Interfacial Debonding Analysis in Terms of Interfacial Tractions for Titanium Boride/AA3003 Alloy Metal Matrix Composites

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Abstract: A micromechanical approach is developed to determine the micro stress within a metal matrix composite under various particle loading conditions. Diamond unit cell/ round particle RVE models are analyzed and compared using two-dimensional finite element methods. Subsequently, effective material properties, the distribution of micro stress in the particle/matrix, as well as traction distribution at the particle–matrix interface, and the effect of different interfacial stiffness, are obtained. Interfacial debonding is analyzed through normal and tangential tractions. Debonding at particle-matrix interfaces is simulated for different volume fractions.

Keywords: AA3003 alloy, titanium boride, RVE model, finite element analysis, interfacial tractions, debonding.

1. INTRODUCTION

Unit cell approach is a novel method for simulating the behavior of composite materials by making use of the capabilities of a finite element software package [1, 2]. An abundance of research has been devoted to obtaining predictions of equivalent moduli of composite media [3-10]. A homogeneous material has identical physical properties at any point in a body, whereas a nonhomogeneous material exhibits physical properties as a function of position within the body [11-14]. The nonhomogenity in the metal matrix composites can be attributed to the presence of dispersed particulates in a matrix and the mechanical behavior of these composites largely depends on the size, shape and properties of these particulates (figure 1).

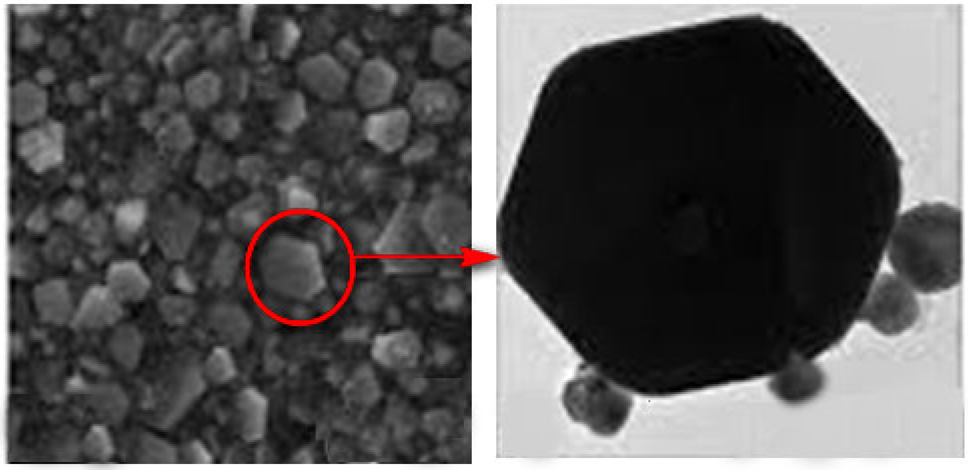

Figure 1: Reinforced particle in a metal matrix composite.

The purpose of this paper is to determine the elastic moduli, major Poisson's ratio and interfacial tractions of titanium boride/AA3003 alloy metal matrix composites. Finite element analysis (FEA) of TiB_2/AA3003 alloy metal matrix composites was executed RVE models comprising of square hexagonal cell/hexagonal particle.

2. MATERIALS AND METHODS

The matrix material was AA3003 alloy. The volume fractions of titanium boride particulate reinforcement were 10%, 20%, and 30%. The representative volume element (RVE) scheme is shown in figure 2. The perfect adhesion was assumed between titanium boride 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 COMBIN14 spring-damper element.

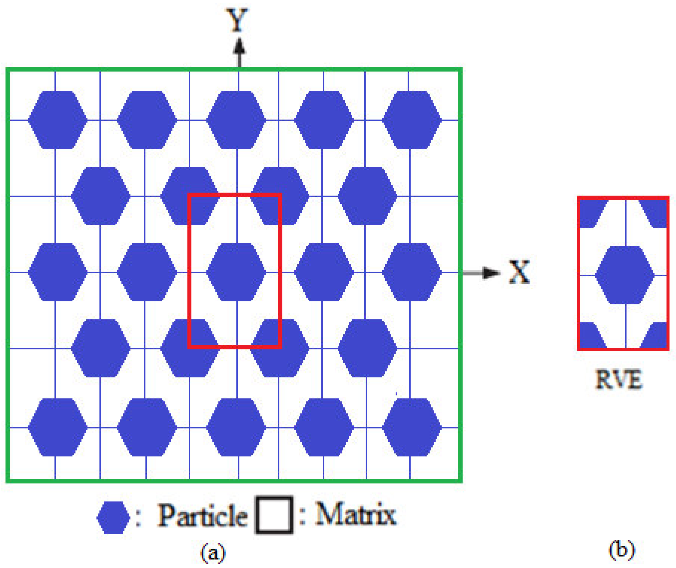

Figure 2: The RVE model: (a) particle distribution and (b) RVE scheme.

