Prediction of Micro-stresses and interfacial Tractions in Boron Carbide/AA6061 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/ellipsoid 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.

Keywords: AA6061 alloy, boron carbide, RVE model, 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/AA6061 alloy metal matrix composites. Finite element analysis (FEA) of B_4C/AA6061 alloy metal matrix composites was executed RVE models comprising of square cell/ellipsoid particle.

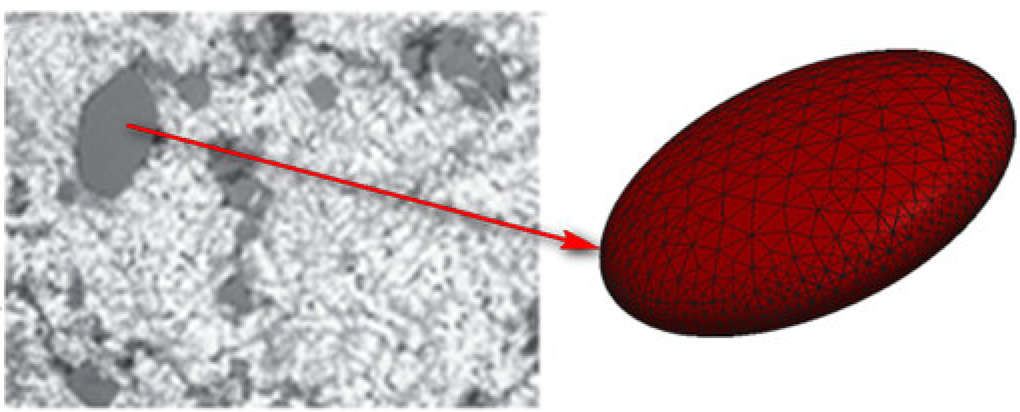

Figure 1: Reinforced particle shape in a metal matrix composite.

2. MATERIALS AND METHODS

The matrix material was AA6061 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 AA6061 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.

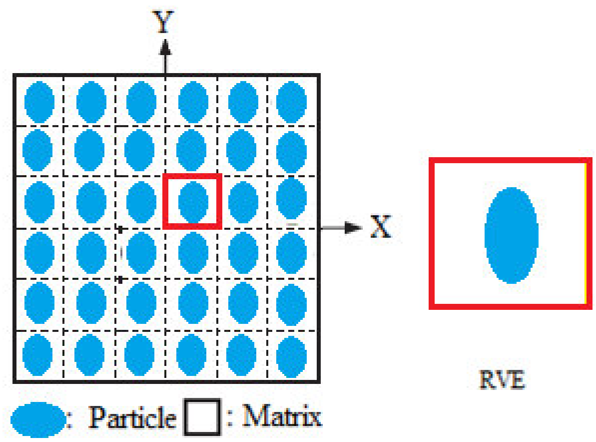

Figure 1: The RVE model: (a) particle distribution and (b) RVE scheme.

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

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

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:

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

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

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

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/AA6061 alloy metal matrix composites. As volume fraction increases, E_x and E_y increase (figure 2a), but G_{xy} decreases (figure 2c). Poisson's ratio of the composite increases with increasing volume fraction of boron carbide (figure 2b).

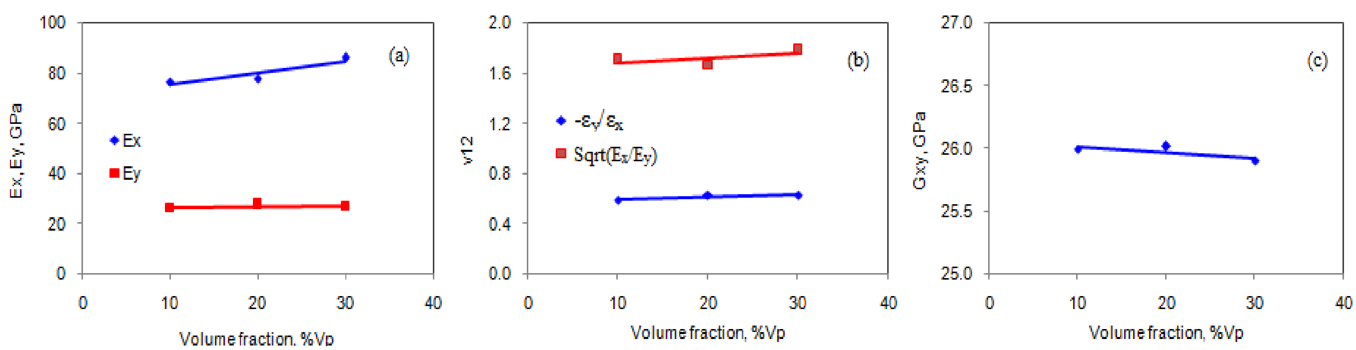

Figure 2: Effect of volume fraction on effective material properties.

