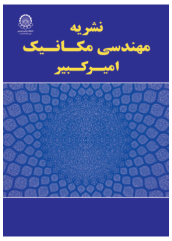

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 50(3) (2018) 149-152
DOI: 10.22060/mej.2016.11547.5116

An Analytical Model and Numerical Simulations to Predict Process Parameters in the Tube Bending Under Internal Fluid Pressure

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ABSTRACT: Nowadays, thin-walled tube bending at small bending ratios (equal to *R/D*, *R*: bending radios, *D*: tubes outer diameter) is a production process widely used in advanced industries. Despite extensive studies into the field of rotary draw bending area, few of them have implemented this process with internal fluid, and they have not reported the exact location of bend defects and the effects of bending ratio on the defects of Hydro-rotary draw bending either. This research has been carried out to obtain the smallest bending ratio, and maximum applicable internal pressure in Hydro-rotary draw bending of thin-walled AA6063 alloy tube using analytical model. In addition, some effective parameters in Hydro-rotary draw bending are simulated with ABAQUS-software. Maximum thinning and critical ovality regions were investigated in addition to the effects of bending ratio and internal fluid pressure on the distribution of thickness and ovality, using simulation, analytical and experimental tests. The results showed that the selected necking criterion would be able to successfully determine the onset of rupture in bending. In order to validate FE-simulation, the effects of bending ratio and internal pressure on defects, such as cross-section ovality and thickness changing have also been investigated through simulation in ABAQUS-software and experiments.

Review History:

Received: 15 April 2016
Revised: 13 November 2016
Accepted: 28 December 2016
Available Online: 28 December 2016

Keywords:

Feasibility tube bending
Process parameters prediction
Internal fluid pressure
Analytical model
Numerical simulation

1- Introduction

Rotary draw bending is a common production process in a variety of industries, including automotive, aerospace, oil, agriculture, furniture, and decoration. This method can reduce the cost of production due to decreasing wastes. Among other advantages of this method, quality, accuracy, high repeatability, automation and mass production can be noteworthy. Rotary draw tube bending provides a close control of metal flow necessary for small radius and thin walled tube [1-7].

Due to the importance of bending in different industries, it has been widely studied numerically, analytically, and experimentally. Lazarescu [8] studied the effect of internal fluid pressure on the quality of AA 1050-O aluminum alloy tube in Hydro-rotary draw bending, at bending ratio of 2.5 and wall factor (D/t) of 16.5. In that study, bending was performed with a manual mechanism. In the experimental tests, pressure die was not capable of moving. It was shown that by increasing internal pressure, ovality and thickening of the intrados would decrease while thinning at the extrados would increase.

Yang and Jeon [9] studied the relationship between cross-sectional deformation and curvature of the tube analytically. In their research, plastic deformation in bending region and elastic deformation in the pressure die area were considered as two main factors in springback occurrence.

Despite extensive studies into the field of rotary draw bending area, few of them have implemented this process with internal fluid, and they have not reported the exact location of bend defects and the effects of bending ratio on the defects of Hydro-rotary draw bending either. This study seems to be the pioneer in using an analytical model to obtain the minimum achievable bending ratio and maximum pressure applied to each of the bending ratios. Maximum thinning and critical ovality regions were investigated in addition to the effects of bending ratio and internal fluid pressure on the distribution of thickness and ovality, using simulation and experimental tests.

2- Experimental Setup

To carry out the experiments, Shuztung 50BR3, a numerical computer control bending machine was used. In all of the experiments, the speeds of the bend die and pressure die were 3.6 rad/min and 2.4 mm/s, respectively, in a way that the relative speed of them would reach zero to avoid sliding between the tube and pressure die, since, as mentioned in the introduction, one of the tasks of the pressure die is pushing the tube to the bending area and preventing it from over-thinning, which can be very helpful when the bending angle is large and the bending radius is small. Not selecting the speed of pressure die correctly would cause defects in bending. Accordingly, a speed higher than the rotational speed of the bending die would result in wrinkling in the intrados due to not using the wiper die in this study and overfeeding of the material to the bending area.

Tube nut, connector, plug and progressive ring were used in order to seal the ends of the tube. In the experimental tests, a hydraulic power supply unit which only could exert constant pressure was used.

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3- Results and Discussion

The pieces formed under internal pressures of 1.5 MPa, 2 MPa, 2.5 MPa, 2.8 MPa, 3.3 MPa, and 3.7 MPa, and at the ratio of *R/D* 1.8 are shown in Fig.1.

