Estimation of Micro-stresses and interfacial Tractions in Boron Carbide/AA5050 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 hexagonal 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 tangential traction increases resulting separation between particle and matrix at the interface.

Keywords: AA5050 alloy, boron carbide, RVE model, hexagonal unit cell, finite element analysis, interfacial tractions.

1. INTRODUCTION

Computational methods using the finite element analysis (FEA) are effective ways to study the micromechanical behavior of metal matrix composites [1-3]. The linkage of modeling on the nanoscale (nm-length scale) with that on the macroscale (length scale of real specimens) is a current challenge in materials science. Particulate-reinforced composites have become increasingly attractive in recent years for their high-strength and creep-resistant properties. Systematic studies of the mechanical behavior of fiber and particle reinforced composites with plane strain and axisymmetric embedded cell models are carried out to determine the influence of fiber or particle volume fraction and matrix strain-hardening ability on composite strengthening levels.

The objective of the present paper is to estimate micro stresses and interfacial tractions of boron carbide/AA5050 alloy metal matrix composites. Finite element analysis (FEA) of B_4C/AA5050 alloy metal matrix composites was executed RVE models comprising of hexagonal cell/round particle.

2. MATERIALS AND METHODS

The matrix material was AA5050 alloy. The volume fractions of boron carbide particulate reinforcement were 10%, 20%, and 30%. The RVE scheme was employed to estimate micro stresses and interfacial tractions through finite element analysis as shown in figure 1. The perfect adhesion was assumed between boron carbide particle and AA5050 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.

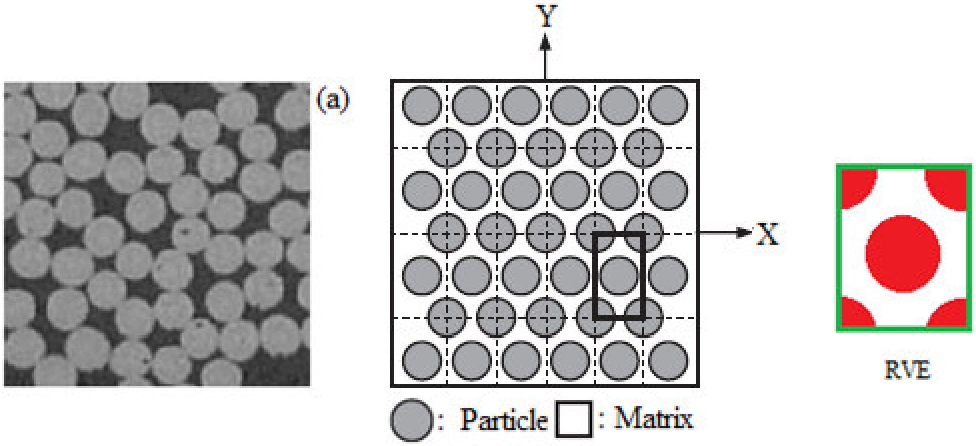

Figure 1: The RVE model: (a) particle distribution, (b) consideration for hexagonal cell/round particle and (c) RVE scheme.

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:

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

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):

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

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

3. RESULTS AND DISCUSSION

Figure 2 signifies the effective material properties of B_4C/AA5050 alloy metal matrix composites. As volume fraction increases, E_x, E_y and G_{xy} decrease, but v_{12} increases. Elastic modulus of boron carbide particle in the longitudinal direction is higher than that of the matrix, particle dominates the longitudinal stiffness (E_x> Ey) of the composite. But, the effective stiffness of the boron carbide/AA5050 alloy metal matrix composites decreases with increase of the particle volume fraction. On the other hand, since Poisson's ratio (0.19) of the particle is less than that of matrix (0.33) in all directions, as volume fraction increases, Poisson's ratio of the composite is higher than those of the boron carbide particle and the matrix AA 5050 alloy.

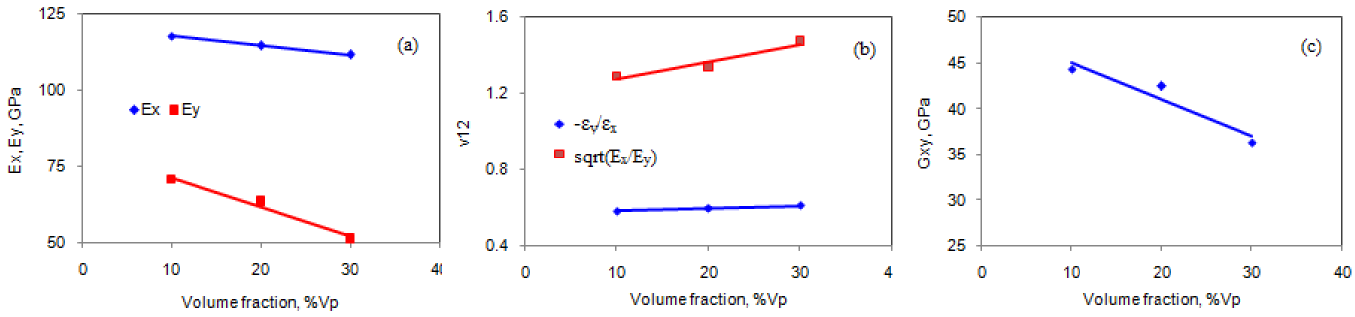

Figure 2: Effect of volume fraction on effective material properties.

