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Effect of temperature and heating rate on mechanical properties of magnesium alloy AZ31

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Abstract: Effects of temperature and heating rate on the mechanical properties of the tensile specimens of magnesium alloy AZ31 were experimentally investigated using a Gleeble-1500 thermo-mechanical material testing system. The metallurgraphs of the fracture section of the specimens were also experimentally observed and analyzed for exploring their failure mechanism under different temperatures and heating rates. The results show that the higher the temperature, the lower the ultimate strength of the specimens. And the higher the heating rate, the higher the ultimate strength of the specimens. The high temperatures and high heating rates will induce microvoids in the specimens which make the specimens failure under relatively low loads.

Key words: AZ31 magnesium alloy; temperature; heating rate; strength; plasticity

1 Introduction

Due to the low density and convenience to take shape and to be recycled, magnesium alloy is desirable for low density components in the automotive industry[1−3]. For example, magnesium alloy is currently considered for automotive applications such as engine blocks and cylinder heads. In order to widely utilize the material, it is important to investigate the mechanical properties of the material under some special surroundings. For instance, though many magnesium alloy materials are used at moderate temperatures, some magnesium alloys will be used in high-temperature or high-temperature-history occasions[3−5]. In these special applied occasions of the material, it is found that the high temperature or high-temperature history will remarkably affect the mechanical properties of the material because of the deposition of highly concentrated energy (DHCE)[6]. It is the reason why an important research field is to explore the mechanical behaviors of the material subjected to high temperature or high-temperature history in recent years. WANG et al[7] researched the flow stress and the hot-compressing deformation of AZ91 magnesium alloy and proposed a constitutive relationship describing this kind hot-compressing deformation. LIN et al[8] developed an anodizing process for AZ31 magnesium alloy and explored the mechanical properties of the material under this kind of process. In this work, in order to investigate the effect of the temperature and heating rate on the mechanical behaviors of the magnesium alloy AZ31 specimens, a series of the tension tests of the specimens at different temperatures and heating rates were performed with a Gleeble-1500 thermo-mechanical material testing system. The microstructures of the tensile-fractured specimens were experimentally observed and used to illuminate the failure mechanism of the material. The investigation results of combining macroscopic and microscopic experiments availably reveal the failure mechanism of the material under high temperatures and high heating rates.

2 Experimental

Firstly, magnesium alloy AZ31 was machined to cylindrical tensile specimens, and the geometric dimensions are shown in Fig.1. The tensile tests of these

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specimens were performed under different temperatures and heating rates with Gleeble-1500 thermo-mechanical material testing system[9−11]. In the experiments, these specimens were heated by applying a direct electrical voltage drop to the two ends of these specimens[12−13]. The temperature within the testing section of these 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[13−14]. The procedures of the experiment are as follows: 1) A set of testing temperatures of 200, 300 and 400 ˚C were prescribed, and the specimens were heated at three different heating rates of 300, 600 and 900 ˚C/s up to the prescribed testing temperatures; 2) Keeping at the testing temperatures for 1 s to ensure the temperature to be equal in all parts of the specimens; 3) Stretching the specimens under 0.01 /s strain rate until they fracture; and 4) Recording the ultimate strength σ_b and the shrinkage ratio ψ of the cross section of these fractured specimens.

In order to make clear the failure mechanism of the specimens under different temperatures and heating rates, the metallograph of the fracture section of the specimens was 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% HNO_3, 1.5% HCl and 1% HF solution for 10−20 s, and then cleaned for observation.

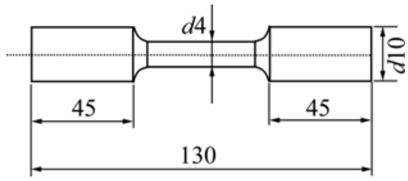

Fig.1 Draft of specimen (Unit: mm)

3 Results and discussion

Fig.2(a) shows the obtained load—displacement curves of the specimens which are heated to three different prescribed testing temperatures of 200, 300 and 400 ˚C with the same heating-rate of 600 ˚C/s. It can be seen from Fig.2(a) that the specimens pass three different

