Evaluation of Debonding and Dislocation Occurrences in Rhombus Silicon Nitride Particulate/AA4015 Alloy Metal Matrix Composites

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Abstract: A micromechanical modeling is carried out to evaluate of debonding and dislocation occurrences in silicon nitride/AA4015 alloy metal matrix composite under various particle loading conditions. Square hexagonal array unit cell/rhombus particle RVE models are worked out using two-dimensional finite element methods. There is strong likelihood of debonding at the particle-matrix interface.

Keywords: AA4015 alloy, silicon nitride, rhombus particle, RVE model, finite element analysis, interfacial tractions, debonding, dislocation.

1. INTRODUCTION

The shear lag model [1] has been used to describe the build up and transfer of particle stress, σp from the point where the particle enters the matrix to some point along the particle axis where the tensile stress has decayed to zero. Failure of the particle/matrix interface occurs when the interfacial shear strength, τmax, is reached.

The shear lag distribution of strain, along a fully bonded particle can be described by [1]

$$e_{app} = e_p \frac{\mathrm{sibh}[n(L_{e-x/r})]}{\mathrm{sinH}(ns)} \quad (1)$$

where eapp is the strain acting on the particle outside the matrix, ep is the particle strain at a distance x inside the matrix, Le is the embedded length, r is the particle radius and s is the particle aspect ratio (Le/r). The n parameter used in this paper is based on the parameter derived by Nairin [2]:

$$n^2 = \frac{2}{E_p E_m}\left[\frac{E_p V_p + E_m V_m}{V_m/(4G_p) + 1/(2G_m)\left((1/V_m)\ln(1/V_p) - 1 - (V_m/2)\right)}\right]$$
(2)

where E_p and G_P ate the particle elastic and shear moduli, E_m and G_m are the elastic and shear moduli of the matrix. V_p is the particle volume fraction and V_m is the volume fraction of matrix. The corresponding interfacial stress, τ at a distance x along the interface, is given by

$$\tau = \frac{n}{2} E_p e_{app} \frac{\cosh[n(L_e - x)/r]}{\sinh[ns]} \quad (3)$$

Is a maximum at the crack plane ($x = 0$). Since both the interfacial shear stress and the stress acting on the particle, are a maximum at the crack-plane then failure should be expected to initiate from this point. When $x = 0$, the Eq. (3) becomes:

$$\tau = \frac{n}{2} E_p e_p \quad (4)$$

If the particle deforms in an elastic manner (according to Hooke's law) then,

$$\tau = \frac{n}{2} \sigma_p \quad (5)$$

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

$$\sigma_p = \sigma_{p,\,uts} \quad (6)$$

ans substituting into Eq.(5) gives a relationship between the strength of the particle and the interfacial shear stress such that if

$$\sigma_{P,uts} < \frac{2\tau}{n} \quad (7)$$

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

$$\tau = \tau max \quad (8)$$

Then by substituting Eq. (8) into Eq.(5) a boundary condition for particle/matrix interfacial fracture can be established whereby,

$$\tau_{max} < \frac{n\sigma_p}{2} \quad (9)$$

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.

Hence, the present research aims to judge the particle fracture or the debonding of the interface between the particle and the matrix in titanium boride/AA4015 alloy particulate metal matrix composites. Finite element method is used to construct and analyze the different (representative volume elements (RVEs) models of periodic rhombus particulates in a hexagonal square array of periodical distribution.

2. MATERIALS AND METHODS

The volume fractions of silicon nitride particle reinforcement were 10%, 20%, and 30% in the matrix AA4015 alloy. The periodic model for the representative volume element (RVE) scheme is shown in figure 1. The perfect adhesion was assumed between titanium boride particle and AA4015 alloy matrix. PLANE183 element was used for the matrix and the nanoparticle. The interface between particle and matrix was modeled using CONTACT -172 element.

