Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(3) (2018) 1-2
DOI:

Experimental Study and Finite Element Simulation for Determining the Forming Window of 6063-O Aluminum Tube in Warm Hydroforming Process

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ABSTRACT: In recent years, aluminum and magnesium alloys have attracted attention due to higher strength to weight ratio, compared with steels. The main limitation of these alloys is the low formability at room temperature. However, researchers have shown that the formability of aluminum alloys increases at high temperatures. In this study, the formability of 6063 annealed aluminum tube has been investigated in warm tube hydroforming process. The effects of pressure and axial feed on the thickness distribution, bursting pressure and the respecting bulge height at different temperatures have been studied experimentally and numerically. In order to numerically predict the onset of fracture, three criteria, namely equivalent plastic strain acceleration (second derivative), major strain acceleration, and thickness strain acceleration were used. Moreover, a geometrical method was adopted in the simulation to determine the wrinkling. By comparing the results, there was an acceptable accordance between experimental and simulation results. It has been shown that as the temperature rises, the bursting pressure decreases and the bulge height increases. In addition, increasing axial feed, enhanced the bulge height. Finally, by using experimental tests and finite element simulation, the process windows of the aluminum alloy tube were obtained at the temperature of 25 °C and 250 °C.

Review History:

Received:
Revised:
Accepted:
Available Online:

Keywords:

Tube hydroforming
Warm hydroforming
Formability
Aluminum alloy
Forming window

1. Introduction

In recent years, the warm tube hydroforming process has attracted attention due to the possibility of producing complex parts in one step, reducing costs and increasing the rigidity of the product due to removal of the assembly joints. The use of warm tube hydroforming, in addition to reducing the energy required for the formation of complex components, requires smaller and cheaper equipment because of the reduced strength of material at higher temperatures than the room temperature [1]. Hence, in recent years, extensive research has been carried out on the tube hydroforming process at elevated temperatures [2]. In order to produce a uniform thickness distribution in a tube, Liu et al [3] used a die with non-uniform temperature distribution in order to reduce the friction coefficient at the feeding site. They performed coupled thermomechanical simulation to investigate the effect of axial feed on thickness distribution. By numerical and experimental investigation of thickness distribution of 1050 aluminum alloy tubes in the warm hydroforming process, Hashemi et al. [2] showed that by increasing temperature, better thickness distribution is obtained in the free bulge process compared to constrained bulge.

In the present study, the effect of temperature and axial feed on the formability of the 6063-O aluminum alloy tubes in the warm hydroforming process has been investigated. At last, the process windows at different temperatures were determined.

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2. Methodology

2.1 Experiments

Bulge experiment was used for conducting the tube formability tests at warm conditions. The assembled die components is indicated in Fig. 1. The die set consists of two punches and dies. The warm tube forming procedure is somehow that after positioning of the tube inside the die, the tube is sealed with the punches from the two ends in order to prevent leakage after the flowing of oil inside the tube through the channel located in the upper punch and to increase the internal pressure. To warm the fluid, tube and die, a 560 W cartridge element is used.

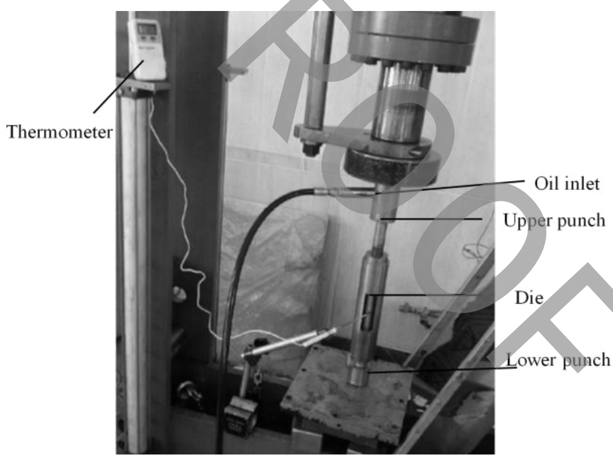

Fig. 1. Die set components mounted on the testing machine

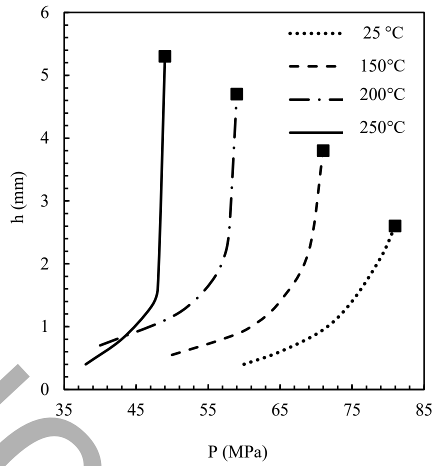

Fig. 2. Simultaneous effects of pressure and temperature on bulge height in free bulge, obtained from simulation

