Interface Debonding and Particulate Facture based on Strain Energy Density in AA3003/MgO Nanoparticulate Metal Matrix Composites

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Abstract: *Square array unit cell/2-D hexagonalparticulate RVE models were used to evaluate interface debonding and particulate fracture using two-dimensional finite element methods. The particulate metal matrix composites are magnesium oxide/AA3003 alloy at different volume fractions of magnesium oxide. The strain energy densities were smaller for the particulate fracture.*

Keywords: AA3003*, magnesium oxide, hexagonal particle, RVE model, finite element analysis, debonding, particulate fracture.*

1. INTRODUCTION

Due to their high strength to weight and stiffness to weight ratio, composite materials are being used extensively in the manufacturing of aerospace structures, automobile parts and other applications. The orthotropic nature of composites adds complexity to the analysis of these materials; however, there enough literature exists addressing the analysis procedure for structures made of composites [1]. Adhesion between particulate and matrix is controlled by properties of the interface. Generally high degree of adhesion is desirable to provide efficient transfer of load between particulate and matrix. The interaction between the reinforcement and the matrix was recognized at an early stage as a critical factor in determining the properties of the resulting MMC. It is necessary to control both the reinforcement-matrix interfacial bonding, in order to optimize mechanical properties, and diffusion and reaction at the interface, in order to minimize particulate degradation [2-11]. The reinforcement-matrix interface in MMCs, as in other composites, can rely on mechanical bonding or chemical bonding [12, 13].

The main objective of this study was to evaluate interface debonding and particulate fracture in AlSiMg alloy. The purpose of this paper is to evaluate debonding in AA3003 alloy/magnesium oxide particulate metal matrix composites.

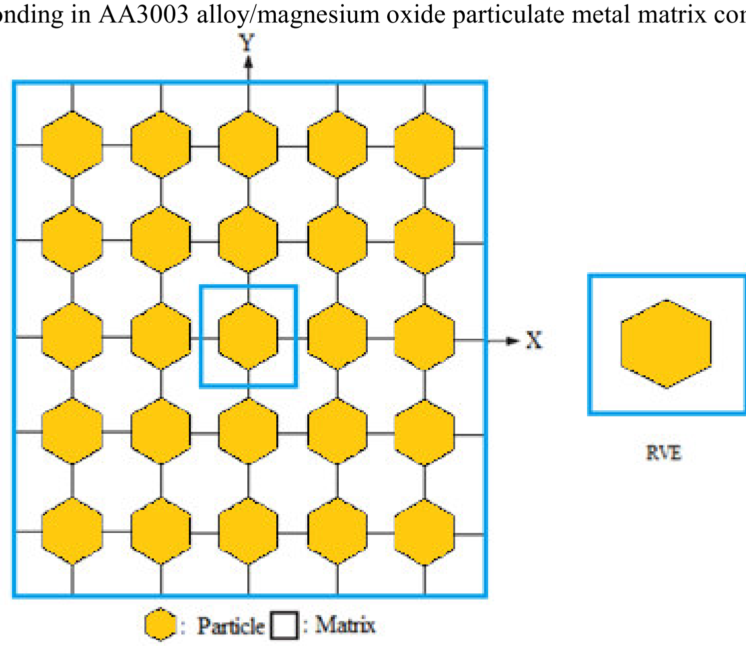

Figure 1: The RVE model: (a) particle distribution and (b) RVE scheme.

2. MATERIALS AND METHODS

The AA3003 alloy/magnesium oxide nanoparticulate metal matrix composites were used in the present work with 10%, 20%, and 30% volume fractions of magnesium oxide. The RVE scheme was constructed from 2-D hexagonal particulates in a square array particulate distribution using ANSYS software code. The perfect adhesion was assumed between magnesium oxide particle and AA3003 alloy matrix. PLANE183 element was used for the matrix and the nanoparticle. The interface between particle and matrix was modeled using CONTACT -172 elements.

If particle fracture occurs when the stress in the particle reaches its ultimate tensile strength, $\sigma_{p,uts}$, then setting the boundary condition at

$$\sigma_p = \sigma_{p,\ uts} \tag{1}$$

and substituting into Eq.(1) gives a relationship between the strength of the particle and the interfacial shear stress such that if

$$\sigma_{P,uts} < \frac{2\tau}{n} \tag{2}$$

Then the particle will fracture. Similarly if interfacial debonding/yielding is considered to occur when the interfacial shear stress reaches its shear strength

$$\tau = \tau_{max} \tag{3}$$

Then by substituting Eq. (5) into Eq.(1) a boundary condition for particle/matrix interfacial fracture can be established whereby,

$$\tau_{max} < \frac{n\sigma_p}{2} \tag{4}$$

This approach suggests that the outcome of a matrix crack impinging on an embedded particle depends on the balance between the particle strength and the shear strength of the interface.

