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Effect of Temperature and Heating Rate on Mechanical Properties of Aluminium Alloy 6061

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The effects of temperature and heating rate on the mechanical properties of the tensile specimens of aluminium alloy 6061 were experimentally investigated using a Gleeble-1500 thermal-mechanical material testing system. It showed that the higher the temperature is, the lower the ultimate strength of the specimens will be. The larger the heating rate is, the lower the ultimate strength of the specimens will be. The higher the temperature is, the smaller the shrinkage ψ ratio ψ of the specimens will be. The larger the heating rate is, the larger the shrinkage ratio ψ will be. The metallurgraphs of the fracture section of these specimens were also experimentally observed and analyzed for exploring the failure mechanism of the specimens under different temperatures and heating rates. It showed that the high temperatures and large heating rates will induce microvoids in the specimens, which make the specimens failure under relative low loads.

Keywords: *Aluminium alloy 6061; temperature; heating rate; strength; plasticity*

1. Introduction

Due to the lightweight and convenience to take shape and to be reclaimed, aluminium alloy materials are desirable for lightweight components for the automotive industry [1-3]. For example, aluminium alloy materials are currently being considered for automotive applications such as engine blocks and cylinder heads. In order to more availably and widely utilize aluminium alloy materials in modern industry, it is important to investigate the mechanical properties of aluminium alloy materials under some special surroundings. For instance, though many aluminium alloy materials are used at moderate temperatures, but some aluminium alloy materials will be used in high-temperature or high-temperature-history occasions [4-6]. In these special applied occasions, it has been found that the high temperature or high-temperature history will remarkably affect the mechanical properties of aluminium alloy materials because of the deposition of highly concentrated energy (DHCE)[4, 5]. It is why in recent years an important research field is to investigate the mechanical behaviors of the aluminium alloy materials subjected high temperature or high-temperature history. In this work, the mechanical behaviors of the tensile specimens of aluminium alloy 6061 under different temperatures and heating rates were investigated with a Gleeble 1500 thermal-mechanical material testing system. The metallurgraphs of the fracture section of the specimens were experimentally observed for exploring the failure mechanism of the specimens subjected different temperatures and heating rates.

2. Experimental methods

The material in this experiment is aluminium alloy material 6061, which was selected due to its steadiness in mechanical property and extensive application in civil and industrial structures. Firstly, the aluminium alloy material was machined to cylindrical tensile specimens, the geometric dimensions of which are showed in Fig. 1. Then the tensile tests of these specimens were performed under different temperatures and heating rates with a Gleeble-1500 thermal-mechanical material testing system[7-10]. In this experiment, these specimens were heated by applying a direct electrical voltage drop to the two ends of the specimens[9, 10]. The temperature within the testing section of the specimens was measured with a chromel-alumel thermocouple welded directly on the surface of the testing section and controlled with a computer, and all the data in the experiment were recorded synchronously with the data acquisition element of the testing system[9-11]. The procedure of the experiment is: (1) A set of testing temperatures 100℃, 200℃ and 300℃ were prescribed, and then the specimens are heated at three different heating rates v=100, 200 and 300℃/s up to the prescribed testing temperatures; (2) Keeping the testing temperatures 2s for ensuring the temperature to be equal in all parts of the specimens; (3) Stretching the specimens under 0.01/s strain rate until they fracture; (4) Recording the ultimate strength σ_b and the shrinkage ratio ψ of the cross section of these fractured specimens.

