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Compensation of springback for high strength steels by thickness reduction

Yüksek mukavemetli çeliklerde geri esnemenin kalınlık azaltma yöntemi ile telafisi

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Compensation of Springback for High Strength Steels by Thickness Reduction Method

Highlights

- *to estimate the springback value at the design stage*
- *to reduce the cost estimation of the measurement accuracy at the design stage*
- *using the thickness reduction method for springback compensation*

Graphical Abstract

In this study, an attempt was made to compensate for springback by balancing the amount of inner and outer thickness reduction of the bending surface in the U-bending process of HSLA 350 steel. In order to compare the experimental and simulation data, the finite element analyses were performed using the Simufact program. Experimental studies and finite element analysis results were close to each other.

Figure. Grafical representation for the work

Aim

The aim of this study is to enable the production of precision parts without springback by using the thickness reduction method.

Design & Methodology

Both experimental studies and finite element analysis were used together. In order to compare the experimental and simulation data, the finite element analyses were performed using the Simufact program.

Originality

The thickness reduction method enables precision part production without springback. In addition, generating the bottom surface of the bent part in the U-bending operation planar is an important issue. It is difficult to obtain this surface planar in conventional bending die processes. In order to find the ideal deformation rate in the thickness reduction method, it is important that the stress values along the radius and the stress values formed on the inner and outer surfaces of the radius region should be examined together

Findings

Experimental studies and finite element analysis results were close to each other. It is observed that linearity are lost on the bottom surface of the U-bending part for deformation amounts greater than 20 % thickness reduction.

Conclusion

In order to find the ideal deformation rate in the thickness reduction method, it was found that the stress values along the radius and the stress values formed on the inner and outer surfaces of the radius region should be examined together.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

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Yüksek Mukavemetli Çeliklerde Geri Esnemenin Kalınlık Azaltma Yöntemi ile Telafisi

Araştırma Makalesi / Research Article

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ÖZ

Sac metal bükme işlemi sac metal üretiminde önemli bir rol oynar ve geri esneme bu işlemin istenmeyen bir sonucudur. Geri esneme miktarı bilinmeden bükme kalıbı işlemi yapılırsa, kabul edilebilir tolerans değerleri içinde parça üretmek zorlaşır. Bükülecek parçanın geri esneme davranışı da bükme kalıbının boyutunu etkiler. Özellikle 90° U bükme kalıbı söz konusu olduğunda, geri esneme kompanzasyonu yöntemiyle bükme kalıbının üretim maliyeti yüksektir. Bu nedenle, tasarım aşamasında geri esneme değerinin tahmin edilmesi önemlidir. Bu çalışmada, yüksek mukavemetli saclarda kalınlık azaltma yöntemi kullanılarak geri esneme değerini azaltmak için deformasyon miktarının tahmini yapılmıştır. Bu çalışmaya göre kalınlık azaltma yöntemi geri esneme kompanzasyonunda etkin bir şekilde kullanılabilir. Tasarım aşamasında ölçüm doğruluğunun tahmin edilmesi, bükme kalıbının maliyetini düşürür ve fazla deneye gerek kalmadan tolerans limitleri dahilinde parçalar üretmek mümkündür. Sonuçlar, 0,2 t değerindeki kalınlık azalmasının U-bükme işleminde geri esneme değerini ortadan kaldırmak için uygun olduğunu göstermiştir. Deneysel, ampirik ve sonlu elemanlar sonuçlarının birbirine yakın olduğu tespit edilmiştir.

Anahtar Kelimeler: Bükme, geri yaylanma, yüksek mukavemetli çelik, U-bükme, kompanzasyon, kalınlık azaltma.

Compensation of Springback for High Strength Steels by Thickness Reduction Method

ABSTRACT

The sheet metal bending process plays an important role in sheet metal production and springback is an unintended consequence of this operation. If the bending die process is performed without knowing the amount of springback, it is difficult to produce parts within acceptable tolerance values. The springback behavior of the part to be bent also affects the size of the bending die. In particular, in the case of a 90° U bend die, the manufacturing cost of the bending die with the springback compensation method is high. Therefore, it is important to estimate the springback value at the design stage. In this work, the estimation of the amount of deformation to avoid springback value was performed using the thickness reduction method for high strength sheet metal. According to this study, the thickness reduction method can be used effectively in springback compensation. The estimation of the measurement accuracy at the design stage reduces the cost of the bending die and it is possible to produce parts within tolerance limits without much experimentation. The results showed that thickness reduction at the 0,2 t value was suitable to eliminate the springback value in the U-bending process. It has been found that experimental, empirical and finite element results are close to each other.

Keywords: Bending, springback, high strength steel, U-bending, compensation, thickness reduction.

1. INTRODUCTION

Sheet metal parts production and bending die design are very important in terms of cost and time in the manufacturing sector. The quality of sheet metal parts generally depends on the bending angle and springback value. Springback value is affected by several interacting factors during the manufacturing process. The most important of these factors are the die design, the geometry of the desired product, the forming parameters, and the yield stress of the material. Therefore, there is no single, universally accepted method that can quantify or describe the springback value for all types of sheet metal fabrication. The most important and undesirable situation that affects the precision in sheet metal forming processes is springback and this situation affects the quality of sheet metal parts.

