DRAW BENDING OF ALUMINUM PIPES USING ECCENTRIC PLUG

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ABSTRACT A draw bending method of pipes using an eccentric plug is proposed to achieve small bend radii. The bending is assisted by expanding the pipe with the eccentric plug, and the occurrence of buckling and wrinkling is prevented by the action of the pulling force in the drawing. The combination of the pulling and pushing forces is optimized to obtain the products without the defects. The effects of the pulling force and the eccentricity on the cross–sectional shape of the bent pipe are examined by a bending experiment using aluminum alloy pipes. The effectiveness of the present process is clarified from an analytical approach using the slab method.

Keywords: draw bending, pipe, eccentric plug, small bend radius, force control

1. INTRODUCTION

The bending of pipes is not easy in comparison with that of sheets and plates, because the buckling and folding tend to occur. In particular, it is difficult to bend thin pipes into small bend radii. For the bending of pipes, special tooling methods have been developed to avoid the buckling, folding and fracture. Filling with loose particles and flexible internal mandrels are employed for the bending of pipes. To extend the variety of the pipe products, a demand for small bend radii is increasingly intensified in industry.

The authors [1] have proposed a bending method of pipes using a floating plug. In this method, the bending is assisted by means of the expansion of the pipe with the plug, because the pipe undergoing deformation due to the expansion is bent even by a small moment. Since the plug is not fixed, the position is shifted during the bending in order to balance the forces acting to the plug. The expansion of the pipe and the shift of the plug make the bending easy. In addition, the small bending moment due to the expansion leads to a small amount of springback in the bent product. However, the buckling and wrinkling appear under severe forming conditions, because the pipe is expanded with the plug by pushing the tail end. It is desirable to develop an approach for preventing the occurrence of the defects.

In the present study, a draw bending method of pipes using an eccentric plug is presented. The occurrence of buckling and wrinkling is prevented by applying the pulling force to the pipe. The effects of the pulling force and the eccentricity on the shape of the bent pipe are examined in both experiment and calculation.

2. METHOD OF BENDING

A draw bending method of pipes using an eccentric plug shown in Fig. 1 is developed to achieve small bend radii. Since the plug is constrained by the groove of the form block in the draw bending, the shift of the floating plug is not free. Thus, the plug is eccentrically fixed to the mandrel. The clamped pipe is drawn by the rotating form block under pushing the tail end. The drawing is introduced to prevent the pipes from the buckling and wrinkling under severe bending conditions. The pushing force is applied to the tail end of the pipe to feed the pipe for the expansion. The bending conditions are summarized in Table 1. The expansion ratio of the pipe is fixed at 20% in the present study.

The dimensions and the flow stress of the aluminum alloy pipe A6063 used for the bending experiment are given in Table 1. The pipes were annealed prior to the bending. The flow stress was measured from the simple compression test. Molybdenum disulfide was employed as a lubricant in the bending.

The effect of the combination of the pulling and pushing forces on the bendability is examined. The combination is expressed by the pulling force ratio. The ratio is controlled by drawing the pipe under applying a pushing force. As the applied pushing force increases, the pulling force decreases.

To evaluate the cross-sectional shape of the bent pipe, the flattening ratio F is defined by

$$F = \frac{2(d_1-d_2)}{d_1+d_2}, \tag{1}$$

where d_1 and d_2 are the lengths of the major and minor axes of the deformed cross-section shown in Fig. 2, respectively. The flattening ratio was measured at the center of the bending region.

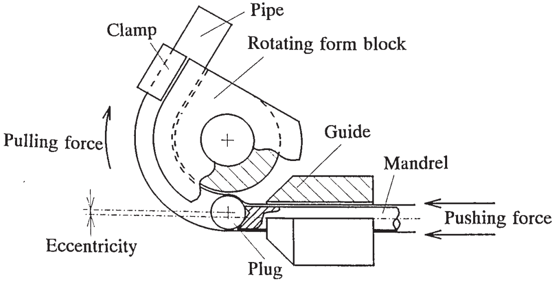

Fig. 1 Draw bending of pipes using an eccentric plug.

Table 1 Working conditions of draw bending.

Expansion ratio	20%
Diameter of plug	10.4mm
Diameter of groove of form block	d=12mm
Diameter of pipe	10mm
Wall thickness of pipe	0.8mm
Flow stress (annealed aluminum)	$\sigma=157\varepsilon^{0.25}$
Lubricant	Molybdenum disulfide

3. EXPERIMENTAL RESULTS

3.1 Concentric plug

The relationship between the flattening ratio F and the bend radius ratio (the ratio of bend radius r to the groove diameter d of the form block) r/d for the concentric plug without eccentricity is given in Fig. 3, where P is the pulling force ratio and is 0% and 100% for no pulling and pushing forces, respectively. For the small r/d of P=0%, the wrinkling appears at the inner surface of the bend. The action of the pulling force prevents the occurrence of the wrinkling, whereas the shape of the bent pipe deteriorates. By appropriately controlling the pulling force, the bending is possible even in r/d=1.2.

Although the bending without the expansion was also performed, the small bend radius was not attained even if the pulling force was applied. The expansion is a key to the bending of pipes.

