Effect of Interfacial Debonding on Stiffness of Titanium Boride/AA5050 Alloy Metal Matrix Composites

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Abstract: Numerical RVE models of square diagonal periodic composites made of titanium boride particulates /AA5050 alloy matrix are developed. The numerical approach is based on the finite element method and it allows extension to metal matrix composites with octagonal titanium boride particulates, providing a powerful tool for fast calculation of their effective properties. The elastic moduli, major Poisson's ratio and interfacial tractions are determine the region of debonding. The maximum debonding occurs at 75^o from the axis of tensile loading of the metal matrix composites comprising of octagonal titanium boride particulates..

Keywords: AA5050 alloy, titanium boride, RVE model, finite element analysis, interfacial tractions, debonding.

1. INTRODUCTION

Micromechanics refers to mechanics of materials effects at the 10^{-6} m scale. There are many books and countless papers focused upon micromechanics. The vast majority of these deal with the effective stiffness. The properties that can be improved for particulate metal matrix composites include stiffness, strength, toughness, processability, stability and durability. Of meticulous interest here are the cases of improving stiffness and strength. The response of metal matrix composites when subjected to mechanical loads is influenced by the material type (particulate and matrix) and configuration such as particulate distribution, volume fraction and shape. Matrix cracking and debonding often show a rather slowly progressing failure with high energy dissipation, while particle breakage may initiate catastrophic collapse of the entire composite with little dissipation of kinetic energy [1-5]. It has been noted from the previous studies that the microscopic failure behavior of the particulate-reinforced composites is still not completely understood. Finite element analysis (FEA) is probably the best candidate for determining the complex stress and strain states in the particulates and matrix [6-15].

The aim of the present paper is to predict material moduli and interfacial tractions associated with the debonding behavior. The finite element method (FEM) tool has been extensively used in the literature to analyze a periodic unit cell, for determining the effective properties of metal matrix composites. Here, the FEM based micromechanical analysis method is applied to square diagonal array particulate metal matrix composites subjected to different volume fractions of titanium boride in the AA5050 Alloy matrix to predict the effective elastic moduli and interfacial tractions. The unit cell concept developed is directed to producing a general procedure for evaluation of the effective properties of composites with complex geometrical reinforcements.

2. MATERIALS AND METHODS

The matrix material was AA5050 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 AA5050 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.

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

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

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:

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

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

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

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

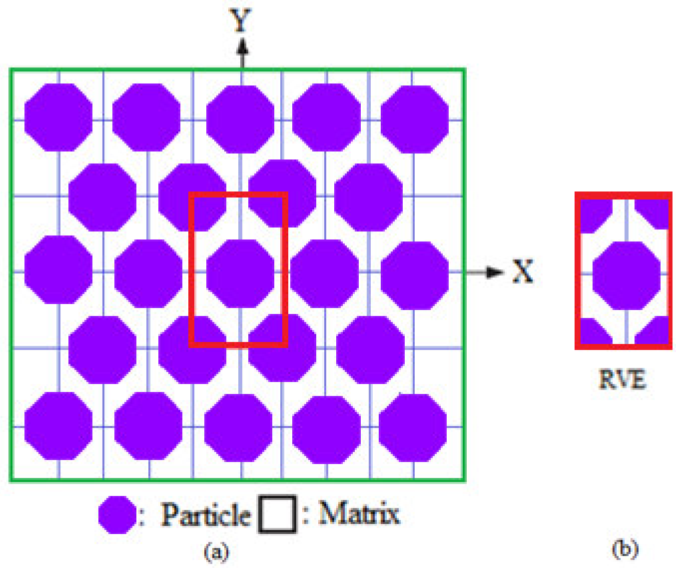

Figure 1: The RVE model: (a) particle distribution and (b) RVE scheme.

3. RESULTS AND DISCUSSION

Figure 3a exhibits an increase in moduli with increasing volume fraction of titanium boride in the matrix AA5050 alloy. Figure 3b indicates a marginal decrease in the major Poisson's ratio. Figure 3c indicates a significant rise in the shear modulus as volume fraction increases from 10%Vp to 20%Vp and it falls for variation of volume fraction of titanium boride from 20%Vp to 30%Vp..

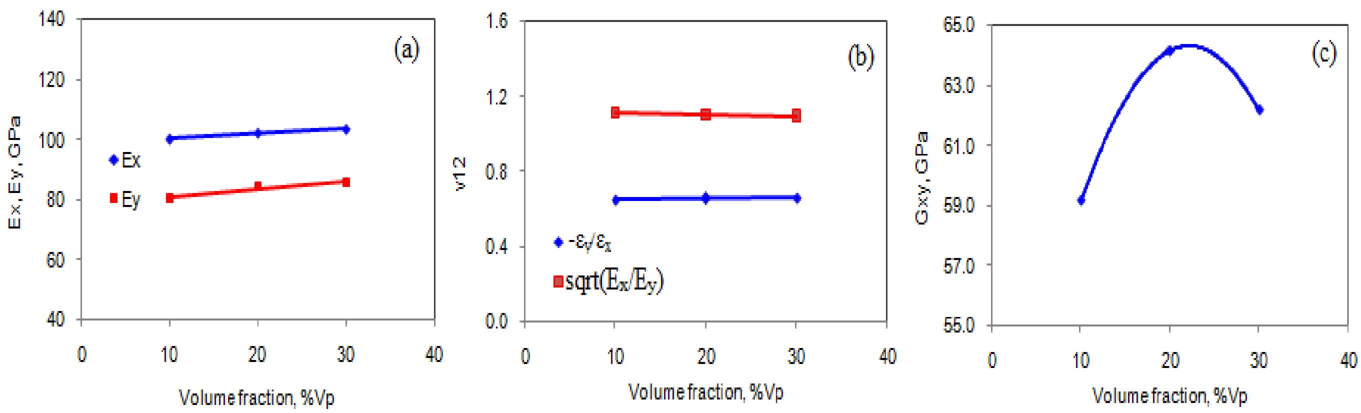

Figure 2: Effect of volume fraction on effective material properties.

