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Numerical Simulation of Tube Free Bending Process based on ABAQUS

Shaohua Zhang, Junwei Chen, Gongzheng Yang, Qian Liu

College of mechanical engineering, North China University of Water Resources and Electric Power, Zhengzhou 450045, China.

Abstract

In order to study the free bending forming process of tube, the basic principle of free bending is analyzed. The mechanical properties of the material are obtained by tensile test. The thickness reduction rate and ellipse ratio are selected as the evaluation indexes. The free bending finite element model of the tube is established by ABAQUS finite element software, and the three-dimensional free bending simulation of the tube is carried out. The simulation results show that the bending tube has good forming quality. In the subsequent work, the free bending forming experiment of the tube is carried out to verify the effectiveness of the simulation process parameters.

Keywords

Plastic Forming; Free Bending; Numerical Simulation.

1. Introduction

The three-dimensional free bending process of tube is a plastic forming process proposed by Japanese scientist Murata et al [1]. This process can continuously bend metal elbows with various radii and angles in a three-dimensional range. A large number of experts from Japan, Germany, etc. subsequently conducted extensive research on this, and developed a three-axis free bending forming system, a five-axis free bending forming system, a six-axis free bending forming system, and a parallel bending mechanism.

2. Principle of free bending forming of tubes

The schematic diagram of the three-dimensional free bending forming process is shown in Figure 1. The key components are composed of a propulsion mechanism, a guiding mechanism, a bending die, and a spherical bearing [2]. Before forming begins, the centers of key components are on the axis of the tube. During the forming process, the advancing mechanism is responsible for pushing the tube to move along the Z axis. On the one hand, the guiding mechanism supports the movement of the tube, and on the other hand restricts the degree of freedom of rotation of the bending die. The spherical bearing can move arbitrarily along the XY axis under the action of two motors. Under the action of the spherical bearing and the guiding mechanism, the bending die can realize the movement in the XY plane and the rotation around the guiding mechanism. Under the combined action of the bending die, the pushing mechanism and the guiding mechanism, the tube can be bent arbitrarily in three-dimensional directions.

When the tube is bent, it is subjected to the bending moment applied by the bending die and the propulsion mechanism [3]. The bending moment of the tube during the bending process is:

$$M = P_t U + P_q L \tag{1}$$

U is the eccentricity of the spherical bearing, L is the length of the bending deformation zone, the propelling force of the spherical bearing on the tube is Pq, and the propelling force of the propulsion

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mechanism on the tube is Pt. The greater the eccentricity, the smaller the length of the bending deformation zone and the smaller the bending limit radius of the tube.

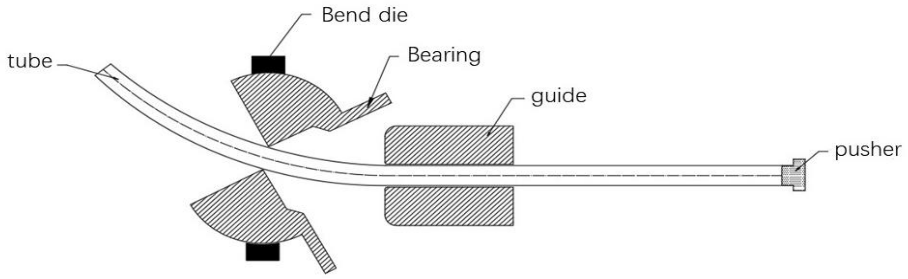

Fig. 1 Three dimensional free bending process diagram

3. Tube mechanical performance test

Before using the Abaqus software for simulation, first determine the mechanical properties of the material. In order to obtain more accurate material parameters, it is necessary to use a tensile testing machine to perform a tensile test on the tube to obtain the mechanical performance parameters of the tube[4]. In the tensile test, one end of the tube needs to be fixed, and the other end is stretched downward at a uniform speed at a stretching speed of 1mm/s. Perform three tensile tests to take the average value. Figure 2 shows the tensile sample of the tube. Table 1 shows the mechanical performance parameters of the tube[5].

Fig. 2 Tensile sample of tube

Table 1. Material parameters of TP2 Copper Tube

Material	Density (tonne/mm^3)	Elastic Modulus (GPa)	Yield Strength (Mpa)	tensile strength (Mpa)	Poisson's ratio
TP2 copper tube	$8.94*10^{-9}$	115	33.48	376.87	0.31

4. Free bending finite element model establishment

Based on the principle of three-dimensional free bending of tubes, firstly, solidworks software is used to draw a free-bending three-dimensional model, as shown in Figure 3, and ABAQUS finite element analysis software is used to perform finite element simulation on the free bending process of tubes. The spherical bearing, the guide mechanism, and the propulsion mechanism are arranged as discrete rigid bodies, the bending die and the tube are in direct contact, and both are arranged as deformable entities.