3.2 Eccentric plug

The relationship between the flattening ratio F and the pulling force ratio P for r/d=1.6 is shown in Fig. 4, where E is the ratio of the eccentricity to the increase in diameter of the pipe for the expansion. For the eccentric plug, the position is forward shifted to make plastic deformation smooth (see Fig. 5). The flattening ratio for the eccentric plug is smaller than that for the concentric plug. The amount of the shift, s, is set for half of the diameter of the plug. In the eccentric plug, the flattening ratio is almost zero in the case of P=50%, and thus the optimal combination of the pulling and pushing forces exists.

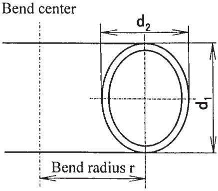

Fig. 2 Flattening of cross–section of bent pipe.

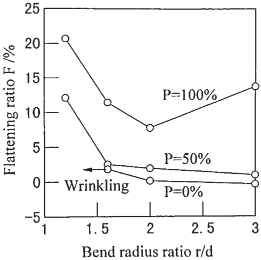

Fig. 3 Relationship between flattening ratio and bend radius ratio for concentric plug.

4. ANALYSIS USING SLAB METHOD

4.1 Slab method

The effect of the pulling force in the draw bending using an eccentric plug is analyzed by the slab method. For an small element of the pipe shown in Fig. 6, an equilibrium equation of force in the longitudinal direction is derived. The obtained equation is integrated over the plastically deforming body under satisfying the boundary condition of the pulling force at the exit of the deforming region, and thus the distribution of stress is calculated. Using the Lévy–Mises constitutive equations based on Hill's anisotropic yield criterion, the stress components are related with the strain components, and then the deforming shape is modified for the obtained strain components. Until the solution converges, the integration of the equilibrium equation and the modification of the deforming shape are repeated.

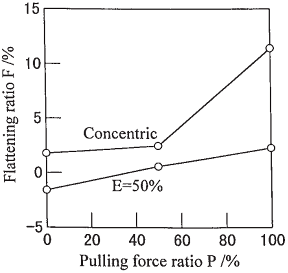

Fig. 4 Relationship between flattening ratio and the pulling force ratio for r/d=1.6.

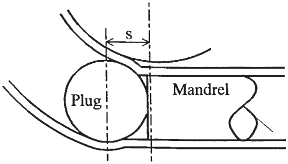

Fig. 5 Shift of eccentric plug for smooth plastic deformation.

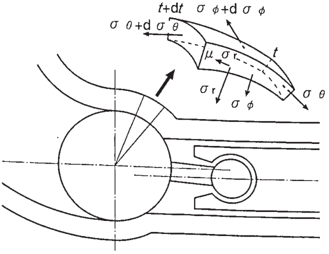

Fig. 6 Equilibrium of force in small element of pipe in slab method.

The pipe undergoes shear deformation at the entry of the deforming region due to the contact with the plug. Since the shear deformation is neglected in the slab method, the effect of the shear deformation is approximately added to the present approach. The decrease in pushing force due to the shear deformation at the entry is taken into consideration as a boundary condition in the slab method. The shear deformation is determined from the difference between the pushing forces obtained by the experiment and the analysis without the shear deformation.

The pulling force is given as the boundary condition at the exit of the plastically deforming region. The distribution of stress at the exit is assumed to be linear as shown in Fig. 7. The pulling force is equal to the integral value of the distribution. The difference between the maximum and minimum stresses, $\Delta\sigma$ at the exit is related with the bending characteristics.

4.2 Calculated results

The relationship between the stress difference $\Delta\sigma$ at the exit and the bend radius ratio r/d for no pulling force (P=0%) is illustrated in Fig. 8. As the eccentricity ratio E increases, the bend radius ratio decreases. This means that the eccentric plug is effective in bending the pipes into small bend radii.

The range of bending for the eccentric plug is given in Fig. 9. The area inside each triangle represents each range of bending. As the eccentricity ratio increases, the range shrinks and the required pulling force increases.

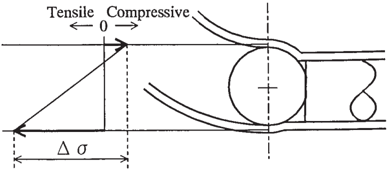

Fig. 7 Distribution of stress for pulling force at exit.

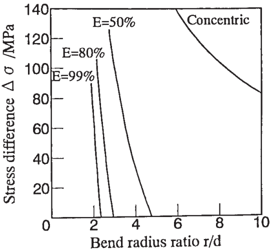

Fig. 8 Relationship between stress difference at exit and bend radius ratio calculated by slab method for no pulling force.

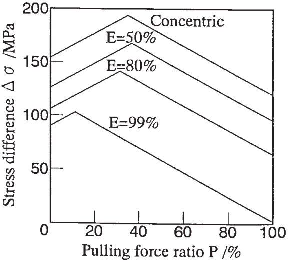

Fig. 9 Range of bending for eccentric plug calculated by slab method.

5. CONCLUSIONS

A draw bending method of pipes using an eccentric plug was presented to obtain products having small bend radii. The bending is assisted by expanding the pipe with the eccentric plug, and the occurrence of buckling and wrinkling is prevented by the action of the pulling force in the drawing. The combination of the pulling and pushing forces was optimized to obtain the products without the defects. The effectiveness of the present process was demonstrated from the analytical approach using the slab method.

REFERENCES

[1] M. Nakamura, S. Maki, M. Nakajima and K. Hayashi, Bending of circular pipe using a floating spherical expanding plug, Proc. 5th Int. Conf. Tech. Plasticity, Columbus, 1(1996), 501–504.