This springback value affects the bending die angle and bending curve. The magnitude of the springback is related to the bending moment of the material due to the thickness stress distribution at each point in the bending plane. Due to their high yield strength and stiffness, it is important that the amount of springback is within acceptable limits during forming and the dimensional accuracy of the produced sheet metal is particularly important during the assembly process. However, the accuracy factor affecting springback is precisely known after forming. The calculation accuracy of the springback depends on the presence of the internal stress distribution of the material during the bending process of the part [1]. Furthermore, the estimated springback value is important in the design phase to get the final dimension tolerances

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of the sheet metal parts. Therefore, several researchers have worked on estimating numerically and experimentally the springback value during the sheet metal forming process for each part and bending type. High strength low alloy steels (HSLA) are widely used in the manufacturing industry as well as in the automotive sector. Especially in the automotive sector, high strength steels are preferred in order to increase driving safety, save fuel, reduce environmental factors and vehicle weights. Cutting, bending and forming operations are widely used to shape these steels. The most serious problem in the press forming of HSLA sheets is their extremely large springback value [26]. Bending is one of the most commonly applied sheet metal forming operations. During bending, the region around the neutral plane in the material is subject to both elastic end plastic deformation. In the bending process, the outer surface of the sheet metal is elongated to form tensile stress, while the inner surface is forced to be compressed by shortening. When the load is lifted, the elastic tension in the bending zone is removed, and the part is springback due to non-directional stress distribution in the layers of the material [2]. The deformation that occurs in the material profile is generally an acceptable value depending on the quality of the material, thickness, applied force and bending radius.

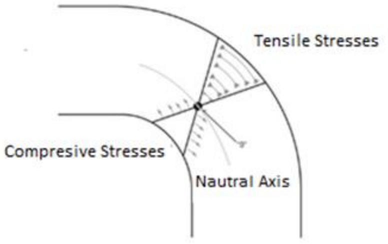
An accurate estimation of the amount of springback depends on the estimation of the post-bending stress in the bending region. Stress in this region is defined by the Bauschinger effect, which describes a softening phenomenon after stress reversal. Therefore, many material models describing the Bauschinger effect have been developed in the literature. In [3], a linear model with the deformation-hardening kinematics approach of the material and nonlinear kinematic elasticity and flow stress model are presented by remodeling the Bauschinger effect [4]. This model could not fully describe the transition from elastic to plastic behavior of the material. In order to better define the plastic-elastic transition behavior of the Bauschinger effect, the isotropic-kinematic strain hardening model is presented and this model is applied to the kinematic strain hardening rules [5]. An isotropic-kinematic material model [6, 7] and springback simulations were performed using various material models [8] by defining surfaces that are displaced by plastic deformation in the same way as the yield surface. As a result of these simulations, the best springback prediction model of the Yoshida-Uemori model has emerged [9-11]. Therefore, the stress distribution simulated in finite element analysis depends on which anisotropic yield functions are used. A later study presents advanced functions that improve Hill's quadratic function [12]. The developed Hill model was used in the finite element analyses performed in this study.

Extensive research in the literature focuses on the springback problem in sheet metal working [13-16]. These researches are generally carried out on the estimation of the amount of springback according to the bending parameters by material properties or analytical methods. Researchers have worked on using analytical, semi-analytical and finite element methods on plastic deformation of sheet materials during bending operations. For V-bending die, the bending angle for springback of the different materials was determined experimentally and the effect of these parameters on springback was investigated [17]. In U and V sheet metal bending an algorithm has been developed that can be applied in U and V bending die by using the finite element method.Corner contact between workpiece and punch and the resulting friction effect, punch geometry, gap between punch, bending angle and other parameters, backward/forward stretching amounts have been analyzed by taking into account the amount of springback according to material thickness [18-20]. According to the die structure and the springback quantities, the springback amounts of hard-to-bend materials such as aluminum alloy sheets, high-strength low-alloy (HSLA) steel sheets [21-23], stainless steel sheets [24], magnesium alloy steel sheets [25-26], titanium alloy materials [27] have also examined. In the L bending process using titanium materials [28-29], it was found that cavity and punch radius decreases, the springback value increases, the strength coefficient (K value) of the material increases and the springback value also increases [30]. As a result of the studies using the finite element method, in the plastic forming process the springback value has decreased, elastic modulus and the deformation in hardened materials have increased [31]. Anisotropy of the material and the effect of the radius of the punch tip on the springback angle both using the finite element method and experimentally have been investigated. From the results of these studies, the finite element method emerges as an adequate tool in the literature for estimating springback [32-36]. The time-dependent/independent flexural behavior and deformation effect of these steels in the U-bending process have been also investigated [38-39].

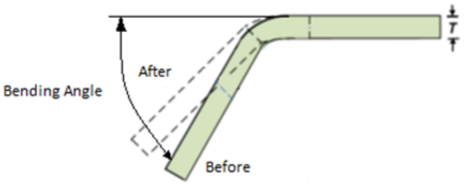
The springback compensation method is not a process of over-bending the angle by simply knowing the springback angle. Instead, the thickness reduction of the bending region according to the properties of the part to be produced is a convenient springback method. It is not sufficient to only compensate for the springback in the U-bending method. It is necessary to maintain the perpendicularity of the edges of the U form while compensating for the springback. Therefore, acceptable thickness reduction depends on perpendicularity tolerance of U-bending geometries. This method is not commonly encountered in the literature. That’s why in this study, the amount of thickness reduction in the bending region was studied to reduce or to eliminate the springback angle. In this study, finite element analysis, experimental study, and empirical results were compared.

