Hot Deformation Behavior of P/M Al6061-20% SiC Composite

Hamed Asgharzadeh[1,a] and Abdolreza Simchi[1,b]

[1]Department of Materials Science and Engineering and Institute for Nanoscience and Nanotechnology, Sharif University of Technology, Tehran, Iran
[a]asgharzadeh@mehr.sharif.edu, [b]simchi@sharif.edu

Abstract

In the present work, hot workability of particulate-reinforced Al6061-20%SiC composite produced by direct hot extrusion technique was studied. Uniaxial hot compression test at various temperatures and strain rates was used and the workability behavior was evaluated from the flow curves and the attendant microstructures. It was shown that the presence of SiC particles in the soft Al6061 matrix deteriorates the hot workability. Bulging of the specimens and flow lines were observed, which indicate the plastic instability during hot working. Microstructure of the composites after hot deformation was found to be heterogeneous, i.e. the reinforcement clusters were observed at the flow lines. The mechanism of deformation was found to be controlled primarily by dynamic recrystallization.

Keywords : Hot workability, Al6061/SiC composite, Microstructure, Hot compression test

1. Introduction

Discontinuously reinforced aluminum (DRA) composites are being recognized as an important class of engineering materials that are making significant progress as a result of their desirable properties, which include high specific stiffness, controlled coefficient of thermal expansion, and increased fatigue resistance [1]. Nevertheless, the inferior ductility and the higher flow stress limit their workability [2].

The high temperature deformation of DRA composites has been widely studied with the aim of improving the hot-working response and reducing cracking. It has been shown that DRA composites are more sensitive to processing variables such as temperature and strain rate than unreinforced alloys. This is due to the presence of hard particles in the soft matrix which cause plastic flow localization at the particle–matrix interface. Moreover, grain boundary sliding occurring at high temperatures and low strain rates can lead to the formation of wedge-shaped cracks at grain boundaries that are initiation sites for damage and affect the mechanical properties of the component [3].

One of the amenable techniques to fabricate high performance DRA composites is direct powder extrusion route [4]. Besides the importance of the procedure, no much work was performed on the workability of DRA composites produced by this method. This paper presents the hot deformation behavior of P/M Al6061-20%SiC composites.

2. Experimental and Results

Nitrogen atomized 6061 aluminum powder and α-SiC particles were used as the starting materials. The chemical composition of the aluminum alloy in wt% was Al-1.4Mg-0.6Si-0.24Cu-0.32Fe-0.08Zn-0.06Mn.

A powder blend composed of Al and 20vol% SiC was prepared by wet blending in n-Butanol. After drying, the powder mixture was compacted in an Al can. The can was then sealed and hot extruded at temperature of 400 ˚C with an extrusion ratio of 17:1. Afterwards, the extruded bar was machined to prepare cylindrical specimens with diameter of 10 mm and the height to diameter ratio of 1. T6 heat treatment was applied on the specimens; solution treatment at 530 ˚C for 2 hr and age hardening at 160 ˚C for 18 hr.

The deformation behavior of Al6061-20%SiC was studied by uniaxial hot compression test. The surfaces of the specimens in contact with dies were lubricated by graphite powder. The testing temperature and strain rate ranged from 350 to 500 ˚C and 10^{-3} to 10^{-1} s^{-1}, respectively. Hot upsetting was performed up to 50% reduction in the height of the specimens. After test, the samples were quenched in water in order to retain the high-temperature microstructure.

The true stress-strain curves of the extruded composite specimens examined at different temperatures and strain rates are shown in Fig. 1. In general, the flow curves exhibit a sharp increase in stress by increasing strain, i.e. work hardening. Afterwards, a slight decrease in the flow stress occurred. The flow stress then reached to a steady state condition. This behavior indicates that the work-softening is an active mechanism during the hot deformation test. Here, it is pertinent to point out that at a constant strain rate, with increasing the deformation temperature lower amounts of the work-hardening rate was noticed. It is well known that at higher temperatures, the glide and cross-slip of dislocations are easier to occur. Therefore, the work-softening mechanisms should play an important role at the high temperatures. On the other hand, it was found that the dynamic yield point increases when using higher strain rates, although the amount of work-hardening rate decreases. Note that while at lower strain rates the deformation remains isothermal, it is adiabatic at relatively higher strain rates. This is in consequence of the inadequate heat dissipation following the non-availability of sufficient durations at higher strain rate deformations.