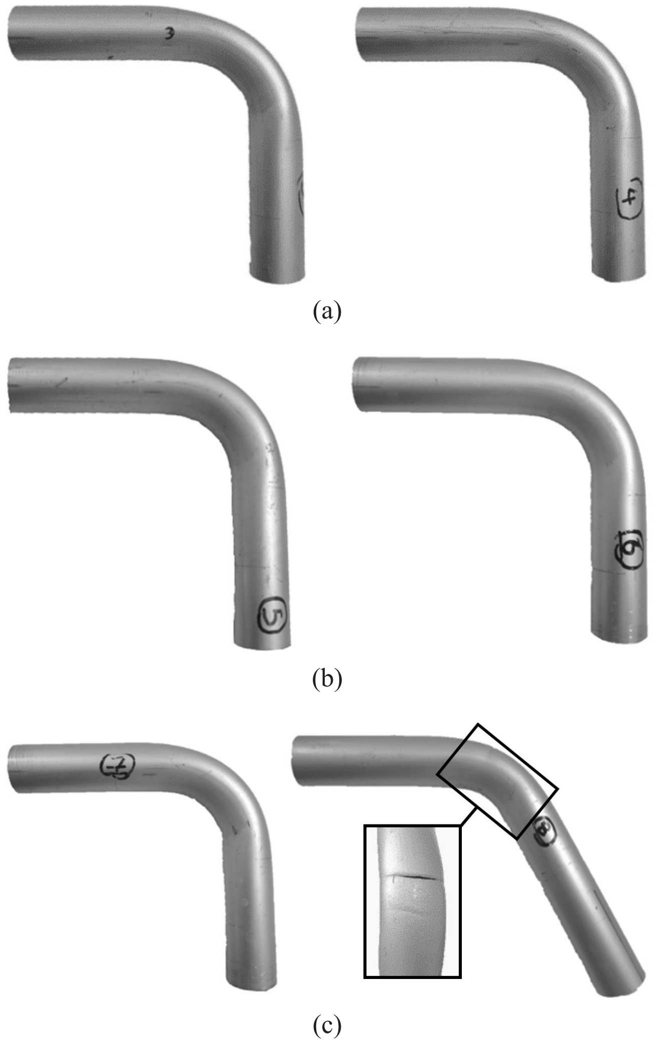

Fig. 1. Bent tubes at different pressures, (a) 1.5 MPa, (b) 2 MPa, (c) 2.5 MPa, (d) 2.8 MPa, (e) 3.3 MPa, (f) 3.7 MPa

Fig.2 shows the internal pressure effects on the thickness distribution. In this figure, maximum thinning and maximum thickening at internal pressures are shown. As can be seen, when pressure increases, thickening decreases but thinning increases. Moreover, thinning increases more sharply than thickening due to the lack of the contact with the dies. Therefore, as mentioned before, the internal pressure could have greater effects on thinning (compared to thickening). At higher pressures due to lower ovality and flattening, more thinning would occur because, without the internal fluid pressure, the tube wall at the extrados would move inward to escape the stress during bending process which in turn would increase ovality and flattening. By applying fluid pressure, the possibility of the extrados moving inward was less than before and less flattening happened, and as a result, became thinner inevitably due to the stress. The tube wall when bending at *R/D* 1.8 and the internal pressure of 3.7 MPa showed the highest thinning, was 18.38 %. Also, there is a good correlation between the trend of analytical,

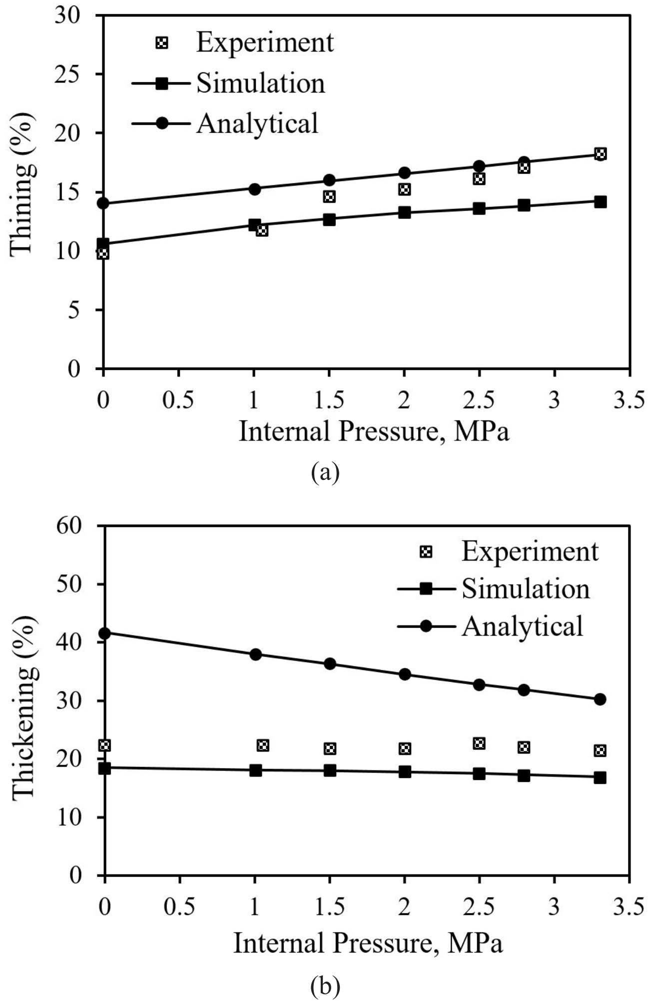

Fig. 2. The effect of internal pressure on, (a) thinning in extrados, (b) thickening in intrados

experimental and simulation results.

4- Conclusions

Based on the investigation, the following results can be stated:

1. The thickening at the intrados fell when the internal pressure increased and the thinning at the extrados also rose. The rise was sharper than fall due to the lack of contact between the extrados and the dies. Therefore, the internal pressure had a greater effect on thinning (compared to thickening).
2. In Hydro-rotary draw bending process, by increasing the bending ratio, tube wall thickness at all regions went closer to the initial thickness of the tube. In other words, the circumferential thickness of the tube became more uniform.
3. There is a good correlation between the trend of analytical, experimental and simulation results.

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Please cite this article using:

J. Soleimani, M. Elyasi, M. Hosseinzadeh, An Analytical Model and Numerical Simulations to Predict Process Parameters in the Tube Bending Under Internal Fluid Pressure, *Amirkabir J. Mech. Eng.*, 50(3) (2018) 447-466.

DOI: 10.22060/mej.2016.11547.5116