Optimization of Machining Parameters for Improving Accuracy of Dimension and Shape of Bent Part in Rotary Draw Bending

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Introduction

This study dealt with the rotary draw bending method most used for tube bending and investigates how applied bending such as normal bending, using mandrels or pressing with booster have an effect on machining accuracy, focusing on dimensional defects due to springback and flat deformation to the transverse plane. Particle swarm optimization (PSO) algorithms was used to investigate the optimal machining conditions for improving machining accuracy.

Rotating Draw Bending and Machining Accuracy Evaluation

Rotating Draw Bending. Rotating draw bending is a machining method used for bending machining by rotating a rotary bend die in a state with a part of a metal tube grasped by a rotary bend die and a clamp die, as shown in Fig. 1. Here, this is referred to as normal machining, and its features comprise little flattening, easy small radius bending, and available continuous bending. In addition, there is applied machining using a booster die and mandrel, for example. In this study, differences in machining accuracy are investigated by comparing it with applied machining and normal processing.

Machining Accuracy Evaluation. Machining accuracy was evaluated using the springback and flatness. When the target bend angle was $\theta_1 = 90°$, the bend angle after machining was θ_2, and the springback $\Delta\theta$ was defined as in Eq. (1). In addition, the raw pipe diameter was d_0, the vertical diameter in the cross-section of the bend part was d_1, and the horizontal diameter was d_2, and the flatness D_f was defined as shown in Eq. (2). The smaller the $\Delta\theta$ and D_f, the better is the machining accuracy.

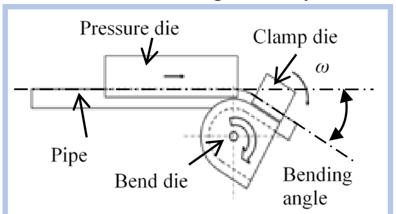

Fig. 1 Schematic diagram of rotary draw bending

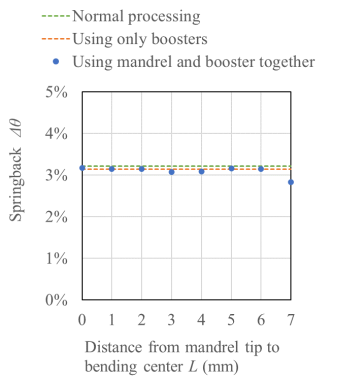

Fig. 2 Change in springback under various processing conditions

$$\Delta\theta = (\theta_1 - \theta_2)/\theta_1 \tag{1}$$

$$D_f = (d_1 - d_2)/d_0 \tag{2}$$

Machining Parameter Optimization Method. The optimal machining condition was examined to improve machining accuracy using the particle swarm optimization (PSO) algorithm. In this study, we constructed an objective function of machining accuracy evaluation as shown in Eq. (3).

$$y = \alpha\Delta\theta + \beta D_f \tag{3}$$

Here, α and β are weighting coefficients, and $\alpha + \beta = 1$.

Simulation using Finite Element Method. For the analysis model, we made non-pipe parts rigid and used a four-node tetrahedral isoparametric element for the pipe. The model was 1/2 scale, and the rotation axis of the bend die, and clamp die was divided into two parts by the symmetry plane serving as a normal line. As for the material properties, we used Young's modulus $E = 193$ GPa, Poisson's ratio $\nu = 0.29$ and yield stress σ_y = 320 MPa, and used a Ludik-type approximation of Eq. (4) for the relation between the true stress σ and the true strain ε in the plastic region for plastic deformation behavior.

$$\sigma = \sigma_y + K_p(\varepsilon - \varepsilon_y)^n \tag{4}$$

Here, ε_y denotes the yield strain, and material constant K_p = 1600 MPa and $n = 0.85$.

Results and Discussion

Figure 2 shows the change in the springback according to the protrusion of the mandrel tip L. Fig. 3 shows the flattening near the center of the bend. Fig. 4 shows the results obtained by machining parameter optimization using the PSO method.

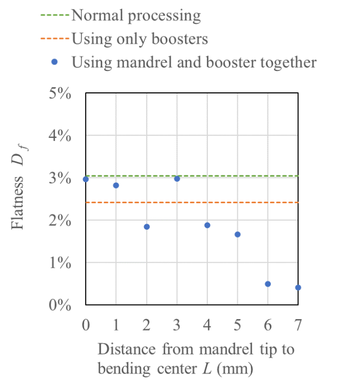

Fig. 3 Changes in flatness under various processing conditions

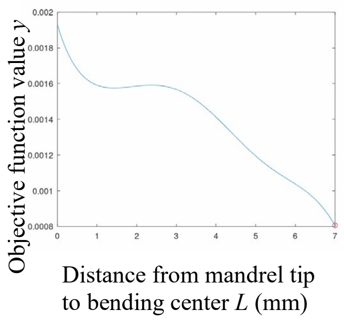

Fig. 4 Machining parameter optimization through using PSO method

Conclusion

The findings were obtained from this study as follows: The springback during applied machining using a mandrel, or using a mandrel and booster together, is almost the same as during normal processing; The flattening near the center of the bend in applied processing using a mandrel, or a mandrel and booster together, decreases more than with normal processing at $L \geq 4$ mm, and the maximum can be suppressed to approximately 0.15%; When the sum of the springback and the flattening is taken as the objective function and the minimum value is obtained, the optimal solution is around $L = 7$ mm.

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