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Numerical and experimental study on in-plane bending of microchannel aluminum flat tube

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ABSTRACT

Microchannel aluminum flat tubes have attracted more and more attention in recent years, especially in ACR (air conditioning and refrigeration) industry. Rotary-draw bending is a versatile and precise method in forming of tubes. Compared with traditional out-of-plane bending method, in-plane bending can cause different forming defects. During the process, wall thinning, sectional distortion, wrinkling, and channel shape degradation are the main defects that affect tube quality in industrial applications. In this paper, an experimental apparatus for flat tube in-plane bending is manufactured, and experiments are performed to examine the forming quality of tubes. Considering the characteristics of the bending process, based on the LS-DYNA software environment, a 3D elastic–plastic finite element model is established and validated by experiment. Using the validated FE model, the forming quality of microchannel flat tube bending process is evaluated quantitatively. Furthermore, the influence mechanism of process parameters, such as bending radius, tool–tube clearance, and channel diameter, has been revealed. The results indicate that the degradation of the tube channels is relatively small under common process conditions; bending radius is the main factor which influences the forming quality of the flat tube; the tool–tube clearance mainly affects the wrinkling of the flat tubes; channel diameter has little effect on the formability of tube.

1. Introduction

Microchannel aluminum flat tubes have been widely used in cooling and heating systems, such as ACR (air condition/refrigeration) tube. The channel diameter of microchannel flat tubes presents a development trend of becoming tinier and tinier to acquire good heat exchange performance (Jiang et al., 2001). Fig. 1 shows a kind of microchannel flat tube with the channel diameter of 0.5 mm. Compared with other bending processes such as roll bending, compression bending, and stretch bending, rotary-draw bending is the most versatile method to produce bended tube parts. As shown in Fig. 2, unlike the traditional out-of-plane bending, in-plane bending of the microchannel tube is studied in this paper. Fig. 3 shows a scheme of the rotary-draw bending process for microchannel flat tube in-plane bending. During the bending process, the tube is subjected to die constraints, clamped against the bending die and drawn by the bending die and clamp die. The tube goes past the tangent point and rotates around the bending center with the desired bending radius. Inevitably, multiple forming defects such as wall thinning, sectional distortion, wrinkling, and channel shape degradation occur in the bending process. As ACR tubes work under large internal pressure, high quality bended tubes are needed. These defects could reduce the strength and shorten its service life. Defects of channel shape degradation even disturb the flow inside the tube.

To improve the forming quality of tube bending, much research has been reported on tube bending technology using experimental, analytical or numerical methods. Paulsen et al. (2001) proposed analytical model to predict the cross-sectional deformation of rectangular hollow section in bending. Noah and Syuji (2002) discover that splitting can be restrained by the use of a square tube with a center rib, and the working limits of aluminum square tubes in the rotary drawing bending can be improved. Yang et al. (2001) concentrated on the wall thinning to leave enough forming space for subsequent hydroforming. Yang and Lin (2004) analytically proposed a wrinkling prediction indicator to study the effects of geometrical dimensions and material parameters on the minimum bending radius before the wrinkling occurs. By embedding the wrinkling prediction indicator into the elastic–plastic explicit FE model, Li et al. (2006) further obtained the wrinkling limit bending radius. Lee et al. (2005) performed a parametric study of oval tubes without a mandrel by FE simulations. Wu et al. (2008) experimen-

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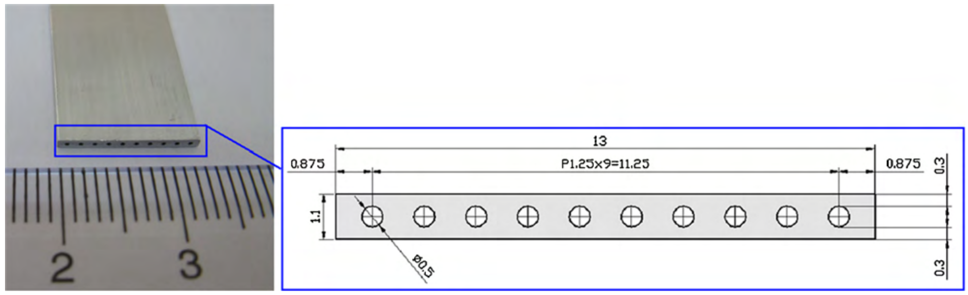

Fig. 1. Microchannel flat tube.

