Valuation of Micro-stresses and interfacial Tractions in Boron Carbide/AA8090 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 array/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: AA8090 alloy, boron carbide, RVE model, finite element analysis, interfacial tractions, ellipsoid particle.

1. INTRODUCTION

Several works have been developed, using analytical, numerical, experimental or hybrid approaches to study the micromechanical behaviour of metal matrix composites. Unit Cell approach is a novel method for simulating the behavior of engineering materials by making use of the capabilities of a finite element software package [1, 2]. 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).

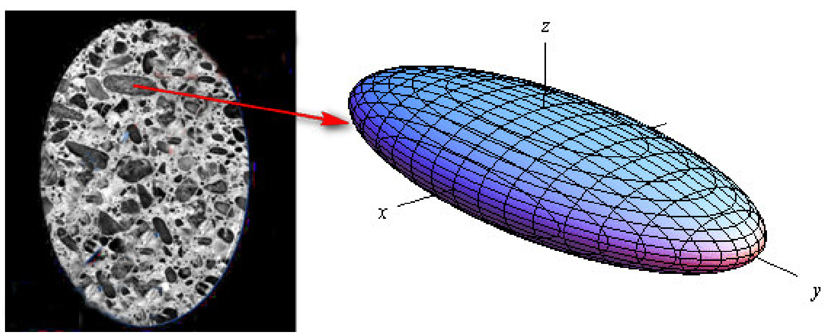

Figure 1: Reinforced particle shape in a metal matrix composite.

The objective of the present paper is to estimate micro stresses and interfacial tractions of boron carbide/AA8090 alloy metal matrix composites. Finite element analysis (FEA) of B_4C/AA8090 alloy metal matrix composites was executed RVE models comprising of square hexagonal cell array/ellipsoid particle. The shape of boron carbide particle was assumed to be ellipsoid.

2. MATERIALS AND METHODS

The matrix material was AA8090 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 2. The perfect adhesion was assumed between boron carbide particle and AA8090 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.

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

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

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

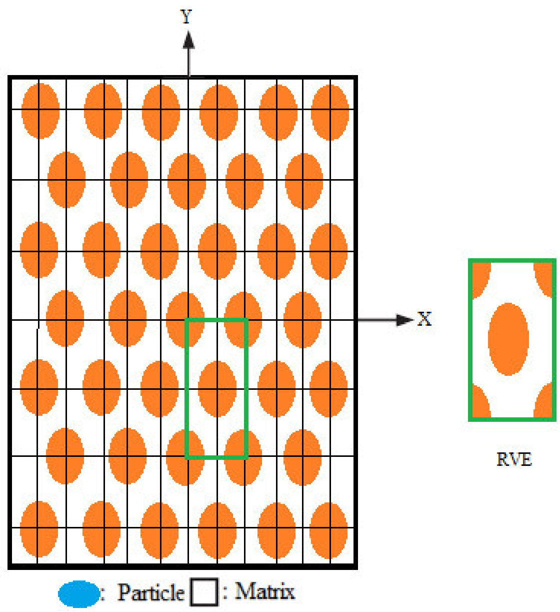

Figure 2: The RVE model: (a) particle distribution and (b) RVE scheme.

For plane strain conditions, the macro stress- macro strain relation is as follows:

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

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):

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

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

As volume fraction increases, E_x and E_y also increase as shown in figure 3a. The major Poisson's ratio decreases with increase of volume fraction of boron carbide from 10%Vp to 30%Vp 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 20%Vp to 30%Vo of boron carbide in the matrix of AA8090 alloy (figure 3c).

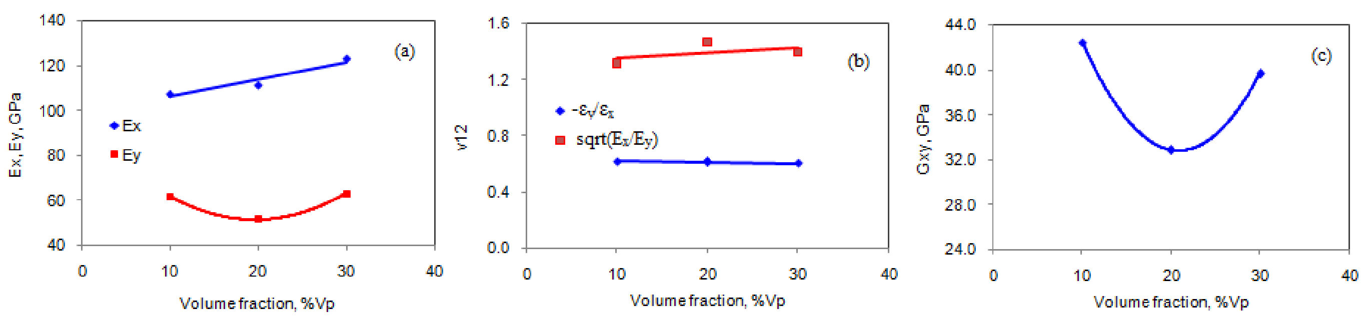

Figure 3: Effect of volume fraction on effective material properties.

