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A Numerical Study on the Effects of Ring Rolling on Materials

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링 롤링 공정이 재료에 미치는 영향에 대한 수치해석적 연구

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ABSTRACT

Ring rolling is a type of forging for manufacturing large-diameter rings. Products manufactured by ring rolling are useful in the aerospace industry because of their excellent mechanical properties and high dimensional accuracy. The major components of the ring rolling process are a mandrel and main roll that shape the inside and outside of the ring, an axial roll that shapes the top and bottom of the ring, and a side rolls to position the ring. In this study, a simulation of ring rolling using finite element method (FEM) was performed. DEFORM, a commercial machining analysis program, was used. Based on the simulations, the mandrel feed force required for machining and the drive torque of the main roll were predicted. It was also possible to identify the metal flow caused by machining.

Keywords : Ring Rolling(링롤링), Forging(단조), FEM(유한요소해석), Force Prediction(힘 예측), Feed Rate(이송 속도)

1. Introduction

Ring rolling is a process of widening the inner diameter of a material by reducing the distance between two rolls. Ring rolling is a method mainly used for making large diameter rings. This process is used to make bearings, flanges, pipe reinforcement rings, and so on. The advantage of the process is that there are no seams in the ring, the processing time is short, waste of material is small and the dimensions are precise. The major advantage of ring rolling is that the strength in the circumferential direction is improved due to the flow net formed through the rotating process.

The following studies were conducted on the ring rolling process. Kim et al. utilized the dual-mesh approach method to the ring rolling simulation. By using fine mesh sector and coarse mesh sector, the problem of computation time, which is the biggest problem of ring rolling simulation, is reduced[1]. Kim, Suk, and Huh optimized the large ring rolling process

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using FEM. Through analysis results, the cause of tilting of the side wall was identified. The position of the initial ring blank was changed to obtain a result close to the target dimension[2]. Kim and Kim analyzed all collaborations related to the process from hot forging to ring rolling using a machining analysis simulator. Through analysis, input materials decreased by 40% and raw material recovery rate increased by 24%[3]. Utsunomiya et al. conducted a FEM analysis of the cold ring rolling process over time. At the beginning of rolling, it was confirmed that the ring vibrates randomly. It is confirmed that the deformation and the stress distribution of the ring have periodicity over time[4]. Yea et al. simulated plain ring rolling and T-profile ring rolling. Through the simulation, the pressure distribution and the roll force were predicted in the ring rolling process and the analytical results were in agreement with the experimental results. As a result, the authors conclude that simulation can be used for equipment design and analysis[5].

In this study, the ring rolling process of large diameter (d_i = 560 mm) flange is simulated through FEM analysis. Through the simulation, the mechanical properties of the flange after molding are analyzed by observing the effect of the process on the material using properties such as residual stress and flow net.

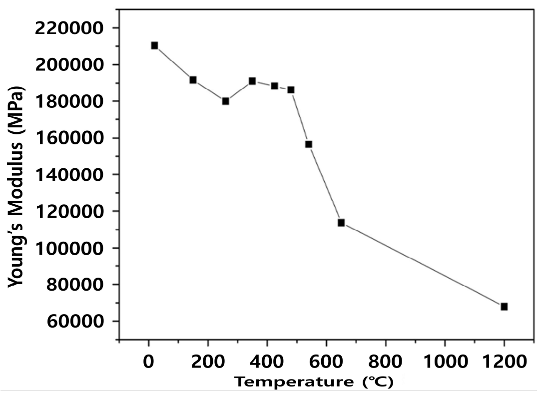

Fig. 1 Young's modulus of AISI-302 stainless steel according to temperature

2. Properties

The material used in this study was AISI-302 stainless steel and the material properties were used in DEFORM (DEFORM version 11.0, Scientific Forming Technologies Corporation, Columbus, Ohio, USA). The physical properties are shown in Fig. 1.

3. Forming Analysis

3.1 Analysis method

In the basic ring rolling process, the raw materials are processed in the order of cross forging, solid forging, and upsetting forging. After upsetting, the basic shape is formed through forging, and then the center is pierced to create a space into which the mandrel can enter. Finally, the ring rolling process is performed in the hot state. In this study, only the ring rolling process was analyzed using the FEM. Unlike the general forging simulations, the ring rolling analysis involves several hundred rotations, which is time-consuming. Before the rolling process used in the analysis, the flange had an inner diameter of 170 mm and an outer diameter of 560 mm.

There are four molds used in the process: main roll, mandrel and two axial rolls. The main roll rotates the material at a constant rotational speed. The mandrel moves toward the main roll and rotates in accordance with the rotation speed of the material. Axial rolls prevent the material from coming up and down, and like mandrels, rotate in accordance with the rotation speed of the material. When simulating the ring rolling process, it is difficult to directly obtain the rotational speed of mandrel and the axial roll. Therefore, the coefficient of friction of the mandrel and the axial roll is given as 0, and the effect is given to rotate at the same speed as the speed of the material[6].

