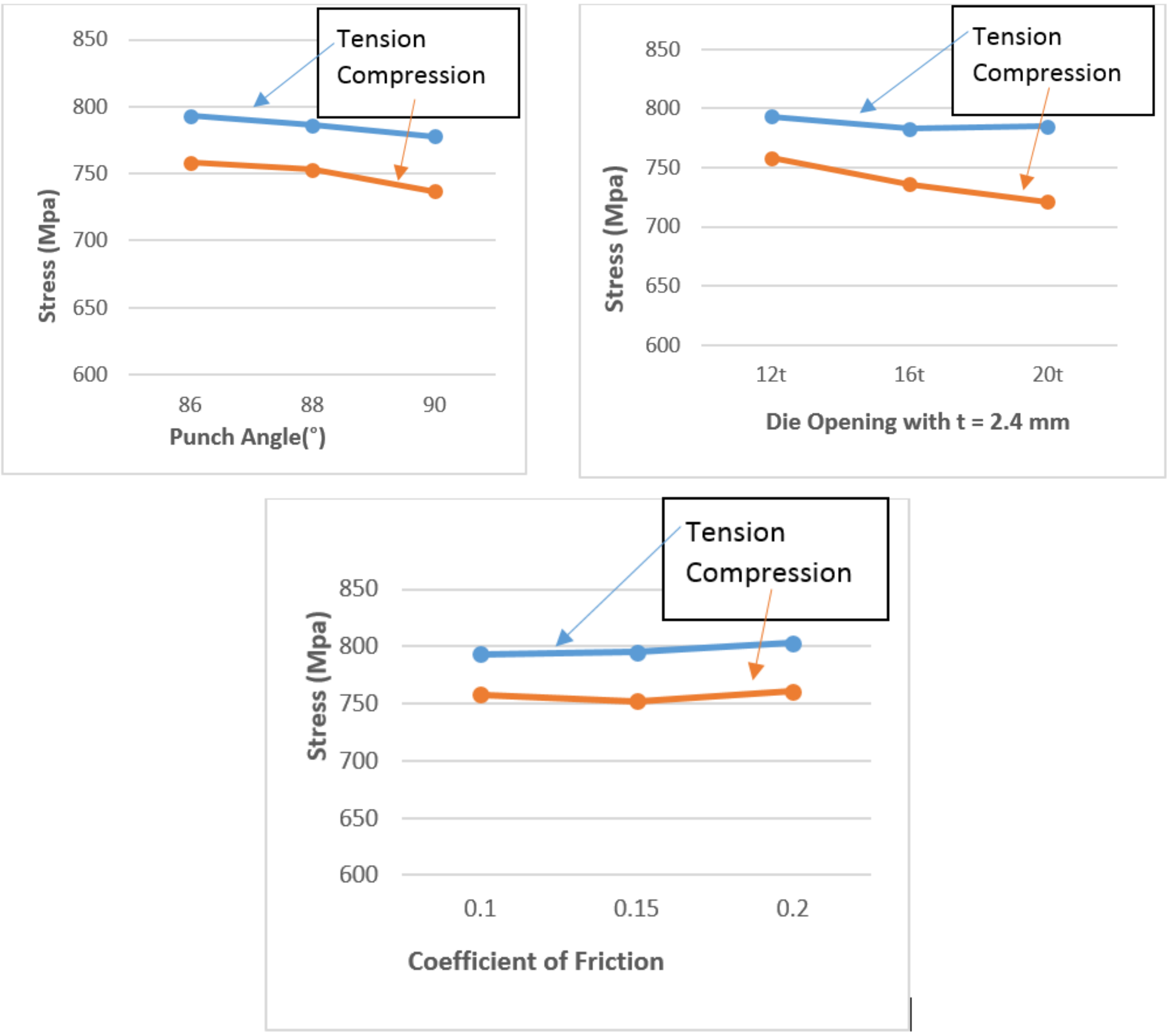

Fig. 3 The relationship between these parameters and stress levels

In the experimental analysis of the bending process for HSLA420 material sheet, the variation in process parameters—specifically the bending angle of the punch, opening of the V-shaped die, and friction coefficient—significantly influences the tensile and compressive stresses experienced by the material.

Impact of Punch Bending Angle:

When increasing the bending angle of the punch from 860 to 880, both tensile and compressive stresses exhibit a decreasing trend. Tensile stress reduces from 793 MPa to 786 MPa, a decline of 0.88%, while compressive stress decreases from 758 MPa to 753 MPa, a decrease of 0.66%. Further increments in the bending angle to 900 result in continued stress reduction, with tensile stress decreasing to 778 MPa (1.02% decrease) and compressive stress decreasing to 737 MPa (2.12% decrease). These observations suggest that higher bending angles lead to decreased stresses in the workpiece.

Effect of Die Opening:

Altering the opening of the V-shaped die influenced stress levels differently. While increasing the opening from 12t to 16t led to a decrease in stress, further increases to 20t showed a mixed effect on tensile stress.

Increasing the opening of the V-shaped die from 12t to 16t leads to a reduction in both tensile and compressive stresses. Tensile stress decreases from 793 MPa to 783 MPa (1.26% decrease), while compressive stress decreases from 758 MPa to 736 MPa (2.91% decrease). Subsequently, further increasing the die opening to 20t results in a marginal increase in tensile stress (0.26%) while maintaining a decreasing trend in compressive stress (2.04%). This indicates that while higher die openings generally lead to reduced stresses, the effect on tensile stress becomes less significant at larger openings.

