EFFECTS OF DEFORMATION CONDITION ON HOT WORKABILITY AND MICROSTRUCTURAL EVOLUTION OF SiC WHISKER REINFORCED AA2124 MATRIX COMPOSITES

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Abstract

High temperature deformation behavior of 15 vol% SiC whiskers reinforced AA2124 matrix composites was investigated by hot torsion tests performed at temperature ranges from 200℃ to 530℃, and strain rate ranges from 1.32×10^{-3}/sec to 2.38/sec, respectively. The hot restoration mechanism was found to be dynamic recrystallization from the studies on the flow curves and the deformed microstructures. Relationship between critical strain ε_c and peak strain ε_p was found to be $\varepsilon_c \simeq 0.5\varepsilon_p$. The dependence of the strain rate $\dot{\varepsilon}$ and temperature T on stress σ could be expressed in terms of hyperbolic sine equation, $\dot{\varepsilon} = 4.16 \times 10^{19}[\sinh(1.36 \times 10^{-2} \cdot \sigma_p)]^{3.98} \exp(-280.37/RT)$. The superplasticity-like behavior was obtained at a strain rate of 7.94×10^{-2}/sec and at temperatures around 500℃. From the fracture surface observations, cavities were initiated at the ends and sides of whiskers and the sliding of interface between SiC whiskers and matrix could be augmented with increasing temperatures resulted in a large failure strain up to 500℃.

Introduction

SiC whiskers reinforced aluminum composites are using as new commercial materials for aerospace and other high-performance markets because of their higher specific stiffness, specific strength and excellent creep resistance etc. compared to monolithic aluminum alloys[1-3]. Aluminum metal matrix composites fabricated using elevated-temperature and powder metallurgy -based aluminum alloys are also attractive candidates for replacing higher -cost titanium alloys in some applications[4]. To meet the engineering standards of those composites the strengthening mechanism of SiC reinforced composites and the role of SiC during forming process such as extrusion, rolling etc., should be verified. Until now the addition of SiC to aluminum alloys increases strength and stiffness of these alloys at room temperature. However the hot working behaviors of these composites, such as dynamic recovery(DRV) and dynamic recrystallization(DRX) are still not very clear[5,6]. Therefore, the purpose of this paper is to investigate the hot deformation behavior of SiC whiskers reinforced AA2124 matrix composites.

Experimental

The materials introduced in this work were 15 vol% SiC whiskers(β-type) reinforced AA2124 matrix composites. The size of the AA2124 (4.69Cu-1.13Mg-0.67Mn-0.14Fe-0.13Si-0.07Zn) alloy powders was about 44 μm. Both matrix powders and SiC whiskers were mixed by ultrasonic blending in methanol solution. The mixed and dried materials were compacted by cold and vacuum hot pressing at 520℃ where the matrix alloy is semi-solid state. Hot extrusion, at an extrusion ratio of 20 : 1 and at 470℃, was used to produce cylindrical bars. Torsion specimens of 10mm gauge length L and 7mm diameter 2r were machined from the extruded bars with torsion axis parallel to the longitudinal direction of extrusion. The torsion tests were conducted at the temperature ranges from 200℃ to 530℃ and at the strain rate ranges from 1.32×10^{-3} to 2.38/sec. Heat was supplied using dual elliptical radiant furnace. The specimens were maintained at a test temperature for 10 min before the test. All specimens were quenched immediately in water after deformation was completed. The flow stresses σ and strains ε were calculated from the measured torque moment M and angular displacement θ (in radians) in torsion using the Von Mises criterion[7] as follows

$$\sigma = \sqrt{3}M(3+m+n')/2\pi r^3 \qquad (1)$$

$$\varepsilon = r\theta / \sqrt{3}L \qquad (2)$$

where m is strain rate sensitivity, and n' is strain hardening exponent regarded as 0 at peak stress. The microstructures were studied by optical microscopy, transmission electron microscopy(TEM). The fracture surfaces were also examined by scanning electron microscopy(SEM). TEM samples were prepared using conventional techniques and were electropolished in a 20 pct HNO_3 - 80 pct CH_3OH solution at approximately - 40 ℃.

Results and Discussions

The microstructures for the extrudates of the 15 vol% SiC whiskers reinforced AA2124 matrix composites are shown in figure 1. The SiC whiskers are arranged preferentially within the extrusion direction as shown in Fig1(a). Some whisker-free regions of width on the order of 10 ~ 20 μm are commonly observed in figure 1(a). However, in the transverse direction of the extrusion the whisker-free regions are small and the distribution of SiC whiskers is homogeneous as shown in figure 1(b).