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

$$\bar{\sigma} = \bar{C}\bar{\varepsilon} \tag{1}$$

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:

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

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

$$t = \begin{Bmatrix} t_z \\ t_n \\ t_t \end{Bmatrix} = T\sigma \tag{3}$$

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

3. RESULTS AND DISCUSSION

Figure 3a exhibits an increase in moduli with incrementally increasing volume fraction of titanium boride in the matrix AA3003 alloy. Figure 3b indicates a marginal increase in the major Poisson's ratio. Figure 3c indicates a significant drop in the shear modulus decreases as volume fraction increases from 10%Vp to 30%Vp.

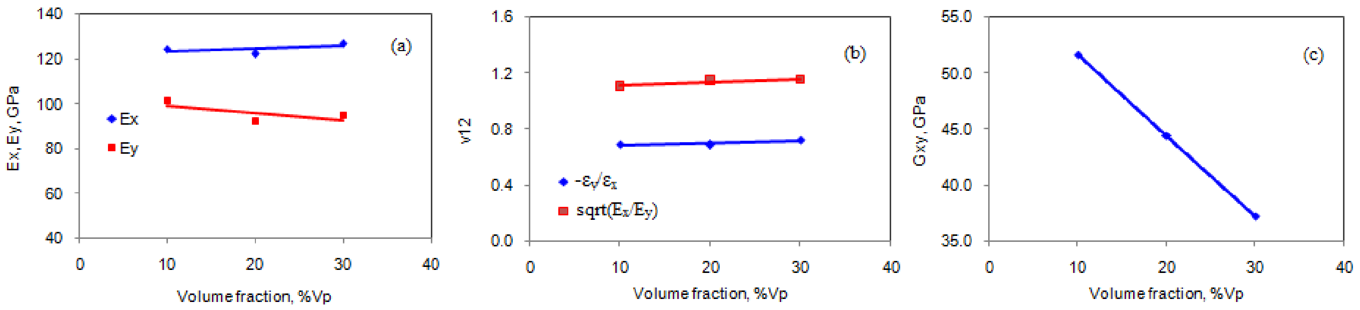

Figure 3: Effect of volume fraction on effective material properties.

Figure 4 shows stress concentrations induced in a unit cell of square hexagonal array under tensile stress. In a unit cell of square hexagonal array under tensile stress, maximum stress concentrations particle (green color) are observed in the titanium boride. The regions of minimum stress (blue color) concentrations occur at the particle-matrix interface in the transverse direction of tensile loading. The stress distribution in and around the particle is symmetric with respect to the mid-point of the particle. The quantity of stress bridging is decreased with the increase of volume fraction of titanium boride in the matrix AA3003 alloy as the stress levels are raised in the titanium boride particles due to more load transfer the matrix to the particle.

