Finite Element Analysis for Assessment of Dislocation and Debonding Events in Silicon Nitride/AA3003 Alloy Metal Matrix Composites

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Abstract: Diagonal square array based RVE models are used to find dislocations and debonding events using finite element analysis within silicon nitride/AA3003 alloy metal matrix composite under various particle loading conditions. The two-dimensional plane strain assumption is made for modeling. In the silicon nitride/AA3003 alloy metal matrix composite comprising of rhombus shaped particles, the occurrence of dislocation is predominant than the debonding.

Keywords: AA3003 alloy, silicon nitride, rhombus particle, RVE model, finite element analysis, interfacial tractions, debonding, dislocation.

1. INTRODUCTION

Modeling interfaces, which are often finite-thickness interphases, in composite materials is complicated. In numerical modeling, it would apparently be straight-forward to discretize interphase zones and thereby explicitly model all effects. This approach has two troubles. First, interphase zones may be much smaller than the bulk materials. Resolving both bulk materials and a thin interphase would require a highly refined model, which may exceed computational capacity. Second, interphase properties may be unknown and/or may vary within a transition zone from one material to another. The use of interface traction laws also replaces numerous unknown and potentially unmeasurable interphase properties with a much smaller number of interface parameters.

The concept of the cohesive zone model has been widely employed to investigate various material failure phenomena. The cohesive tractions exist along crack surfaces, which are smoothly joined together [1]. Micromechanics and a finite element-based cohesive zone model were integrated to study the constitutive relationship of materials with microstructure [2-4]. Particulate metal matrix composites are a class of materials that have evoked keen interest, largely due to the promise of improved properties over conventional metals and alloys. It is known that particle–matrix debonding (figure 1) degrades the elastic modulus of the composite considerably while having practically no effect on its density [5-14].

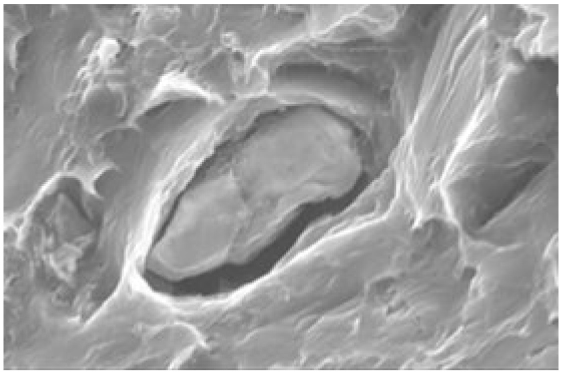

Figure 1: Decohesion in a metal matrix composite.

The intend of this paper is to estimate the effective material properties and debonding of silicon nitride/AA3003 alloy metal matrix composites. For this purpose, the RVE model is selected to be diagonal square array consisting periodical distribution of silicon nitride particulates in the AA3003 alloy matrix. The problem is modeled as plain strain problem and analyzed using finite element analysis code.

2. MATERIALS AND METHODS

The volume fractions of silicon nitride particulate reinforcement were 10%, 20%, and 30% in the matrix AA3003 alloy. The periodic model for the representative volume element (RVE) scheme is shown in figure 2. The perfect adhesion was assumed between Silicon nitride particle and AA3003 alloy matrix. PLANE183 element was used for the matrix and the nanoparticle. The interface between particle and matrix was modeled using a CONTACT-172 element.