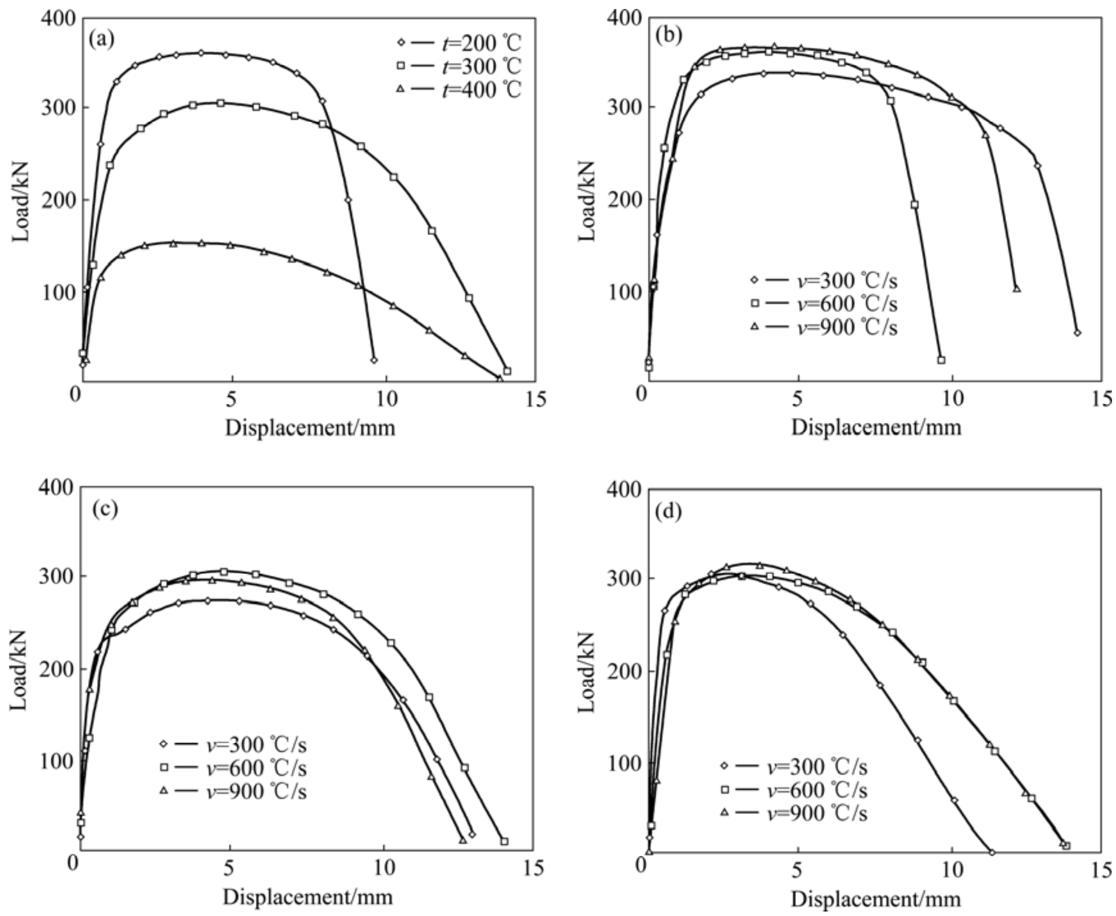

Fig.2 Load—displacement curves under different temperatures and heating rates: (a) v=600 ˚C/s; (b) t=200 ˚C; (c) t=300 ˚C; (d) t=400 ˚C

regions during their tensile course: elastic, strain hardening and necking. 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 testing temperature increases. Figs.2(b)−(d) show the load—displacement curves of the specimens heated to the three different prescribed testing temperatures of 200, 300 and 400 ˚C with three different heating-rates of 200, 300 and 600 ˚C/s, respectively. It can be seen from Figs.2(b)−(d) that the heating rate also affects the load—displacement relationships though the effect is indistinct relative to that of the temperature. It can be seen from Fig.2 that the higher the heating rate is, the higher the ultimate strength of the specimens will be. Figs.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 Figs.3(a) and (b) that the higher the testing temperature, the larger the shrinkage ratio ψ. And the higher the heating-rate, the smaller the shrinkage ratio ψ, which implies that the higher the temperature, the larger the plasticity of the material. The higher the heating-rate, the smaller the plasticity.

Figs.4(a)−(i) show the metallographs of the fracture section of the specimens which experience different temperatures and heating rates. It can be observed from Figs.4(a)−(i) that there are different-size microvoids in

