Determination of Micro-stresses and interfacial Tractions in Titanium Boride/AA1100 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. Square unit cell/hexagonal 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. The major Poisson's ratio increases with increase of volume fraction of titanium boride in the metal matrix composites

Keywords: AA1100 alloy, titanium boride, RVE model, finite element analysis, interfacial tractions, hexagonal shaped particle.

1. INTRODUCTION

In mean-field modeling of particulate composite materials, a composite unit cell is subjected to mean stress or strain and the effective stiffness or compliance tensors are found by averaging strains and stresses throughout the composite [1, 2]. Most prior numerical studies have been limited to modest fiber/matrix modulus ratios of $R = E_f / E_m < 30$ and relatively short fiber aspect ratios, $\rho = l_f/d_f < 30$ [3]. The heterogeneity 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).

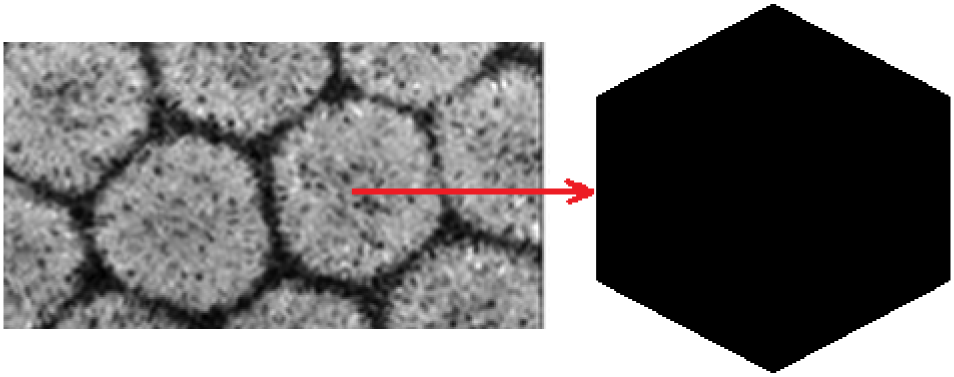

Figure 1: Reinforced particle in a metal matrix composite.

The aim of the present paper is to predict micro stresses and interfacial tractions of titanium boride/AA1100 alloy metal matrix composites. Finite element analysis (FEA) of TiB_2/AA1100 alloy metal matrix composites was executed RVE models comprising of square cell/hexagonal particle. The shape of titanium boride particle was assumes to be hexagonal.

2. MATERIALS AND METHODS

The matrix material was AA1100 alloy. The volume fractions of titanium boride particulate reinforcement were 10%, 20%, and 30%. The RVE scheme was employed to predict micro stresses and interfacial tractions through finite element analysis as shown in figure 2. The perfect adhesion was assumed between titanium boride particle and AA1100 alloy matrix. PLANE183 element was employed for the matrix and the nanoparticle. The interface between particle and matrix was discretized using a COMBIN14 spring-damper element.

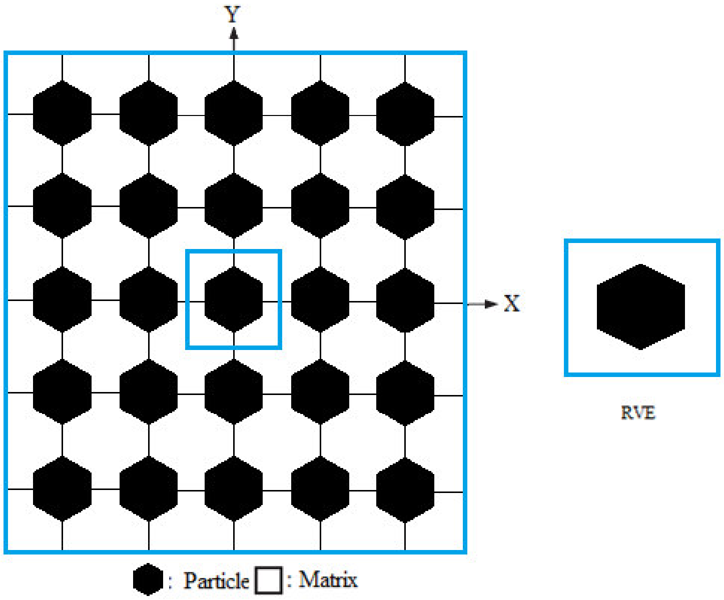

Figure 2: The RVE model: (a) particle distribution and (b) RVE scheme.

