Micromechanical modeling of Titanium Boride/AA7020 Alloy Metal Matrix Composites in Finite Element Analysis using RVE Model

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Abstract: A micromechanical modeling is carried out to estimate the micro stress, and debonding within titanium boride/AA7020 alloy metal matrix composite under various particle loading conditions. Square array unit cell/rectangular particle RVE models are exercised using two-dimensional finite element methods. The debonding has taken place at the interface regions near the vertices of the rectangular particle.

Keywords: AA7020 alloy, titanium boride, rectangular particle, RVE model, finite element analysis, interfacial tractions, debonding.

1. INTRODUCTION

Metal matrix composite materials represent an essential category of current engineered materials since they have several advantages over conventional materials. As a result of their extraordinary applications in our everyday uses, there is a need to predict the mechanical properties of these composites. Using micromechanical techniques and through the analysis of periodic unit cell models or representative volume elements (RVEs) the overall coupled elastomechanical behavior of particulate reinforced metal matrix composites can be obtained from the known constituents properties [1-10]. This approach has numerous advantages such as obtaining the global properties of the composites, studying various damage initiation and propagation mechanisms, etc [11-15].

Therefore, the current investigation aims to predict the effective elastomechanical properties of titanium boride/AA7020 alloy particulate metal matrix composites by calculating their complete elastic and interfacial tractions. Finite element method is used to construct and analyze the different (representative volume elements (RVEs) models of periodic rectangular particulates having square periodical distribution of particulates.

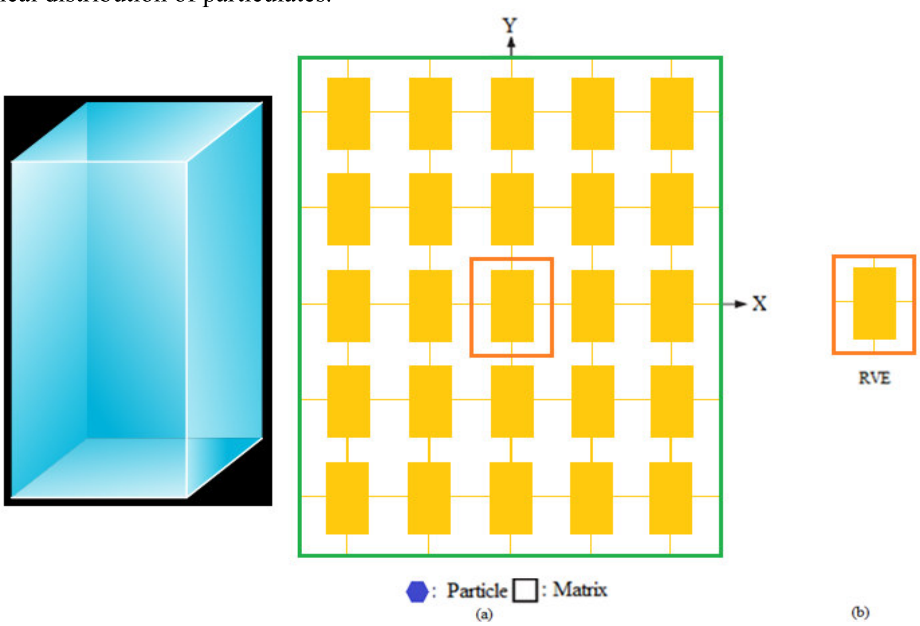

Figure 1: The RVE model: (a) particle distribution and (b) RVE scheme.

2. MATERIALS AND METHODS

The volume fractions of titanium boride particulate reinforcement were 10%, 20%, and 30% in the matrix AA7020 alloy. The periodic model for the representative volume element (RVE) scheme is shown in figure 1. The perfect adhesion was assumed between titanium boride particle and AA7020 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:

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

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):

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

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

1. RESULTS AND DISCUSSION

Elastic moduli E_x and E_y along and normal directions of tensile loading, respectively increase with volume fraction of titanium boride in the matrix AA7020 alloy (figure 3a). The major Poisson's ratio ranges from 0.54 to 0.56 for TiB_2/AA7020 alloy metal matrix composites (figure 3b). Shear modulus increases for the change of volume fraction of titanium boride from 10%Vp to 20%Vp and then it decreases as volume fraction increases from 20%Vp to 30%Vp as shown in figure 3c. This indicates that the interface shearing occurs at low shear stress values for high volume fraction of titanium boride in the matrix AA7020 alloy. At high volume fraction of titanium boride, E_x and E_y are nearly equal. This represents that the rectangular particle exhibits same kind of stiffness along and normal directions of tensile loading.

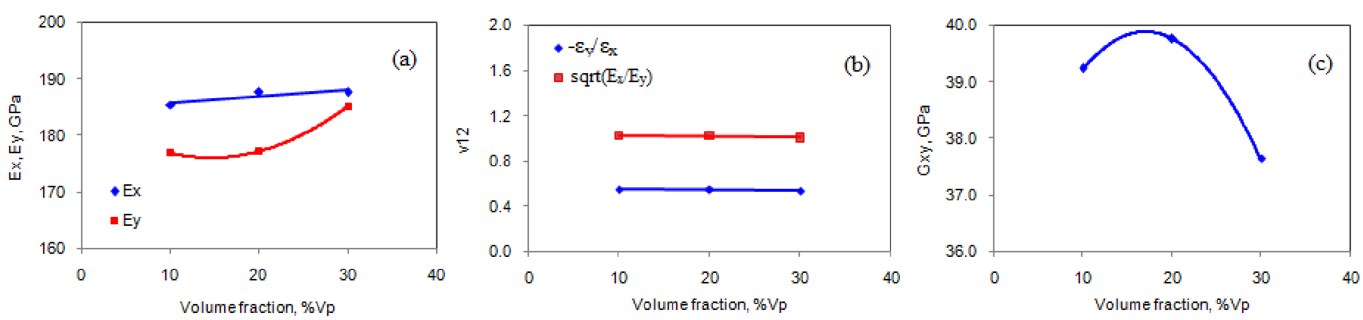

Figure 3: Effect of volume fraction on effective material properties.

