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# Finite Element Analysis of Bending Zone Damage and Springback Behavior After V Bending Process of AA5754 Alloy

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## Abstract

Damages occurring in the bending area of the bent parts and the springback that occurs after shaping are among the important factors affecting the quality of the shaped products. In this study, the formability of AA5754 sheet metal with V bending at room temperature was investigated using finite element analysis. In the study, 4 different die angles (α) (60°, 90°, 120°, 150°), 3 different punch radii (R) (2, 4, 6 mm), and 3 different bending lengths (w) (9.5 mm, 19 and 38 mm) were used. Finite element analyses were performed using 2 different ductile damage criteria (Johnson-Cook (JC) and forming limit diagram (FLD)) and without damage criteria (NDC). As a result of the analyses, considering the die angle, the greatest springback was seen in the 150° die, while the greatest bending zone damage was seen in the 60° die. The largest deformation occurred at small die angles. Again, considering the punch radius, the greatest bending zone damage was seen in R2, while the greatest springback was obtained in R6. The difference (l) between the expansion and contraction zones in the bending area is 0.256 mm in the 60° die and 0.083 mm in the 150° die. It was determined that the greatest damage occurred on the inner surface. The damage angle on the inner surface is 12.14° in the 60° die, and 1.24° in the 150° die. Considering the damage criteria used, the largest springback occurred in FLD and the smallest springback occurred in JC.

*Keywords*: AA5754; Finite element analysis; Springback / Springforward; V bending

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## 1. Introduction

Aluminum alloys have a wide range of usage in industry [1,2]. The main goal for many industries, especially the aviation and automotive industries, is to preserve the required power while reducing body weight to reduce fuel consumption and save costs. In line with this goal, aluminum alloys are one of the most important materials that designers and engineers want to use [3,4].

For example, the body structure of the vehicle is thought to contain about 25% of its weight, which offers a tremendous chance to reduce weight without compromising the vehicle's safety standards. Aluminum alloys have a great potential to reduce the weight of a vehicle due to their important properties such as lightness, average strength, high strength/weight ratio and good corrosion resistance [5,6]. It is stated that a 15-20% reduction in the vehicle body can reduce the vehicle's rolling resistance by 5% and increase braking efficiency, which can provide 5% fuel savings [7]. However, due to the low forming ability and large springback properties of high-strength aluminum alloys, their direct use in shaping complex shaped parts also brings application limitations [8]. Therefore, knowing the forming behavior of metallic materials well is very important for successful shaping of sheet metals [9].

Sheet metal materials are widely used in many fields, especially automotive, white goods and aviation, because they can be shaped easily [10–12]. Methods such as drawing, stamping and bending are commonly used in shaping sheet materials [13–15]. However, during shaping, tearing, thinning, cracking, wrinkling, rupture, etc. many defects occur. One of the most important of these defects is springback. Springback is the tendency of materials to return to their original shape after shape change due to their elastic properties [16,17]. The springback that occurs after the shaping process causes the final product to deform. This causes the quality of the products produced to deteriorate and assembly difficulties to occur. This deformation is a result of the elastic stress that occurs during the shaping of the parts [18–20]. Springback may cause undesirable effects, especially in precise measurements and precise shaping operations. Therefore, its impact should be minimized. Material selection, mold and product design, heat treatment, etc. can be controlled using methods.

Another defect that occurs is the damage in the bending area of the sheet metal that changes position during forming. Damage occurring in the bending area also affects both the lifespan and dimensional properties of the material.

Wang et al. [21] investigated the springback behavior of AA5754 material after L bending under different temperature conditions. As a result of their research, they found that the temperature increase significantly reduces the springback of the material. Again, Şen et al. [22] stated that local heating of the bending zone reduces springback.

Toros et al. [23] investigated the effects of pre-stress on the springback of AA5754-O alloy after V bending, where they changed the yield points by applying pre-stress.