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

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

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:

$$\begin{Bmatrix} \overline{\sigma_x} \\ \overline{\sigma_y} \\ \overline{\tau_{xy}} \end{Bmatrix} = \begin{bmatrix} \overline{C_{11}} & \overline{C_{12}} & 0 \\ \overline{C_{21}} & \overline{C_{22}} & 0 \\ 0 & 0 & \overline{C_{33}} \end{bmatrix} \times \begin{Bmatrix} \overline{\varepsilon_x} \\ \overline{\varepsilon_y} \\ \overline{\gamma_{xy}} \end{Bmatrix} \tag{2}$$

The traction t at any point on the interface can always be decomposed into three components: normal traction t_n, which is perpendicular to the interface at the current point, tangential traction t_t which is tangent to the circumference of the particle at the current point, and longitudinal traction t_z which is parallel to the longitudinal direction of the particle. The interfacial tractions can be obtained by transforming the micro stresses at the interface as given in Eq. (3):

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

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

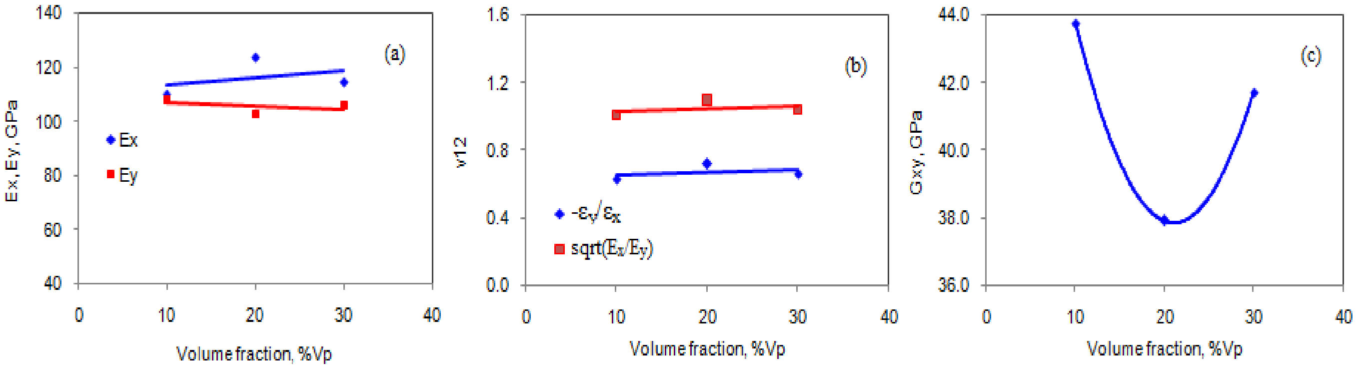

Figure 3: Effect of volume fraction on effective material properties.

3. RESULTS AND DISCUSSION

Elastic moduli, E_x and E_y increase as volume fraction increases (figure 3). The major Poisson's ratio increases with increase of volume fraction of titanium boride in the metal matrix composites (figure 3b). Shear modulus decreases as volume fraction increases from 10%Vp to 20%Vp and later on it increase from 205Vp to 30%Vp of titanium boride in the matrix of AA1100 alloy (figure 3c).

Figure 5 shows stress concentrations generated in a unit cell of square array under tensile stress. In a unit cell of square array under tensile stress, maximum stress concentrations can be observed along the edges (green color) and corners (red color) the titanium boride particle. The regions of minimum stress (blue color) concentrations occur at the particle-matrix interface in transverse direction of tensile loading.

