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Formability and microstructure of AA6061 Al alloy tube for hot metal gas forming at elevated temperature

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Abstract: Free bulging test was carried out at different temperatures ranging from 350 °C to 500 °C to evaluate the formability of AA6061 extruded tube, which can provide technology foundation for complex structures forming in hot metal gas forming (HMGF) process. Maximum expansion ratio (MER) and bursting pressure were obtained to evaluate directly the formability at heated conditions. Vickers hardness at different positions was measured. The fracture surface after bursting was observed with scanning electron microscope (SEM), and the microstructure change along axial and hoop directions was analyzed by electron backscattering diffraction (EBSD). The results show that the largest MER value is 86% at 425 °C. Bursting pressure decreases from 4.4 MPa to 1.5 MPa with temperature increasing. The Vickers hardness of fracture position is a little higher than other positions after gas bulging. The fracture mechanism is still the micro-pore aggregation fracture at elevated temperature, while overheated structure appears seriously at 500 °C. The initial fine equiaxial grain grows as temperature increases, which is elongated simultaneously in both axial and hoop directions.

Key words: aluminum alloy tube; free bulging test; hot metal gas forming; formability; microstructure; fracture morphology; grain morphology

1 Introduction

Weight reduction has become one of the research focuses in the field of materials processing, which can be realized by optimized structural design and usage of light materials [1]. Part with irregular cross-sections is manufactured by using light material and optimized structure, which has obtained more and more applications in automotive and aircraft industries [2,3]. Integrated design concept included in light-weight structure leads to the increase of shape complexity. Such parts, especially those with variable cross-sections, are formed exceptionally by internal high pressure forming [4]. However, poor formability of aluminum alloy at room temperature restricts seriously its wide application. One reasonable solution is to form such materials at elevated temperature, because their formability increases obviously with improving forming temperature. Warm hydro-forming using thermal conductive oil has been one promising method to manufacture complex-shaped parts [5−7]. Unfortunately, it was found that warm hydroforming is quite limited, because the heat resistant temperature of available oil is just about 300 °C [7,8].

Nowadays, hyperbaric gas has now become the ideal pressure medium for forming at higher temperature. Hot metal gas forming (HMGF) has been proposed based on superplastic forming and hot blow forming technique [9]. The feasibility for mass productions in automotive industry has been investigated. Without end feeding, about 150% expansion for aluminum alloy tube and 50% expansion for steel tube were achieved when formed at 480 °C and 1100 °C, respectively.

Formability of several engineering metal tubes has been tested in HMGF process [10]. The microstructures of AZ31 magnesium alloy tube before and after deformation have been investigated by EBSD, with special attention on the anisotropic characteristic of extruded tubes [11−13]. The deformation behavior and formability of aluminum alloy tube at room temperature

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has also been investigated [14,15]. However, there are few results concerning the formability and microstructure change of aluminum alloy tube in HMGF process.

In this work, experimental set-up for tube gas forming at elevated temperature is developed first. Free bulging test is carried out at different temperatures to evaluate the formability of AA6061 extruded tube. The hardness and microstructure change before and after the test are also analyzed. The reasonable temperature range for HMGF of the tested tube is given based on the results.

2 Experimental

2.1 Experimental setup

The tube bulging test was carried out in the platform developed by Engineering Research Center of Hydroforming in Harbin Institute of Technology (ERCH/HIT), as shown in Fig. 1. The tube was placed in the dies and sealed by punches. The upper and lower dies were heated by resistance heating, which act as heat maintainers to heat indirectly the tube, and temperature fluctuation can be controlled effectively. At the same time, the tested tube can be heated directly by induction heating at the position where the deformation is needed. The temperature was controlled by PID regulator with the temperature control accuracy of ±1.0 °C. When the tube was heated to a target temperature, high pressure gas was introduced into the tube until bursting happened. The available highest testing temperature of the experimental set-up is 600 °C, with gas pressure up to 35 MPa.

Fig. 1 Experimental setup for hot metal gas forming

2.2 Experimental procedure

In order to investigate the effect of temperature on formability and microstructure in HMGF process, free bulging test at different temperatures ranging from 350 °C to 500 °C has been conducted. The tested material was extruded tube of AA6061 Al alloy in annealed condition, with 27.8 mm in external diameter and 1.8 mm in thickness. The length of free bulging zone is two times of external diameter of the tube.

After each test, maximum expansion ratio and bursting pressure were obtained to evaluate directly the tube formability at elevated temperatures. Vickers hardness ($HV_{0.1}$) at different positions was measured, with dwell time of 15 s. The measuring position is given in Fig. 2(a). The fracture surface after bursting was observed with scanning electron microscope (SEM), and microstructure change along axial and hoop directions was analyzed by electron backscattering diffraction (EBSD). Figure 2(b) shows the analyzing position of microstructure. The specimen needed to be prepared by electropolishing working at −20 °C within 15 s, with electrolytic solution containing 90% C_2H_5OH and 10% $HClO_4$.

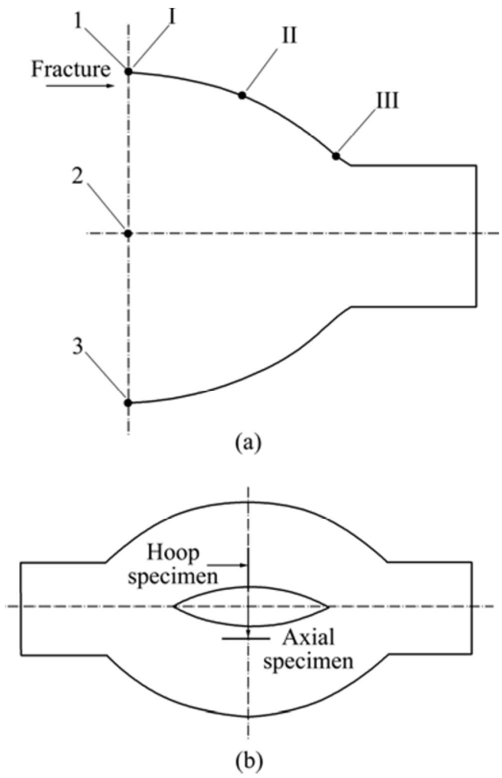

Fig. 2 Positions for hardness (a) and microstructure (b) analysis

3 Results and discussion

Figure 3 shows the tested tube workpieces obtained at different temperatures. Results and discussion are given as follows.

3.1 Bursting pressure

Effect of temperature on deformation resistance can be perceived on the basis of bursting pressure. Figure 4 gives the bursting pressure at different temperatures. It is clear to see that bursting pressure decreases quickly as