Damage is a significant problem for metal-forming applications. Experimental tests are performed primarily to determine the fracture initiation or necking [24,25]. However, these tests are pretty costly and time-consuming. Instead, using a damage approach to estimate the plastic deformation that occurs during forming and to model the gradual mechanical deterioration of material properties is less costly and time-consuming. Many damage approaches have been developed and used for this purpose. Many damage criteria, such as Johnson-Cook (JC), Forming Limit Diagram (FLD), Lemaitre, Cockcroft and Latham (CL), Oyane, Rice and Tracey, Gurson-Tvergaard-Needleman (GTN), Continuum Damage Mechanics (CDM), McClintock, Modified Mohr-Coulomb (MMC), etc., are used to estimate the damage initiation. These proposed models can be easily applied to solve complex metal forming problems, and the results are satisfactory.

In this study, the springback behavior of AA5754 sheet after the V bending process and the damage analysis of the bending zone were investigated using the finite element method. As a result of the research, it was determined that there was almost no study on the damage analysis of the bending area. In this respect, the study has a unique quality.

## 2. Material and Method

Analyzes were performed at room temperature using a 1 mm thick AA5754 sheet. Process parameters are given in Table 1, and finite element analysis parameters are given in Table 2. The stress-strain graph of the material is seen in Figure 1. Simufact Forming was used as finite element software in the study. Analysis studies were carried out using Johnson-Cook (JC) damage model, forming limit diagram (FLD), and without damage criteria (NDC). The Johnson-Cook (JC) damage criterion parameters are given in Table 3, and experimentally obtained forming limit diagram (FLD) parameters are given in Figure 2. The Johnson-Cook (J-C) damage model is defined as a function of the equivalent plastic strain ($\varepsilon_f$), stress triaxiality factor ($\sigma^*$), strain rate ($\dot{\varepsilon}^*$) and temperature ($T^*$) at the moment of fracture and is given in Equation (1).

$$\varepsilon_f = \left[D_1 + D_2 . e^{D_3 . \sigma^*}\right] . \left[1 + D_4 . ln\dot{\varepsilon}^*\right] . \left[1 + D_5 . T^*\right] \quad (1)$$

$$\sigma^* = \frac{\sigma_m}{\sigma_{eq}} \quad (2)$$

$$\dot{\varepsilon}^* = \frac{\dot{\varepsilon}_{eq}}{\dot{\varepsilon}_0} \quad (3)$$

$$T^* = \frac{T - T_{room}}{T_{melt} - T_{room}} \quad (4)$$

$$\sigma_m = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3) \quad (5)$$

$$\sigma_{eq} = \sqrt{\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2\right]} \quad (6)$$

where $D_1$, $D_2$, and $D_3$ are damage constant parameters related to the relationships between failure strain rate and temperature; $D_4$ and $D_5$ are constants determined by strain rate and temperature; $\sigma_1$, $\sigma_2$, and $\sigma_3$ are the principal stresses, $\sigma_m$ and $\sigma_{eq}$ are mean stress and the equivalent stress, respectively.

The die, punch, and sheet metal were designed in 3D (Figure 3) and analyses were made in 3D. The schematic representation of the backward/forward springing measured as a result of the study is given in Figure 4, and the cross-sectional view of the bending area formed after bending is given in Figure 5.

Damage and errors in the bending area were determined by taking a cross-sectional image of the bending area with the help of the Simufact Forming analysis program and measuring it with the program's help. Damage angles ($\beta_1$ and $\beta_2$) express the angular distortion on the inner and outer surfaces of the bending area. JC and FLD are two of the most commonly used damage criteria. The most important reason for choosing these criteria is to present the results of the analyses made without using damage criteria and the analyses made using damage criteria comparatively.

