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Springback analysis of numerical control bending of thin-walled tube using numerical-analytic method

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Abstract

Springback has an important influence on the forming quality of numerical control (NC) bending of thin-walled tube. In the paper, using the numerical-analytic method proposed by authors, the springback mechanism and laws of the tube bending have been analyzed. The results show the following: (1) there are two sources of springback, one is from the plastically curved part of the tube, which has an approximate bilinear relation to the bending angle; the other is from the straight portion, which varies like an exponent line with the bending angle. (2) Based on the above features of springback angle, reasonable regression equations between springback angle and bending angle under different conditions can be obtained. (3) The larger the strength factor, or the smaller the relative bending radius or the hardening exponent, the larger the springback angle. The research may serve as a significant guide to accurate prediction and control of springback.

Keywords: Thin-walled tube; NC bending; Springback; Numerical-analytic method; Process parameter; Material property

1. Introduction

The NC bending of thin-walled tube is widely used in the aviation, auto, oil, etc. industries, because of its versatility and relatively higher forming quality and efficiency than other methods. However, springback is the inevitable phenomenon when the load is released due to the elastic property of the material. This leads to an increase in the radius of curvature and a reduction in the bending angle of the bent tube, as shown in Fig. 1, further leads to the decrease of the dimensional accuracy of the tube part and makes it difficult to fit the tube with others.

Unfortunately, the NC bending process of thin-walled tube is a complex process due to the complicated die structure and coupling interactive multi-factor effects. Particularly, the development of aviation and aerospace industries requires bent tubes much thinner in wall-thickness, larger in tube radius, smaller in bending radius and more precise in the forming process. All these make springback prediction of thin-walled tube bending a problem in need of urgent resolution in the research and development of the process.

In recent years, analytic method and elastic–plastic finite element method (FEM) are two main methods used to analyze the whole springback of tube bending processes. For complicated thin-walled tube NC bending and springback processes, analytic method has poor precision and elastic–plastic FEM is low in efficiency [1]. Therefore, in order to improve computational efficiency with satisfactory accuracy for analyzing bending and resulting springback processes of thin-walled tube, a numerical-analytic method developed by the authors [2] has been used, the sources of producing springback and their changing features, and influence laws have been analyzed, including the effects of the relative bending radius, the strength factor and the hardening exponent of material on springback angle. The results may help for prediction and control of springback of thin-walled tube bending.

2. Research method

2.1. Principle and advantages of the method

The method is based on springback angle computational model developed using the analytic method and simulation results from three-dimensional (3D) rigid-plastic finite element

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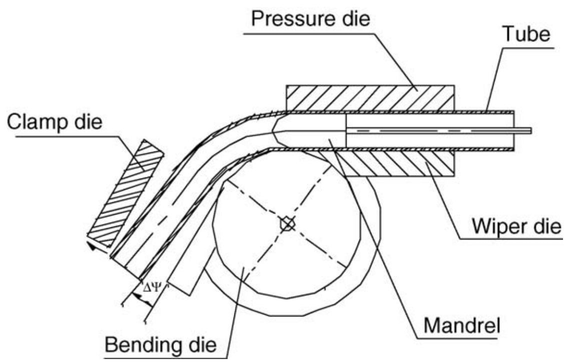

Fig. 1. Sketch of springback of a bent tube upon unloading.

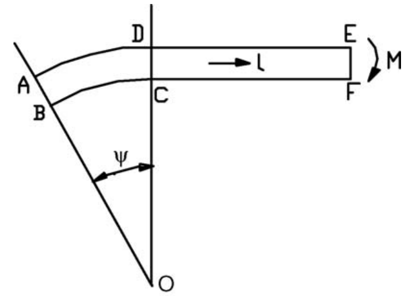

Fig. 2. Typical zone of bent tube.

method (FEM). The principle of the numerical-analytic method [2] is that, bending process is analyzed using the rigid-plastic FEM in order to quickly obtain field variables with satisfactory accuracy, and then springback analysis during unloading is accomplished quickly using an analytic method.

The features of the method are as follows: (1) the method is high in efficiency because it combines advantages of rigid-plastic FEM and analytic method. (2) The method is sound in accuracy. Although the springback model is developed based on an analytic solution to the bending process, the field variables used in the model result from 3D rigid-plastic FEM solutions, which have similar distributions to those from elastic–plastic FEM solutions. And the effects of both axial force and strain neutral axis shift have been included. (3) Research on multi-factor effects can be carried out using the method due to its advantage from the rigid-plastic FEM. (4) The method helps to obtain the changing feature of springback angle with bending angle.

2.2. Analytic model of springback angle

When a tube is formed on an NC bending machine, bending deformation mainly occurs in the area near bending plane. Thus, two typical zones can be defined. One is the plastically curved part of the tube (zone ABCD), the other is the straightway portion in the pressure die area (zone CDEF), as shown in Fig. 2. The total springback angle is the sum of both bending portion and straightway zone, i.e., $\Delta\psi = \Delta\psi_{\text{bending zone}} + \Delta\psi_{\text{straight portion}}$.

For bending zone and straightway portion, as shown in Fig. 3, there exist:

$$\begin{aligned}\Delta\psi_{\text{bending zone}} &= \int_0^{\psi} (\Delta\varphi - \Delta\varphi')\,\mathrm{d}\varphi \\ &= -\frac{R + r_{\mathrm{m}}}{E} \\ &\quad \times \int_0^{\psi} \frac{(R - r_{\mathrm{m}}\sin\alpha)[2M(R - 2r_{\mathrm{m}}\sin\alpha) + Nr_{\mathrm{m}}^2]}{\pi t r_{\mathrm{m}}^3[r_{\mathrm{m}}^2 - 2(R - 2r_{\mathrm{m}}\sin\alpha)^2]}\mathrm{d}\varphi \end{aligned} \tag{1}$$

$$\Delta\psi_{\text{straightway portion}} = \frac{1}{E}\int_0^{l} \frac{M}{I}\mathrm{d}l \tag{2}$$

where E is Young's modulus, N the axial force acting on the section in bending zone, M the bending moment acting on the section in bending portion or straightway, respectively, t the thickness of tube, r_{m} the average radius of tube, α the offset angle of strain neutral axis, R the bending radius, I the moment of inertia and l is the length of the straightway.

The evaluation of the reliability of the numerical-analytic method proposed by the authors has been carried out in paper [2], and the agreement between the numerical-analytic result and the experimental data indicates the method reliable.

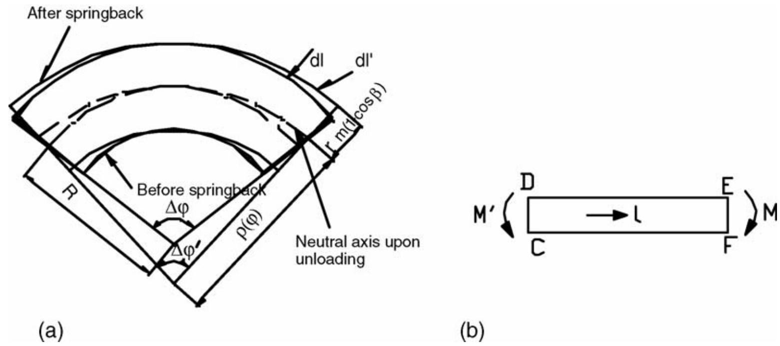

Fig. 3. Springback model of (a) bending portion and (b) straightway zone.