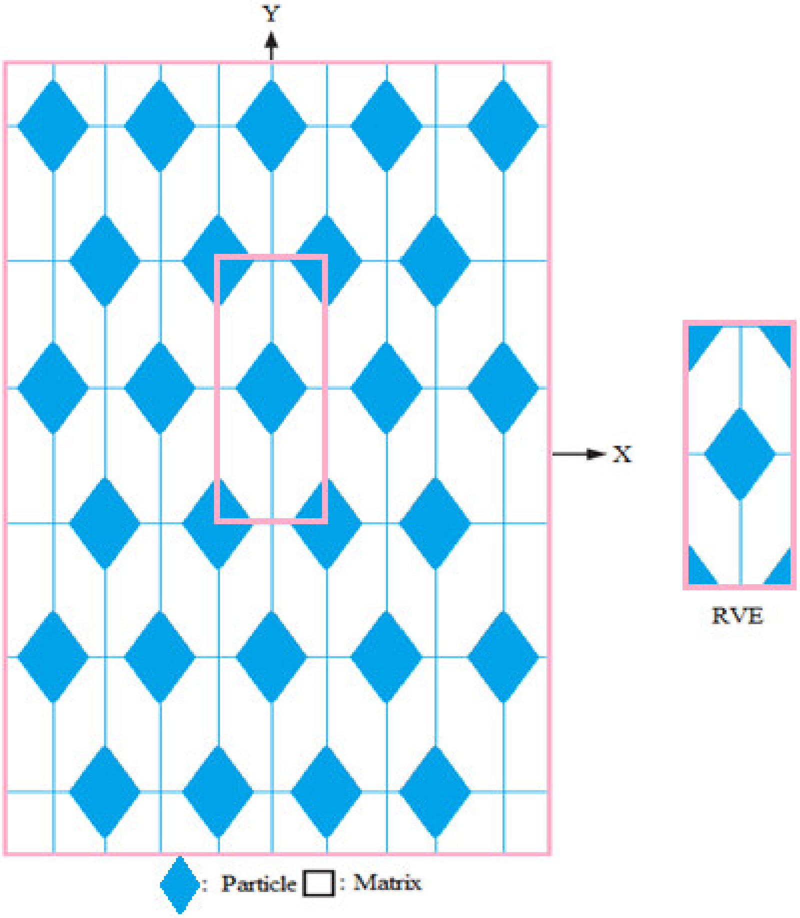

Figure 2: The RVE model: (a) particle distribution and (b) RVE scheme.

Interfaces in composite materials may develop potential energy that is needed for effective property analysis [15]. For an elastic interface, interfacial potential energy is:

$$\varphi_i = \int_{S_i} \left(\int \overline{T} \cdot [d\vec{u}]\right) ds \tag{1}$$

where Si is interfacial area.

The simplest assumption for traction laws is that they are linear and elastic. The tractions become:

Normal traction, $T_n = D_n[u_n]$ and Tangential traction, $T_t = D_t[u_t]$ (2)

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

$$\bar{\sigma} = \bar{C}\bar{\varepsilon} \tag{3}$$

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

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

$$\begin{Bmatrix} \overline{\sigma_x} \\ \overline{\sigma_y} \\ \overline{\tau_{xy}} \end{Bmatrix} = \begin{bmatrix} \overline{C_{11}} & \overline{C_{12}} & 0 \\ \overline{C_{21}} & \overline{C_{22}} & 0 \\ 0 & 0 & \overline{C_{33}} \end{bmatrix} \times \begin{Bmatrix} \overline{\varepsilon_x} \\ \overline{\varepsilon_y} \\ \overline{\gamma_{xy}} \end{Bmatrix} \tag{4}$$

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

$$t = \begin{Bmatrix} t_z \\ t_n \\ t_t \end{Bmatrix} = T\sigma \qquad (5)$$

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

3. RESULTS AND DISCUSSION

Form figure 3a, it is observed that the tensile elastic modulus, E_x and compressive elastic modulus, E_y increase with increase of volume fraction of silicon nitride in AA3003 alloy. The shear modulus, Gxy decreases with increase of volume fraction. As with increase of volume fraction increases the major Poisson's ratio decreases. This indicates that the lateral displacement is higher than the longitudinal displacement. Hence, the silicon nitride particle experiences the lateral compression due to tensile loading on the RVE model. The stress intensities are high at the vertices of rhombus particle (figure 4). The stress bridging decreases with increase of volume fraction of silicon nitride leading to deboning along the edges of rhombus particle along the axial direction of tensile laoding.

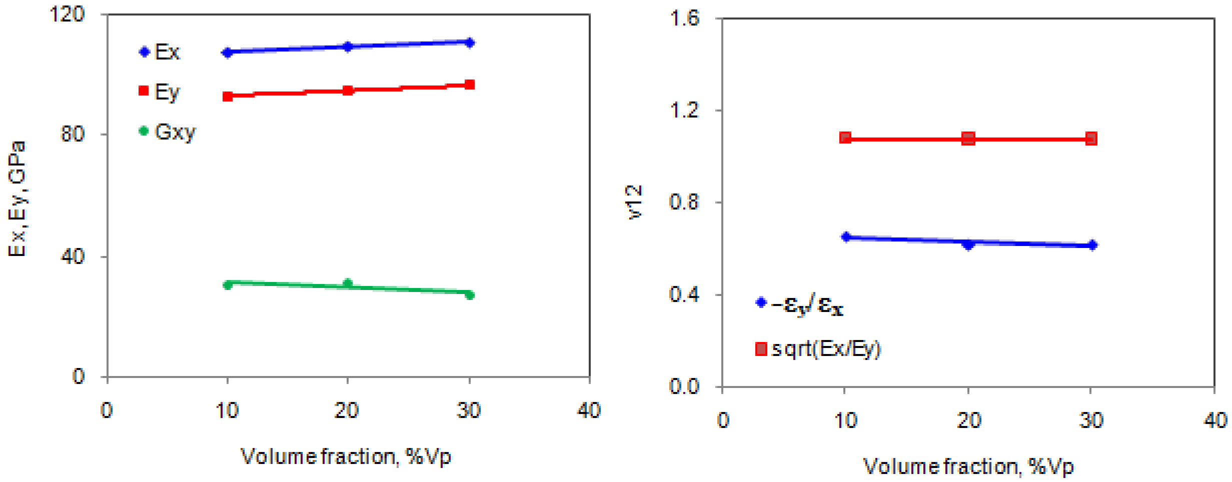

Figure 3: Effect of volume fraction on effective material properties.

