Study on springback of high tension steel following various temperature and local pre-heating in the roll forming process

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Abstract. In this study, we studied spring-back phenomenon following pre-heating and various temperatures on forming sheet in roll forming process using finite element method (FEM) simulations. Material of forming sheet was high tension steel (POSTEN 60), and we analyzed spring-back phenomenon using material properties from room temperature to 500°C. For spring-back phenomenon analysis, FEM simulation results were thermal stress and strain according to temperature distribution on forming sheet. Assumed pre-heating methods were induction heating and laser heating, also this study assumed that pre-heating is same temperature conditions. Finally, the spring-back phenomenon was analyzed by induction pre-heating and laser pre-heating method.

1. Introduction
Roll forming process consists of several pairs of roll die and it is the progressive bending forming of metal sheet for desired cross section. Also, the process is a continuous process for mass production and mold change and setup process time takes less time. This process is well used for its effectiveness in the mass production of long sheet metal products with desired cross section. Another advantage of this process is a material cost savings due to the high material recovery [1]. For this reason, the application range of the roll forming process is wide, it has recently been applied to the automotive industry.

The automotive industry is tendered to replace the high tensile steel for lightweight vehicles. Because high tensile steel is due to have a greater rigidity and lower weight than other materials in the same thickness. However, high tensile steel has a low elongation and a high yield strength, also press working process method is difficult to forming. But forming of high tensile steel in the roll forming process has a high precision of product and abrasion resistance of roll die due to incremental forming. Roll forming process occurs a lot of spring-back phenomenon than other materials because of the low forming force of high strength steel. In order to solve this problem, many engineers did over-bending to predict empirically spring back phenomenon. Until now, spring back prediction focus on design process such as over-bending, but this method has limitations when using high tensile steel. So, to solve this problem, this paper was applied to the pre-heating process in the roll forming process. In the roll forming process, there are many cases using heat such as a tube welding process, but research to pre-heat the sheet with improved formability has not been investigated to date. Many roll forming
process studies have been carried out relative to the other sheet material, roll forming process study using high strength steel is not much [2-6].

In research methods suggested above, similar study is V or U shape bending using stamping process. Sheet bending studies in stamping was done much. Xie H Y, et al. [8] studied through electrical pulse-assisted (EPA) V-bending at 373 K. It was applied to the electrical (pulse) energy to the sheets, and a study of the spring back phenomenon of the V-bending in the stamping process. Fang Z, et al. [9] were studied the spring back effect that occurs after the micro V-bending a classic processing method to manufacture microparts. FEM simulation has been conducted to investigate the size effect in terms of Voronoi tessellation and spring back. Roll forming process has many process parameters such as the forming speed, the material of the forming sheet, the rotational speed of the roll die, friction between the roll and the sheet, so it should be considered a number of process parameters. Many studies have been made on the roll forming process as above. However, roll forming process applied the pre-heating process has not yet been investigated, so this process should be performed by the basic research.

This study was carried out V-bending in order to analyze the phenomenon in 3-pass roll forming process [7], this process is assumed to apply induction and laser pre-heating. The study deduced from FEM simulation results about V-banding sheet in accordance with various preheating temperature after forming. Through the FEM simulation results, a spring-back phenomenon of the pre-heating was analyzed and pre-heating process was checked to ensure it can be applied to the roll forming process.

2. Design of roll forming process
In the roll forming process, V, U, hat shapes of cross-section were basic shapes to analysis the spring back phenomenon. This study was processed V-shape through the roll forming process, configurations of roll forming devices for forming of V-bending are shown in figure 1.

![Figure 1](image1.png)

**Figure 1.** Set-up of the roll forming process in this study.

![Figure 2](image2.png)

**Figure 2.** Bending angle of the 3-Pass roll forming.

In order to process the basic V-banding, roll forming machine is designed in 3 passes. Bending angles of 3 passes were 30°, 60° and 90° respectively (figure 2). Horizontal distance to the previous roll stand is 105 mm and total forming distance is 550 mm. Forming speed of forming sheet is 200 mm/s. The diameters of the upper roll die and the lower roll die were 50 mm and 10 mm respectively, the R value of the roll dies is applied to 0.5 mm to prevent excessive deformation. The width and length size of the forming sheet are each 80 mm, 150 mm, and thickness of the forming sheet is 1 mm.