Figure 3 shows von Mises stresses induced in a unit cell of square array under tensile stress. In a unit cell of square array under tensile stress, maximum stress (red colors) concentrations are observed in the particle, along the transverse direction of tensile loading. As shown in the von Mises stress plots, the regions of minimum stress (green color) concentrations align with the particle –matrix interface along the longitudinal and transverse direction of tensile loading.

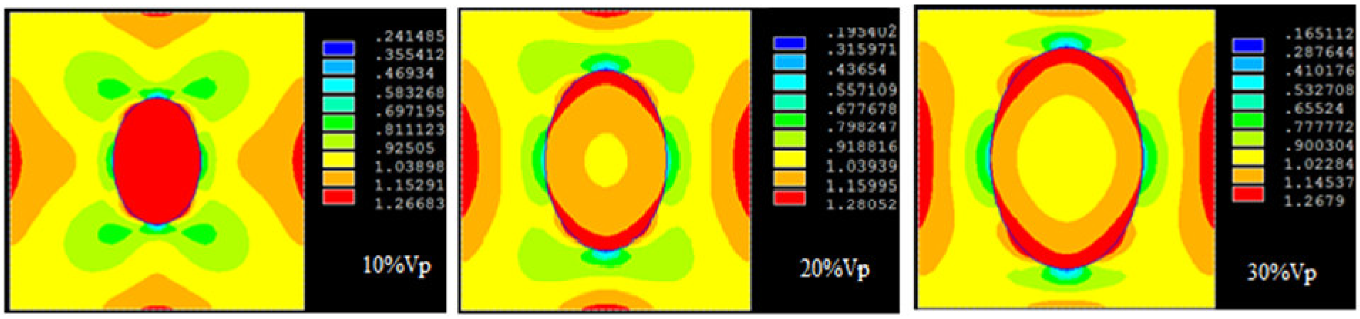

Figure 3: von Mises stress induced in B_4C/AA6061 alloy metal matrix composites.

The interfacial normal traction, t_n decreases with as θ increases from 0^o to 150^o. The direction of macro load coincides with the direction of t_n at θ =0^o, so t_n attains its maximum; 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 decreases as θ increases from 0^o to 30^o, and reaches the maximum at 120^o and then decreases until θ =180^o. In cohesive interfacial models, separation between particle and matrix at the interface elastically increases as interfacial traction increases [4]. For boron carbide/AA6061 alloy metal matrix composites, tangential traction increases. Hence, there is a separation between particle and matrix at the interface.

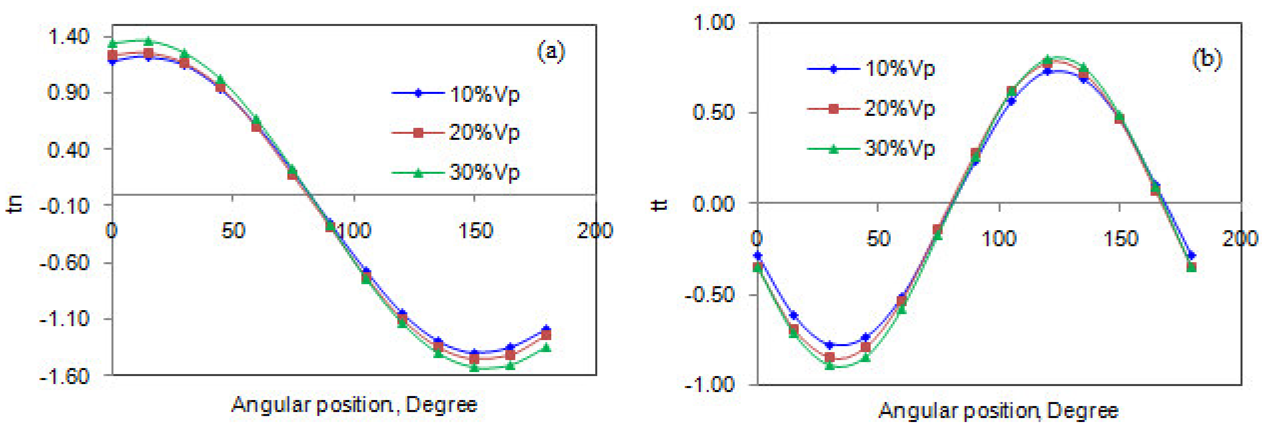

Figure 4: Interfacial tractions along the angle due to tensile loading: (a) longitudinal and (b) tangential.

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/AA6061 alloy metal matrix composites, tangential traction decreases causing a separation between particle and matrix at the interface.

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