Simulation of Micromechanics for interfacial debonding in Silicon Nitride/AA2024 Alloy Metal Matrix Composites

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Abstract: Square RVE scheme with plain strain condition is analyzed using finite element analysis for the silicon nitride/AA2024 alloy metal matrix composite under various particle loading conditions. The debonding is observed along the edges of rhombus particles.

Keywords: AA2024 alloy, Silicon nitride, rhombus particle, RVE model, finite element analysis, interfacial tractions, debonding.

1. INTRODUCTION

Particulate composites represent a large group of materials used in a variety of applications, such as automobile and aerospace industries. The mechanical behavior of these materials depends upon properties of constituents and any microstructural changes that may occur in the body under loading. The damage in reinforced composites appears to be associated with micro cracks initiating and growing within a matrix and along the matrix–particle interfaces. The mechanical behavior of these phenomena has been studied extensively over many years [1-4].

Figure 1 shows overall elastic and secant modulus. $\bar{\mu}$ is the inelastic strain due to debonding during the loading process. Propagation path of debonding initiated from stress concentrations depends on the elastic and strength properties of the materials as well as their interface fracture properties. Research efforts have been concentrated on understanding the causes and mechanisms of debonding failures through theoretical, numerical, and experimental approaches. Research studies in this area can generally be classified as strength and fracture approaches. Interface friction or sliding theories have been also investigated [5]. The micromechanics-based models have not been fully utilized yet in damage evolution, except in finite element methods of unit cell models described [6].

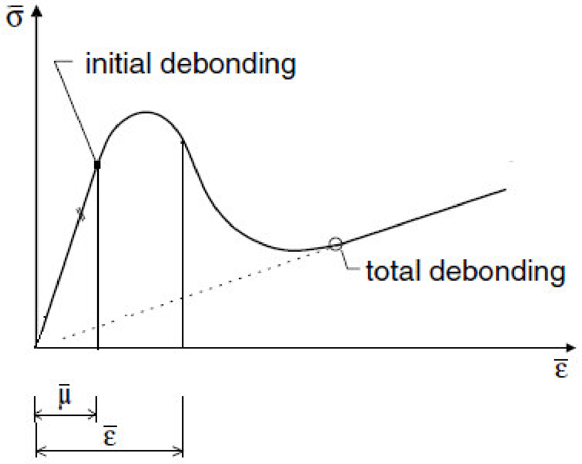

Figure 1: Debonding mechanism

The present work focuses on the prediction of debonding failures through strength approach which involves calculation of the interfacial or bond stress distribution in the particulate metal matrix composites. The analysis is performed in plane strain with linear kinematics. RVE model is of square array consisting periodical distribution of silicon nitride particulates (having 2-dimensional rhombus shape) in the AA2024 alloy matrix.

2. MATERIALS AND METHODS

Silicon nitride is the particulate reinforcement having volume fractions of 10%, 20%, and 30% in the matrix AA2204 alloy. The periodic model for the square representative volume element (RVE) scheme is shown in figure 2. The perfect adhesion was assumed between silicon nitride particle and AA2204 alloy matrix [7-16]. PLANE183 element was used for the matrix and the nanoparticle. The interfacial cohesive zone between particle and matrix is modeled using a CONTACT-172 element.