1.1. Springback Principles (Test Sample)

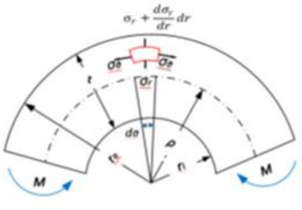
Bending is a frequently used method in sheet metal forming processes. The part subjected to bending undergoes deformation. Changes in the cross-section of the bent material depend on the type of material, thickness bending angle and bending radius. Every plastic deformation is followed by an elastic recovery. As a result of this phenomenon, changes in the dimensions of the plastically deformed workpiece occur when the load is removed. The springback behavior co-exists with the loading–unloading condition along the forming process. This loading–unloading situation continues until the sheet metal leaves the last forming stand. More importantly, the magnitude of springback due to applied loads increases as the difference between the inner and outer surface stresses increases. Generally, all factors that affect the sheet metal's deformation during the manufacturing process also tend to affect the springback. As shown in Figure 2a, by applying a bending force to the sheet metal, compression forces are formed on the bent inner surface of the material and tensile forces are formed on the outer surface. Since these forces are not equal, elastic energy is generated due to the compressive pressure difference force. This energy causes the sheet metal to springback to its original shape. Therefore, the final bend radius will initially be greater than the desired bend radius as shown in Figure 2b. This process can be defined in the plane of strain as in Figure 2c.



a) Springback



b) Type of stress



c) Type of strength

Figure 1. Springback formation in the sheet metal thickness

There are two well-known empirical formulas used for determining the springback. In the first one, the springback is expressed as the ratio of two bending radius R$i.Rf$-1. Ri is the initial bending radius and Rf is the final bending radius. The final dimensions of the workpiece after unloading are defined by Bend Radius (Rf) that occurs after springback [40]. The springback angle can be estimated approximately using Eq. (1) [41].

$$\frac{Ri}{Rf} = 4\left(\frac{Ri.Y}{E.t}\right)^3 - 3\left(\frac{Ri.Y}{E.t}\right) + 1 \qquad (1)$$

(1) (1)

In Eq. (1), E is the Young's module of the material, t is the sheet metal thickness and Y is the yield strength. These parameters have fixed values for the material used, whereas only the bending radius Ri is variable. The springback angle is evaluated according to the springback ratio. This ratio is used to represent the magnitude of the springback during the bending process. In the second equation, the bending angle is represented by θ and the amount of springback is expressed by Δθ. After the bending force is removed from the sheet metal springback occur and hence a relationship between the springback and the strain is established. In Daw-Kwei Leu's analysis, the springback ratio is given by Eq. (2) [42].

$$\frac{\Delta\theta}{\theta} = K\left(\frac{2}{n}\varepsilon_e\right)\left(\frac{2}{n}\varepsilon_e\right)^{n+1}\frac{3}{2E'(1+n)}\left(\frac{t}{2\rho}\right)^{n-1} \qquad (2)$$

In this Eq. (2), the material strength coefficient is called $K = \frac{UTS}{e^{-n}n^n}$ and $E' = \frac{E}{1-V^2}$. The material deformation hardening is represented by quantity n, UTS is the ultimate tensile strength of the sheet metal and ρ is the bending radius that passes through the neutral axis. Considering the type of the material in the Eq. (2) of the springback ratio calculation given above, E, K, V and n have fixed values for the material and, t and ρ are the bending variables. This means the reduction in the surface tension (εe) in the bending radius causes the deformation ratio (Δθ / θ) also to be reduced. In our comparisons, we have used Eq. (2) to calculate empirical results.

2. MATERIAL AND METHOD

HSLA steel which is widely used in automotive and defense industries was designed to achieve high strength compared to low carbon steels. It also has high strength, toughness, formability, weldability and corrosion resistance as well as low carbon content. HSLA steels also have a low level of alloy addition, making them suitable for controlled production processes, such as controlled rolling and accelerated cooling. Standard tensile samples were prepared to determine the mechanical properties of HSLA 350 steel, which has been used in our experiment, used in bending operation.

In order to find the mechanical properties of HSLA steel and to reduce the effect of the rolling direction of the sheet metal, 3 test samples were produced with a wire cut EDM (Electrical wire Discharge machine) machine (Figure 2).

Tensile test samples were cut at different orientations (0°, 45°, and 90°) to the rolling direction (RD) in order to characterize the material’s anisotropy. For each orientation, 3 tests were conducted at room temperature using Instron 3369 (50 kN) testing system.

True stress-true strain graphics were plotted form the results of these test samples (Figure 3) at different deformation speeds (25, 50, 75 m.sec-1). s-1 is represented 1.deformation-1). These values are used in the finite element analysis of materials database and in empirical calculations. In this way, the experimental results can be easily compared with the finite element analysis results and empirical results.

