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ARTICLE

Critical Conditions of Dynamic Recrystallization for B_4C_p/6061Al Composite

Liu Shengpu, Li Defu, Guo Shengli

General Research Institute of Non-ferrous Metals, Beijing100088, China

Abstract: Flow behavior and dynamic recrystallization (DRX) critical conditions of 25vol% B_4C_p/6061Al composite were investigated by isothermal compression tests at temperatures ranging from 350 to 500 °C with strain rates of 0.001 to 1 s^{-1}. The stress-strain curves show that DRX is the main softening mechanism of the composite, and an Arrhenius-type equation is developed using peak stress. Based on the strain hardening rate curves (θ-σ), the critical strain (ε_c) and critical stress (σ_c) are identified to express the initiation of DRX. The results indicate that there is a liner relationship between σ_c and σ_p:σ_c=0.8374σ_p–0.33708. The Zener-Hollomon parameter was also introduced to describe the effect of deformation conditions on critical conditions: $\varepsilon_c=2.39\times10^{-4}Z^{0.11022}$. In addition, the steady-state strains (ε_{ss}) were determined by the θ-ε curves, and then the DRX diagram was established.

Key words: B_4C_p/6061Al composite; dynamic recrystallization; critical conditions; strain hardening rate

B_4C particulate reinforced aluminum matrix composites have been rapidly developed over the past decades because of their excellent mechanical properties such as high strength, high wear resistance, high elastic modulus, good chemical stability, light weight and low thermal expansion coefficient[1,2]. Applications of B_4C_p/Al composites involve neutron absorber materials, armor plate materials and substrate material for computer hard disks[3-5]. However, compared with unreinforced alloys, particulately reinforced metal matrix composites are more sensitive to processing parameters including deformation temperature, strain rate and true strain. The interface between the reinforcements and matrix also plays an important role during the hot deformation process of composite, because the load is transferred from ductile matrix to brittle particles. Then the stress in the vicinity of non-deforming particles is difficult to be released and causes stress concentration, which lead to severe damages such as particles fracture and interface decohesion. As a result, the hot workability of composites is much worse than that of soft matrix.

Generally, the flow behavior of metals or alloys is very complex in the hot forming process. Strain hardening and dynamic softening (dynamic recovery and dynamic recrystallization) often occur simultaneously, which lead to annihilation and rearrangement of dislocations[6]. The dynamic recovery (DRV) begins at the initial stage of deformation and causes the accumulation of dislocation until the dislocation density reaches a critical value for inducing dynamic recrystallization (DRX)[7]. Critical conditions mainly depend on the chemical composition of the material, the grain size prior to deformation, mode of deformation and the deformation conditions[8]. DRX is not only a vital softening mechanism, but also an effective approach to control microstructure and mechanical properties in hot working. It should be noted that the addition of particles can induce extra strengthening of composites through dislocation strengthening and finer grains strengthening[9]. Moreover, the reinforcements also have dual effects on the DRX process of composites. On the one hand, particles can hinder the movement of grain boundary and restrict the growth of recrystallized grains. On the other hand, particles in soft matrix can act as potential sites for nucleation of recrystallization and increase the volume fraction of DRX[10]. As a consequence, it is significant

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Corresponding author: Liu Shengpu, Candidate for Ph. D., General Research Institute of Nonferrous Metals, Beijing 100088, P. R. China, E-mail: lspcailiao@126.com

to understand the dynamic recrystallization behavior of composite for the optimal processing parameters and predict the critical conditions of DRX for composite precisely.

The conventional method used to determine the initiation of DRX for metals or alloys is the metallographic observation, which requires too much workload. An advanced approach based on strain hardening rate (θ) theory was adopted by Poliak and Jonas[11,12], and Ryan and McQueen[13]. They pointed that the peak stress (σ_p) corresponded to the point at which strain hardening rate was zero (θ=0) in the curves of θ-σ and the inflection point of θ-σ curves represented the critical stress. Furthermore, Najafizadeh and Jonas[14] simplified this method by fitting the θ-σ curves with a third order polynomial equation. Liu[15] calculated the exact values of critical stresses by taking the second derivative of θ-σ curves, where $d^2\theta/d^2\sigma=0$. So far, several studies have been conducted to predict the initiation of DRX for various metals or alloys, such as 42CrMo steel[16], 20MnNiMo steel[6], nickel-based superalloy[17], 7075 aluminum alloy[18], and AZ31B magnesium alloy[15]. There are also some attempts on DRX behavior of composites. Sun et al.[19] investigated the initiation and evolution of DRX for 30% SiC/Al composite using the process variables derived from flow curves and developed the DRX kinetics equations. Ko et al[20] predicted the dynamic recrystallization condition for SiC/2024Al composite by deformation efficiency. Yoo[21] developed the DRX model of SiC_w/AA2124 composites and obtained the grain size model in terms of temperature compensated strain rate. However, there were no any surveys on DRX characteristic of B_4C_p/Al composites.

