Numerical and Analytical Prediction of Interface Debonding in AA4015/Boron Nitride Nanoparticulate Metal Matrix Composites

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Abstract: *Diamond array unit cell/2-D hexagonal particulate RVE models were used to predict interface debonding with numerical and analytical procedures. The particulate metal matrix composites are boron nitride/AA4015alloy at different volume fractions of boron nitride. Only interface debonding was observed in all the composites.*

Keywords: AA4015*, boron nitride, hexagonal particle, RVE model, finite element analysis, debonding.*

1. INTRODUCTION

In mean-field modeling of particulate composite materials, a composite unit cell is subjected to mean stress or strain and the effective stiffness or compliance tensors are found by averaging strains and stresses throughout the composite [1]. Most numerical models use periodic RVEs and assume analysis results with periodic boundary conditions are equivalent to bulk composite properties [2-12]. Most simulations were plain strain analyses although some 3D results were generated using axisymmetric simulations.

The objective of this paper is to predict debonding in AA4015 alloy/boron nitride (BN) particulate metal matrix composites. Representative volume elements (RVEs) models were taken from the periodic 2-D hexagonal particulates in a diamond array distribution.

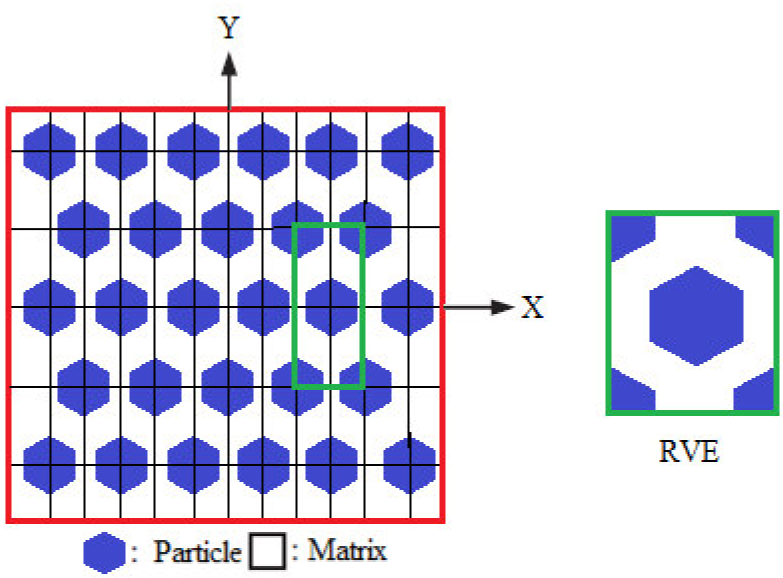

Figure 1: The RVE model: (a) particle distribution and (b) RVE scheme.

2. MATERIALS AND METHODS

The volume fractions of boron nitride used in the present work were 10%, 20%, and 30% BN. The matrix material was AA4015 alloy. The periodic model for the representative volume element (RVE) scheme was constructed from 2-D hexagonal particulates in a diamond array particulate distribution. The perfect adhesion was assumed between boron nitride particulate and AA4015 alloy matrix. PLANE183 element was used for the matrix and the nanoparticulate. The interface between particulate and matrix was modeled using CONTACT -172 elements.

If particle fracture occurs when the stress in the particle reaches its ultimate tensile strength, $\sigma_{p,uts}$, then setting the boundary condition at

$$\sigma_p = \sigma_{p,\,uts} \quad (1)$$

and substituting into Eq.(1) gives a relationship between the strength of the particle and the interfacial shear stress such that if

$$\sigma_{P,uts} < \frac{2\tau}{n} \quad (2)$$

Then the particle will fracture. Similarly if interfacial debonding/yielding is considered to occur when the interfacial shear stress reaches its shear strength

$$\tau = \tau_{max} \quad (3)$$

Then by substituting Eq. (5) into Eq.(1) a boundary condition for particle/matrix interfacial fracture can be established whereby,

$$\tau_{max} < \frac{n\sigma_p}{2} \quad (4)$$

This approach suggests that the outcome of a matrix crack impinging on an embedded particle depends on the balance between the particle strength and the shear strength of the interface.