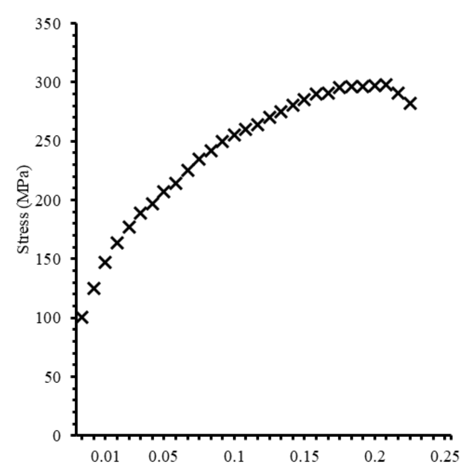


Figure 1. Tensile stress-strain curve for AA5754 at room temperature (strain rate 0.1 $s^{-1}$) [26]

Table 1. The process parameters

| Parameters | Values |
|---|---|
| Die angle (Bending angle), α (°) | 60 (120), 90 (90), 120 (60), 150 (30) |
| Punch radius, R (mm) | 2, 4, 6 |
| Bending length (sheet width), w (mm) | 9.5, 19, 38 |

Table 2. FEM simulation parameters

| Parameters | Values |
|---|---|
| Material | AA5754 |
| Object type | Material: Elastoplastic |
| | Die: Rigid |
| | Punch: Rigid |
| Mesh properties | Mesher: Sheet mesh |
| | Element type: Hexahedral |
| | Element size: 0.610911 mm |
| Friction coefficient | 0.1 (Coulomb) |
| Punch speed (mm/s) | 5 |
| Damage criterion | JC, FLD, NDC |

Table 3. Material constants of the Johnson-Cook (JC) damage model for the AA5754 material [5]

| JC damage model | |
|---|---|
| Constant | Value |
| $D_1$ | 0.24 |
| $D_2$ | 0.2 |
| $D_3$ | -10 |
| $D_4$ | 0 |
| $D_5$ | 0 |

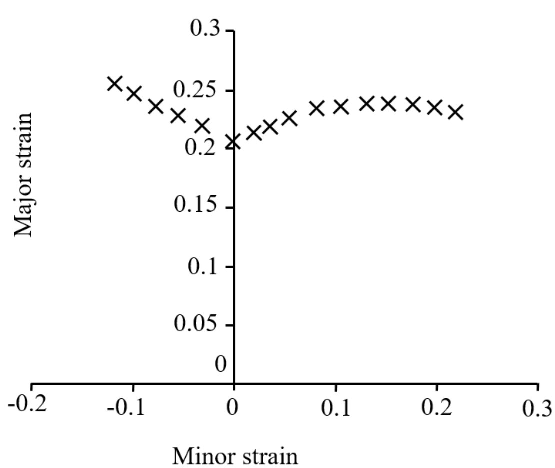


Figure 2. Forming limit diagram (FLD) of AA5754 obtained experimentally at room temperature [27]