Material for forming sheet using roll forming process is high tension steel and the product name of sheet material is POSTEN 60. The POSTEN60 was studied in the previous studies for mechanical properties and the study analyzed high-temperature tensile properties and the residual stress characteristic [10-12]. The paper was applied to POSTEN60 properties with reference to previous studies, and table 1 shows the properties of POSTEN60.
Table 1. Mechanical properties of POSTEN 60 at room temperature.

| Property                        | Value  |
|---------------------------------|--------|
| Young’s modulus/GPa             | 215    |
| Yield strength/MPa              | 532    |
| Ultimate tensile strength/MPa   | 625    |
| Ductility/%                     | 20     |
| Poisson’s ratio                 | 0.3    |

3. Finite element model

In this study, roll forming process thought FEM simulation performed using Abaqus version 13.1 simulation software. FEM simulation of Roll forming process carried out a thermal-structure interaction analyses, spring-back analysis performed static analysis using analysis result of forming sheet.

Pre-heating of the overall of the sheet needs a lot of thermal energy, and it causes many problems such as warping and bowing. Therefore, we consider a local pre-heating method for a small energy consumption and precise forming. This study analyzed the spring back effect on the local pre-heating in the forming sheet. It assumed that the friction between the roll die and the forming sheet, the boundary conditions were given in the sheet to move the forming direction. Pre-heating method is considered the induction type and the laser type on the upper surface of forming sheet. Pre-heating shapes of induction type and laser type were referred to previous studies. Pre-heat shape and size is shown in figure 3 [13, 14].

![Figure 3. Shape and size of pre-heating sources](image)

![Figure 4. Definition of the spring-back angle.](image)

Pre-heating temperatures were applied at room temperature, 100°C, 200°C, 300°C, 400°C and 500°C. Pre-heating position during the roll forming process is a red area in figure 1, and this area is pre-heated before the 1-Pass. The Pre-heating area is moving heat source that moved along the center line of the forming sheet. To analyze the accurate temperature distribution in the forming sheet after forming, Film coefficient of forming sheet is 0.28 W/m²·K, and ambient temperature is 25°C. Heat loss of the sheet due to heat radiation is considered. The heat transfer coefficient of forming sheet is 0.47 W/mm°C.

Forming sheet was solid model and the mesh was concentrated in the center line of forming sheet for accurate bending behavior. The roll dies were a shell model for fast analysis. The spring back calculation method of the molded sheet is shown in figure 4 and the final spring back value was calculated by the static analysis.

4. Results of the FEM simulation

FEM simulation analysis is not possible continuous process such as the actual roll forming process. So the length of the sheet is effective for the optimization analysis to a minimum length of sheet, for the interaction of the two roll pass, length of the forming sheet was designed to 150 mm. For an efficient
analysis of the forming sheet of the roll forming process, analysis results of the formed sheet were measured by dividing the three locations as shown in figure 5.

Figure 5. Measuring point on the forming sheet.

Figure 6. Layer definition of forming sheet.

Because the stress distribution of sheet is different from Point-1 to Point-3, it was selected as the measurement position such as figure 5 [15].

Forming sheet occurred tension and compression at the same time in bending process. So, to determine the characteristics of the tension and compression, forming sheet was analyzed by dividing the layer in the thickness direction from the center line, as shown in figure 6. And the forming sheet was divided into three layers in the thickness direction.

4.1. Temperature distribution of thickness direction

Figure 7 shows the temperature curves of each layer according to the roll pass. The temperature of the forming sheet exhibits a rapid rise in the preheating, and then it was confirmed that the temperature is gradually reduced after preheating. After the final forming, temperature of pre-heating was reduced to about 300°C. Maximum Temperature dwelling Time is different from the induction type and laser type because of two types is due to differences in the pre-heating area.

Figure 7. Temperaure distribution of forming sheet(500°C); (a) Induction type, (b) Laser type.

Directly the preheated 1-layer has reached the maximum temperature, and then 1 layer was soon converged with the other layers. Because the thickness of the formed sheet is 1 mm, and the sheet has a high heat transfer coefficient.

Figure 8 shows the temperature curves in the width direction of the forming sheet. Lee, et al. [16] was proposed concept for the cumulative distance, and this study applied the cumulative distance from the width direction of the sheet. The cumulative distance means away length from the centerline of the sheet. A positive value is the right side of the forming plate and a negative value is the left side of the forming plate. Figure 8 was measured the temperature of the sheet at Point-2 after forming. Heat affected zone is from the centerline (cumulative distance: 0) of the forming plate to 10 mm. The bending area and the heat affected zone are almost the same range and the variables influence the
spring back value.