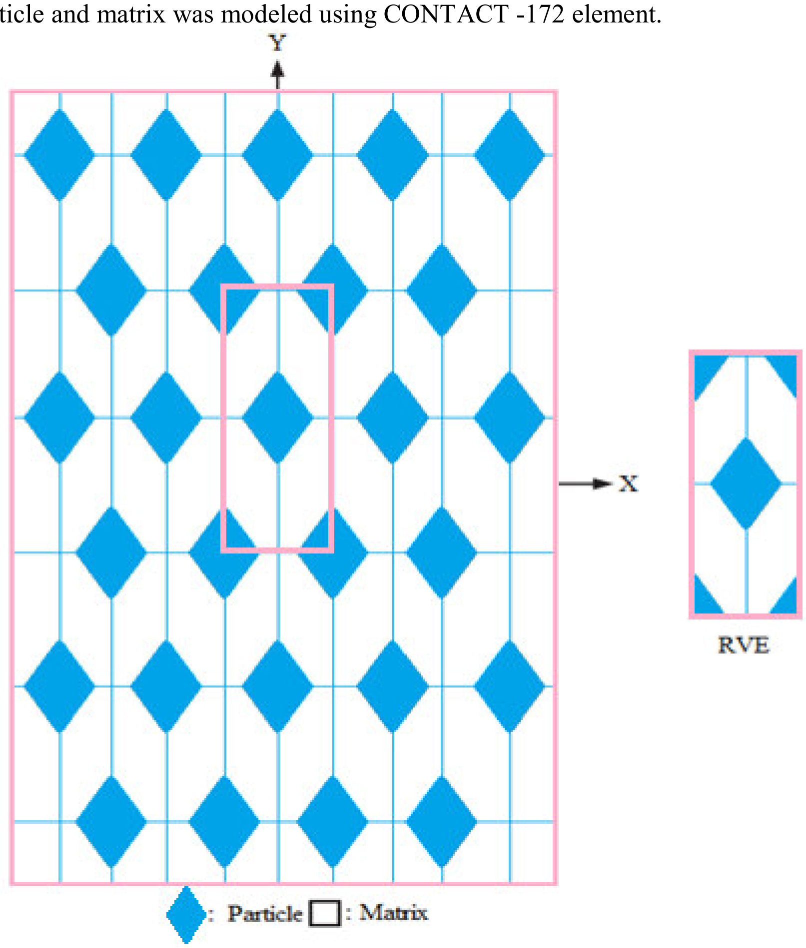

Figure 1: The RVE model: (a) particle distribution and (b) RVE scheme.

Surface tractions, or stresses acting on an internal datum plane, are typically decomposed into three mutually orthogonal components. One component is normal to the surface and represents direct stress. The other two components are tangential to the surface and represent shear stresses. The definition of the tractions in terms of stresses is shown in figure 2.

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

$$\bar{\sigma} = \bar{C}\bar{\varepsilon} \quad (10)$$

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

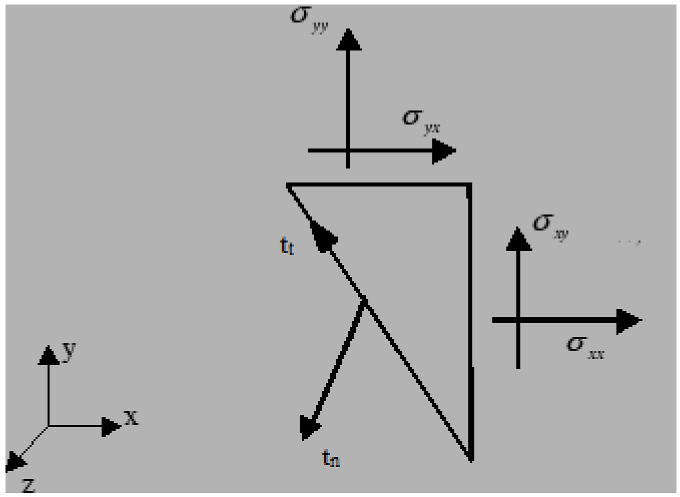

Figure 2: 2-D Free-Body with Tractions and Stress Components.

