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Flow stress of wrought magnesium alloys during hot compression deformation at medium and high temperatures

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ABSTRACT

The plasticity of AZ31 and ZK60 magnesium alloys was studied by means of hot compression deformation tests on Gleeble 1500D machines at different temperatures and strain rates. The results indicate that the thermal simulation curves of AZ31 and ZK60 have different forms under the same deformation condition. The general curves of AZ31 have the character of dynamic recrystallization that the flow stress increases to a peak and then decreases to a steady state. Most deformation curves of ZK60 have the obvious character that around 0.2 in strain the stress reaches the peak and declines rapidly to the lowest, while the other curves have the character of dynamic recrystallization. From the analysis, a deformation temperature should reasonably be selected from 250 °C to 400 °C for AZ31, while it was concluded to be 200 °C or 400 °C for ZK60.

1. Introduction

At present, the volume of wrought magnesium products is considerably less than that of casting products. However, wrought magnesium alloys may have more development potential with the higher strength, improved ductility and other mechanical property advantages [1]. Due to the intrinsic characteristics of the h.c.p. structure, magnesium alloys have poor formability and limited ductility at room temperature [2,3], so their forming technology should be proceeded at the medium and high temperature. The absence of the related data of the forming technological factors is still the first cause of limiting the widespread use of the wrought magnesium alloys. Therefore, it is necessary to investigate on the basic forming data of magnesium alloys which have different brands. AZ31 is one of the Mg–Al–Zn alloys and ZK60 is one of the Mg–Zn–Zr alloys, both of them are the most widely used wrought alloys. In the present study, we conducted hot deformation experiments on AZ31 and ZK60 alloys and recorded the corresponding flow stress curves. By investigating the properties of the curves and the deformation parameters, the optimized deformation parameters have been concluded which can provide the theoretical support to formulate the deformation technology of magnesium alloys.

2. Experimental

Hot compression tests were performed on the Gleeble 1500D machine. The test samples were cylindrical in shape having a diameter of 10 mm and a length of 15 mm. Prior to the compression, the specimens were heated to the deformation temperature in 5 min. The deformation temperature was measured by thermocouples welded onto the center of a specimen surface. The deformation strain, temperature and strain rate were automatically controlled and recorded. Compression was conducted in a temperature ranging from 150 °C to 400 °C. The strain rates were varied from 0.01 s^{-1} to 30 s^{-1}. After the hot compression, the specimens were water-cooled. The compositions of the AZ31 and ZK60 magnesium alloys are given in Table 1.

3. Results and discussion

3.1. Comparison of flow curves of AZ31 and ZK60

Fig. 1 shows the stress–strain curves of the AZ31 alloy under different deformation conditions. The general characteristics of the flow stress curves are similar under all deformation conditions. The flow stress increases to a peak (initial strain hardening) and then decreases to a steady state. Such flow stress behaviors are typical characteristics of hot working that is accompanied by dynamic recrystallization [4,5].

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Table 1
The chemical composition of the AZ31 and ZK60 alloys (wt.%)

Alloy	Al	Zn	Zr	Mn	Si	Fe	Cu	Mg
AZ31	3.20	1.11		0.30	0.0143	0.0015	0.0021	Balance
ZK60	≤0.05	5.6	0.54	0.10	≤0.05	≤0.05	≤0.05	Balance

Figs. 2 and 3 shows that the thermal simulation curves of ZK60 have the different shapes under various deformation conditions. For example the curves have the character of dynamic recrystallization at a strain rate of 1 s^{-1} at 200 °C or 400 °C and the material can be deformed successively, while most curves of ZK60 have the other obvious character that around 0.2 in strain the stress reaches the peak and declines rapidly afterwards and lands the lowest. The declining of the curve illustrates that the test specimen has been destroyed and crackle can be found in the test specimens correspondingly.

The results from these tests demonstrate that AZ31 and ZK60 alloys have different forms of thermal simulation curves and deformation ability owing to their different eutectic microstructures. The grain boundaries are the weaker part of the material. The fracture is formed more easily near the boundaries and spreads along them [6]. There are more grain boundaries in ZK60 magnesium alloy because of the generous eutectic element in ZK60 casting microstructure, which mainly includes rough branch crystal and more secondary Mg–Zn phases which have unfixed shapes [7]. As there are not enough independent slip systems to harmonize the plastic deformation between the boundaries, dislocations always gather around the boundaries and produce stress concentration, and these will give rise to cracks. More serious stress concentration will be produced with higher strain rate (or the lower deformation temperature) and the cracks will expand unsteadily when the stress exceeds the critical value. In AZ31 there is little effect of the second-phase on dynamic recrystallization not only as there is less second-phase material due to the lower content of the alloy metal, but also and especially as the second-phase material dissolves into the matrix material in the deformation process at high temperature.

