Wrinkling behavior of the ultra-thin components with variable cross-sectional perimeter during bending process with local support

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Abstract: The wrinkling behavior of the ultra-thin components during the tube bending process was investigated by finite element analysis and confirmed by experiment and the causes of various typical defects were explored. The tube was bent through three local support methods: without support, hard support, soft support. The results indicate that severe wrinkling behavior of pipes occur during bending process. However, in the case of soft support, the wrinkling behavior of the pipe is suppressed and flattened during the subsequent bulging process.

Introduction

The metallic bent tubular parts play an extremely important role in the automotive and aerospace fields [1]. However, when forming bent pipes, wrinkles are easily formed on the inner side of the bend due to the shortening of the axis. Meanwhile, due to the axis not being in a straight line, it is prone to generate oblique wrinkles.

Conventional fabrication methods of tube bending mainly consist of roll bending [2], stretch bending, push bending [3], and rotary draw-bending [4]. The ratio of diameter to thickness (D/t) of the pipes formed by these methods are generally less than 100, and it is difficult to form pipes with relatively large ratio of diameter to thickness. M. Murata et al. prepare the bent tube with D/t of 21.1 and studied the effect of hardening exponent n on the springback, thickness strain distributions and flatness ratio [5]. Based on the knowledge of wall thickness changes and cross-sectional flattening, the bending limit of 14mm × 1.35mm TA18M titanium alloy pipes under aviation standards was determined, and bending experiments were conducted on the pipe specimens. Hong-wu Song et al. presents a new push bending method with granular media filler for thin-walled tubes with small relative bending radius [6]. The results showed that the granule media aided push bending process can be a feasible choice for thin-walled (D 70 × t 0.7, mm) tubes, which is difficult to achieve with other traditional bending processes for the tubes of small relative wall thickness (≤ 0.015). Saharnaz Montazeri et al. proposes a new compression bending method with internal pressure and prepared the tube with R/D ratio of 1 and D/t ratio of 20 [7].

In recent years, tube hydroforming has attracted widespread attention due to its weight reduction, good structural stiffness, good performance, and highly accurate dimensions, especially reducing the number of welds and subsequent processing machining passes [8]. Therefore, forming bent tubular parts through the tube hydroforming process has become a feasible method. Wang et al. investigated the effect of internal pressure on the axial stress and hoop stress [9]. The results indicate that Internal pressure decreased the axial compressive stress and wrinkling tendency was weakened. But the hoop tensile stress in the outer side of bent arc became larger with the increase of the internal pressure. Besides, the double-layered tube hydro bending method is proposed to solve the difficulties encountered in manufacturing ultrathin-walled elbow tubes by traditional

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bending processes [10]. A bent tube with *D*/*t* ratio of 182 was prepared through this technology, and the wall thicknesses of the two layers decrease as the internal pressure increases.

However, wrinkle defect is one of the typical defects of the tube hydroforming process, which have been widely studied. Feng et al. studied the wrinkling behavior of overlapping tubular blanks during the hydroforming process [11]. Wrinkle defects can be effectively prevented by applying normal load, which is realized by covering a backing plate at the overlap of the outer layer. Liu et al. found that wrinkling is easy to occur in the middle of the side wall of the main tube within the thin-walled Tee-joint hydroforming process [12]. They also proposed that the critical wrinkling stress is proportional to the ratio of hoop stress to axial stress and material strength coefficients, but inversely proportional to work-hardening exponent and ratio of diameter to thickness when internal pressure is constant. T.F. Kong et al. minimize the wrinkling defects through the appropriate control of temperature distribution of the Mg alloy AZ31B tubular material in THF at evaluated temperatures [13]. The results showed that the most satisfactory component could be obtained when the average temperatures of axial-feeding and deformation regions were around 240 and 330°C, respectively.

Therefore, wrinkling behavior is the most important problem in the forming process of components, and researchers have done a lot of research to eliminate the occurrence of wrinkles. However, the wrinkling behavior of the ultra-thin components (D/t bigger than 500) during the tube bending process have not been deeply studied. In this paper, a novel method named Local Support Hydro-bending Process (LSHB) was proposed to restrain tube wrinkling during bending process. the wrinkling behavior of the LSHB was investigated by FE and confirmed by experiment and the causes of various typical defects were explored.