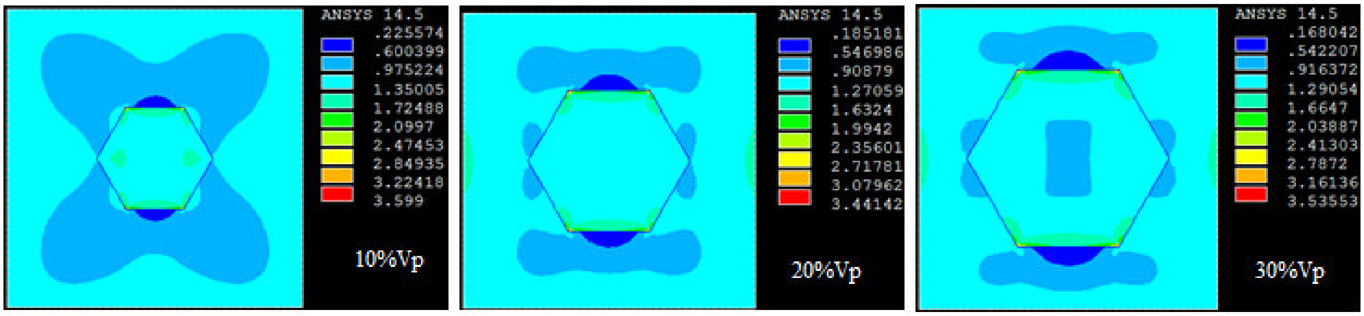

Figure 4: Stress concentrations in B_4C/AA1100 alloy metal matrix composites.

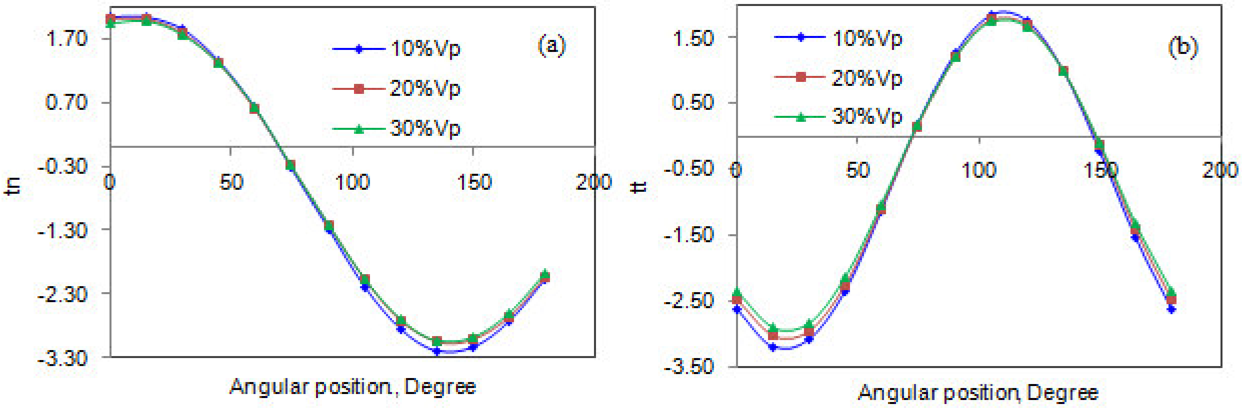

Figure 5: Interfacial tractions along the angle due to tensile loading: (a) normal and (b) tangential.

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 $\theta = 120^o$.

4. CONCLUSION

For effective material properties, variations of Ex, E_y, G_{xy} and v_{12} with respect to V_p, are predicted. Additionally, in unit cells with different particle volume fractions, variations of interfacial tractions along particle perimeter under tension loading. For titanium boride/AA1100 alloy metal matrix composites, interfacial normal traction decreases due to Poisson's effect.

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