e-TIME 2004
National Conference on emerging trends in Mechanical Engineering
February 05-06 2004, KDKCE, Nagpur
Paper Number:e-TIME/110/e-07

EXPERIMENTAL EVALUATION OF ELASTIC LATTICE STRAINS IN THE DISCONTINUOUSLY SiC REINFORCED Al - ALLOY COMPOSITES

A. Chennakesava Reddy
Associate Professor
Department of Mechanical Engineering
JNTU College of Engineering
Kukatpally, Hyderabad – 500 72
dr_acreddy@rediffmail.com

ABSTRACT

In this study, changes in the load behavior were investigated up to high macro-strains, where the effects of particle fracture damage became significant. During the initial period of plastic deformation of the composite, it was observed that the load was transferred from the yielding matrix to the discontinuous reinforcements. Beyond 3% applied strain, the load partitioning behavior was reversed and the load was shed back to the matrix from the particles. It is believed that this latter phenomenon is associated with a synergistic combination of particle cracks and a network of high slip activity, or slip bands, between cracked particles.

1. INTRODUCTION

Discontinuously reinforced aluminum (DRA) alloy composites exhibit excellent high specific stiffness, strength, light weight, and wear resistance. The discontinuous reinforced are fabricated by casting and powder metallurgy techniques as well as conventional metalworking processes like extrusion, rolling, etc [1,2]. There are several military and commercial applications that have been developed in the past a few years. Specific examples include fan exit guide vanes of aerospace engines, and ventral fins of fighter jets. However, DRAs have much lower ductility (typically 5%) and fracture toughness (typically 15-25 MPa√m) than the unreinforced matrix, and this has been a major obstacle to wider structural applications [3,4]. Therefore, significant research efforts are focused on understanding the deformation and damage mechanisms. Very recently, the effect of matrix microstructure and reinforcement fracture on the properties of tempered SiC_p/Al-alloy composites was addressed. Quantitative fractography revealed a presence of SiC fracture in short cycled tempered composites and with a presence for interface or near-interface failure in long cycle- tempered composites [5].

In this paper, the experimental results on the evaluation of elastic lattice strains in the aluminum matrix and SiC particles in an Al-SiC_p composite. A qualitative discussion is presented on the stress-strain behavior in

- Elastic regime
- Matrix plastic deformation regime
- High macro-strain regime where particle fracture damage became significant

2. EXPERIMENTAL PROCEDURE

The Al-SiC_p composite samples were processed using a powder metallurgy technique. The Al- alloy matrix powder (6.8%Zn, 2.0%Mg, 1.2%Cu, 0.10%Zr, and 0.1%Ni, in wt%), and 21 volume percent SiC particle (approximately 18 μm in size) blend was hot pressed and extruded (with a 20:1reduction ratio) to rectangular bars (25.4 mm x 76.2 mm). Then the composite was heat-treated. First, the composite was solution-treated at 480°C for four hours and then water quenched. Then, it was aged at 100°C for 25min (under-aging condition). Cylindrical tensile specimens with a nominal gauge diameter approximately 10 mm were machined from the consolidated materials.

Elastic lattice strain evolution during uniaxial tensile loading of the composite was characterized in situ using the Neutron Powder Diffractometer. Neutron diffraction provides bulk average measurements due to the typically large depth of penetration into most engineering materials. Therefore, it is an effective, nondestructive technique for measuring 'bulk' internal strains in metal matrix composites. Furthermore, by using the spallation neutron source, all possible lattice planes are recorded at fixed detector angles in each measurement. The tensile specimen was incrementally loaded up to 635 MPa (5% strain) at room temperature. The diffraction patterns were measured at a number of load levels. Diffraction patterns corresponding to the axial and transverse strain directions were measured simultaneously.

Lattice parameters for the Al and SiC were obtained by Rietveld analysis [10] from the measured diffraction patterns. Then, lattice strains of each phase, ε, were determined at each applied load level using; $\varepsilon = (a_i - a_0) / a_0$, where a_0 and a_i are the lattice parameters of the composite phases when unloaded and loaded, respectively.

3. RESULTS AND DISCUSSION

The macroscopic stress-strain curve of the composite specimen measured during the tensile loading is shown in Fig-1. It shows that the total strain measured using a strain-gage type extensometer is a function of the applied stress. The data points represent the stress/strain level where the diffraction patterns were measured from which elastic lattice strains are calculated.