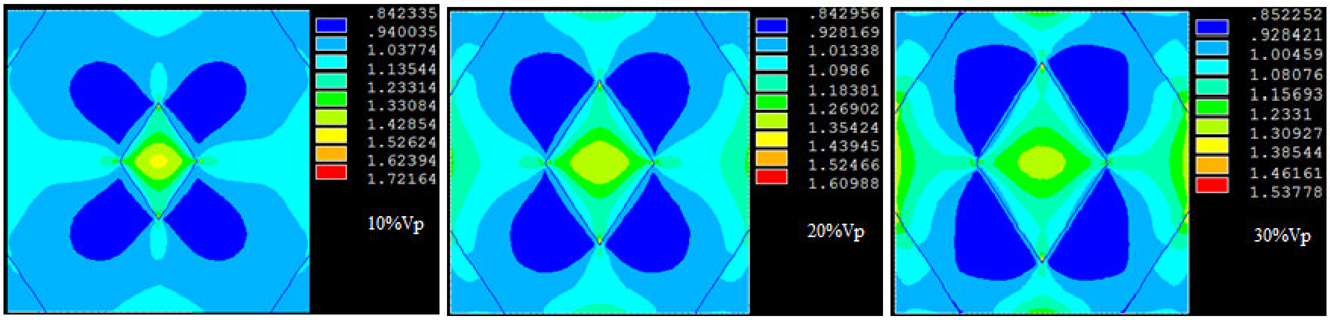

Figure 4: Stress concentrations in Si_3N_4/AA3003 alloy metal matrix composites.

The normal traction (figure 5a) and tangential traction (figure 5b) are respectively, same for all compositions of the metal matrix composites. In the span of 150° along the particle surface, the tangential traction becomes zero twice while the normal traction reaches zero only once. The tangential traction is responsible for the dislocation and the normal traction is attributed for the debonding. Therefore, dislocation events are higher than the debonding occurrence in the silicon nitride/AA3003 alloy metal matrix composites.

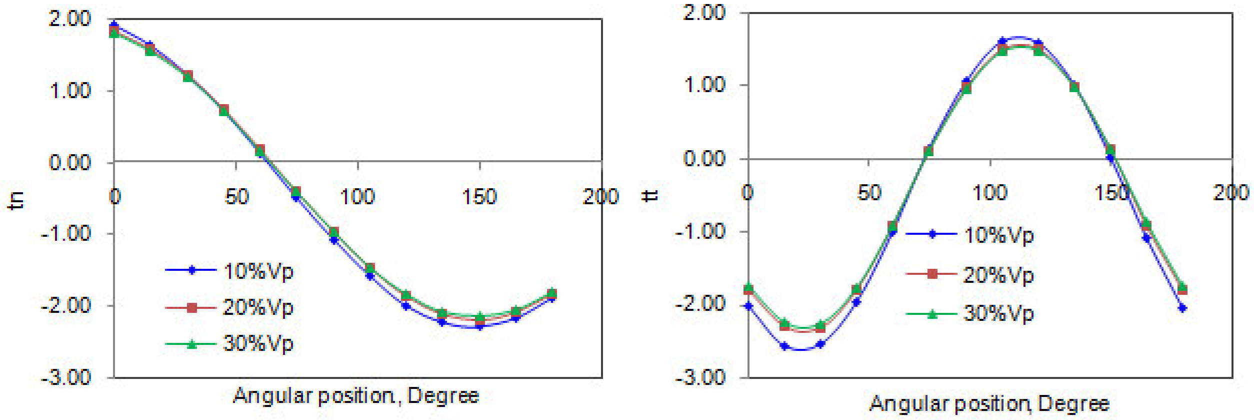

Figure 5: Interfacial tractions along the angle due to tensile loading: (a) normal and (b) tangential.

4. CONCLUSION

Micromechanics and a finite element-based cohesive zone model are integrated to study the dislocation and debonding phenomena in the silicon nitride/AA3003 alloy metal matrix composites. The dislocation events are high in these composites having rhombus shaped particulates.

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