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Effect of heating-rate on failure temperature of pre-loaded brass H62

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Abstract: The response and failure of brass H62 specimens subjected to different levels of pre-loaded stresses and heating rates were investigated using a Gleeble-1500 thermal-mechanical material testing system. The metallographs of the tested material were also observed and analyzed. It is found that the increase of either pre-loaded stress or heating-rate decreases the failure temperature. Metallographic analysis shows that high heating-rate may cause stronger local thermal inconsistency (LTI) and remarkably increase the microdefects in the material, which may markedly degrade the macroscopic mechanical properties of the material.

Key words: brass H62; pre-loaded stress; heating rate; failure temperature; local thermal inconsistency

1 Introduction

It is known that the high and rapid increasing temperature may result in a remarkable change of the microstructures of materials[1−2]. The microstructural change may change the mechanical properties of materials. The study on the changes of the microstructures and the mechanical properties of materials at high and rapid increasing temperature may help to avoid material failure at high and rapid increasing temperature and provide available information for making use of fast-heating technology[3−4].

The failure of materials and structures caused by the high and rapid increasing temperature is receiving increasing attention[5−6]. LIU et al[7] investigated the nonlinear softening of aluminum alloy subjected to fast heating. It was found that the difference in heating-rate history may cause differences in both the grain size and the macroscopic mechanical properties of the material, which was accounted for the dynamics of recrystallization. WANG et al[8] conducted a set of tensile tests of low-alloy steel 30CrMnSi subjected to fast heating histories with different heating-rates. The test results showed distinct differences in both the rupture strength and the metallograph of the material. PENG et al[9] investigated the effect of heating-rate on the mechanical properties of aluminum alloy LY12 and indicated that the material experiencing higher heating-rate histories possessed lower rupture strength and that the pre-stressed material failed at lower temperature, which was attributed to the increase of microdefects due to the strong local thermal inconsistency at high heating-rate.

In this study, a systematic experiment was conducted with a Gleeble-1500 thermal-mechanical material testing system to investigate the effect of heating-rate on the failure temperature of pre-loaded brass H62 specimens. The metallographs of the tested materials were observed and analyzed to investigate the mechanisms of the effect of the heating-rate.

2 Experimental

A Gleeble-1500 thermal-mechanical material testing system was used to investigate the effect of heating-rate on the failure temperature of pre-loaded brass H62 specimens. In the experiment, the specimens were heated with direct current by applying an electrical voltage directly between the two ends of a specimen. The experimental temperature and its rate were measured with a chromel-alumel thermocouple welded directly on the surface of the working section and controlled by a computer. The tensile traction and the temperature were recorded synchronously with the data acquisition element of the testing system, respectively. The geometry of the specimen is shown in Fig.1. To investigate the effect of heating-rate on the failure temperature of pre-

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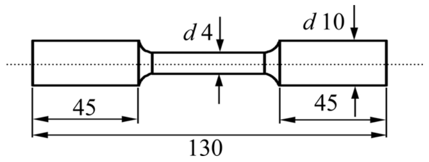

Fig.1 Draft of specimen (mm)

loaded brass H62 specimens, two levels of pre-loaded stresses, 110 and 150 MPa, were prescribed, for each of which three different heating-rates, 200, 600 and 1 000 ℃/s, were assigned. A specimen was preloaded to a prescribed stress level before heated with one of the three prescribed heating-rates. It could be imagined that, with increasing temperature, the specimen might gradually lose the capability of bearing the prescribed pre-loaded stress due to the softening of the material at elevated temperature. The failure temperature can, therefore, be defined as the temperature at which the prescribed pre-loaded stress can no longer be held, which indicates that the specimen has lost the load-bearing capability to the prescribed pre-loaded stress at this temperature.

In order to make clear the mechanisms of the effect of heating-rate on the mechanical properties of pre-loaded brass H62, the metallographs of the deformed material were observed and analyzed. The samples used for the metallographic observation were cut from the vicinity of the fracture section of tested specimens, eroded in a mixed 2.5%HNO_3, 1.5%HCl and 1%HF solution for 10−20 s, and then cleaned for observation.