A linear stress–strain relation at the macro level can be formulated as follows:

$$\bar{\sigma} = \overline{C}\bar{\varepsilon} \tag{5}$$

where $\bar{\sigma}$ is macro stress, and $\bar{\varepsilon}$ represents macro total strain and $\overline{C}$ and is macro stiffness matrix.

For plane strain conditions, the macro stress- macro strain relation is as follows:

$$\begin{Bmatrix} \overline{\sigma_x} \\ \overline{\sigma_y} \\ \overline{\tau_{xy}} \end{Bmatrix} = \begin{bmatrix} \overline{C_{11}} & \overline{C_{12}} & 0 \\ \overline{C_{21}} & \overline{C_{22}} & 0 \\ 0 & 0 & \overline{C_{33}} \end{bmatrix} \times \begin{Bmatrix} \overline{\varepsilon_x} \\ \overline{\varepsilon_y} \\ \overline{\gamma_{xy}} \end{Bmatrix} \tag{6}$$

The interfacial tractions can be obtained by transforming the micro stresses at the interface as given in Eq. (3):

$$t = \begin{Bmatrix} t_z \\ t_n \\ t_t \end{Bmatrix} = T\sigma \tag{7}$$

$$\text{where, } T = \begin{bmatrix} 0 & 0 & 0 \\ cos^2\theta & sin^2\theta & 2sin\theta cos\theta \\ -sin\theta cos\theta & sin\theta cos\theta & cos^2\theta - sin^2\theta \end{bmatrix}$$

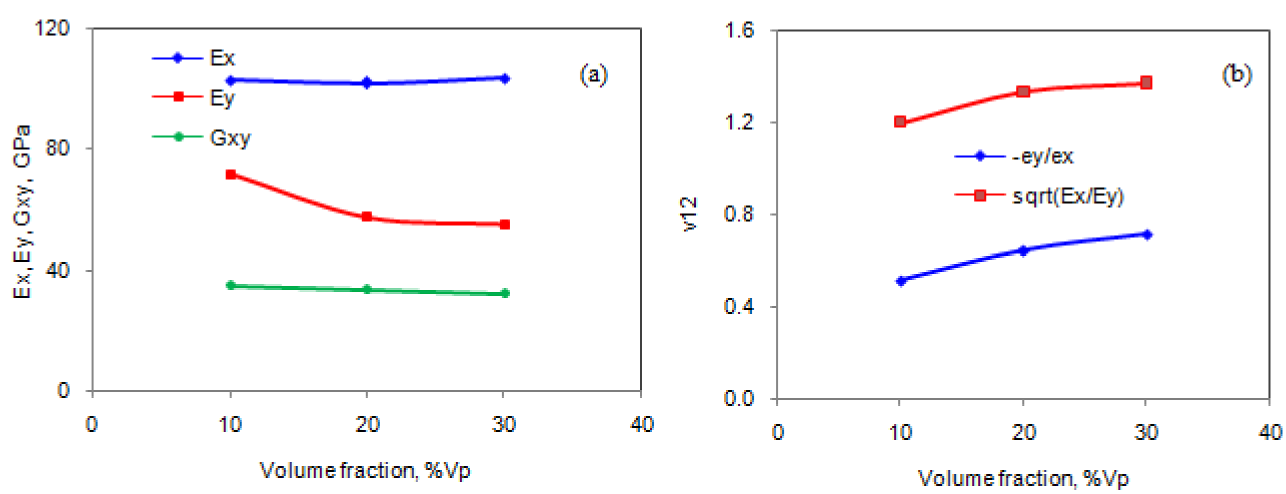

Figure 2: Effect of volume fraction on effective material properties.

3. RESULTS AND DISCUSSION

The effect of volume fraction of silicon nitride on the elastic moduli, E_x, E_y and G_{xy} is shown figure 2a. The tensile elastic modulus was nearly independent of magnesium oxide particulates in the composites, while the compressive and shear moduli decreased with the increase of magnesium oxide. The major Poisson's ratio increased with increase of volume fraction of magnesium oxide (figure 2b).