In order to investigate the failure mechanism of the specimens subjected different temperatures and heating rates, the metallurgraph of the fracture section of the specimens were also observed and analyzed. The samples used for the metallographic observation were cut from the vicinity of the fracture section, eroded in a mixed 2.5%HNO3, 1.5%HCl and 1%HF solution for 10-20s, and then cleaned for the observation[9, 10]

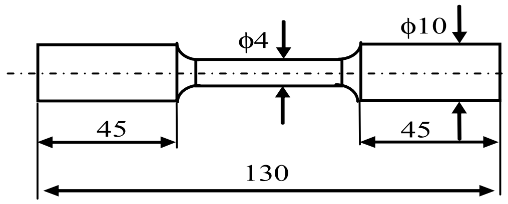
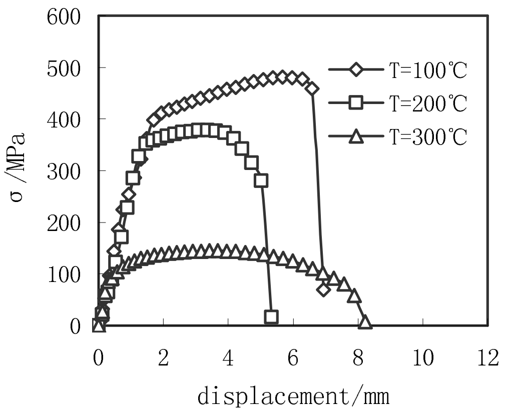


Fig.1 Draft of specimen (mm)

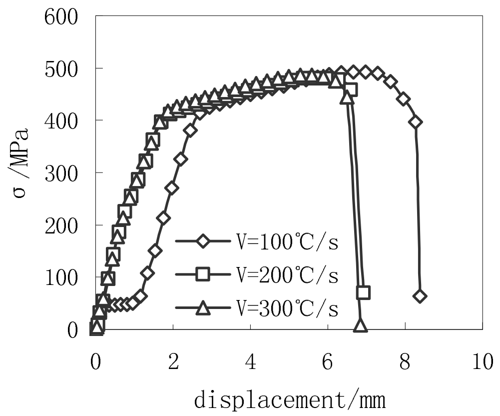
3. Results and discussions

Fig. 2(a) shows the obtained stress-displacement curve of the specimens which are heated to three different prescribed testing temperatures 100, 200 and 300℃ with same heating-rate 200℃/s. It can be seen from Fig. 2(a) that the specimens pass three different regions during their tensile course: elastic, strain hardening and necking ones, and that the ultimate strength of the specimens remarkably decreases with the increase of the testing temperature, which implies that the load-bearing capability of the material will be reduced when the temperature increases. Fig. 2(b)-(d) show the stress-displacement curves of the specimens which are heated to the three different prescribed testing temperatures, 100, 200 and 300℃ with three different heating-rates, v=100, 200 and 300℃/s, respectively. It can be seen from Fig. 2(b)-(d) that the heating rate also affects the stress-displacement relationships though the effect is indistinct relative to the effect of the temperature. It can be seen from Fig. 2(b)-(d) that the larger the heating rate is, the lower the ultimate strength of the specimeturns will be. Fig. 3 (a) and (b) show the relationship between the shrinkage ratio ψ of the cross section of the specimens and the testing temperatures as well as the heating rates. It can be seen from Fig. 3 (a) and (b) that the higher the testing temperature is, the smaller the shrinkage ratio ψ will be. The larger the heating-rate, the larger the shrinkage ratio ψ will be.

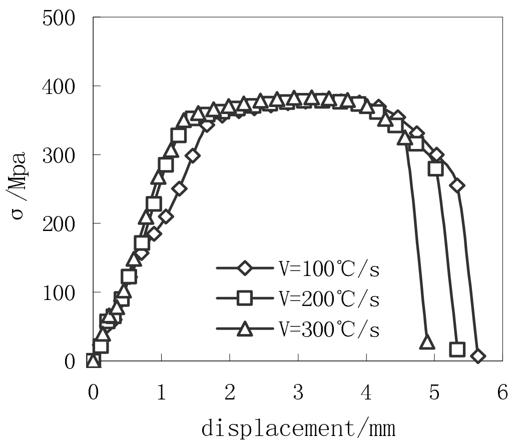
Fig.4(a)-(i) show the metallographs of the fracture section of the specimens which experienced different temperatures and heating rates. It can be observed from Fig.4 (a)-(i) that there are different-size microvoids in the specimens subjected the different temperatures and heating rates, which make the specimens possess different mechanical properties. For example, it is found that there are relative smaller microvoids in the specimens subjected relative lower temperature 100℃ (Fig. 4(a)-(c)), which makes the specimens possess relative higher strength. It is also found that there are relative larger microvoids in the specimens subjected relative high temperature 200℃ (Fig. 4(g)-(i)), which makes the specimens possess relative lower strength. Furthermore, it can be observed from Fig. 4(a)-(i) that under identical temperature the larger the heating rate is, the larger the microvoids are, which make the specimens possess relative lower strength.