3.2. Effect of processing parameters on the flow stress of AZ31

Generally, such flow stress behavior is typical of hot working that is accompanied by dynamic recrystallization, which can be

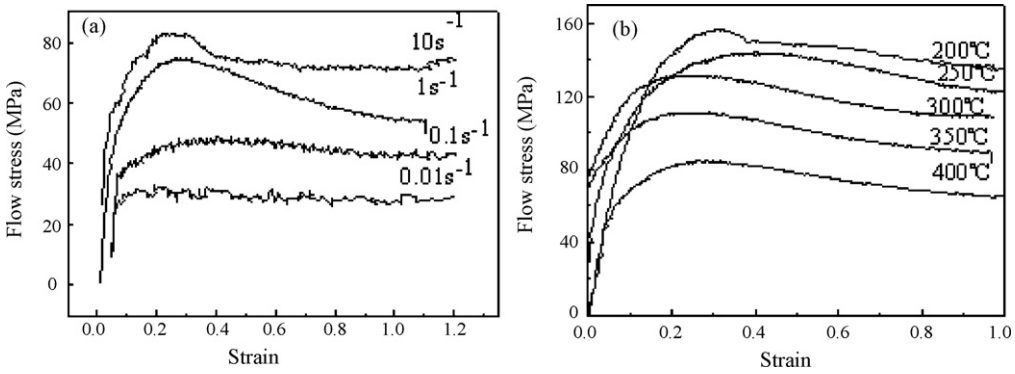

Fig. 1. Flow stress–strain curves of AZ31 alloy in compression at various conditions (a) 400 °C and (b) 1 s^{-1}.

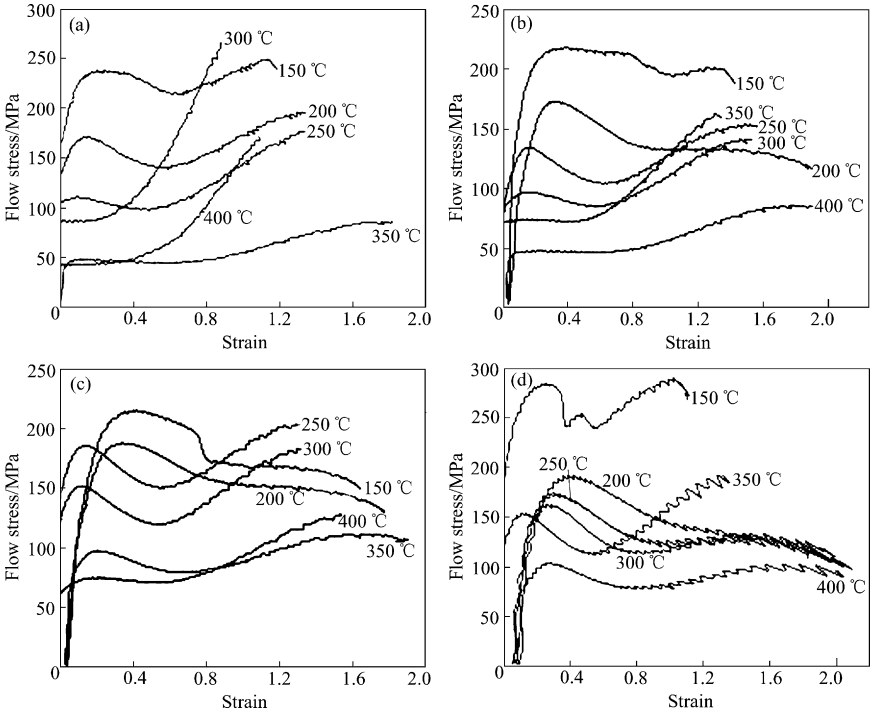

Fig. 2. Flow stress–strain curves of ZK60 alloy in compression at various temperatures. (a) 0.01 s^{-1}, (b) 0.1 s^{-1}, (c) 1 s^{-1} and (d) 10 s^{-1}