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When using Abaqus software for simulation, choose the Auaqus/Explicit solver for analysis. In order to speed up the calculation and make the simulation results more accurate [6], set the mass zoom factor 25, friction 0.1, and general contact. The tube is set as a shell, and the SR4 universal shell element is used to divide the mesh, the bending mold uses the C3D8R eight-node hexahedral element to divide the mesh, and the other rigid body models use the R3D4 mesh, as shown in Figure 3.

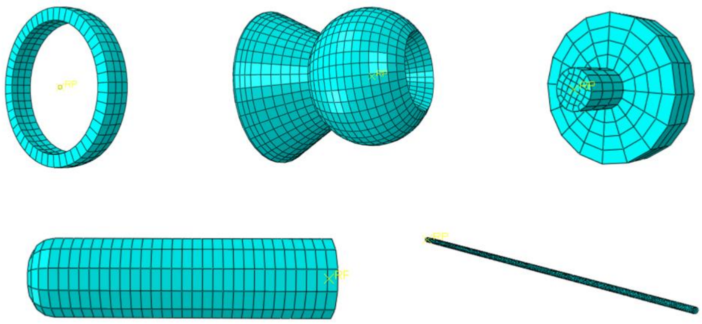

Fig. 3 Mesh generation of tube free bending

5. Simulation of three-dimensional bending of tubes

Based on the three-dimensional free bending component, the ABAQUS simulation software is used to simulate the three-dimensional free bending of the tube. Table 2 shows the three-dimensional bending parameters of the tube.

Table 2. Bending parameters of target tube

Curved plane	Length of straight section L_n/mm	Bending radius R//mm	Bending angle θ/°	Included angle of bending plane ψ/°
P1	100	135	110	90
P2	30	135	120	0
P3	30	135	130	270

It can be seen from Figure 4 that the stress and strain distribution of the formed tube is relatively uniform. With the increase of the bending section, the maximum stress of the tube gradually increases. The maximum wall thickness increase rate of the tube is 4.4%, the maximum wall thickness reduction rate is 2.5%, and the maximum ellipticity is 5.68%. The forming quality of the tube is good.

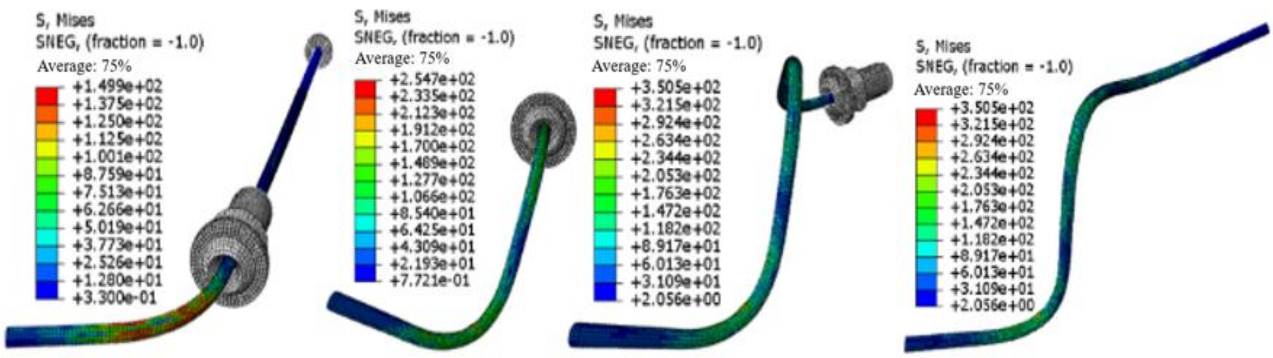

Fig. 4 Free bending process of target tube

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6. Conclusions

In this paper, TP2 copper tube with φ19mm and wall thickness of 1mm is selected as the research object, and the working principle of free bending of the tube is analyzed. The mechanical performance parameters of the tube are obtained through the tensile test. The wall thickness reduction rate and ellipticity are selected as the evaluation indexes of the tube forming quality. A finite element model was established and a three-dimensional bending simulation was performed. The analysis of the forming results shows that the maximum wall thickness reduction rate of the tube is 2.5%, the maximum ellipticity is 5.68%, and the tube forming quality is good. In the follow-up work, free tube bending and forming experiments will be conducted to verify the effectiveness of the simulation process parameters.

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