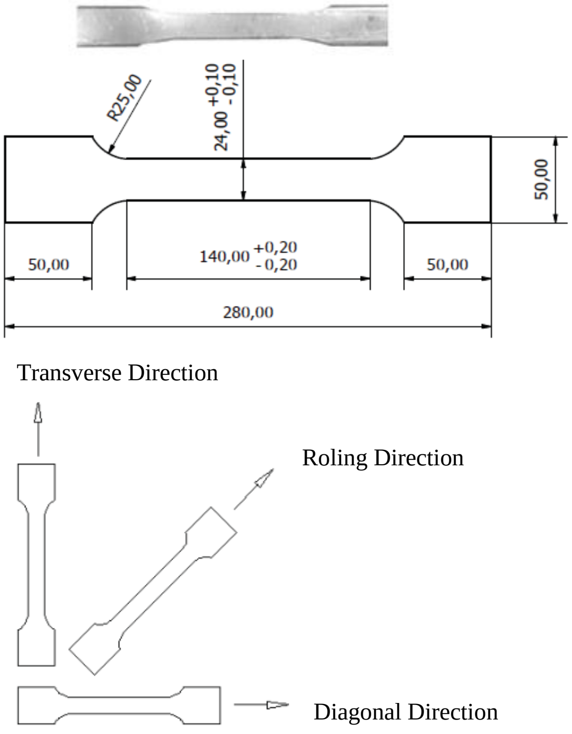
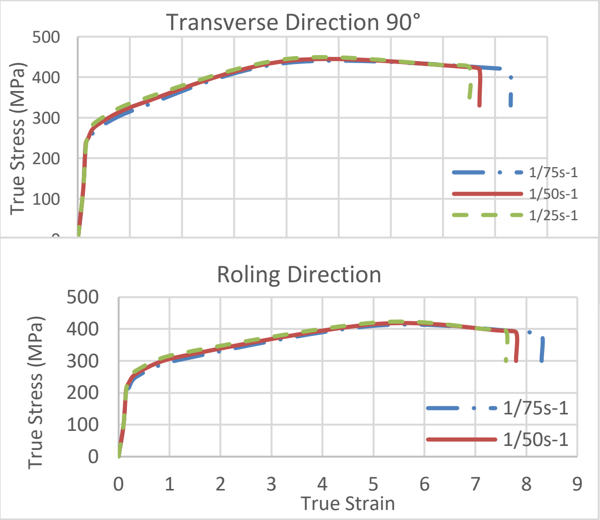


Figure 2. Tensile test sample



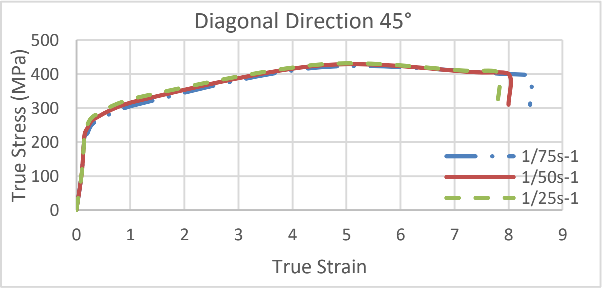


Figure 3. True Stress-Strain curve of HSLA 350 steel for different orientations with respect to the rolling direction

Table 2. Chemical composition of HSLA 350 steel

HSLA350 STEEL					
NOMINAL COMPOZITION (wt %)					
C	0.054	Si	0.069	Sn	0.007
Mn	0.65	Cu	0.015	Al	0.033
P	0.035	Ni	0.07	N	0.008
S	0.005	Cr	0.06	Mo	0.024
V	0.005	Nb	0.02	Ti	0.015
Ca	0.002				

2.1. Experimental Study

A modular U-bending die is designed from 1.2379 tool steel to perform the experiments (DIN 1.2379-X155CrMoV12). Bending operations at different thickness reductions were performed by replacing the bending punch and the female die modules with precision. The designed bending die was hardened to 60 Hardness Rockwell C hardness. Thus, damage to the punch and die surface during the bending operation was prevented. The experiments were performed at room temperature and by using a Drinler trademark CHDC 1000 hydraulic press. The hydraulic press velocity was 50 mm.s-1. All test specimens which were used in the experiment were cut from flat sheet metal of 30 mm width, 100 mm length and 1 mm and 2 mm thickness. Figure 5 shows the thickness reduction generated from the bending radius of the experiment sample. The angle of the test sample was measured by using the Coordinate Measuring Machine (CMM).

The accuracy of the measuring device was taken as 0.05 mm. The edge of the sheet metal was not exactly linear after bending. The curve was formed on the edges of sheet metal. Angle measurements were done by drawing parallel lines to the bending edges during the measurement. Each measurement was repeated three times and the average of these measurements was taken.

The experiments were carried out in the modular U-bending die as illustrated in Figure 8. In the experiments, deformation was made at the rates of 10, 20 and 30% (0.1, 0.2, 0.3 x thickness) of the sheet material thickness.

Plastic deformation was applied to the inner bending surface of the sheet metal in the final stage of the full bending process. In these experiments, the punch bending radius was designed to deform the bending region by 0.1, 0.2 and 0.3x sheet thickness (t). According to this amount of thickness reduction, the internal and external forces were balanced. It is been determined that these thickness reduction ratios are suitable for U-bending.

In this study, an attempt was made to compensate for springback by balancing the amount of inner and outer thickness reduction of the bending surface in the U-bending process of HSLA 350 steel. The die and punch set indicated in the bending steps in Figure 4 was used for this process. Plastic deformation was applied to the inner bending surface of the sheet metal in the final stage of the full bending process. A bending gap of 5 % of the sheet thickness was used to prevent compression and scratching of sheet material during bending.