For plane strain conditions, the macro stress- macro strain relation [3-12] is as follows:

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

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

$$t = \begin{Bmatrix} t_z \\ t_n \\ t_t \end{Bmatrix} = T\sigma \tag{12}$$

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

Influence of volume fraction on the elastic moduli, E_x, E_y and Gxy are shown figure 3a. The tensile elastic, compressive elastic and shear moduli decrease with increase of volume fraction silicon nitride. The major Poisson's ratio is increases with increase of volume fraction silicon nitride for Si_3N_4/AA4015 alloy metal matrix composites (figure 3b). Figure 4 shows stress intensities induced in a unit cell of square hexagonal array RVE under tensile stress. The maximum stress intensities occur at vertices of and within the rhombus particle. The stress bridging is observed between the particles through the matrix.

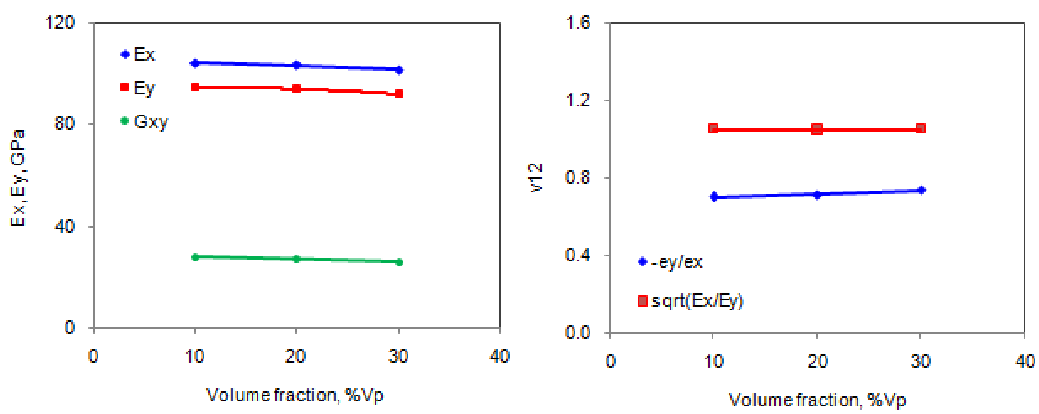

Figure 3: Effect of volume fraction on effective material properties.

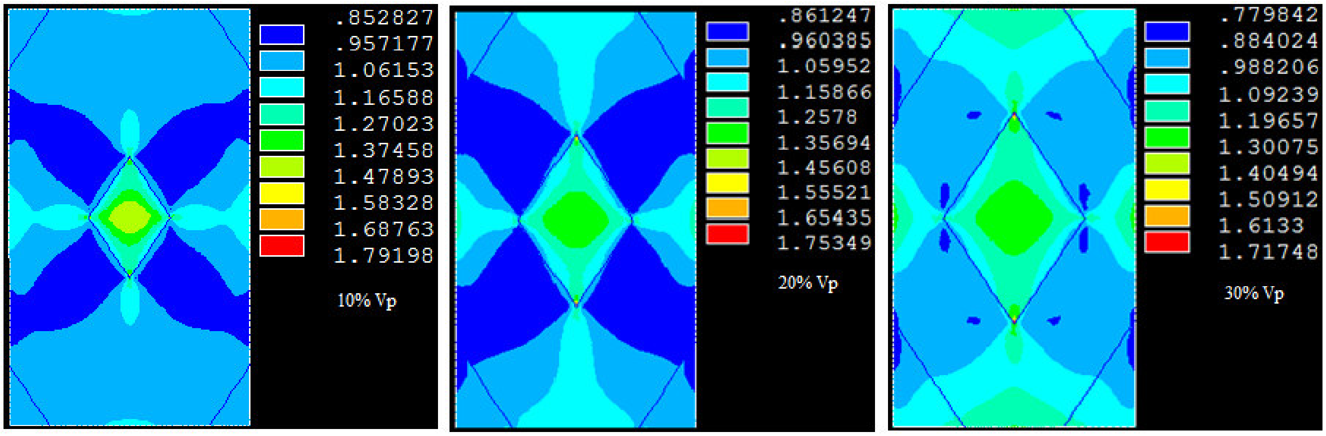

Figure 4: Stress intensities in Si_3N_4/AA4015 alloy metal matrix composites.