2.2. Finite element simulation

Abaqus 10-6 software has been used to develop the Finite Element (FE) simulations. Due to the symmetry of die set, one-half of the axial symmetry was modeled. The tube and die set were modeled as deformable shell to account for heat condition. Since the die set should not be deformed, rigid constraint were applied to them.

3. Results and Discussion

3.1. Free bulge

The effect of temperature and pressure on the bulge height is shown in Fig. 2. It can be seen that by elevating the forming temperature, the bulge height increases, although the less pressure is required. In addition, increasing the forming pressure leads to higher bulge height.

3.2. Process window

To indicate the effect of different loading paths on the forming of the tube, two process windows were acquired at the temperatures of 25 °C and 250 °C shown in Figs. 3 and 4, respectively. To verify the rupture areas of the two forming windows, experiments were carried out (room temperature, pressure of 8.71 MPa, axial feed of 8 mm and temperature of

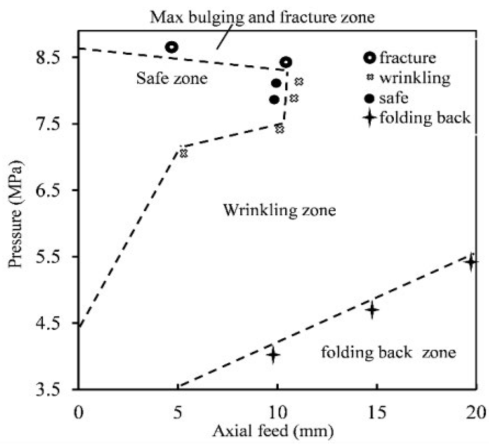

Fig. 3. Process window for 6063-O aluminum alloy at room temperature

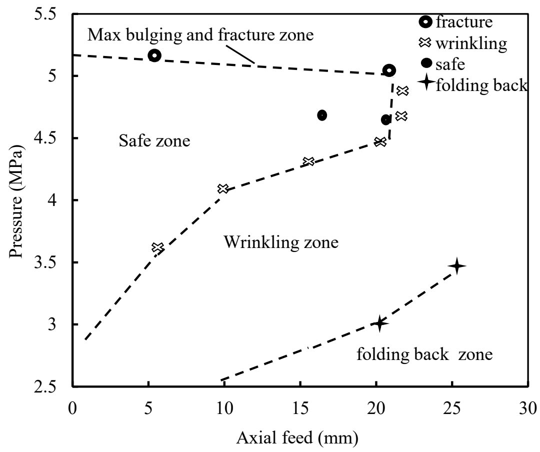

Fig. 4. Process window for 6063-O aluminum alloy at the temperature of 250 °C

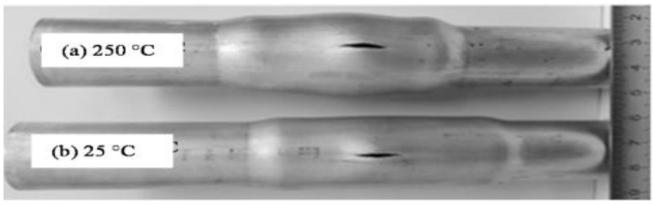

Fig. 5. The hydrobulged tubes obtained at (a) room temperature, pressure of 8.17 MPa, axial feed of 8 mm and (b) temperature of 250 °C, pressure of 5.1 MPa, axial feed of 20 mm

250 °C, pressure of 5.1 MPa, axial feed of 20 mm) that have been shown in Fig. 5.

4. Conclusions

In order to conduct experiments, a warm tube hydrobulging die was designed and constructed. The forming windows were obtained at 25°C and 250 °C and the following results were achieved:

- ✓ The pressure range in the safe zone is almost twice at room temperature compared with 250 °C, but the axial feed is approximately half.
- ✓ The formability of the part was increased with increasing temperature, so that the height of the bulge in the free bulge experiment increased from 2.6 mm at room temperature to 5.2 mm at 250 °C.

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