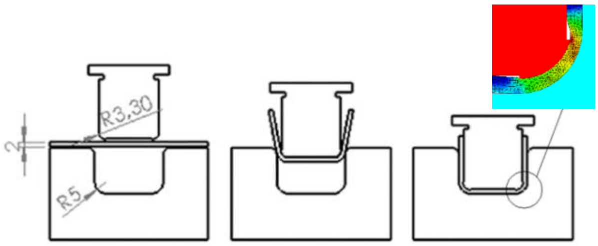


Figure 4. Formation of springback

Figure 5. Modular U-bending die model

When the press load was removed from the sheet material, springback occurs as shown in Figure 4. This springback value varies according to the material, bending angle and the amount of thickness reduction.

2.2. Finite Element Analysis Method

Computer simulation, which is based on the finite element (FE) method, is a powerful tool that gives the possibility to observe the effects of changing any process parameter before the actual tool manufacturing. In order to compare the experimental and simulation data, the finite element analyses were performed using the Simufact program (Figure 7-10). Analyses were carried out at 20° as cold processes. Press speed was taken as 50 mm.sec-1 in the experiments. Coulomb friction model was used and the friction coefficient was taken as 0.1.

When the finite element analysis results are examined, it can be observed that, according to the natural bending axis, the yield strength in the inner region is less than the yield strength in the outer region. This stress difference constitutes the springback. With the applied thickness reduction, the stress values in the inner and outer regions were tried to be equalized. These values were used in equations 1 and 2, which were commonly used in the literature, and the amounts of springback were calculated. When the analysis results were compared with empirical formulas, the literature and test results were taken into consideration, it can be seen that the thickness reduction rate of 20 % of the U-bending process was suitable for springback compensation at high strength steels. Bending die pictures used in the experimental study are given in Figure 5 and the finite element CAD model is given in Figure 6.

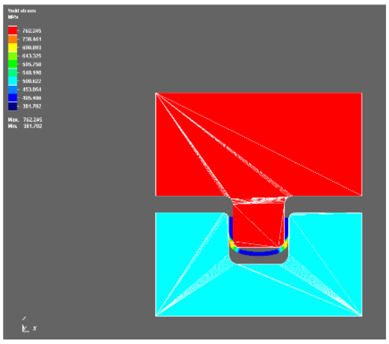
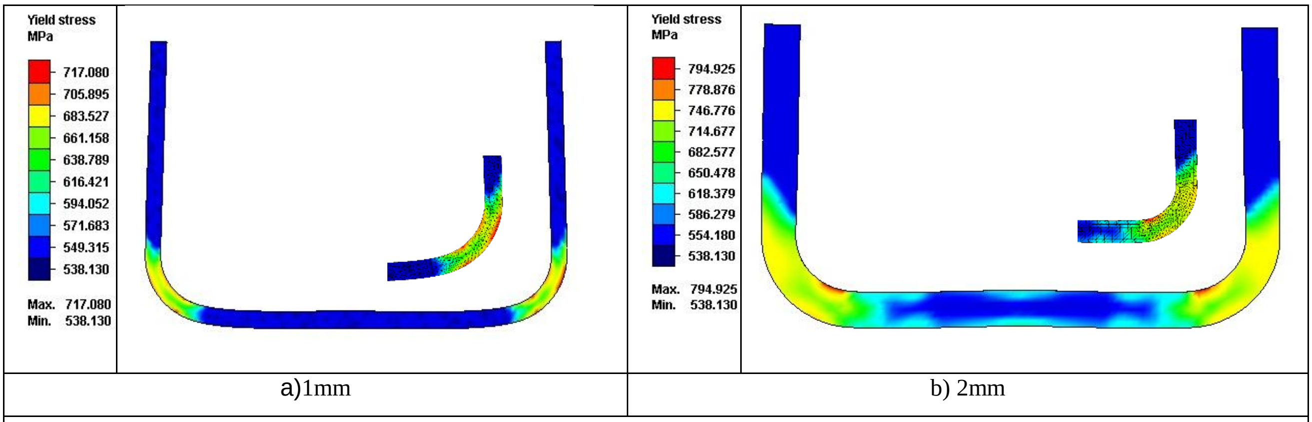


Figure 6. Modular U-bending die for using simulation

2.3. Experimental Results

In Figure 7-10, the results of the analysis using HSLA 350 steel sheet material in 1mm and 2 mm are given. For each sheet metal part, plastic deformation was applied at the rates of 10, 20 and 30% of the sheet metal thickness. The stress which occurs in the bending region as a result of the plastic deformation was investigated. It has been observed that springback does not occur when the stresses on the inner surface of the bending zone and the stresses on the outer surface are equal. At 10 % and 20 % thickness reduction ratios, the bottom surface of the U-bending part was planar, while the bottom surface of the U-bending part loses planarity when the thickness reduction ratio reaches 30 %. It has been observed that the factor that disrupts this planarity is the formation of springback.