The interfacial normal traction, t_n decreases with as θ increases from 0° to 90° and 180° to 270° (figure 5a) and it increases from 90° to 180° and 270° to 360°. The interfacial traction becomes zero at 55°, 130°, 235° and 310° and it reaches maximum at 0°, 180° and 360°. The normal traction t_n turns into negatively maximum between 55° and 130° and again between 235° and 310° due to compression of Poisson's effect. The tangential traction t_t, decreases as θ decreases from 0° to 45°, from 135° to 225° and from 315° to 360°. It becomes zero value at θ =90°, 180°, 270°, and 360°. The incidence of zero value of normal traction represents the debonding at particle-matrix interface. The incidence of zero value of tangential traction indicates the dislocation. The decrease of elastic and shear moduli is strong candidature of debonding.

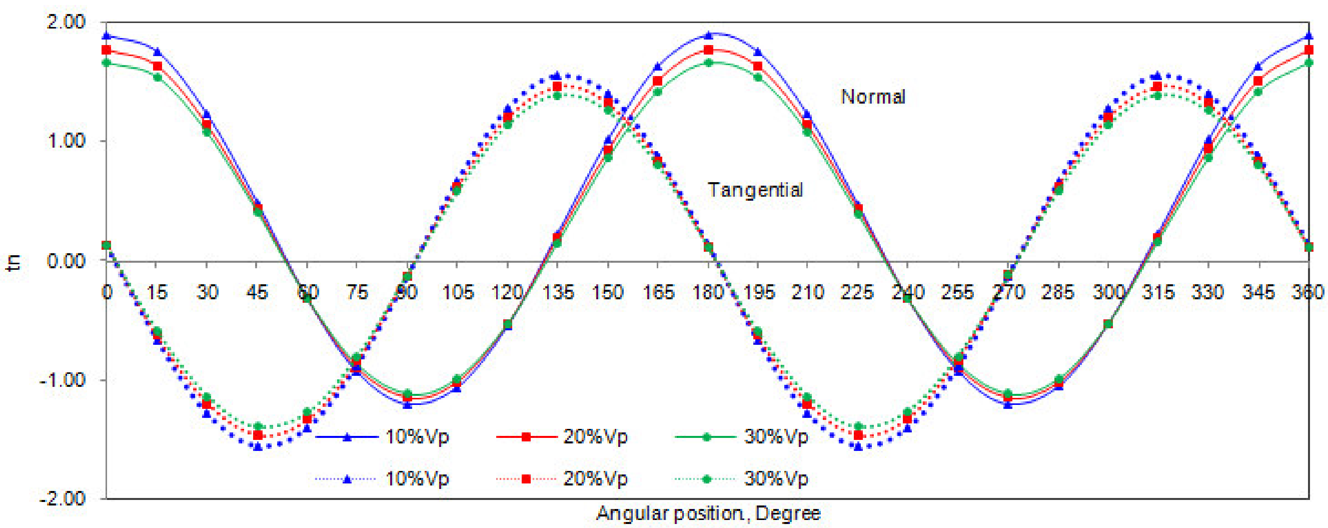

Figure 5: Interfacial tractions along the angle due to tensile loading.

4. CONCLUSION

Elastic and shear moduli decrease with increase of volume fraction of silicon nitride. The deboning between particle and matrix take place and it is confirmed by the decrease of elastic moduli.

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