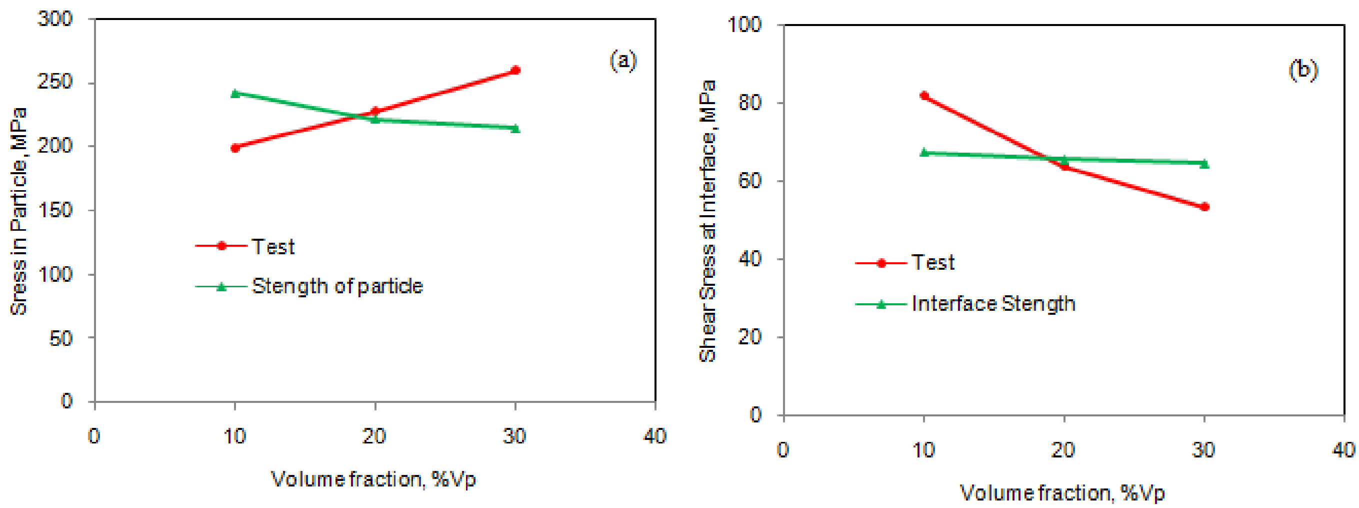

Figure 3: Fracture criteria of: (a) particulate fracture and (b) interface debonding.

The magnesium oxide particulate fracture was noticed as the condition $\sigma_p \leq 2\tau/n$ is satisfied at volume fractions of 20% and 30% magnesium oxide as shown in figure 3a. The strength of magnesium oxide particulate is lower than the shear stress required for fracturing magnesium oxide particulates. The debonding was occurred in AA1100/10%MgO nanoparticulate composites as shown in figure 3b. The condition $\tau_{max} < n\sigma_p/2$ was satisfied for the occurrence of debonding in this composite. The reasons for the interface debonding were of normal traction developed at the interface (figure 4). The strain energy density decreased with the increase of magnesium oxide content in the composites as shown in figure 5. A strain energy density function or stored energy density function is a scalar valued function that relates the strain energy density of a material to the deformation gradient. For the strain energy density lesser than 0.2, the AA3003/MgO nanoparticulate composites had undergone smaller deformation. This was owing to the fracture of MgO particulates.