**Figure 8.** Cumulative distance of forming sheet according to pre-heating (1, 4-layer, Point-2).

4.2. Stress according to measurement point in induction pre-heating type

Figure 9 shows the von-mises stress of 1, 4-layer in each measurement point. The von-mises stress is showing a tendency to increase gradually from Point-1 to Point-3. 1-layer of compression behavior exhibits higher von-mises stress than 4-layer tensile of behavior. The tendency of the graph curves of 1,4-layer is similar, Point-3 shows the von-mises stress difference in the other layer. After final forming, von-mises stress value was derived about 200~300 MPa results of stress at each measurement point.

**Figure 9.** Von mises stress according to 1, 4-layer; (a) Point-1, (b) Point-2, (c) Point-3.

**Figure 10.** Von mises stress according to measurement point.
Figure 10 is a graph for comparing the von-mise stress of the measuring point in the 2-layer. 3 points were derived the highest stress value, Point-1 was derived the lowest stress value. Also, Compared with the figure 9, 2-layer exhibit a higher stress value than 1,4-layer and the final stress value according to measure point in 2-layer was obtained between 400–600 MPa. This result is approximately two times higher than the stress value of 1,4-layer. The reason for this phenomenon is predicted that the local maximum stress value was obtained due to the slip of the tension and compression in the width direction of the interior of the high tensile steel.

In order to observe the thermal stress by temperature, figure 11(a) and 11(b) shows the results of the thermal stress in 1,4-layer of the Point-2. The above results show a different trend in figure 9(b), and figure 11 is not greater thermal stress value of the difference due to the initial thermal stress in the roll forming process in the early and late. Figure 9(b) is not a stress difference in 1,4-layer, but figure 11 shows a stress difference in 1,4-layer. This result is determined to be higher thermal stress by pre-heating before final forming. 1-layer directly affected in a pre-heating, the final thermal stress was 200–250 MPa and 4-layer is subjected to the indirect heat effect of 1-layer, the final thermal stress value was obtained in 380–400 MPa.

![Figure 11](image)

**Figure 11.** Thermal stress according to sheet layer at Point-2; (a) 1-layer, (b) 4-layer.

![Figure 12](image)

**Figure 12.** Thermal stress according to measurement point; (a) 1-layer, (b) 4-layer.

Figure 12 shows the thermal stress of 1,4-layer of each measurement point in accordance with various temperatures in the final formed high tensile steel sheet. Point 3 shows a lower thermal stress value than other points. The tendency of the graph in figure 12 is not constant. But if tendency of the graph in figure 12 significantly divided into three parts, it can be classified such as 100°C, 200–400°C, 500°C. The simulation result is larger the influence of the physical properties of a high tension steel in
this FEM simulation. This FEM simulation analysis was applied to mechanical properties of POSTEN60 from the previous study [10-12]. Applied POSTEN60 gradually decreases tensile strength from room temperature to 200°C and then tensile strength increases due to the blue shortness at higher than 200°C. POSTEN60 has the maximum value in 300°C and then decreased gradually to 600°C. In general steel, blue shortness increases tensile strength and hardness in the vicinity of 250°C and it increased brittle due to reduced elongation. Blue shortness is shown at about 250°C in the tensile test and temperature of blue shortness is different depending on the load rate. In a previous study, POSTEN60 is similar to the yield stress of the tensile strength tends to decrease and yield strength and tensile strength of the POSTEN60 study was found to increase rapidly even after 600°C. Also, the value of the elastic modulus is gradually decreased to 400°C and it has been studied to be rapidly reduced even after 400°C. In this study, for accurate analysis, it was applied to the above properties. Due to this mechanical property of POSTEN60, curves of figure 12 were derived.

4.3. Strain according to measure point in induction pre-heating

Figure 13 shows the equivalent strain of 1, 4-layer for each measurement point. Equivalent strain value is the highest in Point-3. The equivalent strain values of 1,4-layer is almost identical in Point-1 and 2. But the equivalent strain is showing the value of 1,4-layer a big difference in Point-3. The equivalent strain value of 4-layer is 0.233.

