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Mechanical Effects of Pipe Drawing Angle and Reduction Rate on Material

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파이프 인발 각도에 따른 기계적 효과 및 재료에 따른 감소율에 관한 연구

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ABSTRACT

Seamless pipes are fabricated by drilling a hole in a cylindrical material and drawing the material to the desired diameter. These pipes are used in environments where high reliability is required. In this study, the pipe drawing process was simulated using DEFORM, a commercial finite element method (FEM) analysis program. The outer diameter of the steel cylinder used herein before drawing was 70 mm, and the target outer diameter was 58 mm. The drawing process consisted of two stages. In this study, the effect of cross-sectional reduction rate on the pipe was investigated by varying the cross-sectional reduction rate in each step to achieve the target outer diameter. The results of this study showed that the first section reduction rate of 26% and the second section reduction rate of 13.9% caused the lowest damage to the material. Moreover, the FEM simulation results confirmed the influence of the drawing die angle on the pipe drawing process. The drawing die angles of 15° in the first step and 9° in the second step caused the least damage to the material.

Keywords : Pipe Drawing(파이프 인발), Finite Element Method(유한요소해석), Die Angle (다이스 각도), Cross-section Reduction Rate (단면적 감소율)

1. Introduction

The seam of a pipe is generated in the welding process, where the flat pipe raw material is bent to form a circular shape and subsequently welded. Such seams adversely affect the mechanical strength of pipes. To overcome this drawback, seamless pipes are drawn to exact dimensions by using a mandrel and a die. Drawing is a method of fabricating a desired cross-sectional shape by pulling the material along a certain angle by using a die. The act of pulling or drawing is mainly used to reduce the cross section of bars or pipes.

The following studies have been conducted on the pipe drawing process. Dixit and Dixit (1995) studied

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how factors such as the die cross-section reduction rate, die angle, friction coefficient, and back tension affect a die. Kampuš (1999) used commercial FEM programs to compare and analyze the results of models composed of elastoplastic equations to investigate the factors affecting the dimensions and shapes of drawn materials. Moon and Kim (2012) quantitatively analyzed the effects of elastic recovery of materials, elastic deformation of die material, and thermal deformation of die material during wire drawing. Ahn et al. (2016) used an analytical approach to determine the change in the angle of the die and the plug in the drawing process for developing common rail fuel injection tubes. They found that optimizing the angle of the plug rather than that of the die was advantageous for drawing high-pressure fuel injection tubes, which requires precision.

In this work, a drawing process that reduces a 70 mm pipe to 58 mm is studied. The drawing is carried out twice. This study investigates the effects of two factors, namely cross-section reduction rate and die angle, on the pipe material.

2. Properties

In this study, we used AISI 1020 carbon steel as the pipe material, and the properties of this material available in the DEFORM environment (DEFORM version 11.0, Scientific Forming Technologies Corporation, Columbus, Ohio, USA) were used. Table 1 summarizes the mechanical properties of the material.

Table 1 Properties of AISI 1020 carbon steel

Tensile Strength, Ultimate	420 MPa
Tensile Strength, Yield	350 MPa
Elongation at Break	15 %
Modulus of Elasticity	205 GPa
Poisson's Ratio	0.29
Shear Modulus	80 GPa

Table 2 Section reduction rate conditions (Case1 ~ Case5)

	Area (mm^2)	Section reduction rate (%)	Area (mm^2)	Section reduction rate (%)
	First stage		Second stage	
Case1	4138	7.1	2838	31.4
Case2	4006	10.0	2838	29.2
Case3	3705	16.8	2838	23.4
Case4	3416	23.3	2838	16.9
Case5	3296	26.0	2838	13.9

Table 3 Drawing die angle conditions

Drawing angle (°)	
First stage	Second stage
9	9
12	12
15	15
18	18

3. Forming Analysis

3.1 Analysis method

The drawing process used herein consisted of two stages. The first goal of our analysis was to determine the optimum cross-section reduction rate by varying it during the drawing process. The second goal was to find the optimal die angle by varying it. The outer diameter and thickness of the pipe were 70 mm and 5.5 mm, respectively. The target outer diameter and thickness were 58 mm and 4.2 mm, respectively. Table 2 shows the conditions of the section reduction rate drawing.