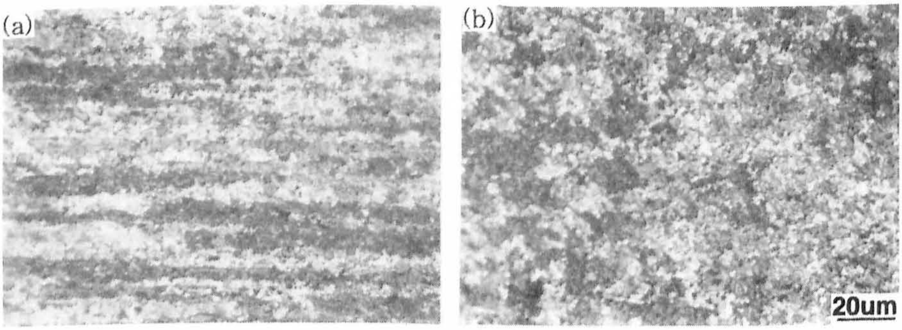

Figure 1. Optical micrographs of the extrudates of 15 vol% SiC reinforced AA2124 composites. (a) longitudinal direction (b)transverse direction

The effective stress-strain curves are shown in figure 2. The flow curves show three different behaviors according to the test temperature. The first one shows that the flow curves are failured at a strain hardening state at temperatures between 200℃ and 350℃. The second one shows that the flow curves have single peak followed by lowered steady state stress regions due to dynamic recrystallization(DRX) at temperatures between 400℃ and 500℃. The third one shows that the flow curves do not show a distinct peak due to plenty of local melting of the matrix at 530℃. The flow stresses increase with increasing strain rate and decreasing deformation temperature, and the flow stresses decrease rapidly at higher temperatures above 300℃, which mean that the matrix alloy could be softened rapidly at those temperature ranges.
At temperatures between 400℃ and 500℃ where the flow curves showed

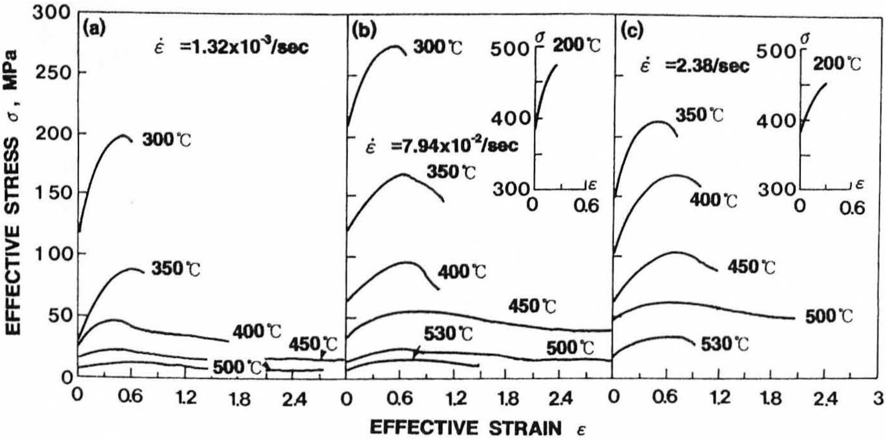

Figure 2. Effective stress-strain curves of hot torsion tests for 15 vol% SiC reinforced AA2124 composites.

distinct DRX behavior as shown in figure 2. Therefore, relationship between critical strain ε_c for DRX and peak strain ε_p could be obtained at these temperature ranges. The relationships[8] of work hardening rate $\dot{\theta}$ vs. flow stress σ are shown in figure 3. From the analysis of the relationships ε_c was found to be about $0.5\varepsilon_p$. In the relation of $\varepsilon_c \simeq x\varepsilon_p$, the value of x is much smaller than those of monolithic alloys[9]. It is supposed that the SiC whiskers promoted DRX nucleations at earlier strain range. However, the interfaces between SiC whiskers and matrix might give the sink source of dislocations resulted in retarding DRX progressing.

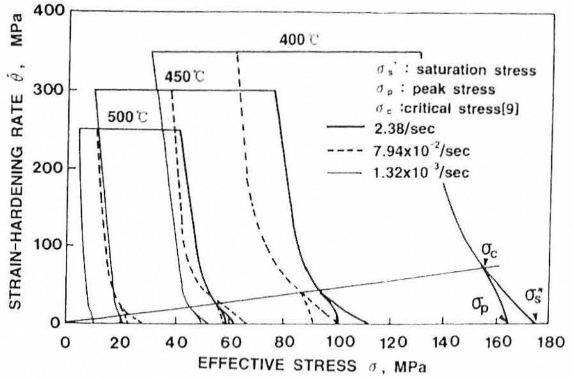

Figure 3. Strain hardening rate vs. stress curves obtained from hot torsion tests for 15 vol% SiC reinforced AA2124 composites.