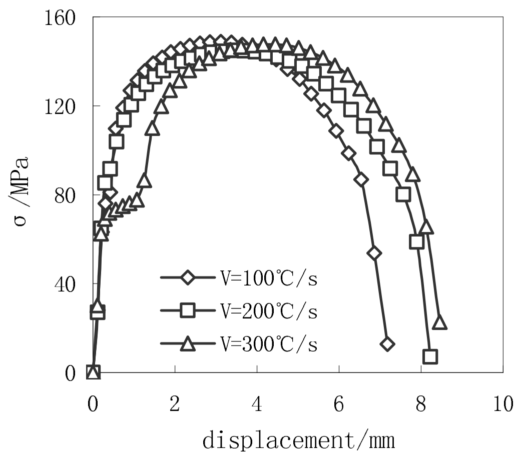
(a) v=200℃/s



(b) T=100℃



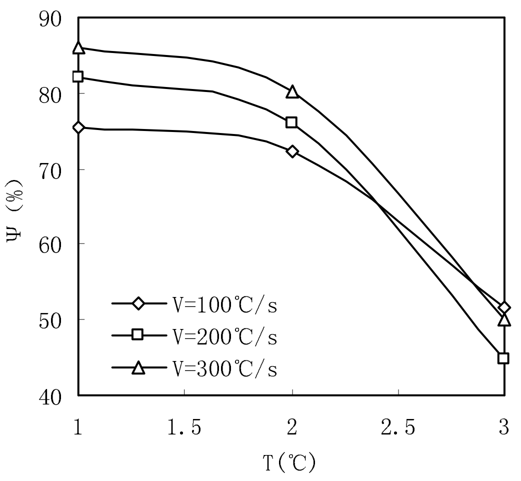
(c) T=300℃



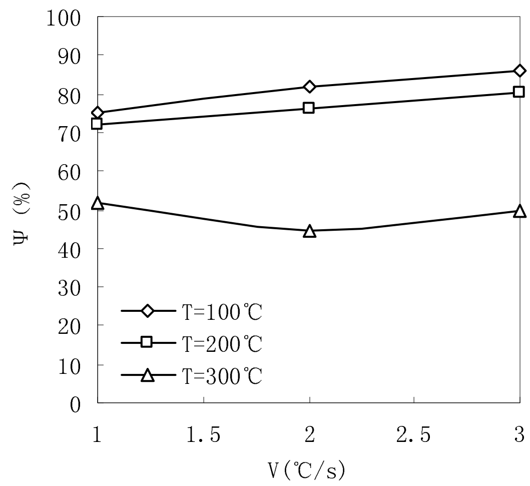
(d) T=400℃

Stress vs. displacement under identical heating rate v=200℃/s and different temperatures (a);
Stress vs. displacement under different heating rates and identical temperatures: (b) 100℃, (c) 300℃; (d) 400℃