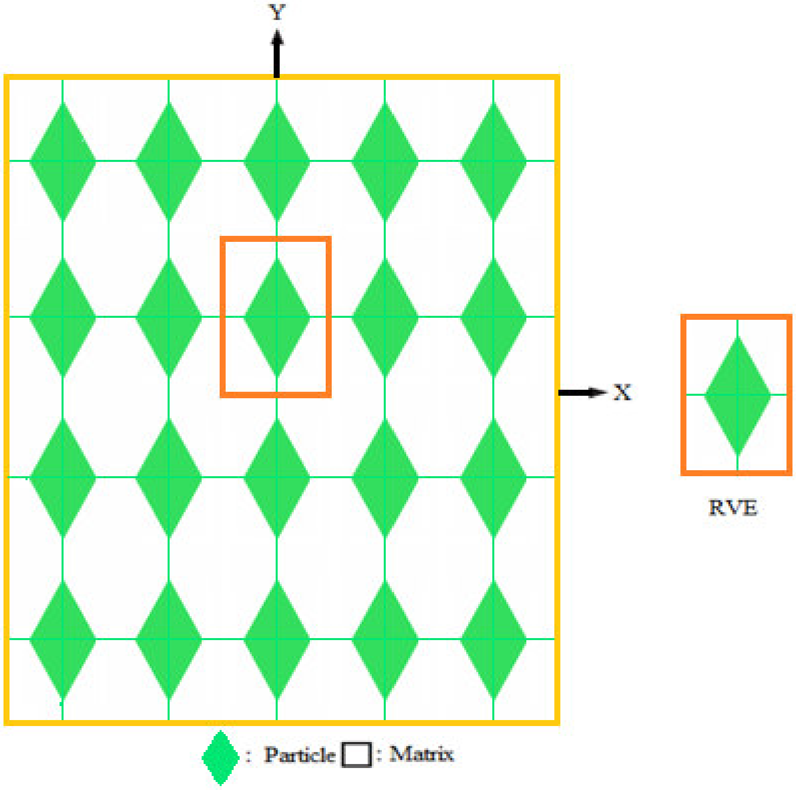

Figure 2: The RVE model: (a) particle distribution and (b) RVE scheme.

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

$$\bar{\sigma} = \bar{C}\bar{\varepsilon} \qquad (1)$$

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:

$$\begin{Bmatrix} \bar{\sigma}_x \\ \bar{\sigma}_y \\ \bar{\tau}_{xy} \end{Bmatrix} = \begin{bmatrix} \bar{C}_{11} & \bar{C}_{12} & 0 \\ \bar{C}_{21} & \bar{C}_{22} & 0 \\ 0 & 0 & \bar{C}_{33} \end{bmatrix} \times \begin{Bmatrix} \bar{\varepsilon}_x \\ \bar{\varepsilon}_y \\ \bar{\gamma}_{xy} \end{Bmatrix} \qquad (2)$$

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

$$t = \begin{Bmatrix} t_z \\ t_n \\ t_t \end{Bmatrix} = T\sigma \qquad (3)$$

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

3. RESULTS AND DISCUSSION

The tensile elastic modulus, E_x increases with increase of volume fraction of silicon nitride in AA2024 alloy matrix as shown in figure 3a. The compressive elastic modulus, E_y decreases with the increase of volume fraction from 10%Vp to 20%Vp of silicon nitride and it increases polynomially from 20% vp to 30% Vp. The shear modulus, Gxy decreases with an increase t in the volume fraction of silicon nitride. The major Poisson's ratio is unchanged with increase of volume fraction of silicon nitride for SiN_4/AA1100 alloy metal matrix composites (figure 3b). Figure 4 shows von Mises stresses induced in a unit cell of square array RVE under tensile stress. The maximum von Mises stress occurs at vertices of the rectangular particulate. The edges of the rhombus experience least stress.

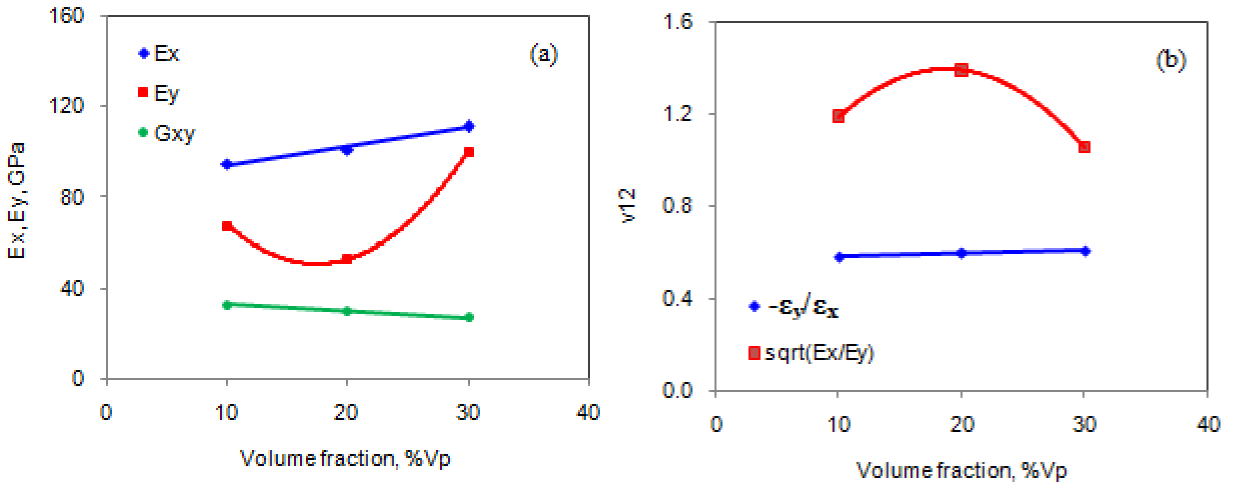

Figure 3: Effect of volume fraction on effective material properties.