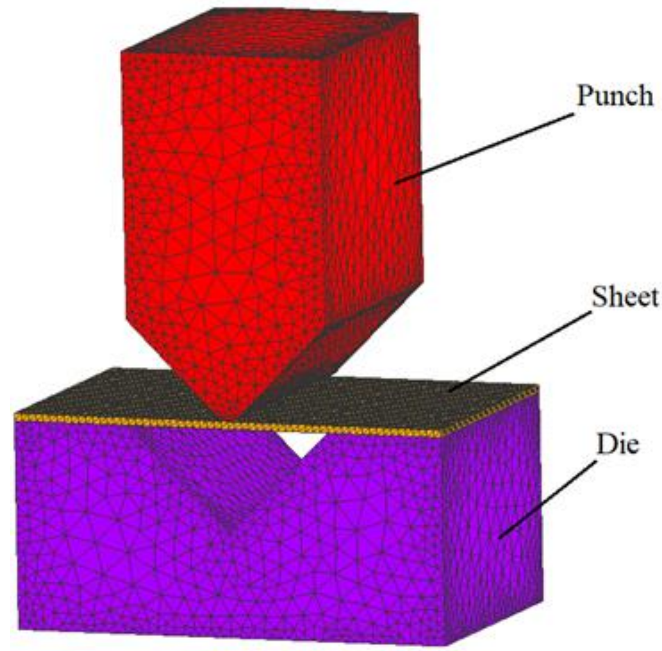


Figure 3. FE analysis image of V bending process

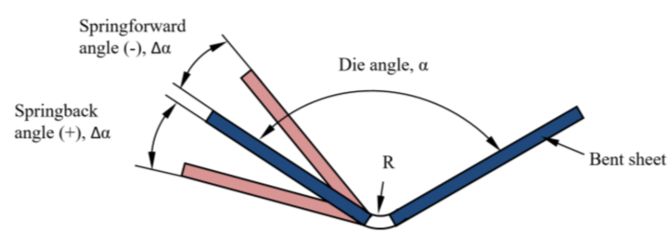


Figure 4. The schematic view of springback / springforward angle

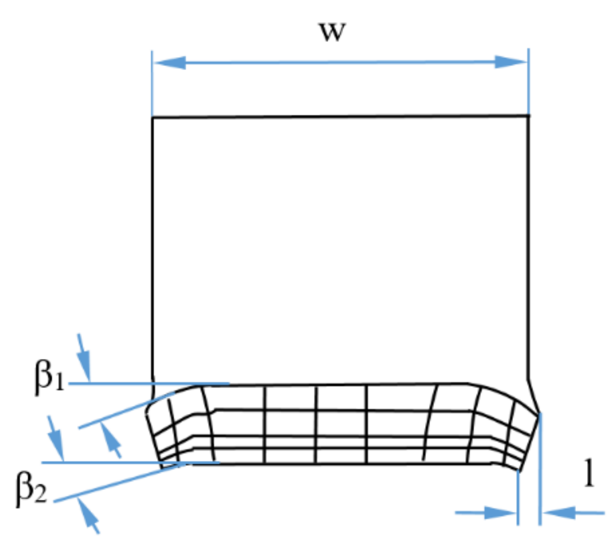


Figure 5. Schematic representation of the cross-section of the bending zone

## 3. Results and Discussion

Figure 6 shows the effect of the die angle on the damage in the bending area. As the die angle increases, the stresses on the inner surface (compression surface) decrease, which reduces the expansion on the compression surface that the punch contacts. In other words, as the bending angle increases, the stresses on the surface contacted by the punch in-crease, which increases the error in the bending region. In the bending region, expansion occurs on the inner surface of the material contacted by the punch due to compression stresses, and contraction (shrinkage) occurs on the outer surface of the material due to tensile stresses. The greater the difference between compressive and tensile stresses, the greater the error that will occur in the bending re-gion. In the graph in Figure 7, the difference (l) between the ex-pansion and contraction zones is 0.256 mm, 0.214 mm, 0.175 mm, and 0.083 mm, respectively. From the measurement results, it is clearly seen how effective the die angle is on the error that will occur in the bending region. Figure 8 shows the effect of die angle on springforward / springback. It can be said that as the die angle increases, the spring angle increases; in other words, as the bending angle increases, the spring angle decreases. When different studies are examined, it has been stated that springback decreases as the die angle increases [20]. It can also be stated that this situation is caused by the material properties and the selected material type significantly affects the springback.

Figure 9 shows the effect of bending length, in other words material width, on the damage in the bending zone. The differ-ence (l) between the expansion and contraction zones is 0.216 mm, 0.214 mm, and 0.211 mm, respectively (Figure 10). From the measurement results, it was seen that the change in bending-length had almost no effect on the error in the bending zone. Similarly, the effect of bending length (material width) on springforward / springback was quite limited (Figure 11).

