International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 14, Issue 5 [May. 2025] PP: 275-280

The Influence Of Punch Angle, Sheet Thickness, And Punch Nose Radius On Springback Error In V-Bend Process For Sus 201 Through Simulation And Analysis

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Abstract
Metal stamping is one of the most common manufacturing processes for shaping sheet metal. During this process, the sheet metal undergoes plastic deformation by the punch, causing it to bend and form the desired shape. The mechanical properties of the material directly influence the formability of the product. Stainless steel grade 201 is a widely used material in various industrial fields today for applications such as machinery manufacturing, food processing, medical equipment, household appliances, and decoration. This austenitic stainless steel grade has nickel partially replaced by manganese and nitrogen, and SUS201 exhibits high strength and good workability. The results of this research not only bring practical value to the sheet metal forming industry but also open up new directions in the application of finite element simulation to improve product quality.
Keywords: *Sheet metal bending, bending angle, bend allowance, inside bending radius, nose radius, punch radius.*

Date of Submission: 14-05-2025 Date of acceptance: 26-05-2025

I. Introduction

Springback is a common phenomenon in sheet metal forming processes. Springback is defined as the angular change after the bending process, Figure 1. In the field of materials science, particularly in sheet metal forming processes, springback has a significant impact. In the manufacturing industry, die designers and manufacturers constantly strive to minimize springback in dies by precise calculation or experiments. This research analyzes the simulation results of the bending of workpieces with different punch angles. This analysis aims to provide sufficient data to control springback during the actual stamping process by adjusting the operating parameters (verified through experimental studies on test samples) of the punch. This process reduces material waste and shortens lead time.

During the bending process, it was found that the thickness of the material sheet has an influence on the springback phenomenon [1]. Studies on the amount of springback in the V-bending process are also increasing, and it is also found that there are significant improvements in reducing the amount of springback [2]. In addition to the elastic modulus, friction conditions and material properties also have an influence on the amount of springback. The influence of process parameters such as bending angle, material sheet thickness and punch radius on the V-bending process was analyzed using the finite element method with Abaqus software. The research team initially reviewed general forming methods [3], then analyzed the quality characteristics such as wrinkling, fracture, surface defects, and dimensional accuracy [4]. Based on theoretical analysis and finite element modeling [5], we propose a method for predicting springback [6], determine optimal forming parameters [7], and simultaneously evaluate the formability and analyze defects. The research was conducted by simulating the stamping process using Abaqus software.

Upon release of the forming force, metals show a tendency to partially return to their original shape due to elastic recovery of the material. The reason for elastic recovery, which is also called springback, is elastic stresses about the neutral axis [8]. In sheet metal forming, springback is an important issue which can lead to important problems during component assembly, if not considered thoroughly [9]. Springback is affected mainly by two factors; mechanical properties and geometric properties. Material's mechanical properties influencing springback are mainly modulus of elasticity, yield strength, strain hardening characteristics, and Poisson's ratio. Some of the essential geometric properties affecting springback are sheet thickness, tooling geometry, and clearance between punch and die or workpiece [10].

This research focuses on analyzing the influence of several process parameters on the springback phenomenon in the stamping of SUS 201 sheet metal. With the aim of improving the accuracy and consistency in production, this study also proposed improvement solutions to optimize the corner bending process. The research results not only bring practical value to the metalworking industry but also open up a new direction in applying simulation technology to improve product quality.

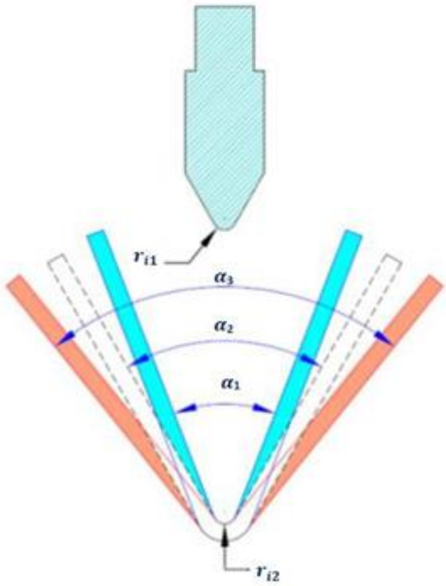


Figure1. Spring back angle

II. Materials and numerical simulation

2.1. Materials

Stainless steel 201, also known as SUS 201, is one of the most widely used among the over 200 common stainless steel grades today, Table 1 and 2.