3 Results and discussion

Figs.2 (a) and (b) show the measured relationships between temperature and time, and stress and temperature of the specimens subjected to the pre-loaded stress of 110 MPa and heated with three different heating-rates of 200, 600 and 1 000 ℃/s, respectively. It can be seen from Fig.2(a) that the temperature increases almost linearly at different heating-rates, which shows that the heating-rates are reliably given and controlled. It can be found from Fig.2(b) that the prescribed pre-loaded stress of σ=110 MPa almost maintains until some failure temperature is reached, then it falls rapidly. It can be observed that the failure temperature of the pre-loaded material reduces with the increase of heating rates (Fig.2(b)). Figs.3(a) and (b) show the measured relationships between temperature and time, and stress and temperature of the specimens subjected to the pre-loaded stress of 150 MPa and heated with three different heating-rates, 200, 600 and 1 000 ℃/s. It can be seen from Fig.3(a) that the temperature also increases almost linearly at different heating-rates. It can be found from Fig.3(b) that the prescribed pre-loaded stress of σ=150 MPa also maintains until some failure temperature is reached. It can be observed that the failure temperature of the pre-loaded material also reduces with the increase of heating rates (Fig.3(b)). Fig.4(a) shows the variation of failure temperature against pre-loaded stress, taking heating-rate as a parameter. It can be seen that, for a fixed heating-rate, the failure temperature of the pre-loaded material reduces with the increase of pre-loaded stress, due to the softening of material at elevated temperature. The variation of failure temperature against heating-rate at different pre-loaded stresses is shown in Fig.4(b). Remarkable reduction in failure temperature can be observed with the increase of heating-rate, which implies that heating-rate may play a significant role in the failure of the pre-loaded material.

Figs.5(a)−(c) show the metallographs of the specimens subjected to pre-loaded stresses of σ=110 MPa and heating-rates of 200, 600 and 1 000 ℃/s, respectively. It can be seen from Fig.5 that the fewer microvoids are observed at lower heating-rate, and the microvoids develop in both density and size with the

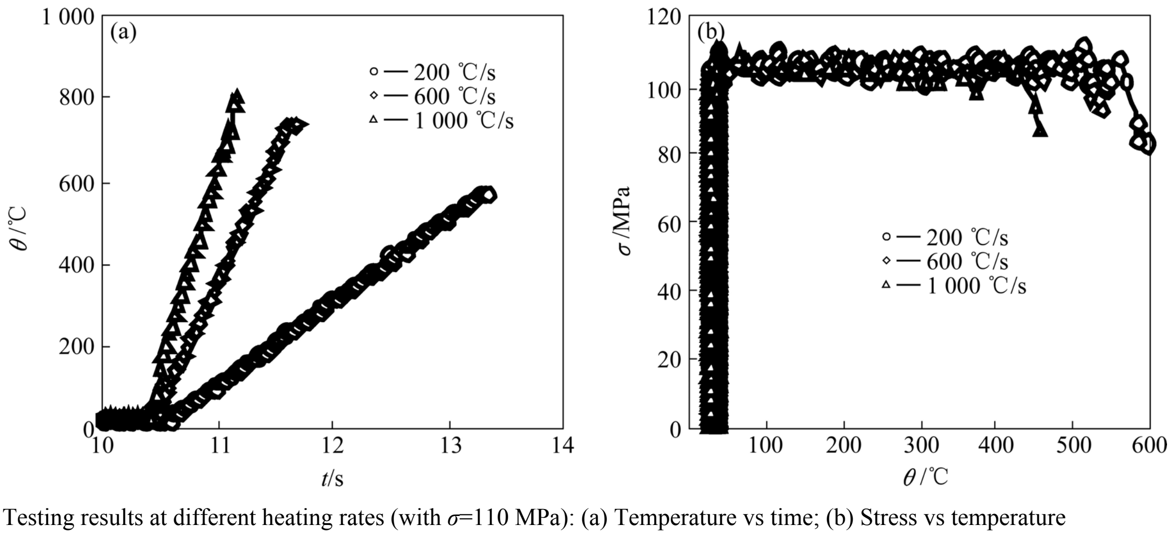

Fig.2 Testing results at different heating rates (with σ=110 MPa): (a) Temperature vs time; (b) Stress vs temperature