Fig. 2 Stress-displacement curves under different temperatures and heating rates



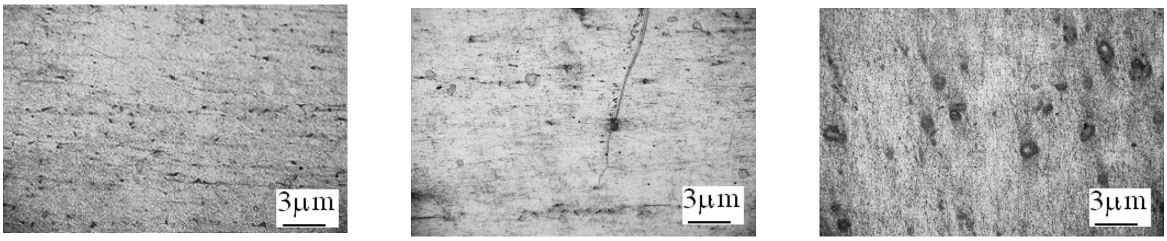
(a)



(b)

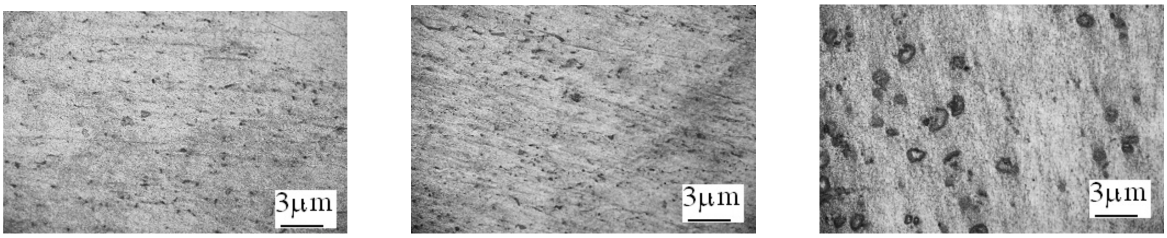
Shrinkage ratio ψ of cross section vs. temperatures (a) and heating rates (b)

Fig. 3 Shrinkage ratio ψ of cross section under different temperatures and heating rates



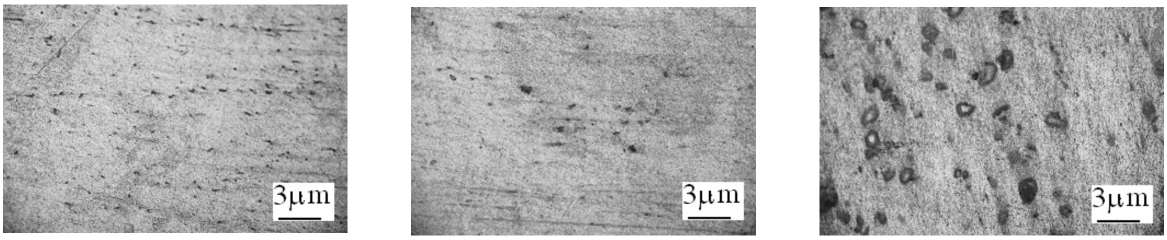
(a) (b) (c)

Temperature: 100℃ and different heating rates: (a) 100℃/s; (b) 200°C/s; (c)300℃/s



(d) (e) (f)

Temperature: 200℃ and different heating rates: (d) 100℃/s; (e) 200℃/s; (f)300℃/s



(g) (h) (i)

Temperature: 300℃ and different heating rates: (g) 100℃/s; (h) 200℃/s; (i)300℃/s

Fig. 4 Metallurgraphs of specimens

4. Conclusions

The tensile tests of the specimens of the aluminium alloy 6061 under different temperatures and heating rates were conducted. The microstructures of the fracture sections of these specimens were observed. From the results of the mechanical and the observational experiments following conclusions were obtained. The higher the temperature is, the lower the ultimate strength of the specimens will be, and the smaller the shrinkage of the specimens will be. The larger the heating rate is, the lower the strength of the specimen will be, and the larger the shrinkage of the specimens will be. The high temperatures and high heating rates will induce microvoids in the specimens. The microvoids will reduce the strength and plasticity of the specimens.

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