Table 1. Chemical composition of SUS 201

Component	Chromium	Nickel	Manganese	Nitrogen
Hàm lượng	16% - 18%	3,5% - 5,5%	5,5% - 7,5%	5,5% - 7,5%

Table 2. Mechanical properties of SUS 201

Tensile strength	515 - 735 Mpa.
Yield Strength	275 - 380 Mpa.
Hardness	85 - 95 HRB.
Elongation	40% - 60%.
Elastic modulus	200 Gpa

To improve the dimensional accuracy of bent products, specifically sheet metal bending, it is necessary to overcome the errors that occur during the forming process, which is to minimize the springback of the bent angle for SUS 201 sheet metal products.

Simulation Parameters: In this study, the V-bending process was performed using SUS 201 sheet metal with a thickness of 1 mm for bending angles of 90°, 120°,60° and a punch nose radius of 15, 10, 20 mm.

2.2. Numerical simulation

The research was conducted on simulation software for the sheet metal bending process. In this paper, Abaqus software was used to simulate cases with variations in bending angle, sheet thickness, and punch nose radius. From the simulation models, the springback values of the models were determined, and solutions to minimize this springback were proposed.

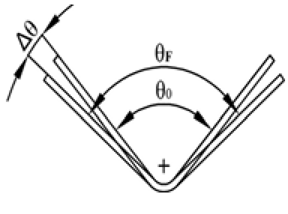


Figure 2. Springback angle

According to the prediction model of sheet metal spring-back for different thicknesses and materials (Figure 2), with the given sheet metal conditions, the curvature K is calculated by the following formula [6]:

$$k = \frac{1}{R_d + \frac{t}{2}} \quad (1)$$

Where:
K: curvature of the sheet metal after deformation
Rd: die corner radius
t: sheet metal thickness
Using the Von Mises criterion [6]:

$$E' = \frac{E}{1-v^e};\ \sigma' = \frac{2\sigma}{\sqrt{3}};\ k' = \frac{2k}{\sqrt{3}} \quad (2)$$

Where:
E': effective modulus of elasticity for plane strain
E: modulus of elasticity of the material
σ': effective yield stress for plane strain
σ: yield stress of the material
k': effective strength coefficient for plane strain
k: strength coefficient of the material
v: Poisson's ratio of the material
Plastic deformation and material moment according to the Ramberg-Osgood model [6]:

$$\sigma = K.\varepsilon^n\ ;\ My = \frac{2}{3} \cdot y' \cdot \left(\frac{t}{2}\right)^2 \quad (3)$$

Where:
σ: Yield stress of the material
K: Strength coefficient of the material
n: Strain hardening exponent
ε: Plastic strain
Force applied by the bending tool [6]:

$$P = \frac{1{,}2 \cdot C \cdot t^2 \cdot TS}{L} \quad (4)$$

Where:
P: external force applied by the punch
C: width of the sheet metal
t: sheet thickness
TS: tensile strength of the material
L: die width

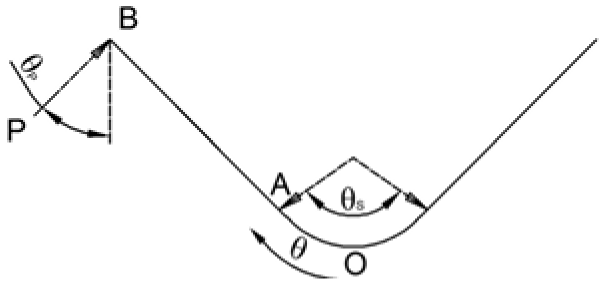


Figure 3.

