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Characterization of hot deformation behavior of AA2014 forging aluminum alloy using processing map

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Abstract: The hot deformation behavior of AA2014 forging aluminum alloy was investigated by isothermal compression tests at temperatures of 350−480 °C and strain rates of 0.001−1 s^{-1} on a Gleeble−3180 simulator. The corresponding microstructures of the alloys under different deformation conditions were studied using optical microscopy (OM), electron back scattered diffraction (EBSD) and transmission electron microscopy (TEM). The processing maps were constructed with strains of 0.1, 0.3, 0.5 and 0.7. The results showed that the instability domain was more inclined to occur at strain rates higher than 0.1 s^{-1} and manifested in the form of local non-uniform deformation. At the strain of 0.7, the processing map showed two stability domains: domain I (350−430 °C, 0.005−0.1 s^{-1}) and domain II (450−480 °C, 0.001−0.05 s^{-1}). The predominant softening mechanisms in both of the two domains were dynamic recovery. Uniform microstructures were obtained in domain I, and an extended recovery occurred in domain II, which would lead to the potential sub-grain boundaries progressively transforming into new high-angle grain boundaries. The optimum hot working parameters for the AA2014 forging aluminum alloy were determined to be 370−420 °C and 0.008−0.08 s^{-1}.
Key words: AA2014 aluminum alloy; hot deformation behavior; constitutive model; processing map; softening mechanism

1 Introduction

AA2014 aluminum alloy, as a kind of forging alloy, is one of the most important aeronautical materials owing to the excellent combination properties of high strength, high toughness and good corrosion resistance [1,2]. The aeronautical forgings such as aircraft landing gear hub and engine components have been extensively applied. The production of such forgings undergoes complex processing steps like cogging and die forging. However, the flaws may be generated during deformation owing to narrow forging temperature range and unstable forged microstructure. Controlling the forging processes to attain a uniform microstructure seems to be very important. Thus, it needs a comprehensive understanding of the hot deformation behavior of the alloy to develop a reasonable forging process.

In recent years, the Arrhenius equation has been adopted extensively to research the effect of deformation conditions on the flow behavior and microstructure evolution and to reveal the relationship between Zener−Hollomon parameters and dynamic softening mechanism of aluminum alloys. Those studies generally suggested that the flow stresses diminish with rising the deformation temperature and decreasing strain rates [3−5]. Moreover, considerable researches have shown that dynamic recrystallization (DRX) occurs in aluminum alloy during hot deformation, and the occurrence of DRX must be below or equal to a critical Z value [6−8].

It is worth emphasizing that the processing map is also useful for optimizing hot working processes. JIN et al [9] developed the processing maps of a 7050 aluminum alloy and obtained an optimum window (410−460 °C, 10^{-4}−10^{-3} s^{-1}) for the reasonable continuous dynamic recrystallization with the power efficiency of about 50%. LIN et al [10] investigated the hot working of 7075 alloy with the help of processing

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map and pointed out a domain with coarse precipitates distributed in the grain interior and at boundaries, which may lead to the deep inter-granular corrosion and large areas of denudation layer. LI et al [11] found that the main softening mechanism of an Al−Cu−Li−Sc−Zr alloy was dynamic recovery (DRV) at 440 °C, 0.1 s^{-1} and the DRX could be easily observed at 470 °C and 0.001 s^{-1}.

Up till now, most researchers focus on the research of the flow behavior and the corresponding softening mechanism. While there are only few reports on obtaining a uniform and fine grain size microstructure by utilizing constitutive equation and processing map. Meanwhile, the hot deformation behavior of AA2014 aluminum alloy also needs to be further studied. Thus, in the present study, a strain revised constitutive model was used to investigate the flow behavior of the AA2014 aluminum alloy. And the softening mechanism was studied by microstructure observation. More importantly, an optimum window with single softening mechanism and uniform microstructure was established by the processing map as well as the activation energy.