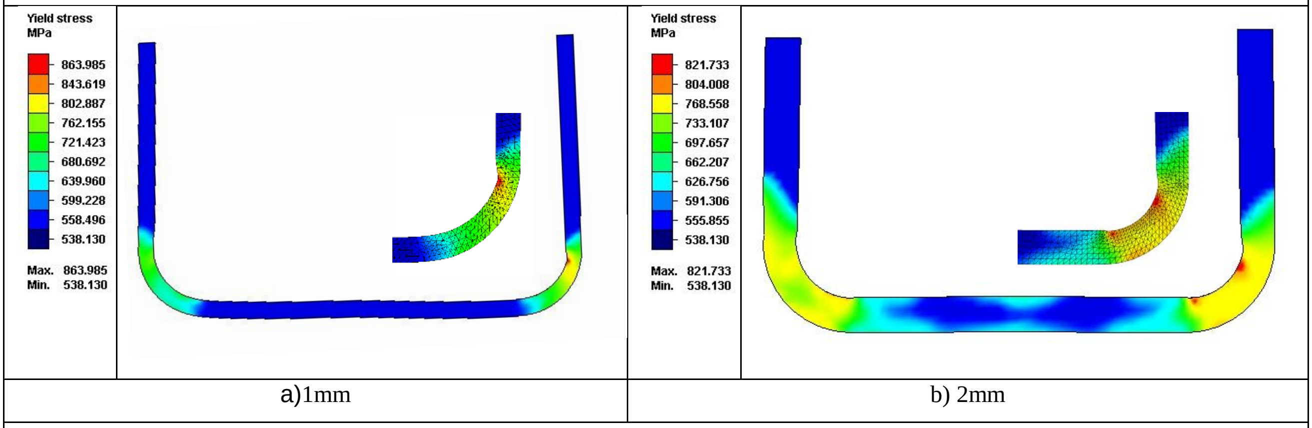
Experimental studies and finite element analysis results were close to each other. It is observed that linearity are lost on the bottom surface of the U-bending part for deformation amounts greater than 20 % thickness reduction. This is because the amount of deformation occurring in the regions close to the bottom surface of the bending radius is higher than the other regions. In order to determine the reason for this, the amount of deformation in the radius area, which is the deformation zone, was examined. The stress values occurring in the radius area according to the deformation rate are given in Figure 11-18. The starting points on the graphs are the closest point to the bottom surface. As can be seen from these graphics lower stress values occur points away from the button surface, especially at the deformation ratio of % 30. The excess stress value at these points prevents the bottom surface from being linear.



a)1mm

b) 2mm

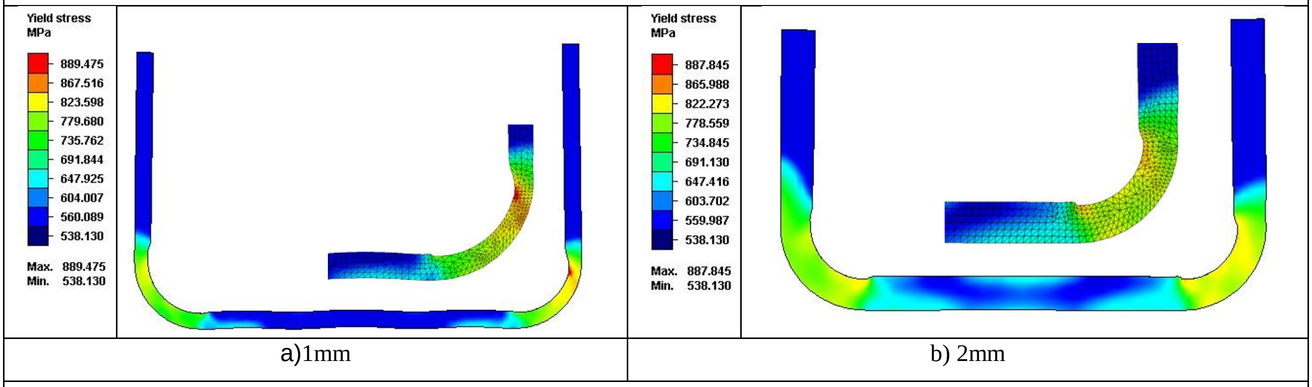
Figure 7. Bending Analysis without thickness reduction



a)1mm

b) 2mm

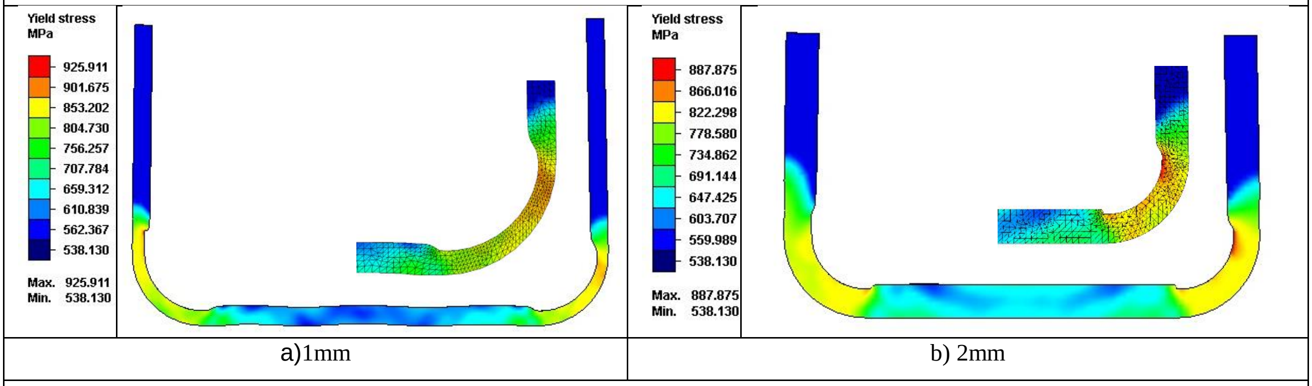
Figure 8. Bending Analysis with 10 % thickness reduction