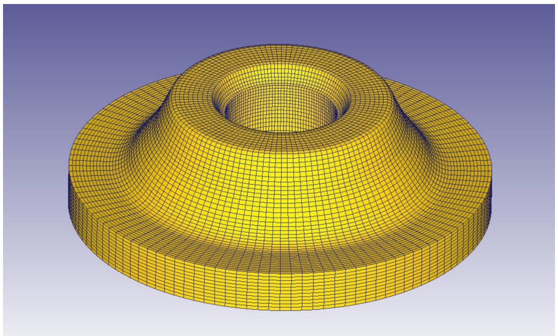

Fig. 2 3-D flange grid (Number of structured grids: 46320)

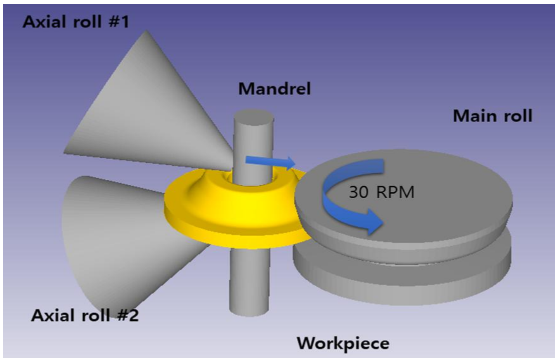

Fig. 3 Configuration of analysis and transfer condition of molds

3.2 3-D modeling

The mold was assumed to be a rigid body and the temperature condition was assumed to be constant temperature. Therefore, the grid was generated only on the flange. The shape of the grid is shown in Fig. 2. In the 2-D shape, 386 rectangular grids were generated and rotated about the axis to generate 120 cross-sections, resulting in a total of 46320 hexahedral grids. The material is AISI-302 stainless steel, and it assumes a rigid plastic body because of the large material change.

3.2 Boundary conditions

The basic configuration of the simulation is shown in Fig. 3. As described above, in the case of a general ring rolling process, the mandrel and the axial roll are driven to follow the rotation speed of the material. Since it is difficult to obtain the rotational speed in the analysis, the coefficient of friction with the material is set zero. Since this process is hot forming, the influence of temperature should be considered. The temperature of all molds was set to 20°C and the material gave an initial condition of 1200°C. The coefficient of friction between the main roll and the material was set to 0.7, which is a general value of hot forging.

The movement speed of the mandrel was set as a function of time. The feed rate function is shown in

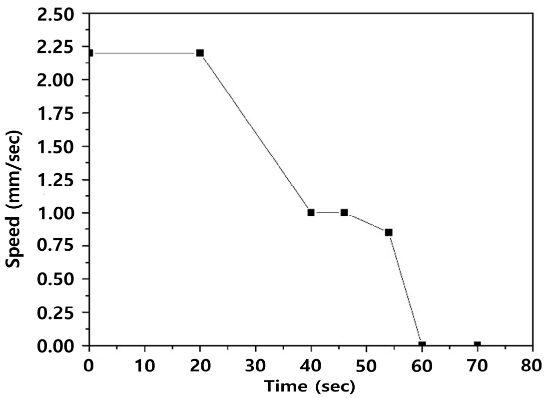

Fig. 4 Feed rate function of mandrel according to time

Fig. 4. The moving speed of the mandrel gradually decreases. In the end, the mandrel does not move but becomes a state of rotating only, and the step of finishing the shape of the material. The whole process takes about 70 seconds and the analysis is divided into 20,000 steps. In the general process case, the process is performed within a few hundred steps, but in the case of the ring rolling, since the process is a rotating process, the process is completed by several tens of rotations. Therefore, unlike a general forging process that ends with a single stroke, a large amount of computation time is required. Newton-Raphson algorithm was used for the calculation. The maximum number of iterations was limited to 200 per step.

4. Results and Discussion

The results were analyzed through effective strain, residual stress, damage, flow net, and the required force and torque for driving the mold. Since the shape of the flange is axisymmetric, the shape was sliced for analysis.

4.1 Effective strain & residual stress

Ring rolling is a forming method in which the size of the shape is gradually increased while rotating the material. The main roll material, axial roll material has the greatest force on the surface. As shown in Fig. 5, the inside of the flange has little strain, whereas the outer surface of the flange has a relatively large strain because the deformation occurs a lot in the outer surface. Also, the largest strain was found at the edges. This is because the material is repeatedly deformed in the vertical direction.