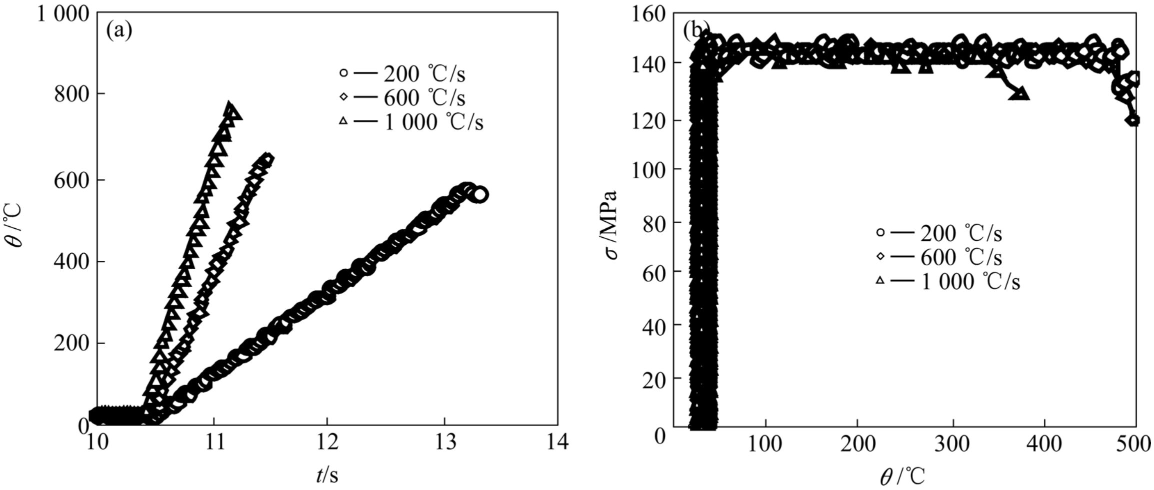

Fig.3 Testing results at different heating rates (with σ=150 MPa): (a) Temperature vs time; (b) Stress vs temperature

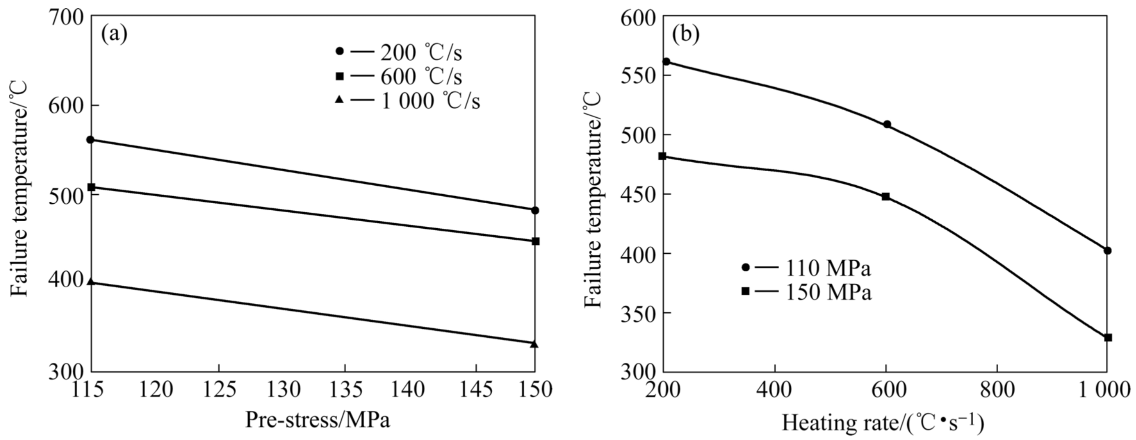

Fig.4 Failure temperature at different pre-stresses and heating-rates: (a) Failure temperature vs pre-stress; (b) Failure temperature vs heating rates

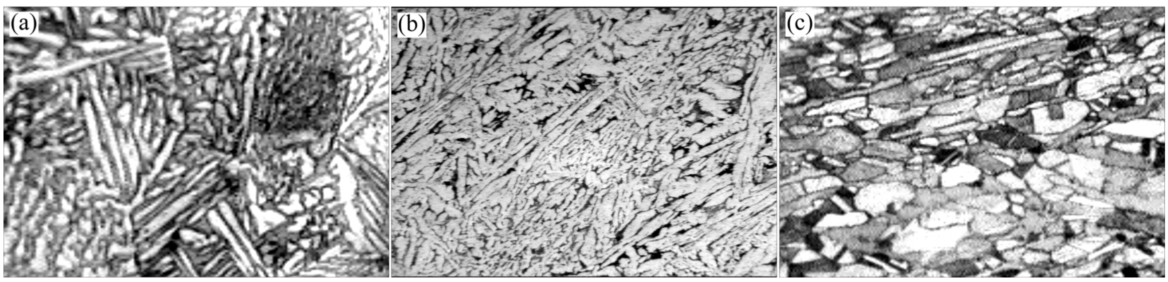

Fig.5 Metallographs at pre-stress of σ=110 MPa and different heating rates: (a) 200 ℃/s; (b) 600 ℃/s; (c) 1 000 ℃/s