In our analysis of changes in the drawing angle, the best condition in the first drawing step is selected and used as the input value for the second drawing step. Table 3 shows the conditions used in the die angle change analysis.

3.2 Pipe Design

A two-dimensional CAD model of the pipe was created using CATIA V5 (CATIA V5 R21, Dassault

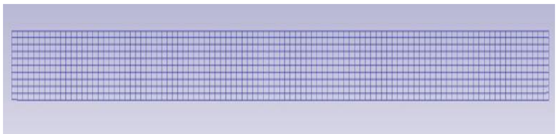

Fig. 1 The 2-D mesh used for FEM analysis

Systèmes, Vélizy-Villacoublay, France) and converted to the 2D dxf CAD format. The commercial finite element program DEFORM utilized to create a rectangular grid, as shown in Fig. 1. The number of elements was 100 × 10. The material was AISI carbon steel 1020. We assumed that the material was a rigid plastic body, and the mandrel and the drawing die were rigid bodies.

3.3 Analysis Condition

Given that the product used in the simulation was a circular pipe, the axisymmetric assumption was used. The basic analysis configuration is shown in Fig. 2. As shown in Fig. 2, the forming tool consisted of a mandrel inserted in the center, drawing die, and chuck for pulling the pipe. Generally, in pipe drawing, the end of the pipe is swaged through the pointing process, and the swaged part is pulled out by grabbing it. Instead, in our FEM simulation, non-separable contact between the chuck and the pipe was considered, meaning that when the chuck is transported, the pipe material is also transported, such that the material is pulled together. The effect of temperature was not considered for cold working, and the coefficient of friction between the mandrel material and the drawing die material was 0.1, which is generally used as the value for the steel die in cold forming.

The y-directional feed rate of the chuck was set to 8 mm/s. The moving distance of the chuck per time step was set to 0.275 mm. Given that the length of the minimum element was 0.55 mm, the travel distance per step was determined to be 1/2 of the minimum element length. The number of steps in one run of drawing was 800, and these steps

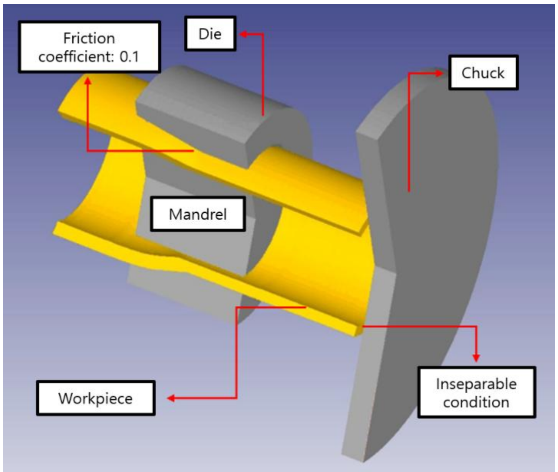

Fig. 2 Boundary conditions of FEM analysis

amounted to 25 s in terms of time. The length of the material used in the analysis was 100 mm. The Newton–Raphson algorithm was used for the calculation. The maximum number of iterations was limited to 200 per step.

4. Results and Discussion

The damage to the material due to the drawing load was considered the analysis result. The pullout load was determined based on the force exerted on the chuck during the drawing process.

4.1 Change in Section Reduction Rate

4.1.1 Drawing load

In the case of a change in the section reduction rate, the second process is determined when the first process is determined. The analysis results are shown in Fig. 3. The larger the section reduction rate, the larger was the drawing load. However, as shown in Fig., the average drawing loads of the 1st and 2nd draws were almost equal. These results indicate that the drawing machine with a capacity of 70 tons or more was adequate for the drawing process in this study.