Materials and research methods

Material and Experiments. The GH3030 superalloy tube was used in the experiment. The tensile properties of GH3030 are shown in the Table 1. The working principle diagram of local support is shown in Fig. 1. During the bending process of pipes, the outer side of the bending is subjected to tensile stress, and the combined force points towards the inner side of the bending and acts on local supports, which gives the inner side of the bend an additional normal support force. The schematic diagram of bending process with soft support is shown in Fig. 2. It is mainly divided into four stages: placement stage, mold closing stage, liquid filling stage, and bulging stage. First, the soft support was put into the blank, and the position of the support was adjusted, and then put the blank into the mold, which is called the placement stage. When the upper mold goes down, the pipe contacts the mold and undergoes bending deformation due to the action of the mold. When the distance between the upper mold and lower mold is 0mm, the deformation completed, and it is called the mold closing stage. After the mold is closed, the support was taken out from the tube, the left and right punches were feed for sealing, and the tube was filled with liquid. This stage is the liquid filling stage. Finally, increase the pressure inside the pipe to reach p_2, so that the billet is formed by attaching to the mold, which is the bulging stage. For the tube bending process with hard support, the soft support should be replaced by hard support.

Table 1. Results of mechanical properties of the material.

Alloy	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
GH3030	335	1035	30.1

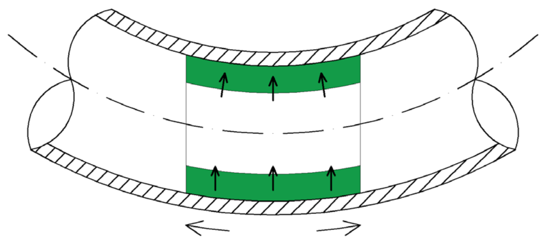

Fig. 1. Working principle diagram of local support.

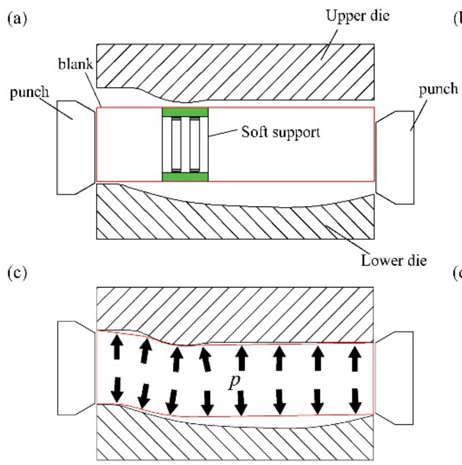

Fig. 2. The schematic diagram of bending process with soft support: (a) placement stage, (b) mold closing stage, (c) liquid filling stage, and (d) bulging stage.

Numerical modelling. In this study, Dynaform 5.9.4 was selected as the numerical simulation software to illustrate the wrinkling behavior of the material. The finite element models of three bending process were showed in Fig. 3. The dies are defined as rigid bodies, and the blank is defined as Belytschko-Tsay shell elements. The hard support is defined as 304 stainless steel, and the soft support is defined as polyurethane.

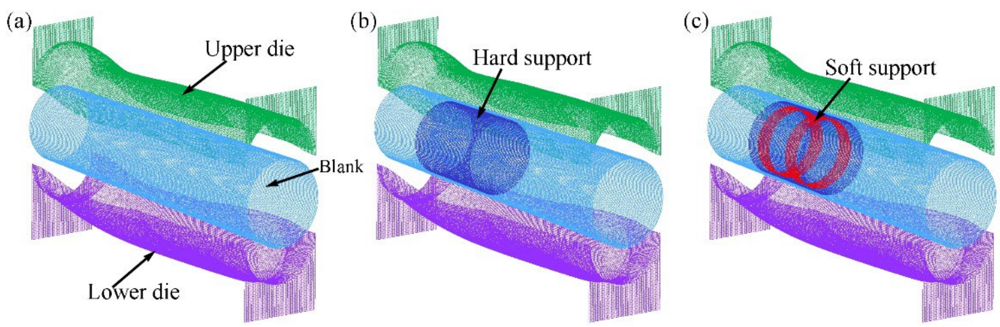

Fig. 3. Experimental setup of (a)the tube hydro-bending process, (b) Local Support Hydro-bending Process with hard support, (c) Local Support Hydro-bending Process with soft support.