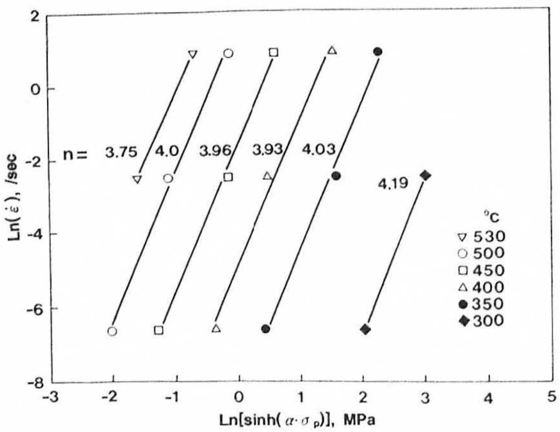

Figure 4. Hyperbolic sine law relationships of Ln[sinh($\alpha \cdot \sigma_p$)] vs. Ln ($\dot{\varepsilon}$) for hot deformation of 15 vol% SiC reinforced AA2124 composites.

The dependence of test temperature T and strain rate ε on flow stress σ is identified by thermal activation process[10]. The flow stress σ_p behaviors with deformation temperature T and strain rate $\dot{\varepsilon}$ were examined by hyperbolic sine equations such as

$$\dot{\varepsilon} = A_1[\sinh(\alpha \cdot \sigma_p)]^n \exp(-Q/RT) \qquad (3)$$

where A_1, α and n are derived constants, and Q is the activation energy, and R is gas constant. From the analysis of the data fitted to the power law at the temperature ranges from 450℃ to 530℃ and to the exponential law at the temperature ranges from 300℃ to 400℃, α was found to be 1.36 x 10^{-2} MPa^{-1}. From the plots of Ln[sinh($\alpha \cdot \sigma_p$)] vs. Ln ($\dot{\varepsilon}$), n was determined to be 3.98, and constant temperature lines are maintained parallel during the data fitting process as shown in figure 4.
The activation energies Q were obtained by the relationships between Ln[sinh (ασ)] and 1/T at constant strain rate. The value of Q was subsequently used to represent temperature-compensated strain rate termed as Zener-Hollomon parameter Z[10]. The constitutive equation for hot deformation of the composite could be described by hyperbolic sine law and Zener-Hollomon parameter as follows :

$$Z = \dot{\varepsilon}\ \exp(280.37/RT) = 4.16\times10^{19}\ [\sinh(1.36\times10^{-2} \cdot \sigma_p)]^{3.98}$$

Figure 5 shows the microstructures with varing Z. At low Z range, dislocation density is low and large grains are observed as shown in figure 5(a) and

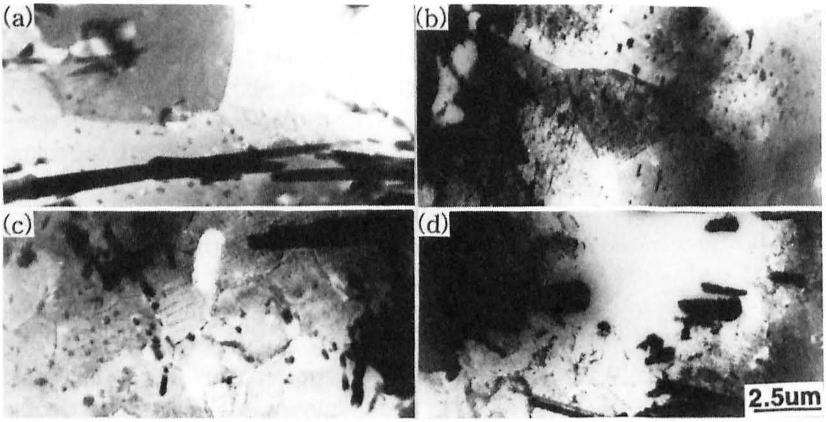

Figure 5. TEM microstructures of hot deformed 15 vol% SiC reinforced AA2124 composites. (a)$Z=1.17x10^{16}$/sec;530℃ and $1.32x10^{-3}$/sec (b)$Z=1.43x10^{19}$/sec; 450℃ and $7.94x10^{-2}$/sec (c)$Z=2.56x10^{22}$/sec;350℃ and $7.94x10^{-2}$/sec (d) $Z=7.67x10^{23}$/sec;350℃ and 2.38/sec

figure 5(b). However, at high Z range, dislocation locking by precipitates and subgrain formed during hot torsion is observed as shown in figure 5(c) and figure 5(d). The tangle or locking of dislocations in an equiaxed grain are observed. These phenomena of dislocation motion and grain shape explain that the hot resotration mechanism of the composite should be DRX. As Z is increased from $1.17x10^{16}$/sec to $7.67x10^{23}$/sec the grain size is decreased from 4 μm to 1 μm.