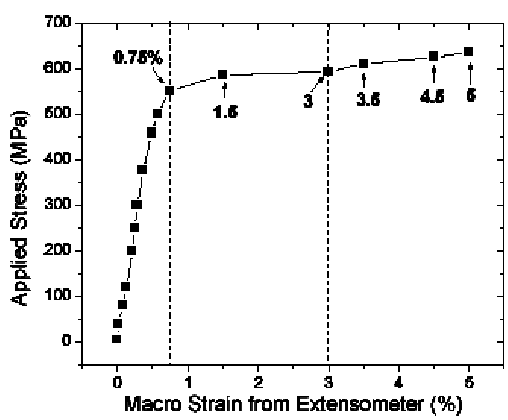

Fig-1 macroscopic stress-strain curve

The strain measured by the extensometer, shown in Fig-2, is an average over all the constituent phases. On the other hand, the elastic lattice strain component of the matrix and reinforcement particles can be monitored by tracking the strains calculated by the changes in lattice parameter of each phase. Fig-2 shows the overview of elastic lattice strain evolution in the aluminum matrix and SiC particles in the composite, measured using neutron diffraction, as a function of the applied stress. The curves show the initial elastic regime of composite deformation, and more importantly, illustrate changes in slope at higher applied stresses (or strains) that must be associated with changes in load partitioning behavior. The changes in the slope of stress-lattice strain curve at high applied stresses are shown more clearly in Fig-3.

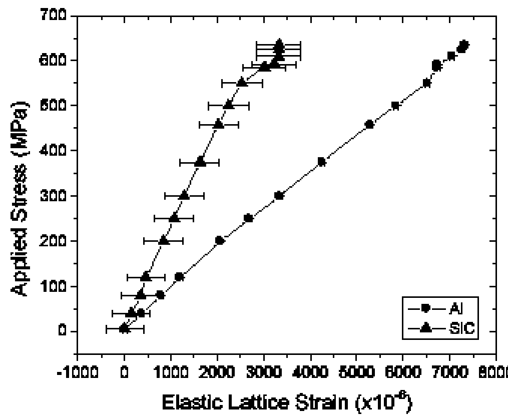

Fig-2 The evolution of the measured elastic lattice strains in the aluminum matrix and SiC particles in the composite as a function of applied stress.

3.1 Elastic Regime

The macroscopic stress-strain relationship is linear up to approximately 0.75% applied strain (as shown in Fig-2). This indicates that the constituents deform elastically. In this regime, the slopes for the individual phases are determined primarily by the elastic modulus and volume fraction of the phases, and to some extent by the shape of the particles. The normalized diffraction peak widths of the matrix and the reinforcement particles are shown in Fig-4 as a function of the applied total strain. It shows that the peak widths of both phases do not change during the elastic regime of deformation.

3.2 Matrix Plastic Deformation Regime

As the applied strain increases beyond 0.75%, the elastic strain accumulation rate for the two phases changes, Fig-34. The slope for the matrix–stress/lattice-strain curve increases. Correspondingly, the slope for the SiC particle phase decreases, i.e. the rate of elastic strain accumulation increases. These changes in slope are due to the change in load sharing between the matrix and the reinforcement. Upon yielding, the stress carrying capability of the matrix tends to saturate (due to its work hardening coefficient), and the shear flow of the matrix past the reinforcement is able to transfer more load to the reinforcements that remain elastic. This load transfer manifests as an increase in elastic lattice strain of the particle. During this regime of deformation, the diffraction peak widths of each phase also exhibit significant changes, Fig-4. Much of this peak width increase is likely associated with non-uniform deformation of the constituent phases, arising from non-uniformities such as non-uniform particle distribution, different sizes and shapes of particles, as well as higher dislocation density and non-uniform plastic deformation of the ductile Al-alloy matrix. Some particle cracks may also occur at strains above 2%, and this would also lead to increase in peak width for the SiC particles.

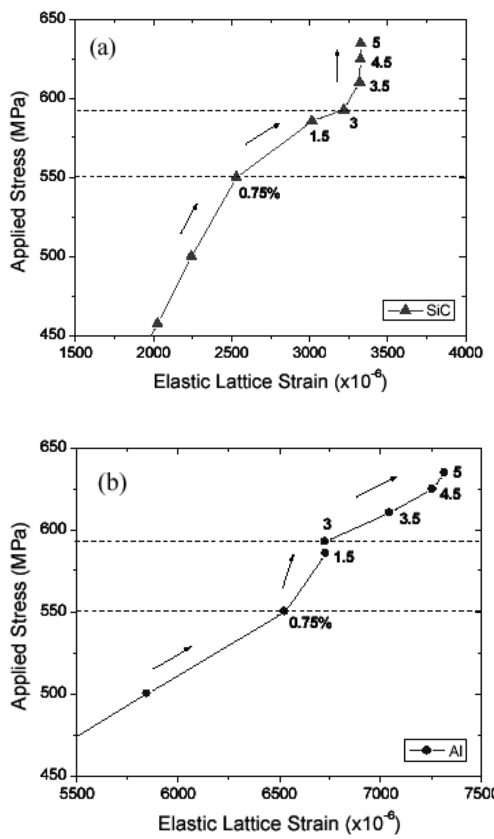

Fig-3 Evolution of elastic lattice strains in (a) SiC and (b) Al as a function of applied stress.

However, this latter effect is likely to be small, because the particles on the average exhibited significant increase in elastic lattice strain.