a)1mm

b) 2mm

Figure 9. Bending Analysis with 20 % thickness reduction



a)1mm

b) 2mm

Figure 10. Bending Analysis with 30% thickness reduction

The average stress values along the radius for 1mm sheet metal thickness are given in Figure 11-14. While the maximum strain was 463.71 Mpa without thickness reduction in the U-bending, 563.47, 621.24, and 665.30 Mpa values were obtained at a deformation rates of 10, 20 and 30 % respectively. The average stress values along the radius for 2 mm sheet metal thickness are also given in Figure 15-18. For this case, without thickness reduction in the U-bending, the maximum strain has been obtained as 471.68 Mpa. Moreover, 551, 689.8, and 693.50 Mpa values were obtained at deformation rates of 10, 20 and 30 % respectively. On the other hand for both 1mm and 2 mm sheet metal parts, it was determined that the overall strain values between the initial points and endpoints at a 20 % deformation rate were close to each other. Therefore, the bottom surface of the U-bending part appears to be linear. Since the values between the initial points and the endpoints (points close to the bottom surface) are significantly different from each other the 30 % deformation rate causes the bottom surface of the U-bending piece to lose its linearity.

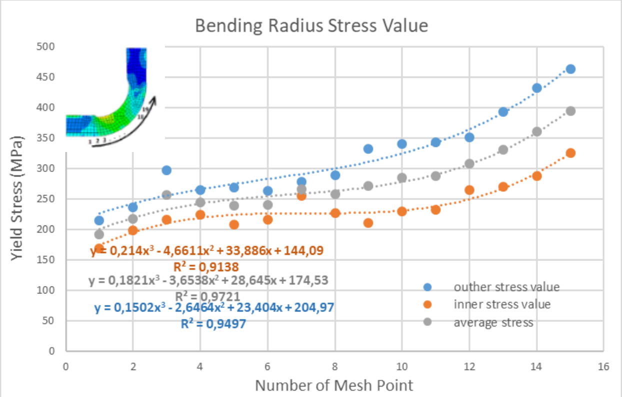


Figure 11. HSLA 350 stainless steel without thickness reduction for 1mm sheet metal

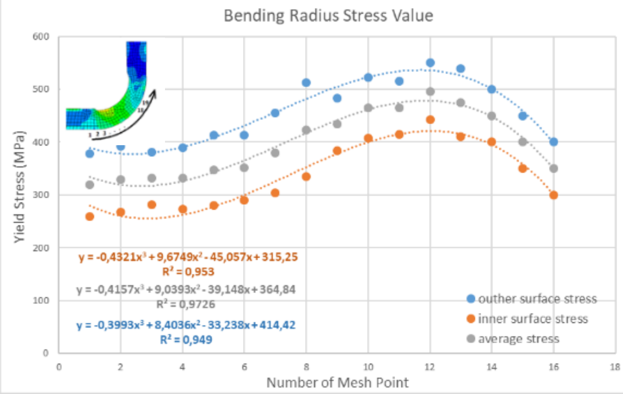


Figure 12. HSLA 350 stainless steel 10 % thickness reduction for 1mm sheet metal

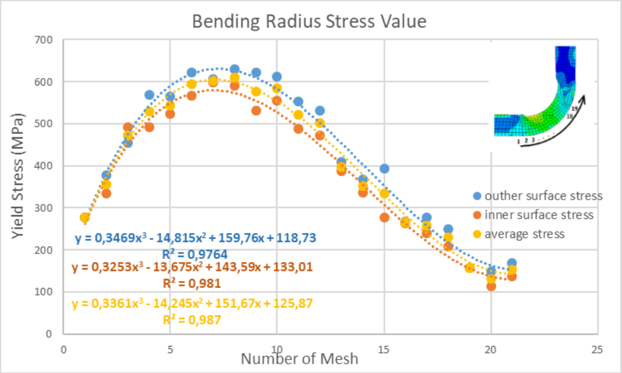


Figure 13. HSLA 350 stainless steel 20 % thickness reduction for 1mm sheet metal

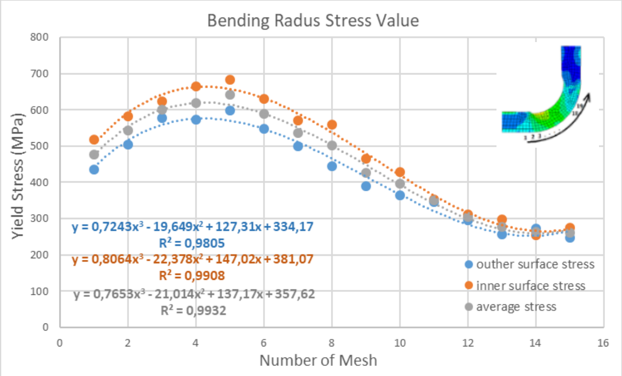


Figure 14. HSLA 350 stainless steel 30 % thickness reduction for 1mm sheet metal

After determining the suitability of the 20% deformation rate in the stress values examined along the radius, the stress values formed on the inner and outer surfaces of the radius region were also examined. It has been observed that the inner surface and outer surface strain values are close to each other at a 20 % deformation rate. In the experimental studies, it has been observed that the corner angles of the U-bending part are very close to 90 degrees and the springback is very small or non-existent. Below graphics for different deformation values are given. When these graphics are examined, it can be seen that the inner and outer surface stress values formed in the bending region are different.