Figure 4 shows von Mises stresses induced in a unit cell of square diamond array under tensile stress. The maximum stresses are observed in the titanium boride (green color) and vertices of octagonal particles near interface (red color). The regions of minimum stress (blue color) 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. There is no bridging of stress (i.e. isolated stress distribution) in the TiB_2/AA5050 alloy metal matrix composites.

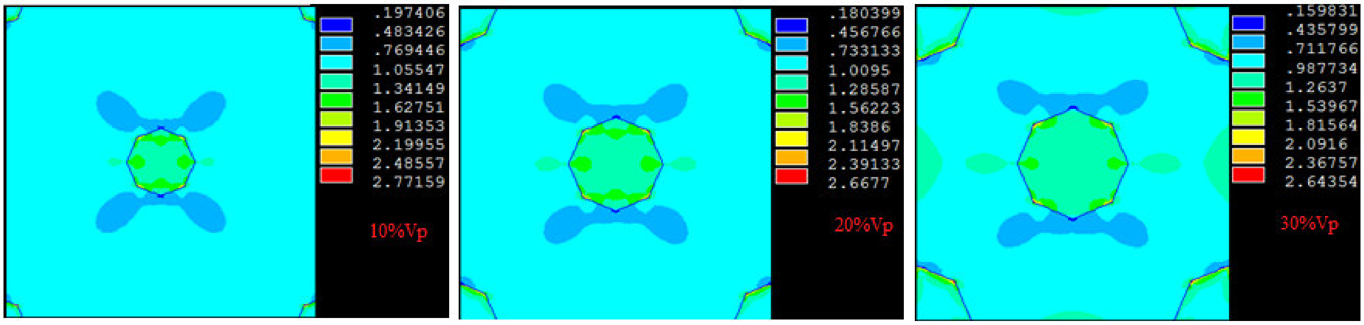

Figure 3: von Mises stresses induced in TiB_2/AA5050 alloy metal matrix composites.

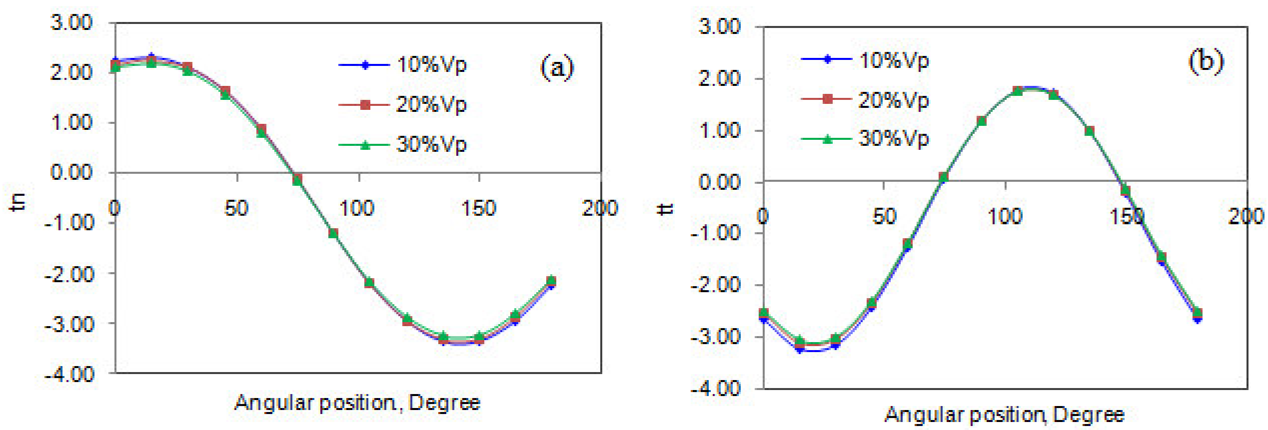

Figure 4: Interfacial tractions along the angle due to tensile loading: (a) normal and (b) tangential.

The interfacial normal traction, t_n decreases with as θ increases from 0^o to 135^o (figure 5a) and it becomes zero at 75^o and maximum at 0^o coinciding with tensile loading (figure 4a). The tangential traction t_t, increases from 30^o to 120^o, and it attains zero at 75^o to the tensile loading (figure 4b). Prior to debonding, the normal stress is maximum at $\theta = 0°$. At some point in the progress of debonding, the normal interfacial traction. t_n decreases and becomes zero at 75^o. This is due to increasing debond length and a decrease in the normal component of stress with increasing angular orientation. For maximum debonding region, the value of tangential stress t_t, also reaches zero. The maximum debonding occurs at 75^o from the axis of tensile loading.

4. CONCLUSION

The progress of interfacial debonding is estimated in terms of normal and tangential tractions and interfacial separation. In these relations, the traction decreases with separation of titanium boride particle with matrix AA5050 alloy and reaches to zero traction, signaling debonding.

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