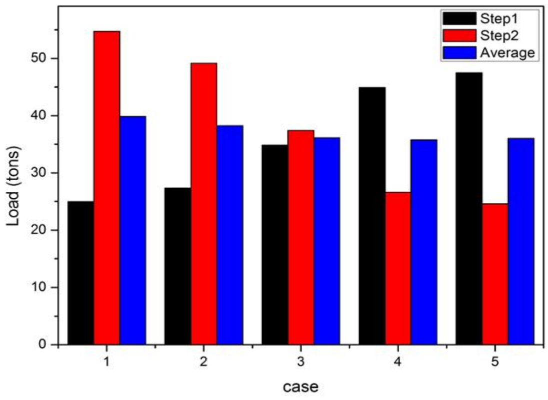

Fig. 3 Average drawing load of each case

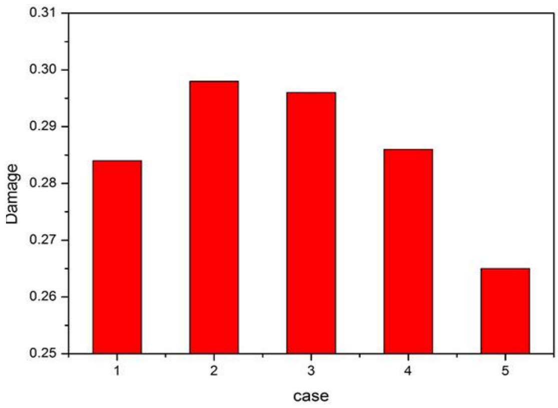

Fig. 4 Average damage to the material

4.1.2. Damage

In case of damage, unlike the pullout load, the difference was visible in each case. The results are shown in Fig. 4 in terms of the average damage in each case. In a comparison between Cases 2 and 5, the damage value in case 2 was 12% higher than that in case 5. Therefore, it was confirmed that when the material was drawn by changing the sectional reduction rate, the least damage to the material was achieved when the section reduction rate was large in the first process and small in the second process.

4.2 Changing the Drawing Angle

4.2.1 Drawing load

As shown in Fig. 5, the difference in drawing loads between the angles of 15° and 18° was not large. However, the lowest average drawing load occurred at 15°. Therefore, the optimum angle for the first process was set to 15°.

With the abovementioned optimum die angle for the first process, we analyzed the second process, and the results are shown in Fig. 6. As shown in the figure, the smaller the die angle in the second process, the smaller was the drawing load. The difference between the smallest draw load incurred

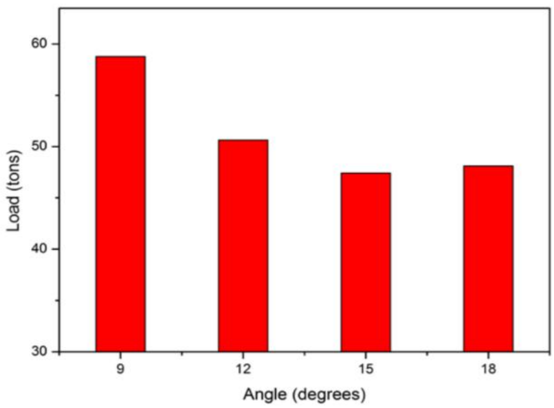

Fig. 5 Average drawing load according to drawing die angle (first process)

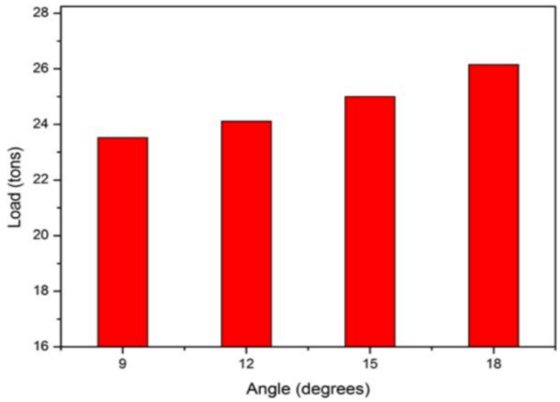

Fig. 6 Average drawing load according to drawing die angle (second process)

with the angle of 9° and the largest draw load incurred with the angle of 18° was approximately 3 tons.

Therefore, when changing the drawing angle, the optimum die angle was set to 15° for the first process and 9° for the second process.

4.2.2 Damage

The die angle of 15° was selected as the optimum die angle based on the drawing load. However, when the die angle is 18°, there was almost no difference in the drawing load. Therefore, the appropriateness of the optimum die angle was judged based on damage to the material. Fig. 7 shows the damage to the pipe as a function of the die angle. Between the angles of 15° and 18°, the former caused significantly less damage than the latter. Moreover, with the angle of 18°, the magnitude of damage was higher than that for all other angles. When the die angle was set to 9° or 12°, the damage was less than that incurred by setting the angle to 15°. However, in terms of drawing load, the lowest drawing load was incurred with the angle of 15°, and therefore, this value was set as the “optimum die angle.”