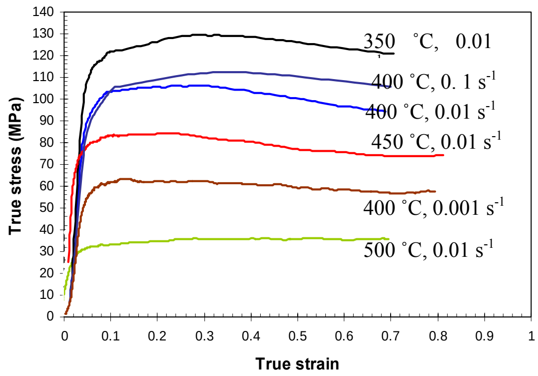

Fig. 1. True stress-strain curves of Al6061-20% SiC at different temperatures and strain rates.

The dependence of peak flow stress (σp) on strain rate ($\dot{\in}$) and temperature (T) for Al alloys and their composites can be expressed by Arrhenius equation as below [2]:

$$\dot{\in} = A[\sinh(\alpha\sigma_p)]^n \exp\left(-\frac{Q}{RT}\right) \quad (1)$$

where n is the stress exponent, Q is the activation energy for high temperature deformation, R is the gas constant, and A and α are constants. By plotting $\log\dot{\in}$ vs. $\log\sinh(\alpha\sigma)$ and $\log\sinh(\alpha\sigma)$ vs. 1000/T, the value of activation energy was determined as 195 kJ mol^{-1}. The value of Q is significantly higher than the activation energy of pure aluminum (143 kJ mol^{-1} [2]). Since the hot deformation behavior of metals with high stacking fault energy such as Al is controlled by dynamic recovery [5], the higher activation energy of the composite material indicates that dynamic recrystallization instead of dynamic recovery is responsible for the observed softening behavior.

Fig. 4 shows that the plastic instability occurred during the hot deformation of Al6061-20% SiC composite at 350 ˚C and strain rate of 0.01 s^{-1}. The plastic instability was appeared in the form of bulging. Flow lines can also been seen in the cross-section. Furthermore, clusters of SiC particles are visible. Note that these cluster regions restricts the plastic flow of the Al alloy, resulting in localized deformation of the matrix. Therefore, SiC particles were elongated along the high strained zones. These clusters are accompanied by void formation, indicating the large zones of stress concentration in the structure during forging [6]. Certainly, these zones have an adverse effect on the workability of the material.

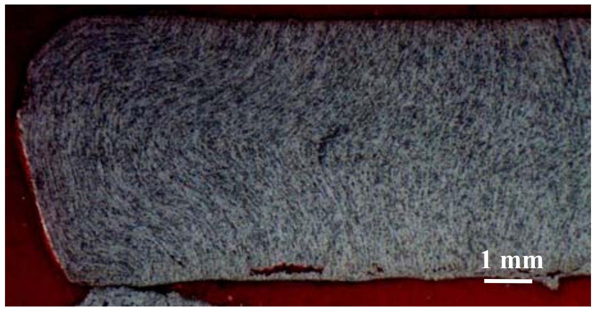

Fig. 2. Macrostructure of Al6061-20% SiC after 50% compression at T= 350 ˚C and $\dot{\in} = 0.01$ s^{-1}.

3. Summary

In the present work, the hot workability of Al6061-20% SiC produced by direct hot extrusion of the composite powder blend was studied. It was found that dynamic recovery and recrystallization are active mechanisms from the flow curves. Nevertheless, the activation energy of deformation was determined to be higher than that of the unreinforced Al matrix. This indicates that dynamic recrystallization may be operative. Meanwhile, with increasing the testing temperature the effect of work-hardening is decreased, and thus the flow stress reached to a steady state condition. Plastic instability of the composite material was appeared in the form bulging and formation of flow lines. Nevertheless, shear bands were not observed.

4. References

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