Results and Discussion

Numerical simulation results. The numerical simulation results of three bending processes are analyzed, as shown in Fig. 4. It can be seen that when the tube bent without support, the wrinkles occur on the inner side and lateral side of the bending. This is mainly because the inner side is subjected to compressive stress due to the shortening of the axis, which easily generates compressive stress wrinkles. During the bending process, due to the force exerted by the upper and lower molds on the tube not being in a straight line, oblique wrinkles are formed at the lateral side of the tube. In addition, according to the cross-section at the bending of the tube, the length of cross-section at the upper half is 823.3 mm, and the length of cross-section at the lower half is

580.2 mm, which indicates that the length of the upper part is much greater than that of the lower part. Therefore, it is difficult to flatten the upper part during the bulging stage. This is another reason why the side edges of the tube wrinkle during the bending process. In order to suppress the appearance of oblique wrinkles at lateral side, local support is added to the bending process. As shown in Fig. 4, oblique wrinkles are significantly reduced due to the addition of local support. This is because due to the effect of the support, the cross-section distortion of the tube is less. The length of the upper and lower parts of the tube is similar, and there is no accumulation phenomenon in the upper part of the pipe, so it is easy to flatten during the bulging stage. However, for the hard support, the trend of transverse wrinkles on the inner side of the bend is increasing, as shown in Fig. 6(a). This is because during the bending process, the hard support cannot undergo bending deformation, resulting in stress concentration at the boundary attachment between the hard support and the tube.

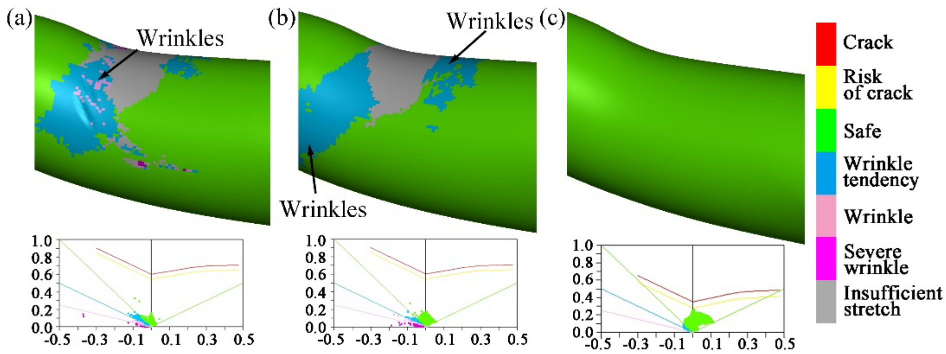

Fig. 4. Simulation results of (a)the tube hydro-bending process, (b) Local Support Hydro-bending Process with hard support, (c) Local Support Hydro-bending Process with soft support.

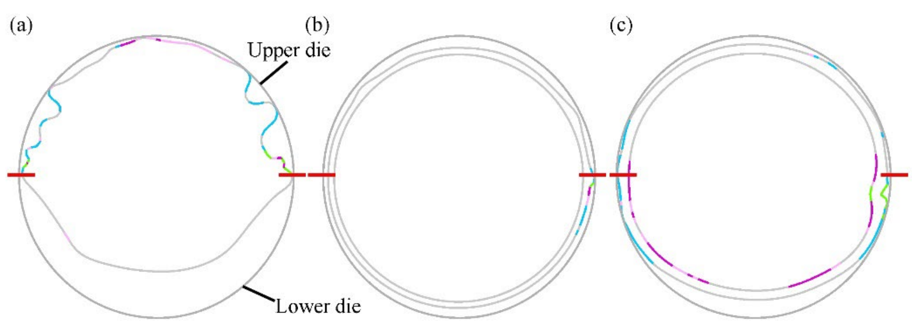

Fig. 5. The cross-section at the bending of the tube after mold close (a)the tube hydro-bending process, (b) Local Support Hydro-bending Process with hard support, (c) Local Support Hydro-bending Process with soft support.

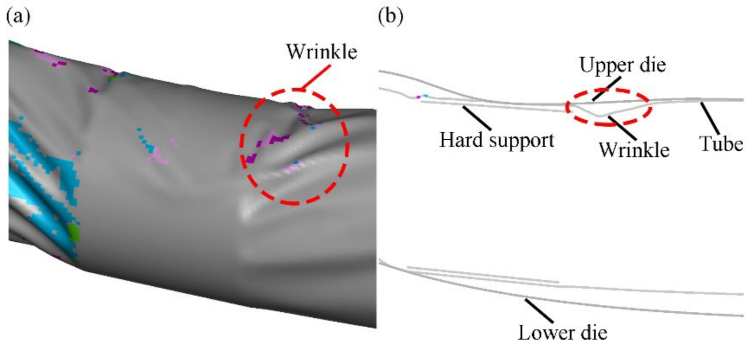

Fig. 6. (a) Simulation result of Local Support Hydro-bending Process with hard support after mold closing, (b) the axial section.