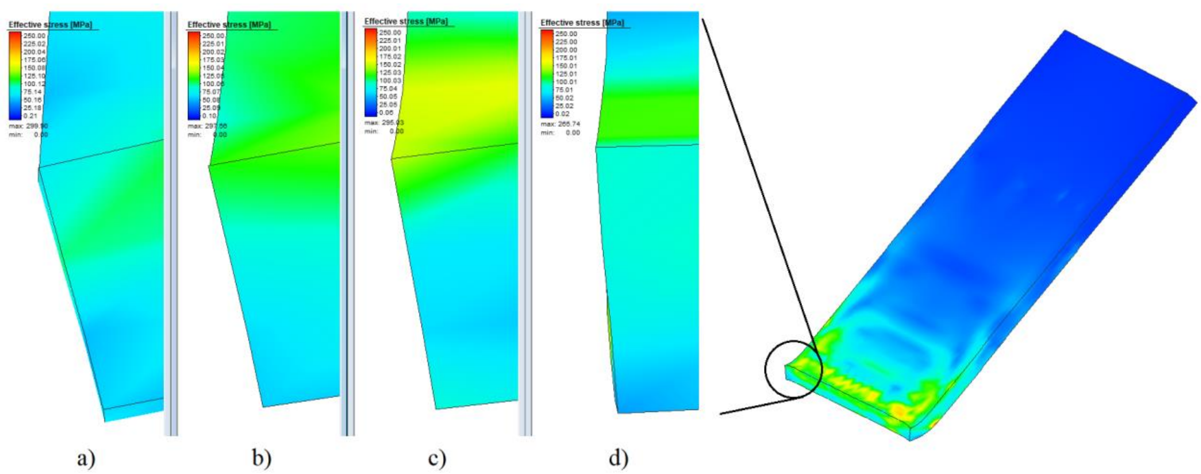


Figure 6. Cross-sectional view of the effect of the die angle on the bending zone a) α=60° b) α=90° c) α=120° d) α=150° (for JC-R2-w19)

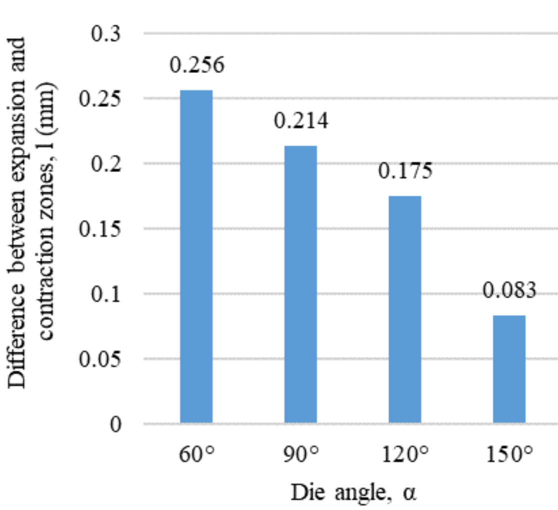


Figure 7. Effect of die angle on damage in the bending zone (for JC-R2-w19)

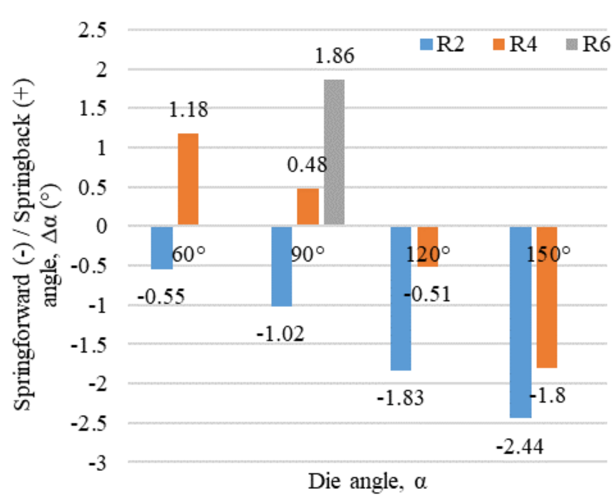


Figure 8. Effect of die angle on springforward / springback (for JC-w19)