Figure 4 shows stress concentrations generated in a unit cell of square hexagonal array under tensile stress. In a unit cell of square hexagonal array under tensile stress, maximum stress (yellow, green and red colors) concentrations can be observed in the boron carbide particle or at the neighboring region of the particle–matrix interface. The regions of minimum stress (blue color) concentrations occur at the particle-matrix interface in transverse direction of tensile loading.

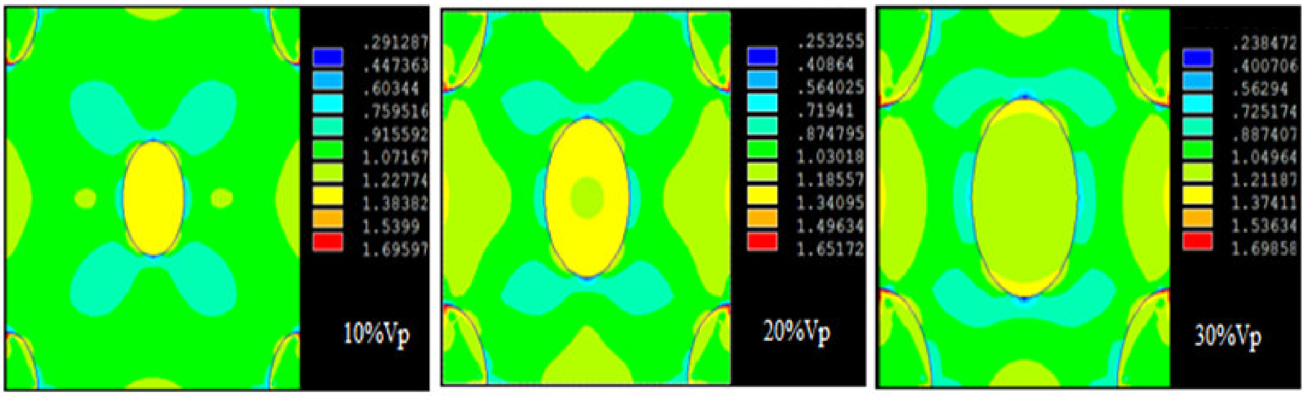

Figure 4: Stress concentrations in B_4C/AA8090 alloy metal matrix composites.

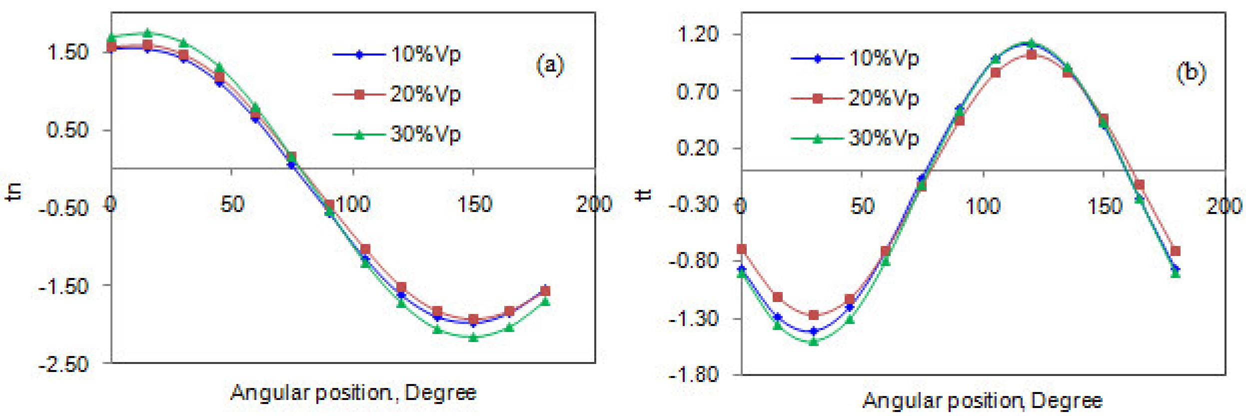

Figure 5: Interfacial tractions along the angle due to tensile loading: (a) longitudinal; (b) normal and (c) tangential.

The interfacial normal traction, t_n decreases with as θ increases from 0^o to 150^o (figure 5a). The direction of macro load coincides with the direction of t_n at θ =0^o, so t_n attains its minimum at 150^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 30^o, and then increases until θ =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 boron carbide/AA8090 alloy metal matrix composites, interfacial normal traction decreases due to Poisson's effect.

REFERENCES

1. R. Hill, Elastic Properties of Reinforced Solids: Some Theoretical Principles, Engineering J. Mech. Phy. Solids, Pergamon Press Ltd. Great Britain, 11, pp. 357-372, 1963.
2. Z. Hashin, Analysis of composite materials, A survey, J. Applied Mech., vol. 50, pp. 481-505, 1983.