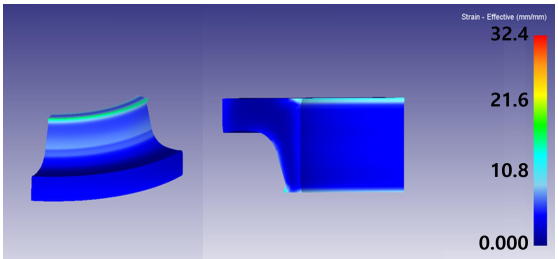

Fig. 5 Effective strain inside the flange after the forming process (Sliced model)

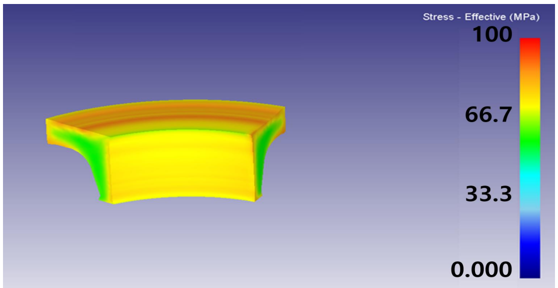

Fig. 6 Residual stress inside flange after forming process (Sliced model)

Along with the effective strain, residual stresses generated inside the flange after ring rolling were confirmed (Fig. 6). The residual stress in the inside of the flange was relatively lower than in the case of the outside. It was confirmed that the residual stress was greater at the contact portion with the mandrel than axial roll contacted. It is considered that the force applied to the flange by the axial roll during the process is larger than the force applied by the mandrel. The residual stress in the flange was about 50 MPa.

4.2 Flow net & load prediction

The flow net generated during ring rolling was confirmed by cutting the flange. In order to obtain the actual flow net, it is necessary to simulate upsetting forging to ring rolling process. In this study, however, only the ring rolling process was simulated. Therefore, only the flow net generation tendency can be confirmed during the ring rolling process. Fig. 7 shows the flow net of the horizontal plane of the flange. The flow net was formed more densely than the shape before forming as the gap gradually decreased in the circumferential direction. Dense flow net increases the mechanical strength of the product.

The force applied to the mold during the process can predict the force required in the actual process. In the ring rolling process, most of the load is applied to the mandrel and the main roll. The mandrel requires a force to push the material

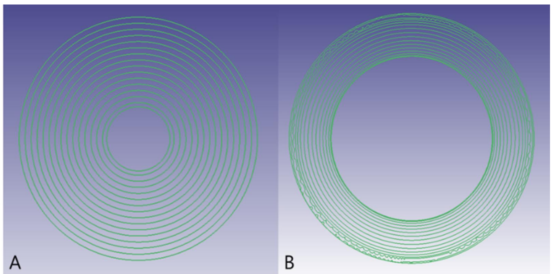

Fig. 7 Flow net inside the horizontal plane

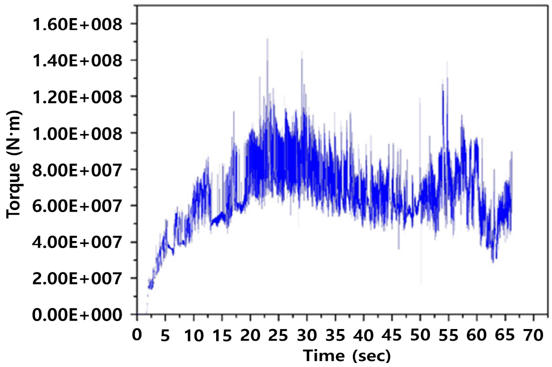

Fig. 8 Torque according to the time required to drive the main roll

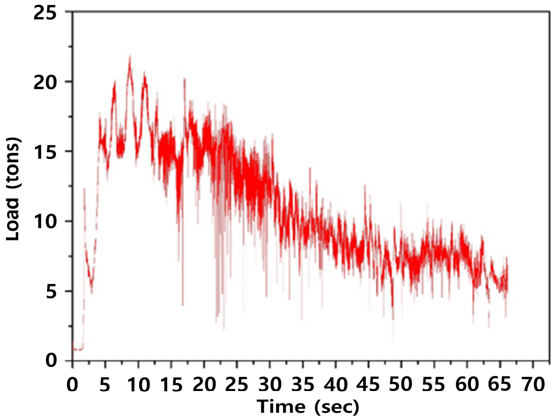

Fig. 9 Force according to the time required to transfer the mandrel

horizontally, and the main roll requires a torque that can rotate the material while being pressed by the material. The forces and torques expected to be required are shown in Fig. 8 and Fig. 9. The maximum force applied to the mandrel in the horizontal direction was found to be about 22 tons. Applied force decreased as the mandrel feed rate decreased. The maximum torque required for rotation of the main roll was about 1.5E+8 N·m. Unlike the decreasing force required in the mandrel, a nearly uniform amount of torque was required after reaching the maximum torque in the main roll. A certain amount of torque is required because there is slippage between the material and the main roll.

5. Conclusion

AISI-302 stainless steel flanges, which require good dimensional accuracy, were simulated by ring rolling. The goal of the forming simulation is to analyze the process of extending the flange with an inner diameter of 170 mm to 560 mm. Forming analysis to increase the flange bore was found to require 22 tons of load for forming and it was predicted that a torque of 1.5E+8 N·m would be required to rotate the main roll. After analyzing the process using the numerical method, the data were obtained such as effective strain, residual stress. Since most of the deformation is made on the outer surface of the flange, it is confirmed that all values such as strain and residual stress are higher in the outer surface. It is expected that the flow net generated by the ring rolling process will increase the mechanical performance of the product because the intervals become denser as it passes through the process.

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