2 Experimental

The experimental material in the isothermal compression tests was AA2014 aluminum alloy, which was industrially homogenized at 490 °C for 12 h and air cooled. Its chemical composition is listed in Table 1. The original microstructure and the distribution of the second phase particles are shown in Fig. 1. According to the analysis of EDS, particles in bright color with greater percentage are Al_2Cu (θ) phases, and the gray color particles are impurity phase Al−Fe−Mn−Si, while the dark dots on the bright θ phases are Al−Cu−Mg−Si phases. Also, the fine dispersion particles are precipitates during the slow cooling of homogenization.

Table 1 Chemical composition of AA2014 aluminum alloy (mass fraction, %)

Cu	Mg	Si	Mn	Fe	Ga
4.41	0.69	0.64	0.52	0.12	0.028
Zn	Ti	V	P	Al	
0.011	0.014	0.013	0.014	Bal.	

In order to investigate the hot compression behavior of AA2014 aluminum alloy, isothermal compression tests were carried out on a Gleeble−3180 simulator at the deformation temperatures of 350, 400, 450 and 480 °C, the strain rates of 0.001, 0.01, 0.1 and 1 s^{-1}, and the strain up to 0.7. Cylindrical compression specimens were machined with a size of 10 mm in diameter and 15 mm in height. A thermocouple was welded on the specimen to ensure a continuous temperature measurement during the entire heating, deformation and quenching cycle. Cylindrical specimens prior to isothermal compression were heated to deformation temperatures at a heating rate of 5 °C/s and held for 3 min. After compression, the specimens were quenched to room temperature immediately to maintain the deformation microstructures. The deformed specimens were sectioned parallel to the compression axis along the direction of centerline for OM and TEM observation. Metallographic specimens were etched in a Keller's agent. TEM specimens were electro-polished by the twin-jet electro-polishing method using a solution of 70% CH_3OH and 30% HNO_3 at −30 °C. Microstructure observations were performed on a Tecnai $G^2$20 TEM and a Sirion 200 field emission gun SEM, equipped with EBSD detector and Channel 5 software and the parameters used were as follows: accelerating voltage 25 kV, step size 3 μm.

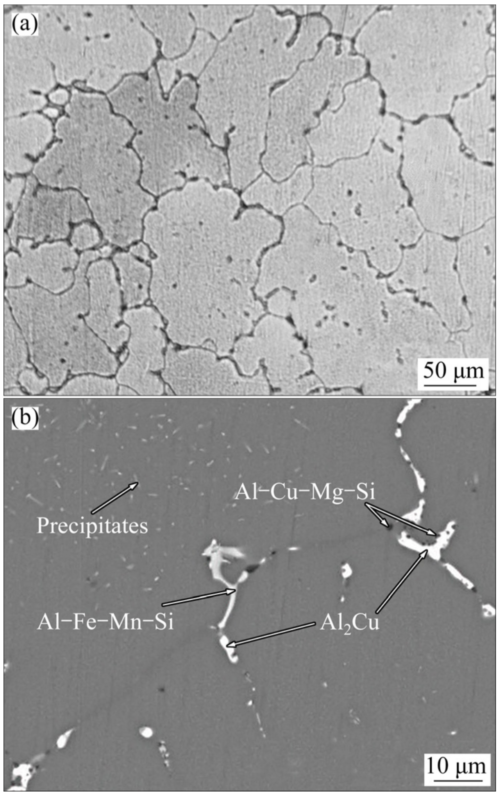

Fig. 1 Initial microstructures of AA2014 aluminum alloy: (a) OM; (b) SEM

3 Results and discussion

3.1 True stress−strain curves

The true stress−strain curves obtained during the isothermal compression tests are shown in Fig. 2. As can be seen from the flow curves, the effects of deformation temperature and strain rate on the flow stress are significant under all the test conditions. The stress level decreases with increasing deformation temperature and decreasing strain rate. The flow stresses rise rapidly and