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Effect of geometrical parameters on forming quality of high-strength TA18 titanium alloy tube in numerical control bending

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Abstract: The forming quality of high-strength TA18 titanium alloy tube during numerical control bending in changing bending angle β, relative bending radius R/D and tube sizes such as diameter D and wall thickness t was clarified by finite element simulation. The results show that the distribution of wall thickness change ratio Δt and cross section deformation ratio ΔD are very similar under different β; the Δt and ΔD decrease with the increase of R/D, and to obtain the qualified bent tube, the R/D must be greater than 2.0; the wall thinning ratio Δt_o slightly increases with larger D and t, while the wall thickening ratio Δt_i and ΔD increase with the larger D and smaller t; the Δt_o and ΔD firstly decrease and then increase, while the Δt_i increases, for the same D/t with the increase of D and t.

Key words: high-strength TA18 tube; geometrical parameters; forming quality; finite element simulation; numerical control bending

1 Introduction

High-strength TA18 titanium alloy tube (HS-TA18 tube) has attracted increasing applications in hydraumatic, fuel tubing systems for advanced aircraft and spacecraft due to its advantages of high specific strength, excellent corrosion resistance and fatigue resistance, and good welding performance [1]. Among various tube bending methods such as stretch bending, roll bending, compress bending and push bending, the numerical control (NC) bending is the unique one to incrementally obtain the HS-TA18 bent tubes due to high precision, high efficiency, low consumption and automation advantages [2]. However, the NC bending is a complex physical process with multi-die constraints and multi-factor coupling, as shown in Fig. 1. During NC bending process, the unequal stress and strain distributions of the tube lead to wall thinning/thickening and cross section deformation. Many different tube sizes, bending angles and radii of bent tubes have been used in various fields for different requirements, and the wall thinning/thickening and cross section deformation vary with different tube sizes, bending angles and radii of bent tubes. Thus, in order to obtain the common knowledge of multi-index limited bending deformation behaviors of HS-TA18 tube under different bending angles/radii and tube sizes, it is necessary to study the laws of wall thinning/thickening and cross section deformation with geometrical parameters change.

In recent years, many scholars have studied the deformation behaviors of different kinds of tubular materials on various bending process by analytical, experimental and finite element (FE) simulation methods. While, most of them focus on a single bending defect for specific tube diameter and wall thickness. The bending deformation behaviors of different tube sizes considering multi-defects are less studied. In literatures [3−6], the analytical formulae to predict wall thickness variation and cross section distortion of circular tubes in bending process based on plastic deformation theory were derived. LIU et al [7] deduced an analytical formula of collapsing

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deformation of thin-walled rectangular tube during rotary draw bending process based on the theory of plate and shell. MENTELLA and STRANO [8] presented the relationship between geometrical parameters of tube and cross section distortion in rotary draw bending. The analytical models of thin-walled tube bending in terms of stress/strain distributions, wrinkling tendency, wall thinning degree and cross section distortion degree according to the geometrical characteristic of rotary draw bending and plastic deformation theory were deduced by LI et al [9]. Although the friction contact conditions cannot be considered in the theoretical model, it can built the intrinsic relationship between bending deformation behaviors and geometrical parameters of tube.

By FE and experimental analysis, FANG et al [10−13] established a three-dimensional (3D) elastic plastic FE model of 21-6-9 high-strength stainless steel tube in NC bending and revealed the effect laws of mandrel types/parameters, material parameters and friction conditions on wall thickness change and cross section distortion. The influences of the push assistant loading conditions on wall thickness change and cross section distortion of thin-walled aluminum alloy tube in NC bending were numerically studied by LI et al [14]. LĂZĂRESCU [15] numerically researched the effect of bending radius on wall thinning and cross section distortion for circular aluminum alloy tube in rotary draw bending. By experimental analysis, LI et al [16] found that the effects of process parameters on wall thinning and cross section deformation for large diameter thin-walled 5052O aluminum alloy tubes in NC bending were similar to those for small diameter thin-walled tubes. In Refs. [17,18], the effect laws of dies and process parameters on wall thickness distribution and cross section deformation of aluminum alloy 3A21 thin-walled rectangular tube in rotary draw bending were experimentally obtained. In terms of the annealing treatment TA18 titanium alloy tubes, ZHAN et al [19] numerically investigated the wall thickness change and cross section deformation under various operating parameters and mandrel parameters for the NC bending of medium-strength TA18 tubes, proposed quickly determining the range of mandrel extension length and obtained appropriate process parameters. By embedding the variation of contractile strain ratio with deformation into FE simulation for NC bending of high-strength TA18 tubes, the prediction accuracy for wall thinning, cross section deformation and springback angle was improved [20]. LI et al [21] addressed the springback behaviors under variations of material and process parameters of high-strength TA18 tube in cold rotary draw bending using the theoretical analysis, FE simulation and experiments, and proposed a two-level springback compensation methodology to achieve the precision bending.

In the previous researches, the influences of the process parameters or material parameters on bending deformation behaviors of the stainless steel, aluminum alloy and titanium alloy tubes were generally carried out. However, the study on the bending deformation behaviors of high-strength titanium alloy tubes with respect to wall thickness change and cross section deformation under different geometrical parameters have not been reported. Therefore, in this work, a 3D elastic plastic FE model of the HS-TA18 tube in NC bending is established under ABAQUS code. Then, the influence laws of geometrical parameters including bending angle β, relative bending radius R/D and tube sizes such as tube diameter D and wall thickness t on bending deformation behaviors are explored in terms of wall thickness change and cross section deformation. The results of this study can provide useful knowledge on bending deformation behaviors of tube NC bending under different geometrical parameters and help efficient design and optimization forming parameters for tube NC bending process.

2 Forming principle and indices for tube NC bending

Figure 1 shows the schematic diagram of the tube NC bending process. As shown in Fig. 1, the bending die, clamp die and pressure die are three basic bending dies which are applied to fulfilling tube bending. The tube is firstly clamped against the bending die by clamp die and pressure die; then the bending die and clamp die rotate simultaneously around the center, and the tube goes past the tangent point and rotates along the groove of bending die to gain the desired bending angle and bending radius; finally, the mandrel retracts, and the tube is unloaded. The wiper die and mandrel are needed to reduce the wrinkling risk and cross section deformation of tube for

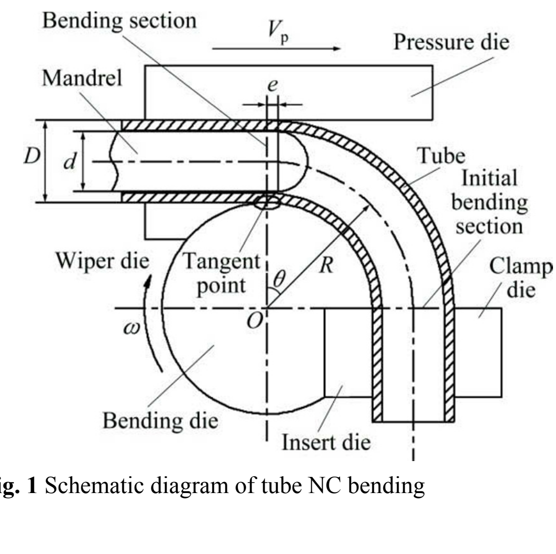

Fig. 1 Schematic diagram of tube NC bending