Experimental results. The experimental results are shown in Figs. 7-9. We can see that the experimental results are consistent with the simulation results. The oblique wrinkles are formed at the lateral side of the tube during the tube hydro-bending process. The transverse wrinkles generate on the inner side of the bend, as shown in figure 8. However, for the Local Support Hydro-bending Process with soft support, the workpiece with good surface quality are obtained. This indicates that soft support can effectively avoid oblique wrinkles on the side of the tube and transverse wrinkles on the inner side of the tube during the bending process.

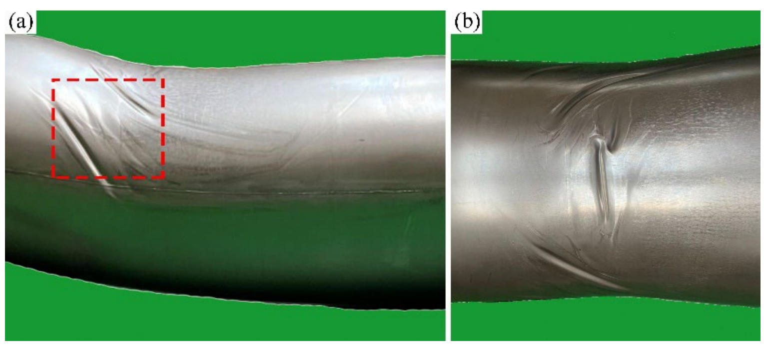

Fig. 7. Experimental piece of the tube hydro-bending process.

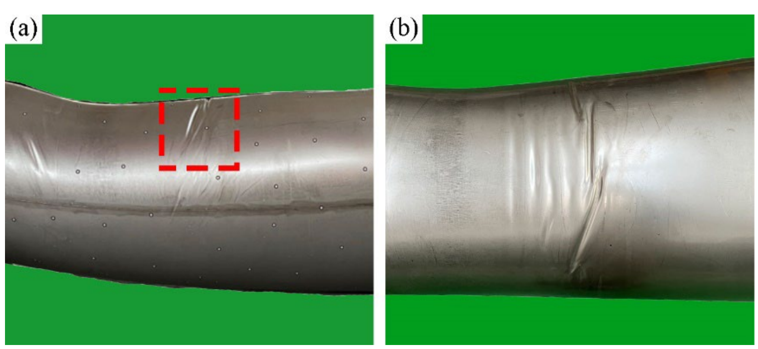

Fig. 8. Experimental piece of Local Support Hydro-bending Process with hard support.

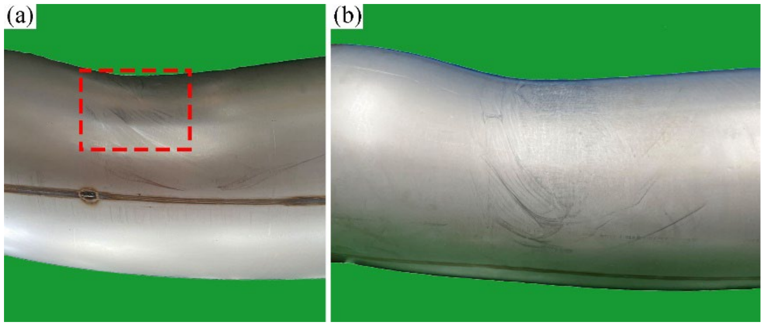

Fig. 9. Experimental piece of Local Support Hydro-bending Process with soft support.

Conclusions

This work investigated the wrinkling behavior of the ultra-thin components during the tube bending process and were confirmed by bending experiment. Besides, different support methods were added to bending process: hard support and soft support. The main conclusions could be summarized as follows:

(1) There are two typical wrinkle defects appearing on the part during the tube bending process: transverse wrinkles and oblique wrinkles. The transverse wrinkles are mainly caused by compressive stress. While, the oblique wrinkles are mainly due to shear stress.

(2) The soft support can effectively avoid oblique wrinkles on the side of the tube and transverse wrinkles on the inner side of the tube during the bending process.

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