![Figure 13. Equivalent strain according to 1, 4-layer; (a) Point-1, (b) Point-2, (c) Point-3.](image1)

Figure 14 shows the equivalent stress value of the three measurement points on the 2-layer. Each measured point has shown a rapid increase deformation each time passing the roll pass and 2-layer was found to be obtained at a high strain value than 1,4-layer. The interior of the forming sheet was confirmed that is a greater effect of bending force than 1,4-layer for the surface of the sheet.

![Figure 14. Equivalent strain of 2-layer according to measurement point.](image2)

Figure 15 shows the thermal strain value according to the temperature of pre-heating and thermal
strain was compared with respect to 100°C and 500°C at Point-2. In final forming, Heat strain was 500°C higher than 100°C and heat strain at 500°C is 0.5 higher than the equivalent strain at room temperature. Heat strain is invisible whenever clear trend over each roll pass, as shown in figure 14. And figure 15 of the curve could be confirmed when only significantly increased over the 3-Pass.

![Figure 15. Thermal strain at 2-Point; (a) 1-layer, (b) 4-layer.](image)

![Figure 16. Thermal strain according to measurement point; (a) 1-layer, (b) 4-layer.](image)

Figure 16 is a thermal stress graph of the respective temperature. Thermal strain values were obtained point-3 higher than point-1. Although stress is lower as the temperature increases such as figure 12, the thermal stress was increased. With reference to the simulation results in high temperature, the stress is reduced when the temperature increases but the strain is increasing.

4.4. Compare with induction type and laser type

Figure 17 shows the thermal stress according to pre-heating type. The thermal stress in figure 17(a) is significantly increased when the forming sheet passes over a roll die. The area of the induction type and laser type graph is identified as similar. In addition, the result was similarly derived.

Figure 18 shows the thermal stress according to roll pass. The strain is increased when the forming sheet passes over a roll die. The results of the two types of pre-heating show a difference in 4-layer. As mentioned above, pre-heating has less influence about the stress, but the thermal strain of effects is large. In this study, the main difference of Induction of type and laser type is area of the pre-heating shape. Because of the laser type is approximately 11.8 times larger than the induction type, the simulation results shown in figure 18 was derived.
4.5. Result of spring back

Figure 19 shows the spring-back of each measurement point according to the pre-heating temperature about the two kinds of heat sources. A positive value means increase spring back and a negative value
means over-bending in figure 19. In previous research, V-bending has no concept of a negative value, but this study has a negative value because the roll forming process is a progressive process. The measurement result shows a very similar result to the spring back value of the room temperature, the induction pre-heating and laser pre-heating at the Point-1 and 2. In the laser heating, the spring back of Point-3 is much improved.

Spring-back effect according to the pre-heating temperature is not a significant difference. The spring back phenomenon is determined that the effect on a large area of pre-heating shape than the temperature of pre-heating temperature. Also, the spring back value is predicted to differ according to the correlation between the heat affected zone and bending area in forming sheet.

5. Conclusion
In this study, the spring back was predicted by the preheated plate in the roll forming process. FEM simulation analysis was derived von-mises stress, equivalent strain in room temperature, and thermal stress, thermal strain in high temperature.

The conclusions of this study are as follows:

- Forming sheet has a high temperature convergence in the thickness direction and temperature reduction depends on the pre-heating method in after forming.
- Stress behavior of 1,4-layer is similar and von-mises stress tends to increase with the point in 2-layer at room temperature. In the high temperature, the thermal stress difference in temperature is not large by the blue shortness effect of high tensile steel.
- In the room temperature, the equivalent strain is increased gradually when the bending force is applied and equivalent strain exhibits a rapid increase in processing by the die. Thermal strain is increased higher the preheating temperature and thermal strain of 1,4-layer is not a big difference in high temperatures.
- Laser pre-heating area is about 11.8 times larger than the magnetic induction pre-heating area. Thermal stress by the pre-heating of the two methods is similar, but the laser type is a larger thermal strain value than the induced type.
- In results of springback analysis, forming a sheet tends to increase the springback value as forming process, and in the laser heating, the spring back of Point-3 is much improved.
- Pre-heating has less influence about the stress, but the thermal strain of effects is large in the roll forming process.

Also, the spring back value is determined to be able to control the spring back value in accordance with the pre-heating shape and area. And through the FEM simulation, defects in the roll forming products are expected to be predicted in the pre-heating roll forming process.

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