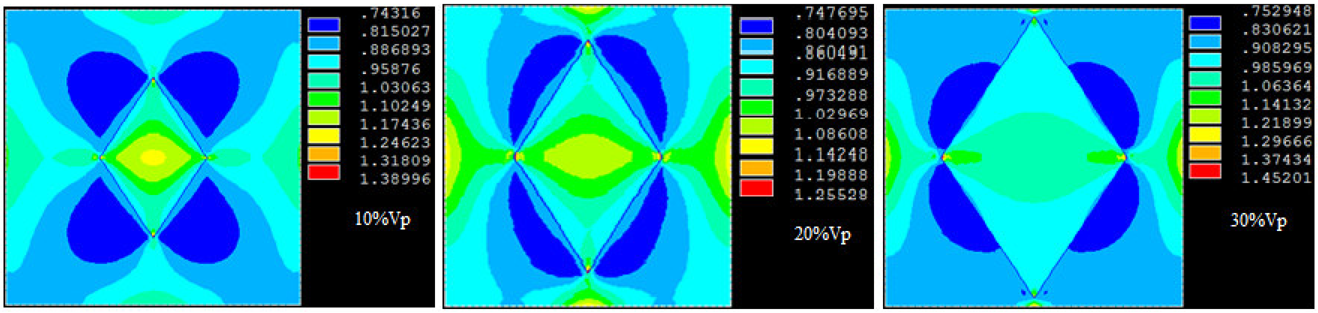

Figure 4: Stress concentrations in Si_3N_4/AA1100 alloy metal matrix composites.

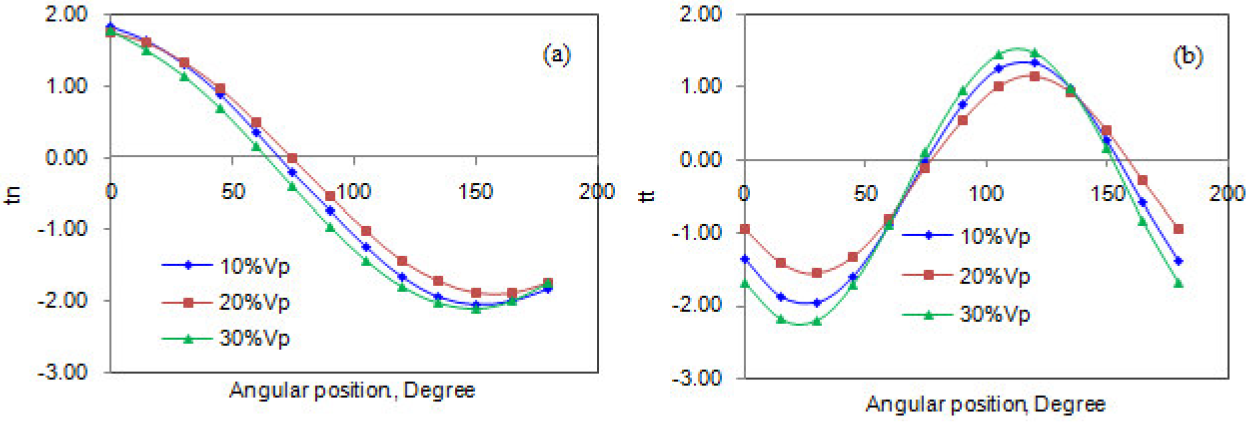

Figure 5: Interfacial tractions along the angle due to tensile loading: (a) normal and (b) tangential.

The debonding analysis is performed in two dimensions using a plane strain assumption through strength approach. The normal traction reaches zero at nearly 75^o and it becomes minimum at 150^o (figure 5a). The tangential traction approaches zero at nearly 75^o and 150^o (figure 5b). The minimum values of tractions indicate the debonding of silicon nitride particle with the matrix.

4. CONCLUSION

In this work, the plain strain condition is employed to assess the interfacial debonding of the particle-matrix interface. The debonding appears at the edges of the rhombus particle. The debonding increases with increase of volume faction of silicon nitride.

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