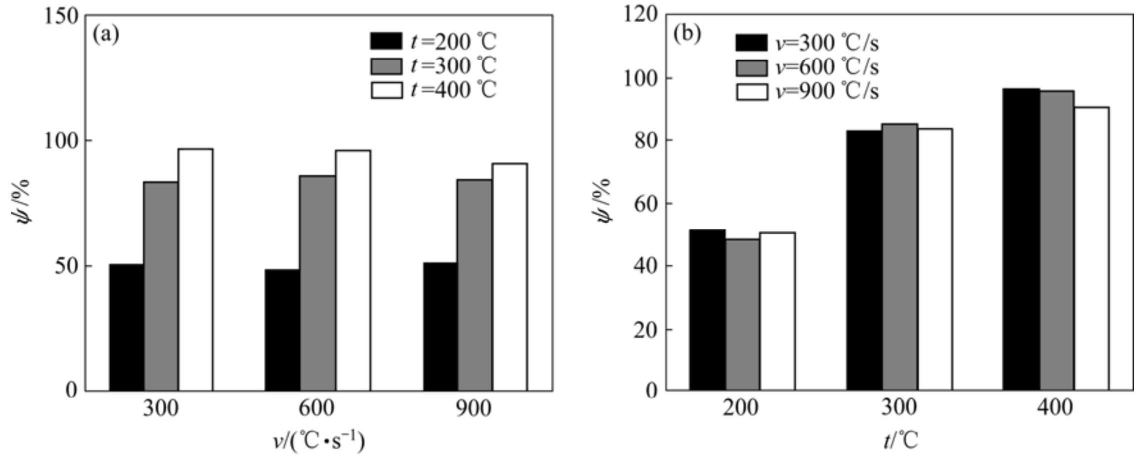

Fig.3 Shrinkage ratio ψ of cross section under different temperatures(a) and heating rates(b)

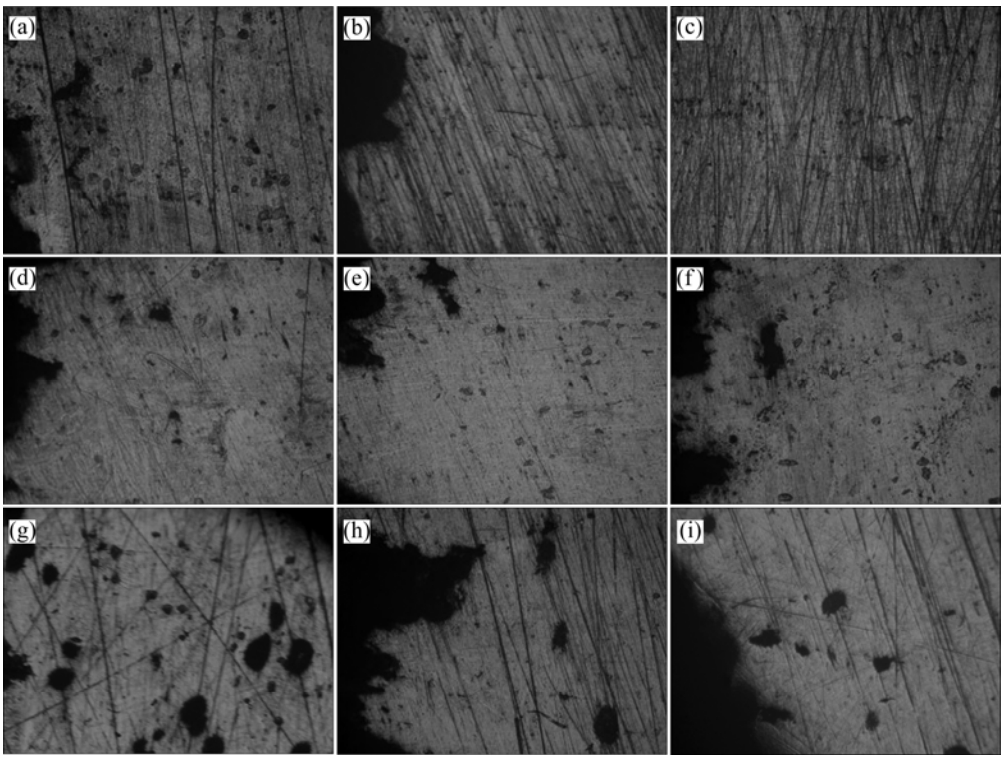

Fig.4 Metallurgraphs of specimens: (a) 200 ˚C, 300 ˚C/s; (b) 200 ˚C, 600 ˚C/s; (c) 200 ˚C, 900 ˚C/s; (d) 300 ˚C, 300 ˚C/s; (e) 300 ˚C, 600 ˚C/s; (f) 300 ˚C, 900 ˚C/s; (g) 400 ˚C, 300 ˚C/s; (h) 400 ˚C, 600 ˚C/s; (i) 400 ˚C, 900 ˚C/s

the specimens subjected to the different temperatures and heating rates, which makes the specimens possess different mechanical properties. For example, it is found that there are relatively small microvoids in the specimens subjected to relatively low temperature of 200 ˚C (Figs.4(a)−(c)), which makes the specimens possess relatively high strength. It is also found that there are relatively larg microvoids in the specimens subjected to relatively high temperature of 400 ˚C (Figs.4(g)−(i)), which makes the specimens possess relatively low strength. Furthermore, under identical temperature, the higher the heating rate, the smaller the microvoids, which makes the specimens possess relatively high strength. The microvoids are relatively small in the specimen subjected to a relatively high heating rate. The reason is that the voids in the specimen subjected to a relatively high heating-rate do not fully grow during a relatively short time.

4 Conclusions

1) The higher the temperature, the lower the ultimate strength of the specimens.

2) The higher the temperature, the larger the plasticity of the specimens.

3) The higher the heating rate, the higher the strength of the specimen.

4) The high temperatures and high heating rates will induce microvoids in the specimens. The microvoids will reduce the strength of the specimens.

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