The bending moment at the die root O is represented by M_0 and is derived using the pressure distribution along the bending portion S between points O and A, Figure 3[6]:

$$M_0 = P.[l.\cos(\theta_b - \theta_p) + R.\sin(\theta_b - \theta_p)] \quad (5)$$

θ_p: The angle applied by the die at point B is perpendicular to the plane of the sheet metal
=> $\theta_p = 0$.

$$l = \sqrt{\frac{4.E'.t}{L.\sigma}} \text{ and approximately } l = \frac{L}{2}, \theta_b = (\theta_p - \theta_l) \text{ và } S = R.\theta_b \quad (6)$$

Predicting Angle Springback [6] :

$$\theta_l = \frac{1}{t}.\varepsilon\ \ .Y_b.l\ ;\ \theta_s = \frac{S}{t} \cdot \varepsilon \cdot R \cdot (1 + M') \quad (7)$$

l: Distance between the bending force application point and the workpiece support point
θ_b: Bending angle at point B
θ_p: Punch action angle

S: Bending arc length
L: Mold opening length
ε : Plastic strain
γ_b: Bending radius
M_o: Bending moment at the bending angle
M': Adjustment factor
$\Delta\theta$: Spring-back angle
θ_l: Straight spring-back angle
θ_S: Curved spring-back angle
Therefore, the spring-back angle is calculated by the formula: $\Delta\theta=\theta_s+2\theta_l$
The punch depth during the simulation is calculated using the following formula [8]:

$$y = \frac{V}{2\cdot\tan\left(\frac{\alpha}{2}\right)} - (r_i + t)\cdot\frac{1-\sin\left(\frac{\alpha}{2}\right)}{\sin\left(\frac{\alpha}{2}\right)} \quad (8)$$

Where,
ri: punch nose radius
y: punch depth
v: die opening width
t: sheet thickness
Steps to perform the simulation on Abaqus:
Step 1: Draw and assemble the sheet metal bending model.
Step 2: Input the initial parameters for the model.
Step 3: Mesh and perform the simulation.
- The simulation process using Abaqus software goes through the following stages, Figure 4.

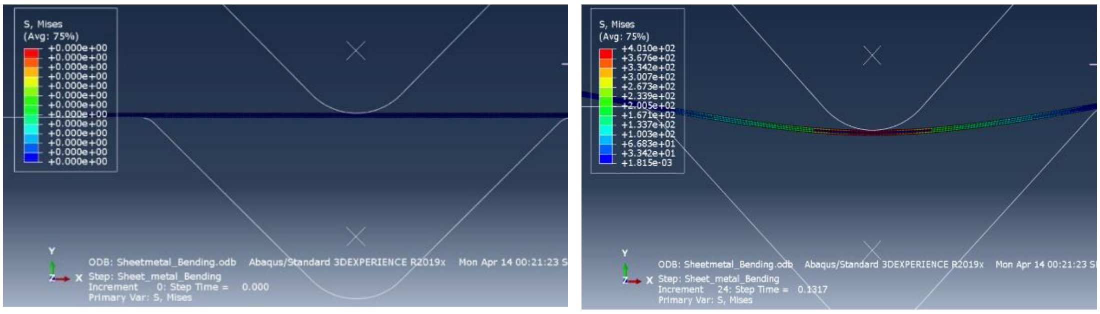


Figure 4 . Initial stage of the sheet metal stamping process

This is the step where the sheet metal begins to experience force from the punch, causing the workpiece to start bending into the die cavity, Figure 5.

