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A Refined Model of Three-roller Elastoplastic Asymmetrical Pre-bending of Plate

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Abstract: The geometry of plate after edge pre-bending mode is compared with that after roll-bending mode and the relationship among edge pre-bending angle, pre-bending edge length, and cylindrical desired radius is presented for a three-roller plate bender with bottom rollers adjustable horizontally. The analytical moment-curvature model and springback model for pure bending are established, assuming that the stress-strain relationship of material is linear, and the material is in plain strain and yields according to Mises yield criterion. The mathematical model for three-roller edge pre-bending of plate is developed considering the effect of pre-bending edge length, bottom roller radius, friction between plate and roller, etc. The plate tensile test and plate bending test are done and the numerical results agree well with the test data. The results are shown graphically and analyzed in the following aspects: (1) the error between numerical results and test data of top roller force; (2) the influence of bottom roller radius, relative curvature, and bending arc length on springback angle; (3) the relationship between springback ratio and edge pre-bending angle.

Key words: plate; elastoplastic; three-roller; edge pre-bending; asymmetrical bending; springback

Large and medium size tubes and tubular sections are extensively used in many engineering applications such as the skeleton of oil and gas rigs, the construction of tunnels, and commercial and industrial buildings[1]. In view of the crucial importance of the bending process, it is rather surprising to find that roll-bending processes in the field have been performed depending upon the experience and skill of the operator who works with the temples or by trial and error[2].

Hansen and Jannerup[3] developed the implicit equations set for three-roller steady roll-bending process, assuming that the material of beam has exponential stress-strain relationship and is under axial stress condition and considering the effect of the shift of beam-roller contact point and the springback in unloading stage on the plate nonlinear deformation. Then, the computational accuracy of the model for steady roll-bending process was enhanced by using the polygonal approximation method[4] and the finite difference method[5] to approximate the moment-curvature function $M(\tilde{\kappa})$. Gandhi and Raval[2] proposed an empirical formula about the relationship between top roller displacement and cylindrical desired radius of plate for the steady roll-bending process, which can be expressed as an exponential function. The models in the references above are only available for the steady roll-bending sub-mode. Then, Hua and Lin[6] studied the effect of material hardening index on the four-roller steady continuous roll-bending sub-mode and edge pre-bending sub-mode[7] and employed the equilibrium differential equations to develop the large curvature bending model[8]. Hu[9] presented the mathematical models of steady roll bending sub-mode and unsteady roll-bending sub-mode of thin plate on the three-roller symmetrical bender, and found that the curvature accuracy of plate would be reduced and the pre-bending edge would be lengthened if neglecting control of unsteady roll-bending sub-mode. The effect of number of roll-bending passes and top roller displacement of each pass on multi-pass three-roller steady roll-bending process was researched by Shin[10], and the results of finite element simulation show that multi-

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pass steady roll-bending makes more uniform curvature of the curved section than single-pass steady roll-bending does because of neglecting control of edge bending mode and unsteady roll-bending sub-mode.

Literature review shows that there are no mathematical models and experimental results available on three-roller edge pre-bending sub-mode of moderate-thick plate, which is important for improving cylindrical production accuracy. Just like plate roll-bending process, the edge pre-bending process would be influenced by plate overall dimensions, mechanical properties (Young's modulus, yield stress and hardening index), setup variables (roller radius, top roller displacement), springback, fiction between plate and roller, etc. The edge pre-bending process of moderate-thick plate on three-roller bender with bottom rollers adjustable horizontally is studied in this paper with considering the above factors. The relationship among edge pre-bending angle, pre-bending edge length, cylindrical desired radius is presented as a function which is useful for technician to calculate one of the three parameters, when the two other parameters are known. The moment-curvature model and springback model of plate elastoplastic pure bending are developed in the interval of material strain $0 \leqslant \varepsilon \leqslant 0.05$, assuming that the stress-strain relationship of material is linear, and the material is in plain strain and yields according to Mises yield criterion. Lagrangian polynomial is used to fit the moment-curvature function $M(\tilde{\kappa})$ to improve accuracy of the proposed edge pre-bending model. The standard tensile test of plate sample is done to get the mechanical properties of plate material, and the plate bending test on the WAW-E100 high-accuracy testing machine is conducted to verify the numerical results of the pre-bending model. Then, the numerical results and test data of relationship among top roller force, edge pre-bending angle, springback angle, etc. are shown graphically and detailed analyzed.

1 Geometry of Bending Plate

Three-roller plate bender with one top roller movable vertically and two bottom rollers adjustable horizontally is widely utilized in the field and easily reconstructed by adding automatic control equipment. The whole process of edge bending and roll-bending finished by three-roller bending machine in Fig. 1 includes edge bending mode and roll-bending mode. The edge bending mode consists of edge pre-bending sub-mode (sequences 2 and 4 in Fig. 1) and edge roll-bending sub-mode (sequences 3 and 5 in

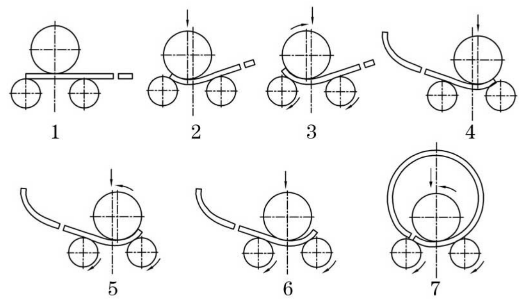

Fig. 1 Whole process of plate three-roller edge-bending and roll-bending

Fig. 1), and the roll-bending mode consists of steady roll-bending sub-mode (sequence 6 in Fig. 1) and unsteady roll-bending sub-mode (sequence 7 in Fig. 1).

The dash line profile $ABEFCA$ in Fig. 2 is the perfect geometry of the curved plate after the unsteady roll-bending mode (sequence 7, Fig. 1), which would turn to be circle after single-beam welding and rounding processes. The edges CA and BA in the profile are welded together and are made to be the short arc $\overset{\frown}{CB}$. The profile $ABEFCA$ includes the lines CA and BA finished in edge pre-bending mode (sequences 2 and 4 in Fig. 1), the short dash arcs $\overset{\frown}{BE}$ and $\overset{\frown}{FC}$ in edge roll-bending mode (sequences 3 and 5 in Fig. 1), and the large dash arc $\overset{\frown}{EF}$ in roll-bending mode (sequences 6 and 7 in Fig. 1). The actual line profile ABD in Fig. 2 is the plate geometry after edge pre-bending mode, and line BD is tangential to the dash arc BE. So, the edge pre-bending angle θ could be expressed as:

$$\theta = \arctan(\delta / R) \tag{1}$$

where, θ is edge pre-bending angle (after springback);

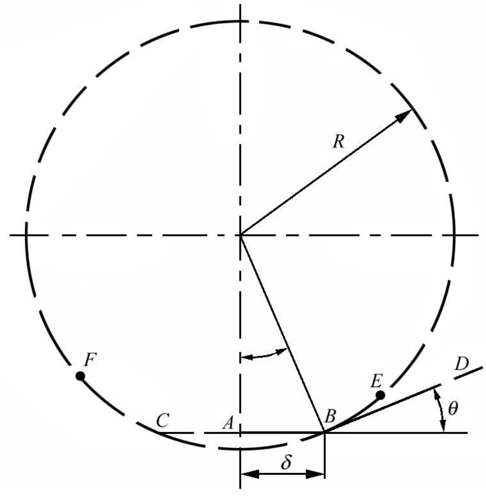

Fig. 2 Geometry of curved plate in edge bending and roll-bending processes