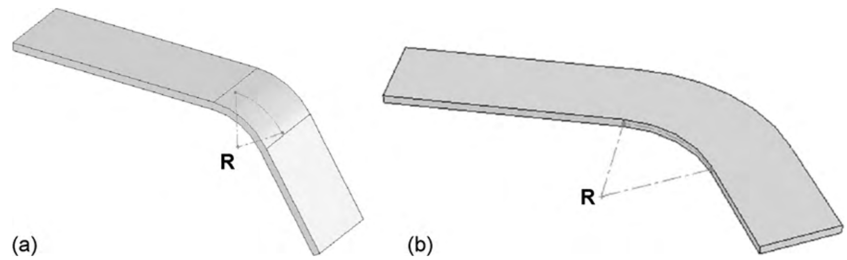

Fig. 2. Schematic diagram of bending modes: (a) out-of-plane bending; (b) in-plane bending.

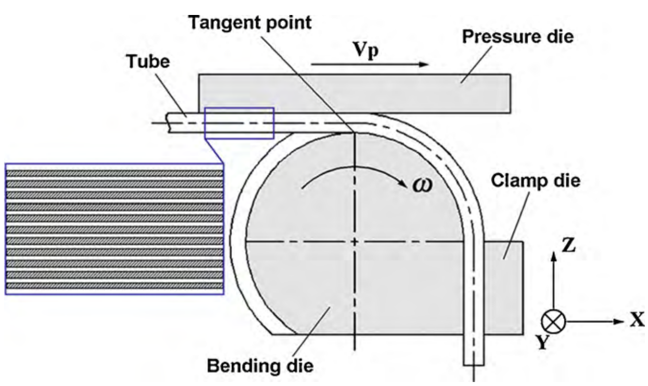

Fig. 3. Scheme of porous microchannel flat tube rotary-draw bending process.

tally studied the influences of temperature, bending velocity and original grain size on the bend-ability of magnesium alloy tubes. Tang et al. (2008) established a finite element model of circular copper tube bending to study the roles of surface booster system.

However, up to now, few studies have been reported to explore the deformation of microchannel flat tube bending process, especially in the mode of in-plane bending. Therefore, in this paper, aimed at investigating the deformation behaviors of the microchannel flat tube during the in-plane bending process, an experimental apparatus for flat tube in-plane bending is manufactured to conduct the bending experiment and examine the forming quality of the bended tubes. Meanwhile, a 3D elastic–plastic FE model is established and validated by experiment. Using the validated FE model, the forming quality of microchannel flat tube bending process is evaluated quantitively. Furthermore, the influence of process parameters, such as bending radius, tool–tube clearance, and channel diameter, is revealed.

2. Experimental method

Fig. 4(a) shows the sketch of the apparatus designed specially for microchannel flat tube bending. Unclosing the upper cover of experimental facility, the components of bending apparatus mainly include bending die, clamping die and pressure die. A hand lever is appended to drive the tools. According to the different width of flat tubes, the space between the clamp die and the straight-line part of bending die is designed for adjustment with a certain range.

Fig. 4(b) shows the actual bending experiment of the tube. The parameters of dies are set in terms of the dimensions of research object which is shown in Fig. 1: the length of clamp die is 60 mm; the

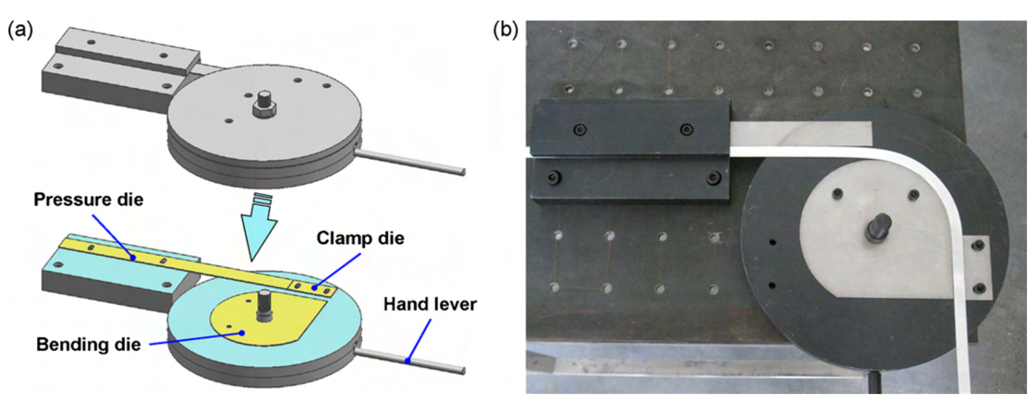

Fig. 4. Bending experiment: (a) sketch of bending apparatus; (b) actual bending experiment.