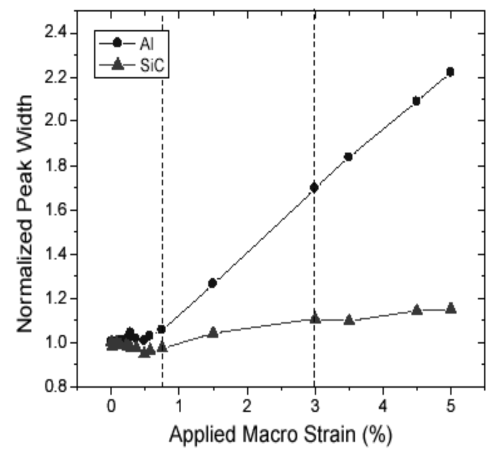

Fig-4 Evolution of normalized diffraction peak widths of the matrix and particles as a function of applied macro strain.

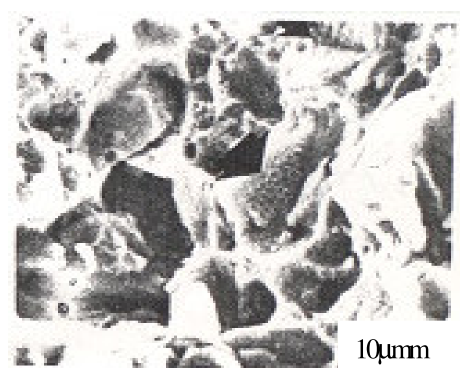

Fig-5 The fracture surface of the specimen

3.3 High Macro-Strain Regime

Beyond 3% applied strain, the slope of the matrix curve reverses its trend and decreases, Fig-3. This indicates that load is being transferred back to the matrix with continuing matrix plastic flow. Simultaneously, it is observed that the average elastic strain in the SiC particles saturates, particularly above 3.5% applied strain. Part of this behavior may be ascribed to particle fracture, which was observed to be the dominant damage mode in this composite, heat-treated to a high-strength under-aged (UA) condition. However, this explanation, at applied strains above 3.5%, requires that the decreased (almost zero) elastic strain in the cracked particles exactly balance out the increased elastic strain in the uncracked particles, whose stress must increase due to additional plastic strain imposed on the composite. The current analysis (Fig-3) of the neutron diffraction results simply provides the average change in lattice parameters of all the particles and matrix. If indeed there does exist this balance of lattice strains, then one should observe a significant increase in the peak width for the SiC particles. On the other hand, Fig-4 appears to indicate an opposite effect, in that the rate of increase in peak width is much smaller than the in the regime between 0.75% and 3% applied strain.

The metallographic observations had indicated that at most 20% of all particles had cracked by the time failure occurred at a total strain of 5.2%. The 4:1 higher volume fraction of uncracked to cracked particles would suggest that, if anything, the SiC curve should have had a finite positive slope rather than the observed infinite slope beyond 3.5% strain. Therefore, there must exist an alternate mechanism that prevents further loading of SiC particles beyond 3.5%, and this restriction would also be consistent with the observed reduced rate of peak width increase (since those particles cannot get loaded further and thereby fracture). One such possibility is a network of high slip activity of the matrix, or slip bands, between cracked particles; the latter must be the larger-sized ones, based on reasoning from Weibull distribution statistics. These slip bands would be macroscopic in nature and extend perhaps in a zig-zag manner from one face of the composite to the other, at different positions along the gage length. Additional strains would then be localized in these bands, which would give rise to small increases in elastic stress in the matrix through a work hardening effect. More importantly, such a network would prevent additional elastic stress to accrue in the 80% SiC particles that are located between the slip bands.

4. CONCLUSIONS

The evolution of elastic lattice strains in the matrix and reinforcement particles were observed during tensile loading of a Al-15% SiCp composite using in-situ neutron diffraction. The load partitioning behavior was investigated from the elastic and plastic regimes to high macrostrain regime where the effects of particle fracture damage became significant. Above 0.75% applied strain, the matrix started to yield and the load transfer from matrix to reinforcement was observed as expected. Beyond 3% applied strain, the load partitioning behavior was reversed and the load was shed back to the matrix from the particles. The anomalous strain partitioning behavior, beyond 3% macro strain, is likely due to particle fracture. The saturation in SiC straining, and the corresponding reloading of Al, may be due to slip in the matrix associated with particle cracks.

References

1. Maruyama B and Hunt W.H, Journal of Metals, V51, 1999, 59-61.

2. Kotiveerachari B, and Chennakesava Reddy A "Interfacial effect on the fracture mechanism in GFRP composites", *CEMILAC Conference, Ministry of Defence*, India, August 1999, pp. V1 (B), 85-87.

3. Chennakesava Reddy A, "Fracture behavior of brittle matrix and alumina trihydrate particulate composites", *Indian Journal of Engineering & Materials Sciences*, V9, 2002, 365-368.

4. Knott J.F, "Fundamentals of Fracture Mechanics", *Butterworths*, 1973

5. Dhinga A.K, Fishman S.G and Karmakar D, *Journal of Metals*, V33, 1981, 12-20.

6. Chennakesava Reddy A and Kotiveerachari B, "Effect of matrix microstructure and reinforcement fracture on the properties of tempered SiC/Al-alloy composites", *National conference on advances in materials and their processing*, December 2003, India.