In the second process, the damage value was not significantly different, as shown in Fig. 8. Since the first process was the same, the magnitude of damage did not change with the die angle in the second process. However, as shown in Fig. 8, the smaller the die angle, the smaller was the magnitude of damage. Therefore, for the second process, 9° was found to be valid as the optimum die angle because both the drawing load and magnitude of damage were the lowest.

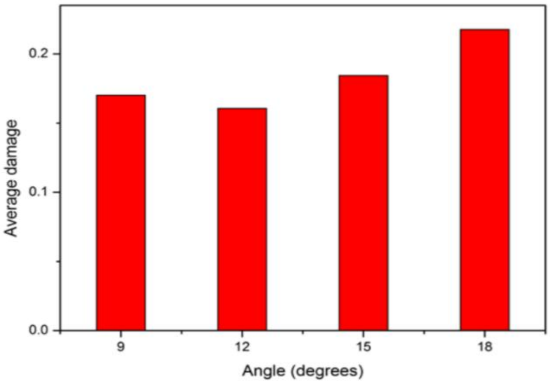

Fig. 7 Damage according to each die angle (first process)

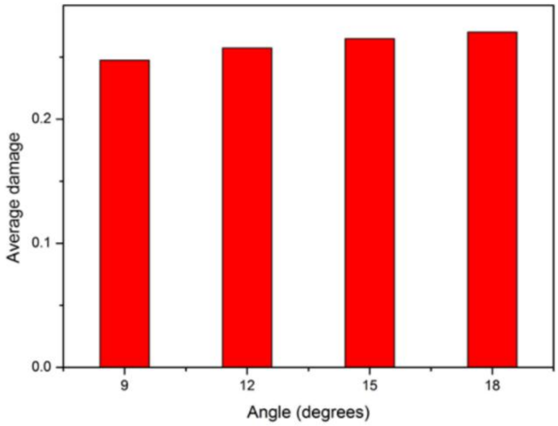

Fig. 8 Damage according to each die angle (second process)

4.3 Pipe Length

Equation 1 shows the volume conservation equation of the material.

$$V=\frac{\pi}{4}\left(D_{o1}^{2}-D_{i1}^{2}\right)h_{1}=\frac{\pi}{4}\left(D_{o2}^{2}-D_{i2}^{2}\right)h_{2} \quad (1)$$

where Do1, Di1, and h1 denote the outer diameter, inner diameter, and length of the pipe before drawing, respectively, and Do2, Di2, and h2 denote the outer diameter, inner diameter, and length of the pipe after drawing. Because there is minimal loss or compression of the material during drawing, the length of the material after the process is predicted using the above equation. When the length of the inserted material is 100 mm, the length of the theoretical drawn material using Equation 3 is

Fig. 9 Length of pipe after drawing

approximately 160.52 mm. We confirmed that the difference between the abovementioned theoretical length and the simulated length of 163.585 mm was approximately 1.9%, as shown in Fig. 9.

5. Conclusion

AISI 1020 carbon steel seamless pipe drawing, which requires good dimensional accuracy, was simulated. The pipe drawing analysis was divided into two main parts. First, process analysis was conducted by changing the cross-sectional reduction rate. The second analysis involved changing the angle of the drawing die.

In case of the analysis with varying section reduction rate, case5 (section reduction rate: 1st stage-26%, 2nd stage-13.9%) was confirmed to be the best case in terms of the average drawing load and damage, as shown in Figs. 4 and 5.

In the analysis for finding the optimum die angle, drawing load was used as the index for determining the optimum die angle. In the first process, we confirmed that the smallest draw load was applied when the die angle was 15°. The optimum die angle for the second process was determined using the die angle of 15° for the first process. In the second process, the smallest draw load on the chuck was incurred when the die angle was 9°. After the analysis, the length change of the material was compared with the length change of the theoretical material. As a result, it was confirmed that there was a difference of approximately 1.9%.

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