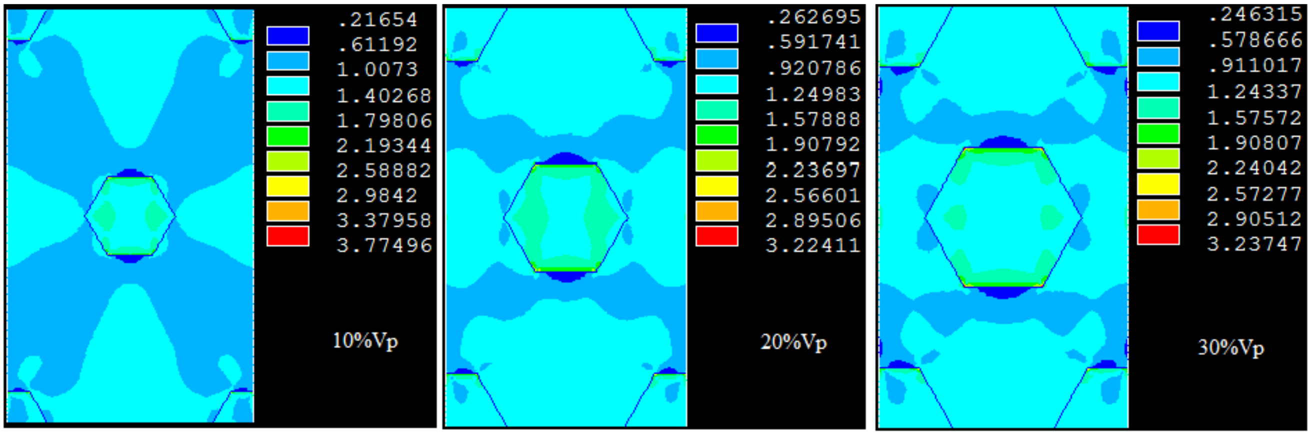

Figure 4: Stress concentrations in TiB_2/AA3003 alloy metal matrix composites.

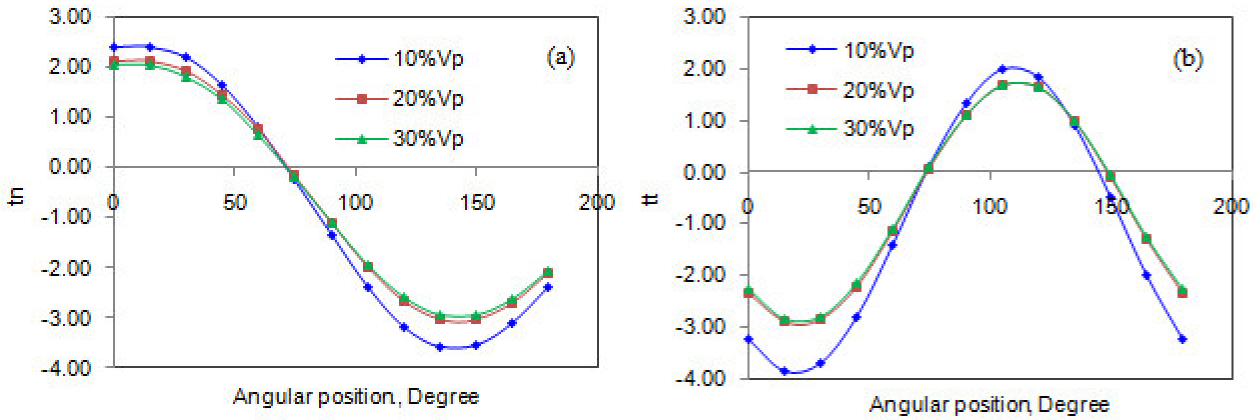

Figure 5: Interfacial tractions along the angle due to tensile loading: (a) normal and (b) tangential.

To understand the effects of stress distribution on the debonding process, the normal and tangential interfacial stresses t_n and t_t are plotted from $\theta = 0°$ (the loading direction) to $\theta = 180°$, in figure 5. The interfacial normal traction, t_n decreases with as θ increases from 0^o to 135^o (figure 5a). The direction of macro load coincides with the direction of t_n at $\theta = 0^o$, so t_n attains its minimum at 135^o due to compression by the Poisson's effect. As for tangential traction t_t, whose variation with θ is shown in figure 5b, its value decreases as θ increases from 0^o to 15^o, and then increases until $\theta = 105^o$. The normal stress plots are symmetric about the angular position $\theta = 0°$, while the tangential stresses are antisymmetric about this angle. Prior to debonding, the normal stress is maximum at $\theta = 0°$. With progressive debonding, the peak tensile stress t_n initially increases in magnitude but subsequently decreases. This behavior may be explained as a consequence of two competing phenomena, viz. an increase in average stress due to increasing debond length and a decrease in the normal component of stress with increasing angular orientation. The compressive region also increases with increasing decohesion. For the tangential stress t_t, the maximum value at the debonding region is also found to first increase slightly and then decrease with progressive debonding.

4. CONCLUSION

For effective material properties, variations of Ex, E_y, G_{xy} and v_{12} with respect to volume fraction, are predicted. Additionally, in unit cells with different particle volume fractions, variations of interfacial tractions along particle perimeter under tension loading. The progress of interfacial debonding is estimated in terms of normal and tangential tractions and interfacial separation. In these relations, the traction increases with separation reaches a maximum and subsequently subsides to zero traction, signaling debonding. The boundary conditions include periodicity conditions. Even with periodic geometric features, a distinct non-periodic debonding path evolves at higher volume fractions.

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