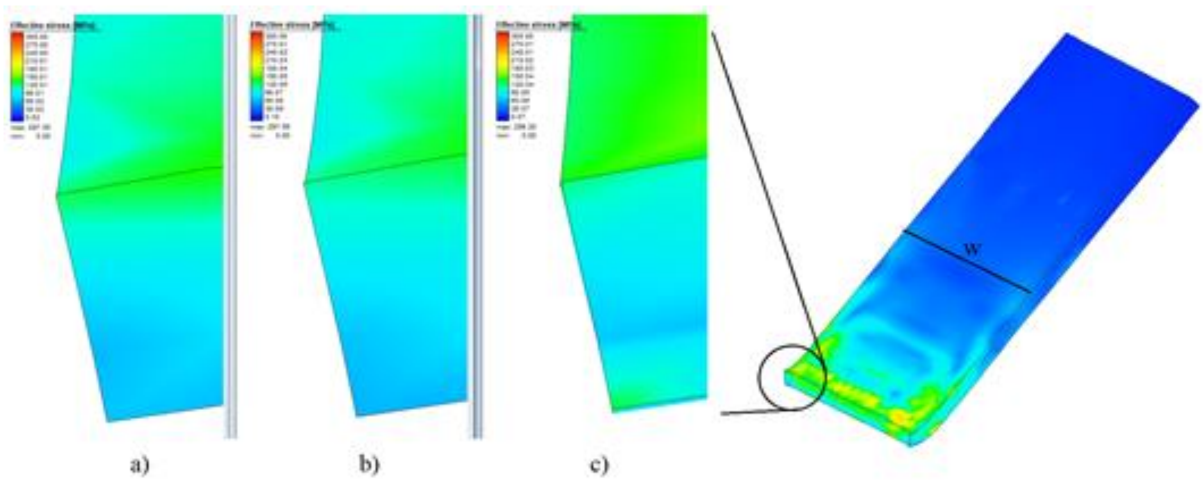


Figure 9. Cross-sectional view of the effect of bending length (w) on the bending zone a) w=9.5 mm b) w=19 mm c) w=38 mm (for JC-R2-90°)

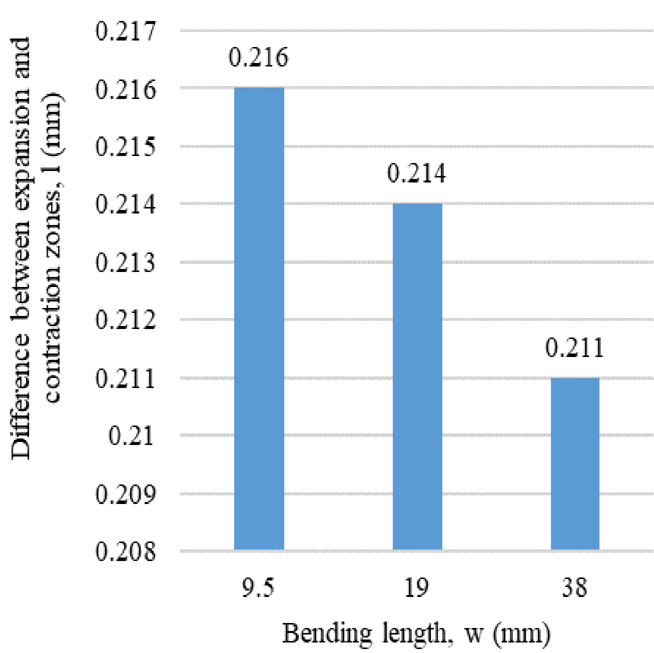


Figure 10. Effect of bending length on damage in the bending zone (for JC-R2-90°)

Figure 12 shows the effect of the punch radius on the bending zone. The measurement difference (l) between expansion and contraction in the bending area is 0.214 mm, 0.159 mm, and 0.128 mm, respectively (Figure 13). This shows that the bending damage decreases as the bending radius increases. As the punch radius increases, the pressure in the bending area spreads over a wider area. In other words, as the bending radius increases, the contact area of the punch increases, which causes the stress on the surface to spread. As the tension difference between the inner and outer surfaces of the bending zone decreases, the error size that will occur also decreases.