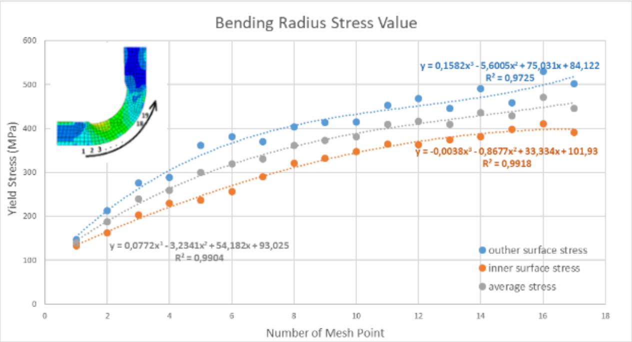


Figure 15. HSLA 350 stainless steel without thickness reduction for 2 mm sheet metal

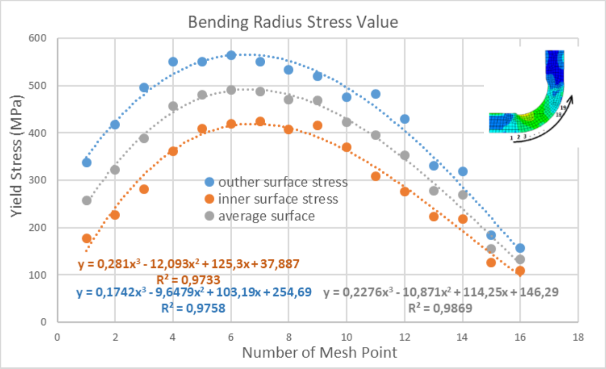


Figure 16. HSLA 350 stainless steel % 10 thickness reduction for 2 mm sheet metal

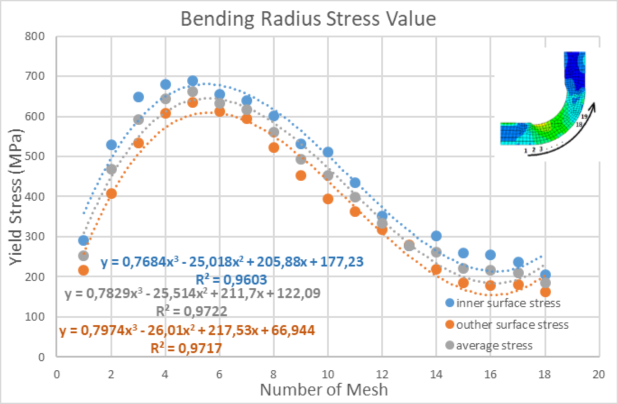


Figure 17. HSLA 350 stainless steel 20 % thickness reduction for 2 mm sheet metal

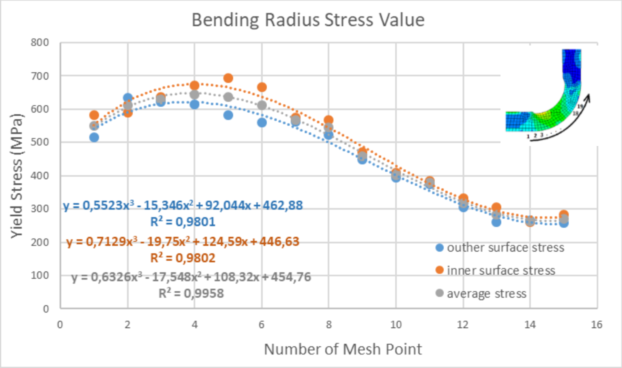


Figure 18. HSLA 350 stainless steel % 30 thickness reduction rate for 2 mm sheet metal

3.CONCLUSION

Especially in the U-bending process, it is very difficult to produce a bending die using the springback compensation method. Since it is difficult to get the parts produced from the bending die due to the reverse angle, different designs must be made. Therefore, more expensive bending die tool manufacture is required. The thickness reduction method enables precision part production without springback. In addition, generating the bottom surface of the bent part in the U-bending operation planar is an important issue. It is difficult to obtain this surface planar in conventional bending die processes. In order to find the ideal deformation rate in the thickness reduction method, it was found that the stress values along the radius and the stress values formed on the inner and outer surfaces of the radius region should be examined together. The stress value U-bending part of the radius affects the linearity of the bottom surface of the bending part, while the inner and outer surface tension values change the amount of springback. When the stress level on the inner and outer surfaces of the radius, which is the bending zone, are equal, the amount of springback decreases or does not occur at all.

As a result of the experiments, it was observed that the deformation to be applied at the rate of 20 % (0,2 t) of the sheet metal thickness eliminates the springback value. It was seen that this method can be applied in U-bending operations without the need for complex expensive bending die production.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

YAZARLARIN KATKILARI (AUTHORS' CONTRIBUTIONS)

Ayşegül GÜLTEKİN TOROSLU: Performed the experiments, analyse the results and wrote whole manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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