3. RESULTS AND DISCUSSION

The effect of volume fraction of boron nitride on the elastic moduli, E_x, E_y and G_{xy} is shown figure 2a. The marginal decrease of E_x, E_y and G_{xy} were noticed with the increase of BN content in the composites. The major Poisson's ratio was nearly constant for all volume fractions of BN (figure 2b). The reasons could be the narrow mismatches of elastic moduli and Poisson's ratios of AA4015 alloy matrix and BN particulates. The elastic moduli of AA4015 alloy matrix and BN particulates are, respectively 68.9 GPa and 100 GPa. The Poisson's ratios of AA4015 alloy matrix and BN particulates are, respectively, 0.33 and 0.27.

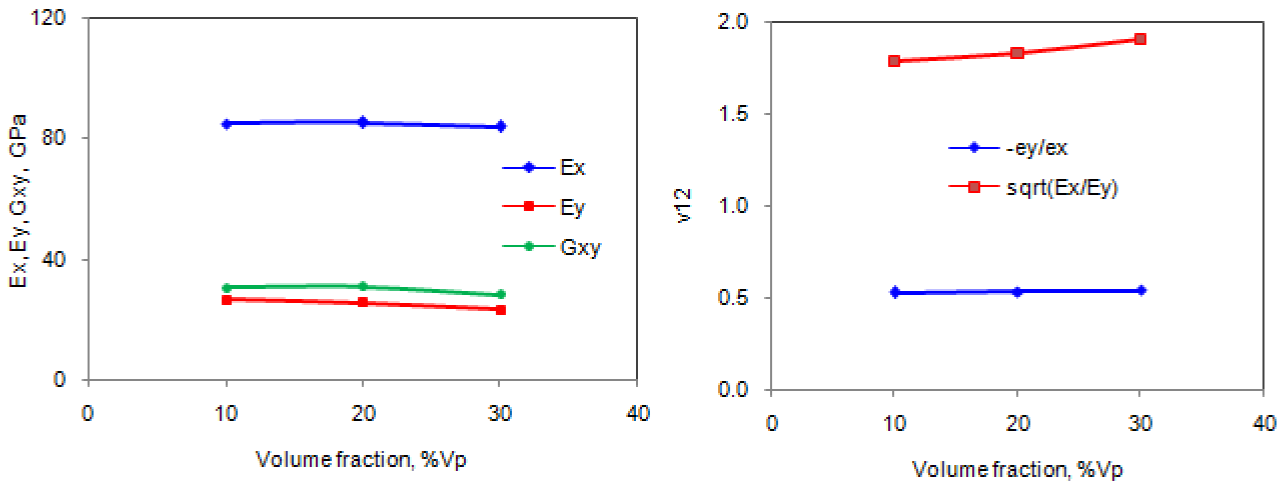

Figure 2: Effect of volume fraction on effective material properties.

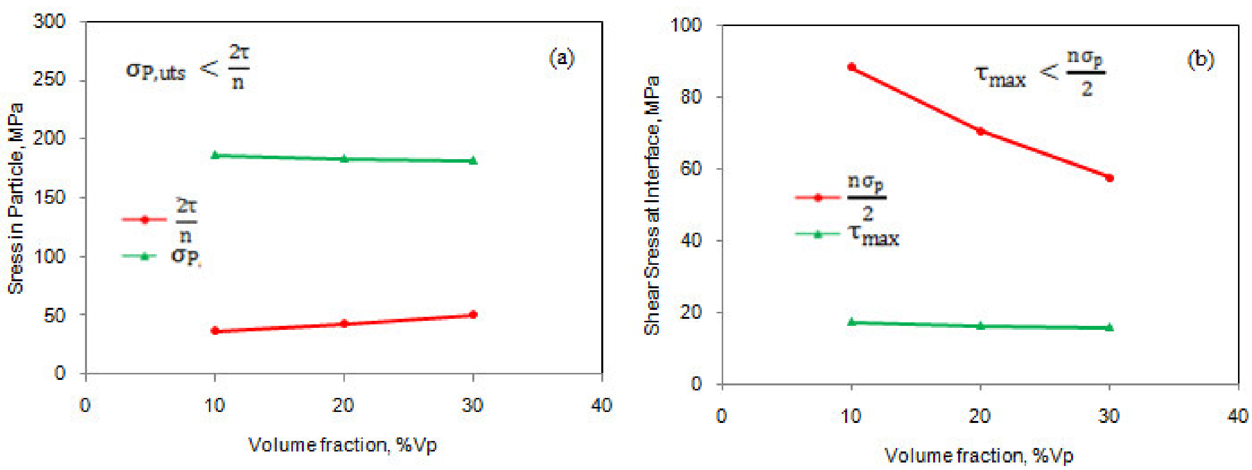

Figure 3: Fracture criteria of: (a) particulate fracture and (b) interface debonding.