In Figure 14, the effects of punch radii and damage criteria on springforward / springback are given together. While bending operations performed with 2 mm radius punches resulted in springforward (negative), springback (positive) occurred in punches with 4 and 6 mm radius. Again, the greatest springback was obtained in punches with a radius of 6 mm. Considering the damage criteria, the highest springback was obtained in FLD. JC and NDC results were close to each other.

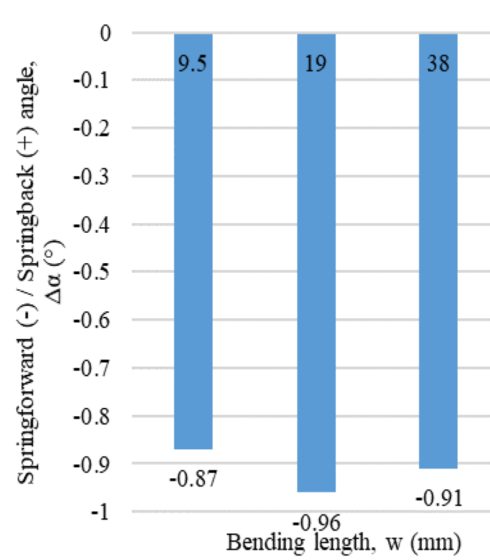


Figure 11. Effect of bending length on springforward / springback (for JC-R2-90°)

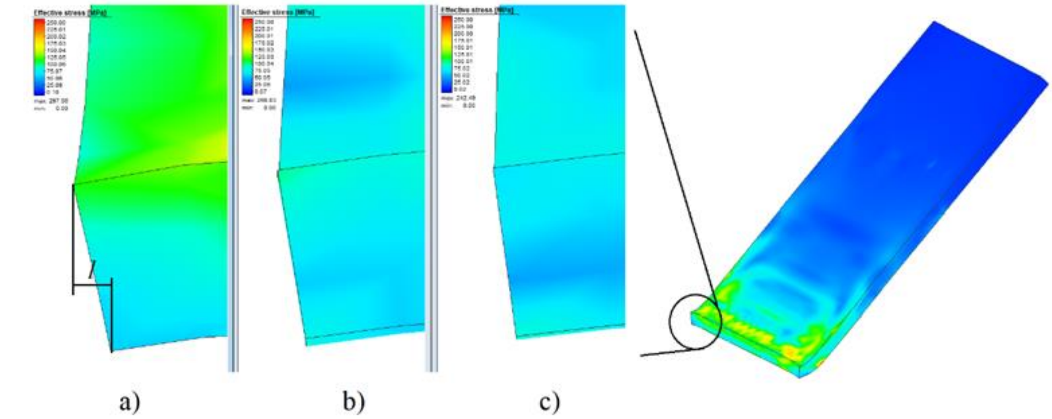


Figure 12. Cross-sectional view of the effect of punch radius on the bending zone a) R2, b) R4, c) R6 (for w19-90°)

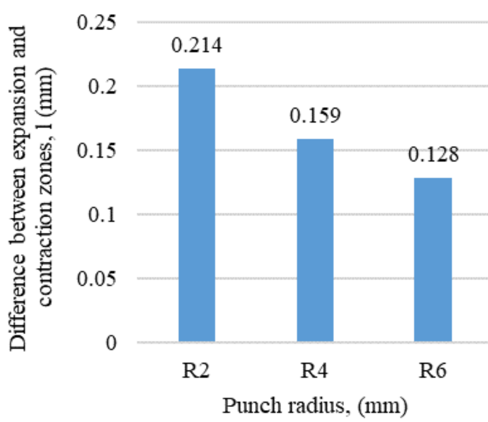


Figure 13. Effect of punch radius on damage in the bending zone (for w19-90°)