Influence of Friction Coefficient:

Increasing the friction coefficient generally led to an increase in both tensile and compressive stresses. The rise in coefficient from 0.1 to 0.2 resulted in notable stress increments.

Increasing the friction coefficient from 0.1 to 0.15 results in a slight increase in both tensile and compressive stresses. Tensile stress rises from 793 MPa to 795 MPa (0.25% increase), while compressive stress decreases from 758 MPa to 752 MPa (0.79% decrease). Further increasing the coefficient to 0.2 leads to continued increments in both tensile and compressive stresses, with tensile stress reaching 803 MPa (1.01% increase) and compressive stress rising to 761 MPa (1.19% increase). These findings suggest that higher friction coefficients correlate with increased stresses in the material.

In summary, the experimental observations highlight the intricate relationship between process parameters and the mechanical behavior of HSLA420 material during bending. Understanding these relationships is crucial for optimizing the bending process and achieving desired material properties while minimizing stress-related issues.

Comparison with Experimental Results

Comparison between simulation and experimental data indicated disparities, particularly concerning the influence of punch bending angle and die opening. While similarities existed in stress relationships with angle parameters, variations in die opening were attributed to differences in friction coefficient.

Study of Spring-back on Sheet Blanks

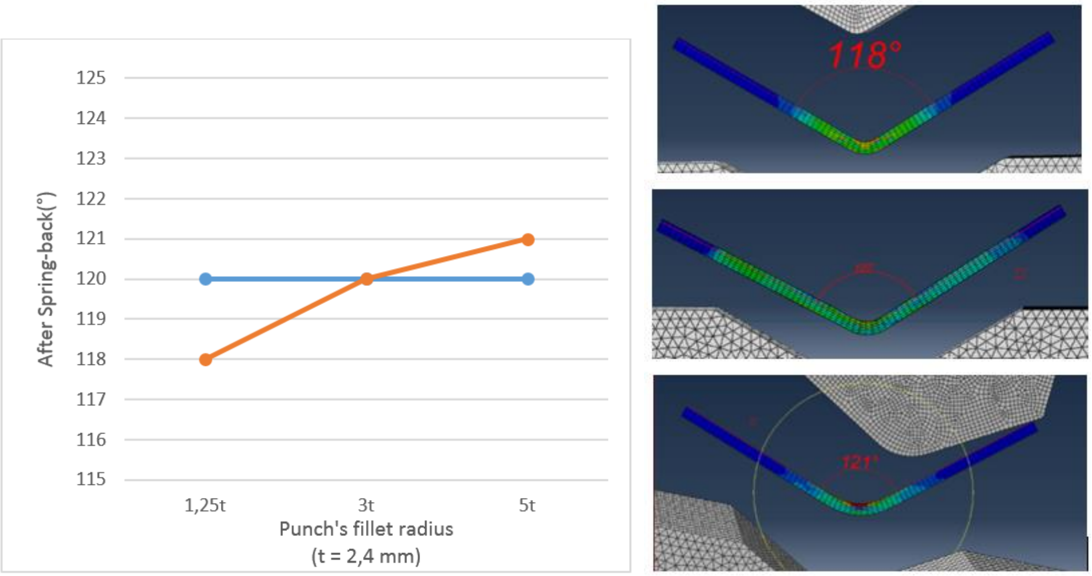

Fig. 4. Impact of the punch's fillet radius on the spring-back phenomenon

Further investigation into the impact of the punch's fillet radius on the spring-back phenomenon (Fig. 4) was conducted through simulation experiments. Three cases were analyzed with varying fillet radii, revealing distinct deformation behaviors:

Case 120° and punch's fillet radius of 1.25t:

Small fillet radius induced positive elasticity, causing the workpiece to exhibit a smaller opening angle after unloading.

Case 120° and punch's fillet radius of 3t:

Increasing the corner radius mitigated positive elasticity, resulting in the workpiece's opening angle aligning with the die.

Case 120° and punch's fillet radius of 5t:

A larger fillet radius led to inverse elasticity, with the workpiece exhibiting a larger opening angle after unloading.

4. CONCLUSION

In this study, we delved into the intricate process of bending V-shaped bars using HSLA 420 hard alloy steel, employing advanced computational tools such as ABAQUS SIMULIA software. Our exploration focused on understanding the multifaceted influence of various parameters, including the bending angle of the punch, opening of the die, and friction coefficient, on the mechanical behavior of the material, particularly in terms of tensile and compressive stresses, as well as the intriguing reverse-forward elasticity phenomenon.

Through the systematic application of the Taguchi method and ANOVA table, we meticulously analyzed and elucidated the impact of these parameters on the deformation characteristics of HSLA 420 material. Leveraging the capabilities of Abaqus software, we conducted comprehensive simulations, generating valuable data for meticulous analysis. By scrutinizing nine distinct experimental cases and juxtaposing our findings with existing literature, we discerned nuanced patterns and deviations, thus enriching our understanding of the intricate interplay between process parameters and material behavior.

Our investigation underscores the pivotal role of the die opening in influencing both tensile and compressive stresses, highlighting its significance in the bending process. Furthermore, we unveiled the profound influence of the fillet radius of the punch on the intriguing reverse-forward elasticity phenomenon, shedding light on a critical yet often overlooked aspect of metal forming processes.

Moving forward, to optimize tensile and compressive stresses while mitigating the reverse-forward elasticity phenomenon, it is imperative to prioritize the meticulous analysis of die opening and punch fillet radius. By honing in on these critical parameters, manufacturers and researchers can devise tailored strategies to enhance the performance and efficiency of metal bending processes, thus paving the way for advancements in manufacturing technologies.

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