The particulate fracture was not observed in all the composites as shown in figure 3a. The BN particulate fracture was not occurred as the condition $\sigma_p \leq 2\tau/n$ is not satisfied. However, the condition $\tau_{max} < n\sigma_p/2$ is satisfied for the occurrence of debonding in all the composites (figure 3b). The strain energy density increased in the AA4015 alloy matrix with an increase in the volume fraction of BN (figure 4). This indicates the increase of deformation in the AA4015 alloy matrix even though the reinforcement of BN increased. The strain energy density decreased at the interface with an increase in the volume fraction of BN. This represents the debonding tendency at the interface between AA4015 alloy matrix and BN nanoparticulates. The strain energy density in the BN nanoparticulates was lower than that developed in the matrix and at the interface. The spectrum of strain densities are shown in various regions of RVE cells (figure 5). At 30% volume fraction of BN, the strain energy density was locally variable within in the BN nanoparticulate.

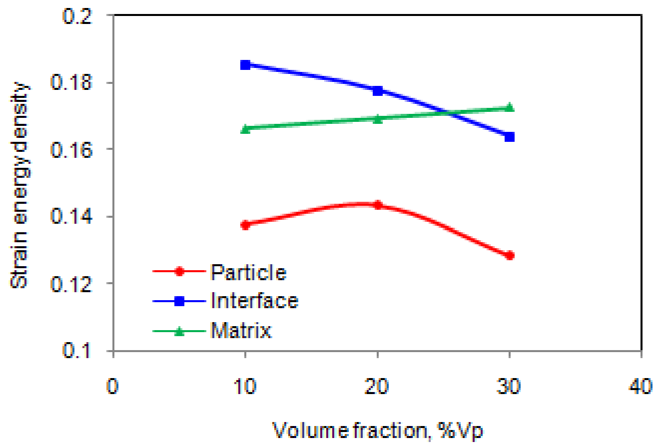

Figure 4: Effect of volume fraction on strain energy density.

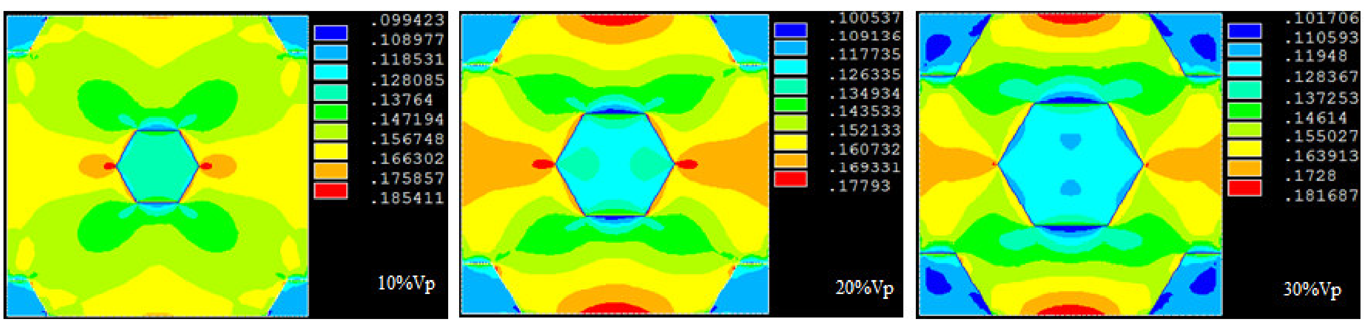

Figure 5: Results obtained from finite element analysis: stress energy densities.

4. CONCLUSION

The interface debonding occurred in the composites at all volume fractions of BN. The strain energy decreased with an increase in the volume fraction of BN. The BN particulates had experienced local deformation due to transfer of load from the matrix to the particulates.

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