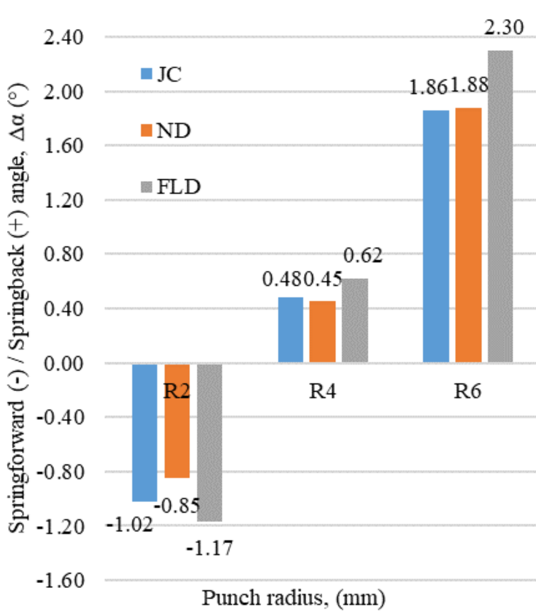


Figure 14. Effect of punch radius on springforward / springback (for w19-90°)

The angles formed on the inner and outer surfaces of the bent part are given in Figure 15, and the results obtained are given in Figure 16. When the figures are examined, as the die angle in-creases, the angles on the inner and outer surfaces de-crease. In other words, the highest internal and external surface damage angle was obtained in the 60 ° die. In other words, as the bending angle in-creases, the compressive and tensile stresses on the in-ner and outer surfaces also increase, which increases the error on the bending edge.

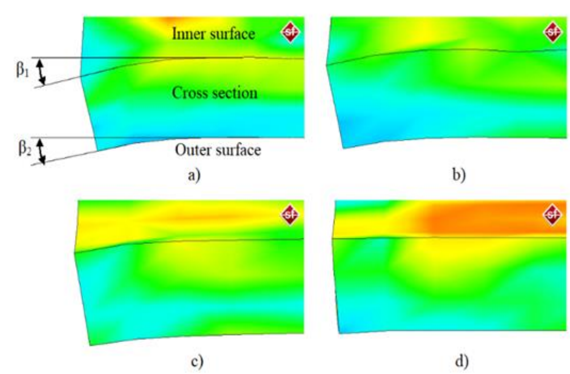


Figure 15. Damage angles on the inner and outer surfaces after bending a) 60°, b) 90°, c) 120°, d) 150° (for JC-w19-R2)

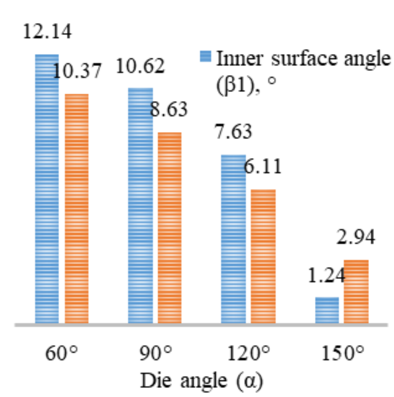


Figure 16. Effect of die angle on the damage angle on the inner and outer surfaces of the bending zone (JC-w19-R2)

## 4. Conclusions

In this study, the springforward / springback and damage analysis of the bending zone occurring after the V bending process of AA5754 aluminum alloy was performed and the results are given below.

- As the die angle increases, the damage to the inner and outer surfaces of the bending zone decreases. In other words, as the bending angle increases, the damage increases.
- As the punch radius increases, the damage in the bending area decreases. The greatest damage occurred at a punch radius of 2 mm.
- The effect of sheet material width on the distance between expansion and contraction zones is so limited that it can be ignored.
- Springforward occurred for the R2 punch radius, and springback occurred for the R4 and R6 punch radius. It can be said that the most important factor affecting the formation of springforward and springback is the punch radius.
- In the measurements made by keeping the bending length and die angle constant, the highest springforward / springback was found in FLD.

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## Conflict of Interest Statement

The author declares that there is no conflict of interest in the study.

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