Creep Behavior of Hot Extruded Al-5% SiC Composite Powder

A. Hosseini Monnazah[1,a], A. Simchi[2,b], S.M. Seyed Reihani[3,c]

[1,2,3]Department of Materials Science and Engineering, Sharif University of Technology, 14588 Tehran, Iran
[a]monazzah@mehr.sharif.edu, [b]simchi@sharif.edu, [c]reihani@sharif.edu

Abstract

The creep behavior of Al-5vol.% SiC composite was investigated. The composite powder was produced by mechanical milling and hot extruded at 450ºC at ratio of 16:1. A creep test was carried out at a constant load at 598, 648, and 673 K. Using the steady-state equations , the threshold stress and the stress exponent of the creep as a function of temperature were determined. The stress exponent was found to be 3 at the temperature of 673 K and 8 at 598 and 648 K. The dependency of the threshold stress to temperature obeys the Arrhenius relationship with the energy term of 29 kJ mole^{-1}.

Keywords: Creep, Al-SiC, Powder extrusion, Threshold stress

1. Introduction

In recent years, the high temperature creep behavior of discontinuously reinforced aluminum matrix (DRA) composites has been a topic of considerable interest, primarily because that material has a high potential for use in structural applications at elevated temperatures [1]. Similar to dispersion strengthened alloys, these composites exhibit high values of apparent stress exponent and apparent activation energy [2]. Recently, the creep behavior of DRA composites produced by powder metallurgy (P/M) has gained much attention due to the advantages of the process in homogenous distribution of reinforcement particles [3]. In this paper, the creep behavior of mechanically milled and hot extruded billets of particulate Al-5%SiC composite is presented.

2. Experimental and Results

Al-5 vol.% SiC composite powder was prepared by mixing Al (D_{50}= 50 μm) and SiC (D_{50}= 8 μm) powders in a Turbula mixer for 20 min and subsequently mechanical milling in a planetary ball mill for 12 hrs. The ball to powder ratio of 10:1 was applied. The milled composite powder was then degassed and encapsulated in an Al can**.** After pre-compaction at 220 MPa, the prepared can was extruded at 450 ºC at ratio of 16:1. The test specimens were fabricated by electro-discharge machining followed by annealed at 400 ºC for 2 hrs. The creep test was carried out at 598, 648 and 673K. The applied stresses ranged from 10 to 40 MPa.

Fig. 1 shows the variation of steady state creep rate with applied stress for the examined Al-5% SiC composite. Apparently, the curves of the creep rate versus applied stress exhibit a clear curvature characteristic. The slope of curvature increases as the applied stress decreases. This is an indicator for the presence of a threshold stress below which the creep can not occur.

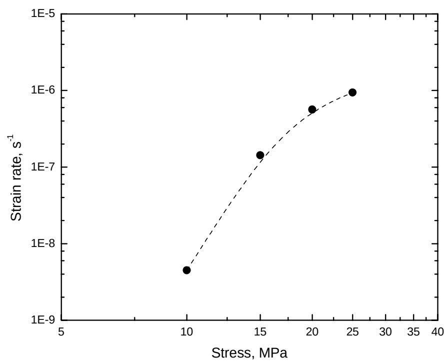

Fig. 1. Steady state creep rate as a function of stress for the Al-5%SiC composite at 673 K.

This suggests that the creep behavior of the composite can be described by the following power law creep equation [4]:

$$\dot{\varepsilon} = A\left(\frac{\sigma - \sigma_0}{G}\right)^n \exp\left(-\frac{Q}{RT}\right) \quad (1)$$

where A is a constant, σ_0 is the threshold stress, G is the shear modulus, n is the true stress exponent, Q is the activation energy, R is the gas constant, and T is absolute temperature. In order to determine the threshold stress, the linear extrapolation method [5,6] can be used. Here, log $\dot{\varepsilon}$ versus log σ were replotted into a linear scale diagram of $\dot{\varepsilon}^{1/n}$ versus σ. If the straight fitting line can be reasonably drawn, its intersection with the horizontal axis of zero strain rate is regarded as the value of σ_0. Fig. 2 shows the $\dot{\varepsilon}^{1/n}$ versus σ diagram with the best fitted lines. In Table 1, the values of the threshold stress and the true stress exponent are reported. The correlation coefficients of the linear extrapolation method are also given.

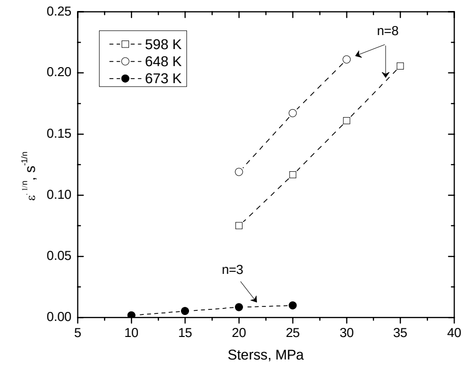

Fig. 2. Relation between $\varepsilon^{\cdot 1/n}$ and σ in double linear co-ordinates for the Al-5%SiC composite.

It is apparent that the measured threshold stress depends on the testing temperature. This suggests that the threshold stress arise from the interaction between the mobile dislocations and a dispersion of fine incoherent particles, having sizes in the nanometric range [7]. In fact, the oxide layer of the atomized powder is broken during mechanical alloying and is distributed inside the matrix. It also seems reasonable that the fracture of SiC during mechanical milling and extrusion occurs [1], which may account for the origin of the threshold stress. The relation between the threshold stress and temperature may be explained by an Arrhenius-type equation as following [5]:

$$\frac{\sigma_0}{G} = B\exp(\frac{Q_0}{RT}) \quad (2)$$

where Q_0 is an energy term which is associated with the binding energy between dislocation and obstacles in the glide plane and *B* is a constant. By plotting the σ_0/G-$1/T$ diagram in semi-logarithmic scale, the slope of the line yields the energy term as 29 kJ $mole^{-1}$. It has been reported [5] that the value of Q_0 of the matrix is consistently within a narrow range of ~20-30 kJ $mole^{-1}$ for values of an *n* range of ~3 to 5. This value is within the range generally associated with the binding energy between the dislocation and solute atoms. The value of the true stress exponent was found to be 8 at temperatures of 598 and 648 K. Therefore, it can be suggested that the invariant substructure model [8] is valid, i.e. the presence of second-phase particles may serve to retain a constant subgrain size. At 648K, the value of *n* decreases to 3, indicating that the mechanism of creep has been changed. Under this condition, the viscous glide of dislocations controls the creep behavior.

Table 1. The power law creep data for the Al-5%SiC composite

Temperature [K]	Threshold Stress [MPa]	True Stress Exponent	R^2
598	11.6	8	0.9997
648	7.1	8	0.9995
673	5.7	3	0.9722

3. Summary

The creep behavior of the Al-5%SiC composite prepared by mechanical milling and hot extrusion was studied. The curves of the creep rate versus applied stress show a clear curvature characteristic, which is an indicator for the presence of a threshold stress. The measured threshold stress is dependent on test temperature, suggesting that the origin of the threshold stress arises from an interaction between the mobile dislocations and a dispersion of fine incoherent particles. The binding energy between dislocation and obstacles in the glide plane was found to be 29 kJ $mole^{-1}$. The change in the value of the true stress exponent with increasing testing temperature indicated that the mechanism of creep was changed from the invariant substructure model to viscous glide of dislocations.

4. References

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