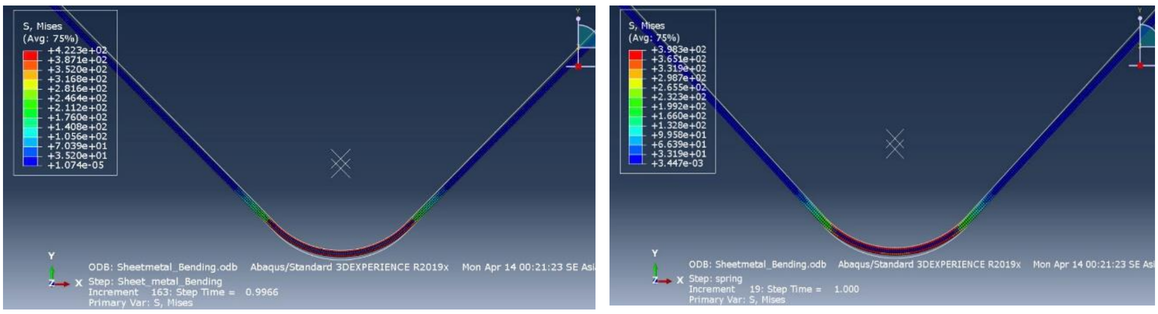


Figure 5. Final stage of the sheet metal stamping process

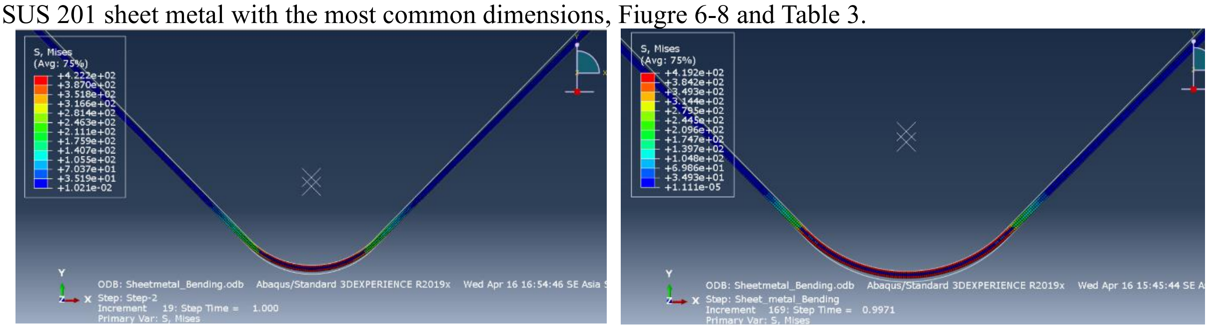
This is the step where the workpiece has been shaped by the punch and die. After this, the punch stops applying force to the sheet metal, and at this point, the necessary parameters can be extracted for research purposes.

In the bending zone: The maximum stress during the sheet metal stamping process is 401 ÷ 422 MPa, exceeding the yield strength of the sheet metal, which is approximately 275-380 MPa. Therefore, the sheet metal undergoes plastic deformation without fracturing or tearing. The two ends of the sheet metal experience very little stress and will spring back slightly with minimal deformation.

In the free bending zone: After the load is released (punch stops applying force), the springback phenomenon immediately appears during the bending process. At this point, the stress in the middle part of the sheet metal that has not yet yielded will cause it to spring back, making the two ends move inwards relative to the outer sides of the bent shape, resulting in the springback angle of the sheet metal.

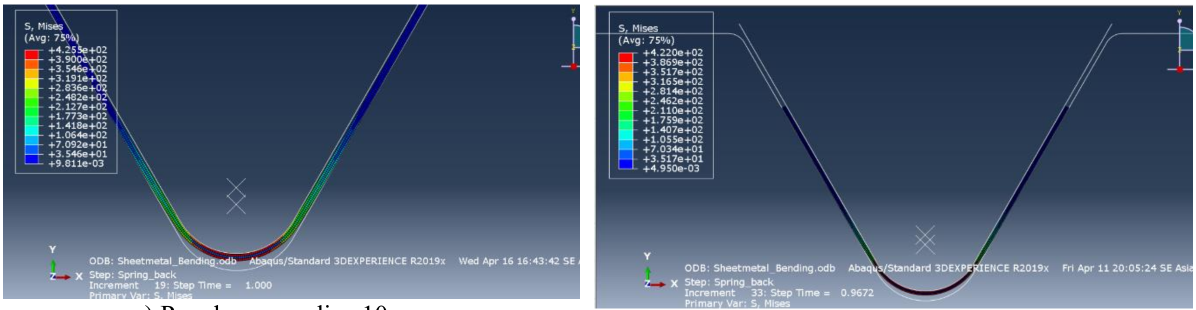
III. Results and discussion

By varying parameters such as sheet thickness, bending angle, punch nose radius, and die opening for 1 mm thick SUS 201 sheet metal with the most common dimensions, Fiugre 6-8 and Table 3.