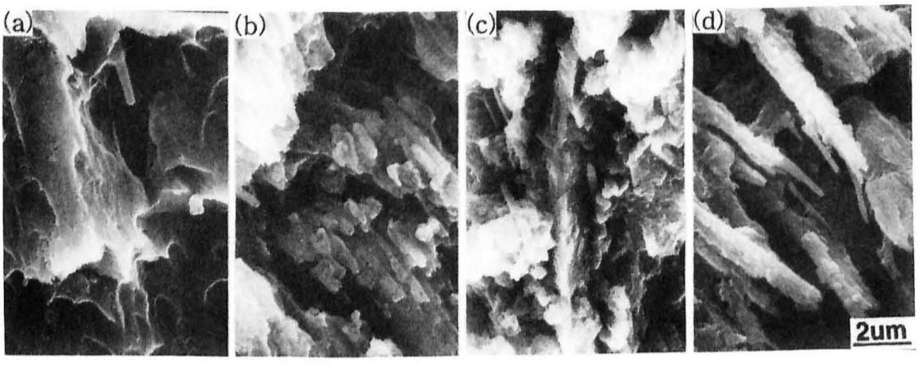

Figure 6. SEM microstructures of hot deformed at a strain rate of $7.94x10^{-2}$/sec for 15 vol% SiC reinforced AA2124 composites. (a)200℃ (b)350℃ (c)450℃ (d)500℃

The fracture surfaces were examined at a strain rate of 7.94×10^{-2}/sec and are presented in figure 6. At low temperature of 200℃, cracks could be initiated at a void space between matrix and whiskers as shown in figure 6(a). With increasing temperatures from 300℃ to 500℃ the SiC whiskers are rearranged to the deformation direction of matrix. At 500℃, the enveloped by matrix and large length of SiC whiskers are observed as shown in figure in 6(d). As the temperature increased the damages of the SiC whiskers are reduced, which explain that the local melting of matrix could help the sliding of interface between SiC whiskers and matrix.

The strains to failure are represented in figure 7. The failure strains increase with increasing temperature from 200℃ to 500℃ at a constant strain rate. However, at 530℃ the failure strains are decreased rapidly at all considered strain rates. It is supposed that the large amount of local melting of matrix was occurred at that temperature, which was resulted in smaller failure strains. In this experimental the maximum ductility was obtained at 500℃ and 7.94×10^{-2}/sec, where the failure strain is about 5.56. At this deformation condition the combination of local melting of matrix and strain rate could promote the sliding of the interfaces between SiC whiskers and matrix. The ductilities are increased with increasing strain rates from 1.32×10^{-3}/sec to 7.94×10^{-2}/sec, and decreased as the strain rates increased from 7.94×10^{-2}/sec to 2.38/sec. Similar results were observed in a previous report[11], which showed that superplasticity-like behavior was observed at high strain rate range around 10^{-1}/sec in high temperature deformation of SiC reinforced composites.

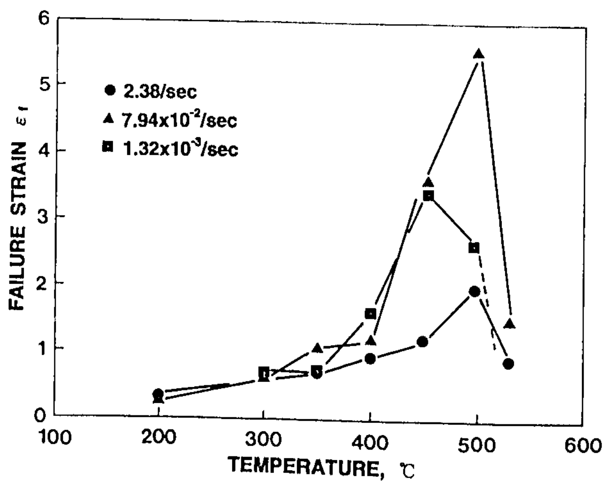

Figure 7. Strains to failure for hot deformation of 15 vol% SiC reinforced AA2124 composites.

Conclusions

By hot torsion tests of 15 vol% SiC whiskers reinforced AA2124 matrix composites the hot restoration mechanism was identified to be dynamic recrystallization(DRX). The critical strain ε_c for DRX was found to be $\varepsilon_c \simeq 0.5\ \varepsilon_p$. The dependence of the strain rate $\dot{\varepsilon}$ and temperature T on stress σ could be expressed as

$$\dot{\varepsilon} = 4.16 \times 10^{19}[\sinh(1.36 \times 10^{-2} \cdot \sigma_p)]^{3.98} \exp(-280.37/RT).$$

Superplasticity-like behavior was observed at temperatures around 500℃ and at a strain rate of 7.94×10^{-2}/sec. At low temperature cracks could be initiated at a void space between matrix and whiskers. With increasing temperature the SiC whiskers are rearranged to the deformation direction and large length of SiC whiskers are observed.

Acknowledgement

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