The 6061Al alloy is an outstanding candidate for matrix of the metal matrix composite industrial applications due to its ideal mechanical properties. In the present work, the flow behavior of B_4C_p/6061Al composite at different deformation temperatures and strain rates has been analyzed to determine the critical conditions based on the strain hardening rate method. Furthermore, the DRX diagram of the composite has been established.

1 Experiment

The B_4C_p/6061Al composite used in this investigation contained 25 vol% B_4C particles with the average size of 5 μm, which was produced by PM (power metallurgy) route. The mass percentage of individual elemental alloy power of 6061Al alloy is shown in Table 1.

The samples with height of 15 mm and diameter of 10 mm were prepared. Graphite lubricant was used to minimize the friction between the dies and specimens. Isothermal hot compression tests were carried out on the Gleeble-1500 thermal simulator at temperatures ranging from 350 to 500 °C at an interval of 50 °C and the strain rate ranging from 0.001 to 1 s^{-1}. Each specimen was heated to the deformation temperature at a rate of 10 °C/s, and held for 180 s at isothermal condition before compressing. Then the specimens were compressed to 50% reduction. Finally, at the end of compression the specimens were immediately quenched in water to reserve the deformed microstructure.

Table 1 Composition of 6061Al alloy (wt%)

Mg	Si	Cu	Fe	Cr	Mn	Ti	Al
0.89	0.65	0.25	0.25	0.075	0.03	0.02	Bal.

2 Results and Discussion

2.1 Analysis of stress-strain curves

The influence of different deformation temperatures and strain rates on the flow behavior of 25vol.% B_4C_p/6061Al composite is shown in Fig.1. According to the characteristics of stress-strain curves, the composite undergoes greater work hardening at a very small strain especially at lower temperatures (350 and 400 °C) and higher strain rates (1 and 0.1 s^{-1}) because there is no enough time for energy accumulation and lower grain boundaries mobility. In other words, the dynamic softening during this stage is too weak to counteract the effects of strain hardening. With the increase of strain, the effect of softening is enhanced due to the occurrence of DRX. The flow stress increases up to a peak stress and then decreases until it reached a steady state. The steady stage is more obvious at higher temperatures (450 and 500 °C) and lower strain rates (0.001 and 0.01s^{-1}). The occurrence of steady state means a new balance between softening and strain hardening is achieved.

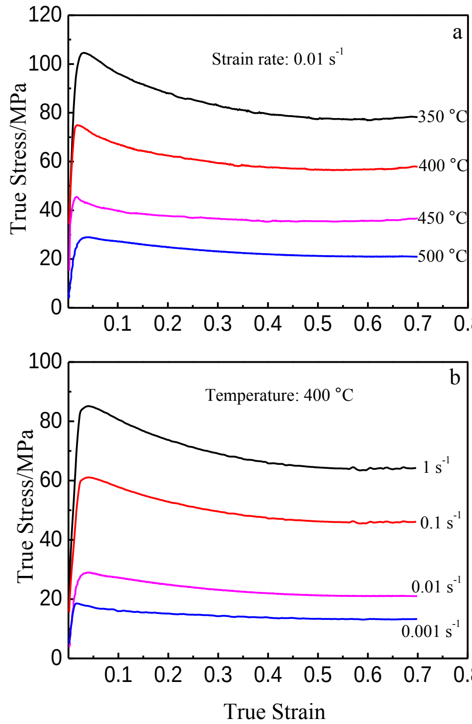

Fig.1 Flow stress curves of 25 vol% B_4C_p/6061Al composite: (a) $\dot{\varepsilon}$ =0.01 s^{-1} and (b) T=400 °C