Figure 4 shows stress concentrations developed in a unit cell of square array RVE under tensile stress. The maximum stress concentrations happen at vertexes of rectangular particle (red color). The regions of minimum stress (blue color) concentrations occur at the particle-matrix interface along the edges of the rectangular particle. The stress distribution in and around the particle is symmetric with respect to the mid-point of the particle. The edges of the rectangular particle are safe but not the vertexes under applied tensile loading.

The interfacial normal traction, t_n decreases with as θ increases from 0^o to 135^o (figure 5a) and it becomes zero at 60^o and maximum at 0^o. The normal traction t_n turns into maximum compressive at 135^o due to Poisson's effect. The tangential traction t_t, increases as θ increases from 15^o to 105^o, and it reaches zero value at θ =75^o. Prior to debonding, the normal stress is maximum at θ = 0°. While debonding in progress, the normal traction, t_n decreases in magnitude gradually and becomes zero at 60^o. The debonding is supposed to take place at 45^0, but ensued at 60^o owing to higher compressive stress at 45^0 rather than at 60^0 near the particle-matrix interface. There is a clear indication of load transfer from the matrix to the particle via the interface as seen from change of raster image colors. The near-interface regions of the particle have experienced higher tensile stresses than at the core or center regions of the particle.

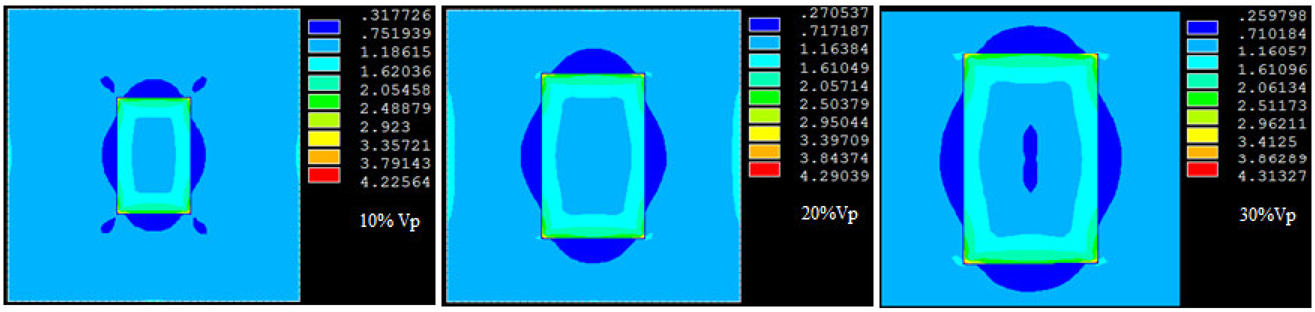

Figure 4: Stress concentrations in TiB_2/AA7020 alloy metal matrix composites.

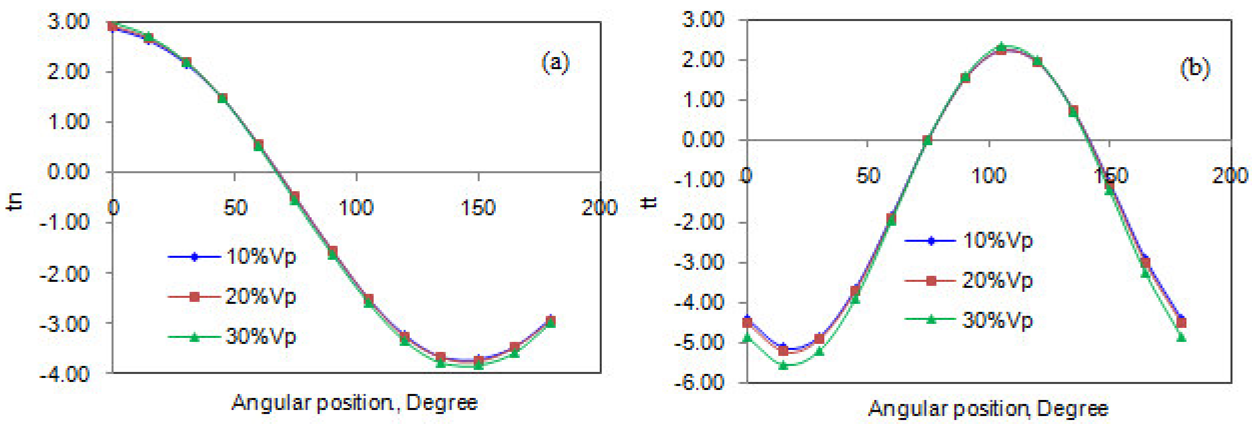

Figure 5: Interfacial tractions along the angle due to tensile loading: (a) normal and (b) tangential.

2. CONCLUSION

Elastic moduli are nearly equal at high volume fraction of titanium boride. The deboning between particle and matrix take place at the vertexes of the rectangular particle but not at its edges.

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