increase of heating-rate. Fig.6 show the metallographs of the specimens subjected to pre-loaded stresses of σ=150 MPa and heating-rates of 200, 600 and 1 000 ℃/s, respectively. It can also be seen from Fig.6 that more and distinct microvoids can be observed with the increase of the heating rates. A common characteristic in Figs.5 and 6 is that, the microdefects in the material, which are mainly small microvoids, increase remarkably with the increase of heating-rate, which corresponds to the reduction of the failure temperature. Comparison between the metallographs of the material subjected to identical heating-rates but different pre-loaded stresses, σ=110 and 150 MPa (Figs.5 and 6), shows more microdefects in the material with σ=150 MPa compared with those in the material with σ=110 MPa. It can be concluded that the microdefects in the material increase with the increase of the pre-load stress, which is corresponding to the reduction of the failure temperature.

The changes of the microstructures and the mechanical properties of the pre-loaded material at high

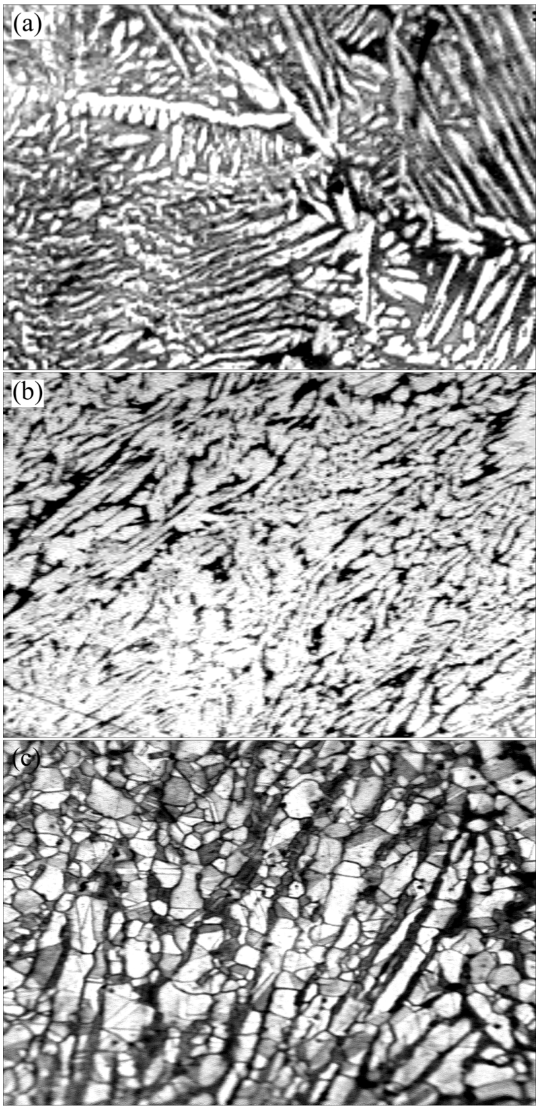

Fig.6 Metallographs at pre-stress of σ=150 MPa and different heating rates: (a) 200 ℃/s; (b) 600 ℃/s; (c) 1 000 ℃/s

heating-rates can be attributed to the local thermal inconsistency (LTI)[10] in the material, which may enhance the local residual stress and, in turn, expedite the nucleation, growth and coalescence of microvoids or other microdefects in the material. Severe LTI at high heating-rate can result in very high local temperature, severe local residual stress and large amount of microvoids and microcracks, which may markedly degrade the mechanical properties of material and make the material fail even at a low level of pre-loaded stress.

4 Conclusions

Using a Gleeble-1500 thermal-mechanical testing system, a set of experiments are conducted to investigate the dependence of the failure temperature of pre-loaded brass H62 on the heating-rate and pre-load stress. It is found that the increase of either pre-load stress or heating-rate decreases the failure temperature. The metallographs of the tested material are also analyzed to investigate the mechanisms of the heating-rate effect. Metallographic analysis shows that the high heating-rate may cause stronger local thermal inconsistency (LTI) and remarkably increase the microdefects in the material, which may markedly degrade the macroscopic mechanical properties of the material.

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