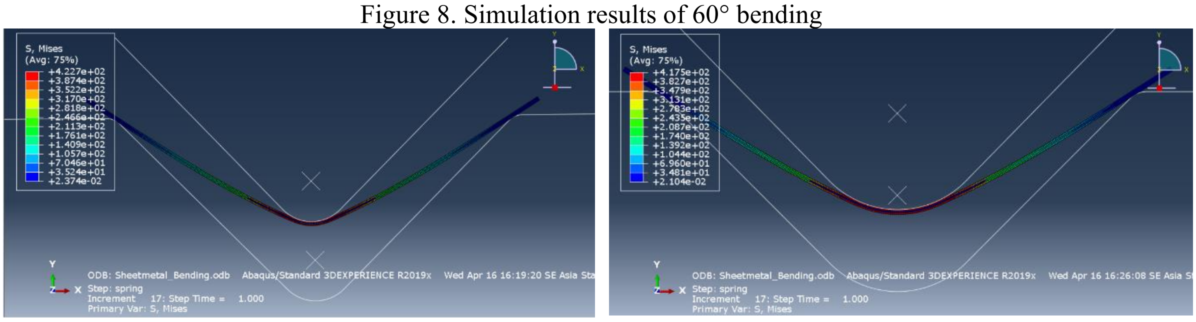
a) Punch nose radius 10 mm b) Punch nose radius 20 mm

Figure 6. Simulation results of 90° bending



a) Punch nose radius 10 mm b) Punch nose radius 20 mm

Figure 8. Simulation results of 60° bending



a) Punch nose radius 10 mm b) Punch nose radius 20 mm

Figure 8. Simulation results of 120º bending

Table 3. Influence of punch nose radius

No.	Bending Angle	Punch Nose Radius (mm)	Sheet Thickness (mm)	Springback Angle (º)
1	90º	10	1	0.053
2	90º	15	1	0.276
3	90º	20	1	0.142
4	60º	10	1	0.384
5	60º	15	1	-0.36
6	60º	20	1	-0.12
7	120º	10	1	-0.025
8	120º	15	1	0.27
9	120º	20	1	0.004

Changing the punch nose radius dimensions allows us to generate comparative models: The punch nose radius is an important parameter affecting the springback of the sheet metal. With a smaller punch nose radius, the maximum stress at the bending point is greater, Figure 9.

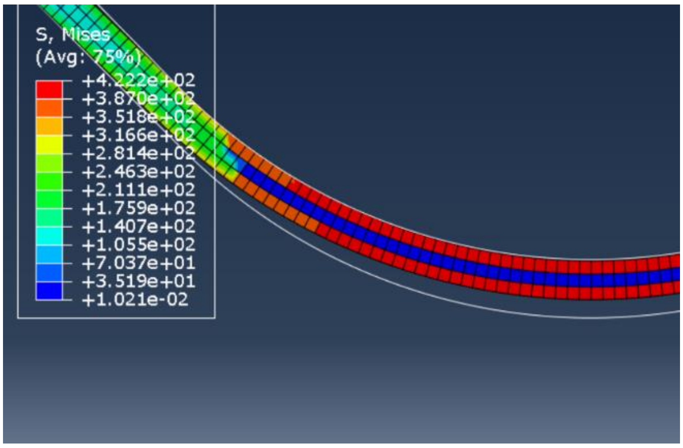


Figure 8. Maximum stress at the deformation zone of the sheet

IV. Conclusion

For bending angles of 120° and 60°, the springback angle is relatively small. Therefore, when bending these angles, using a punch nose radius of 20 mm is better than using other punch nose radii. For a 90° bending angle, the springback of the bent part when using a punch nose radius of 10 mm is the smallest.

In mass production of bent sheet metal with springback, it is necessary to adjust the punch nose radius according to the required bending angle to achieve accuracy in sheet metal bending. At the same time, attention should be paid to the punch nose radius and the die corner radius; a small radius can easily lead to cracking.

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