Figure 3 shows von Mises stresses 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 (green and red colors) concentration can be observed in the neighboring region of the particle–matrix interface, along the loading direction. As shown in the von Mises stress plots, the regions of minimum stress (blue color) concentration align with transverse direction of tensile loading.

In figure 4a, it can be observed that the value of normal traction, t_n decreases as θ increases from 0^o to 150^o in the unit cells. As θ increases, the component of the macro load in the normal direction of the interface decreases, so t_n also decreases. Poisson's effect causes compression, so t_n reaches the minimum (might be negative). As for tangential traction t_t, whose variation with θ is shown in figure 4b, its value increases as θ decreases from 0^o, and reaches the minimum at 30^o and then increases until θ $=120^o$. In cohesive interfacial models, separation between particle and matrix at the interface elastically increases as interfacial traction increases [4]. Hence, the stress induced in the composite decreases resulting the reduction of elastic modulus.

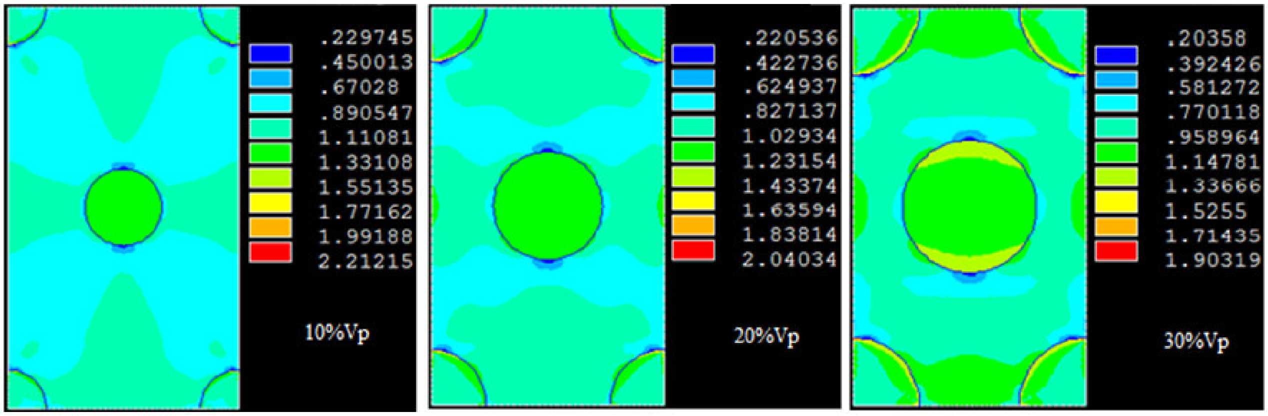

Figure 6: von Mises stress induced in B_4C/AA5050 alloy metal matrix composites.

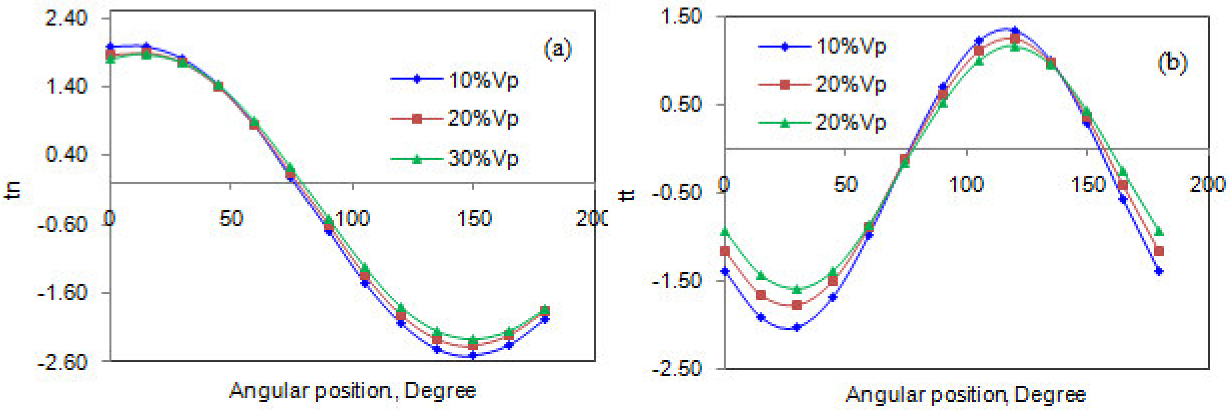

Figure 4: Interfacial tractions along the angle due to tensile loading: (a) longitudinal and (b) tangential.

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 boron carbide/AA5050 alloy metal matrix composites, interfacial traction increases resulting separation between particle and matrix at the interface.

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