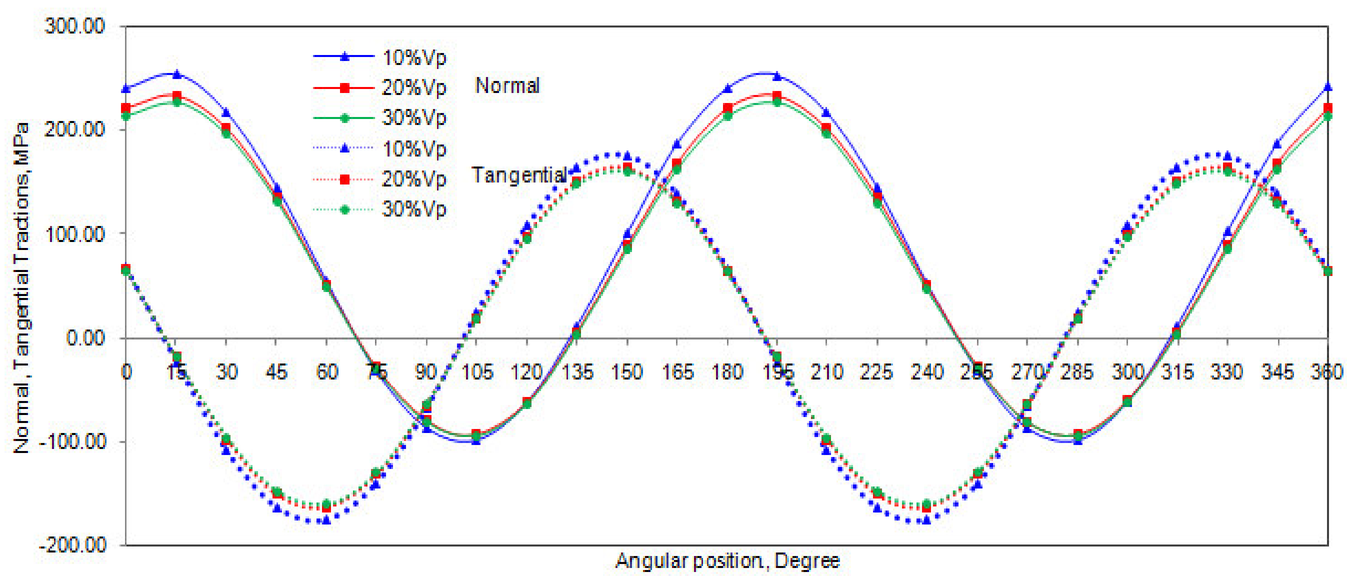

Figure 4: Normal and tangential interactions.

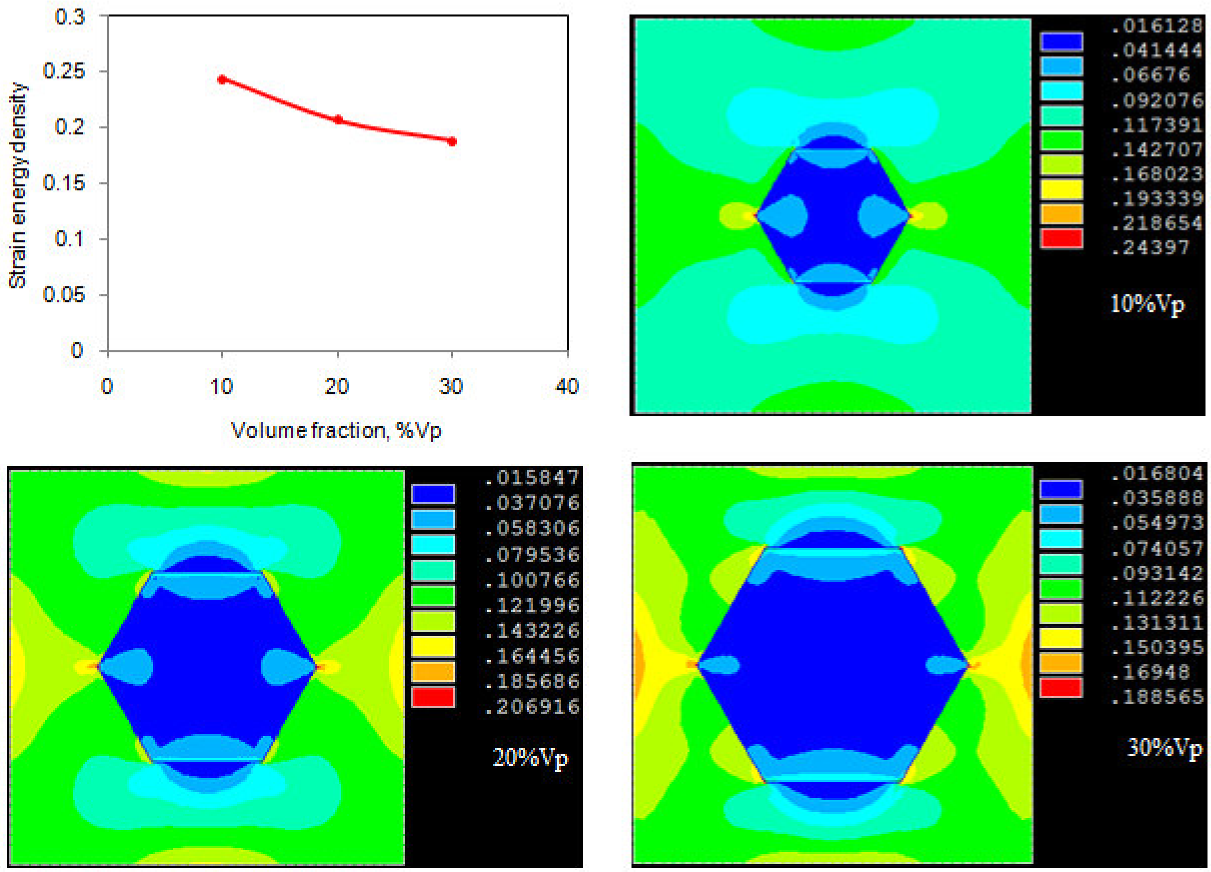

Figure 5: Results obtained from finite element analysis: strain energy densities.

4. CONCLUSION

The interface debonding took place at 10% volume fractions of MgO in the composite. The MgO particulate fracture wa observed in the composites having 20% and 30% MgO. The strain energy density was lower for particulate fracture than that for interface debonding.

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