Effect of Elastic Moduli Mismatch on Particulate Fracture in AA7020/Silicon Nitride Particulate Metal Matrix Composites

[1]H. B. Niranjan and A. Chennakesava Reddy[2]

[1]Assistant Professor, Department of Mechanical Engineering, MS Ramaiah Institute of Technology, Bangalore, India
[2]Assistant Professor, Department of Mechanical Engineering, MJ College of Engineering and Technology, Hyderabad, India
dr_acreddy@yahoo.com

Abstract: *Hexagonal array unit cell/spherical particulate RVE models were employed to predict particulate fracture using two-dimensional finite element methods under plane strain conditions. The particulate metal matrix composites are silicon nitride/AA7020 alloy at different volume fractions of silicon nitride. There is strong probability of silicon nitride particulate fracture at its high (30%) volume fraction in the AA7020 alloy matrix.*

Keywords: AA7020*, silicon nitride, round particle, RVE model, finite element analysis, particulate fracture.*

1. INTRODUCTION

The property of metal matrix composites was improved by the uniform distribution of reinforcement and the refinement of subgrain size particulates. Since most ceramics are available as particles, there is a wide range of potential reinforcements for particle reinforced composites [104-108]. The particulate materials are silicon carbide [1], boron carbide [2-4], alumina [5] and titanium boride [6-8]. Silicon nitride particulates were tested with matrix alloys such as AA1100 alloy [9], AA2024 alloy [10], AA3003 alloy [11] and AA4015 alloy [12]. The AA 7020 alloy is a high strength material used for highly loaded structural applications.

The aim of the present paper is to predict the particle fracture of AA7020 alloy/silicon nitride particulate metal matrix composites. Finite element method is used to construct and analyze representative volume elements (RVEs) models of periodic circular particulates in a hexagonal array distribution.

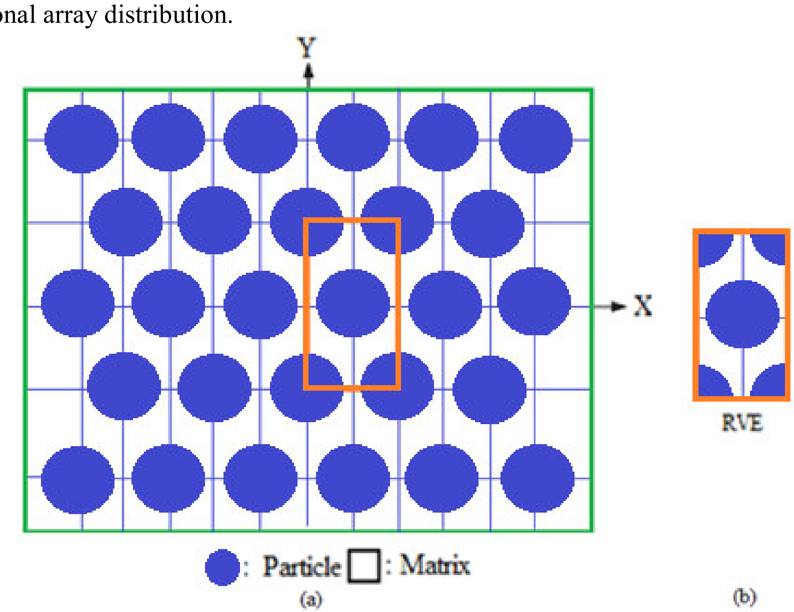

Figure 1: The RVE model: (a) particle distribution and (b) RVE scheme.

2. MATERIALS AND METHODS

The AA7020 alloy/ silicon nanoparticulate metal matrix composites were used in the present work with 10%, 20%, and 30% volume fractions of silicon nitride. The periodic model for the representative volume element (RVE) scheme as shown in figure 1 was used to analyze the composites with finite element software code. The RVE scheme was abstracted from round particulates in hexagonal array particulate distribution. The perfect adhesion was assumed between silicon nitride particle and AA7020 alloy matrix. PLANE183 element was used for the matrix and the nanoparticle. The interface between particle 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

Influence of silicon nitride on the elastic moduli, E_x, E_y and Gxy are shown figure 2a. The tensile elastic modulus and shear modulus were nearly constant. The compressive elastic modulus was low for 30% silicon nitride in the matrix Aa7020 alloy. The major Poisson's ratioincreases with increase of volume fraction of silicon nitride (figure 2b).

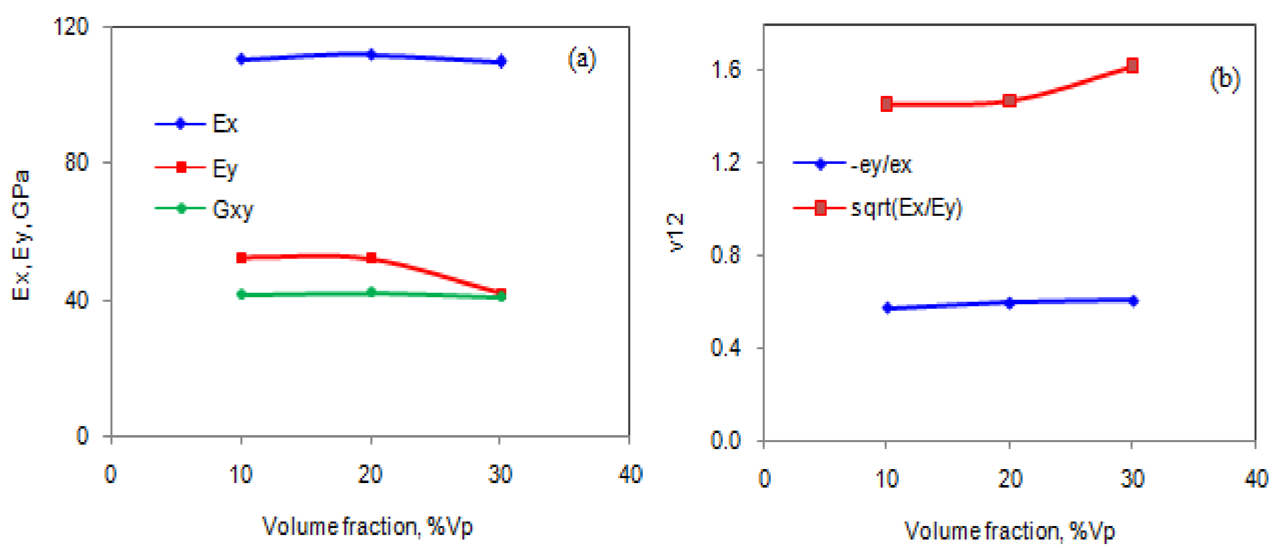

Figure 2: Effect of volume fraction on effective material properties.

The particulate fracture was observed at 30% silicon nitride in the composite as per the condition $\sigma_p \leq 2\tau/n$ as shown in figure 3a. The debonding was also in all the composites as shown in figure 3b. The debonding and particulate was due to heavy load transfer the AA7020 matrix alloy to the silicon nitride particulates.

The stress induced in the particle or at the interface was higher than that induced in the matrix as shown in figure 4. The induced stresses increased with the increase of volume fraction of silicon nitride in the composites. The shear stress developed at the interface was approximately the same in all the composites (figure 4c). The interface debonding had occurred in the direction of tensile loading. The main reason for the particulate fracture was on account of the elastic moduli mismatch between the AA7020 alloy matrix and silicon nitride particulates. The elastic moduli of AA7020 alloy matrix and silicon nitride are, respectively, 72GPa and 317 GPa. The mismatch is 245 GPa.

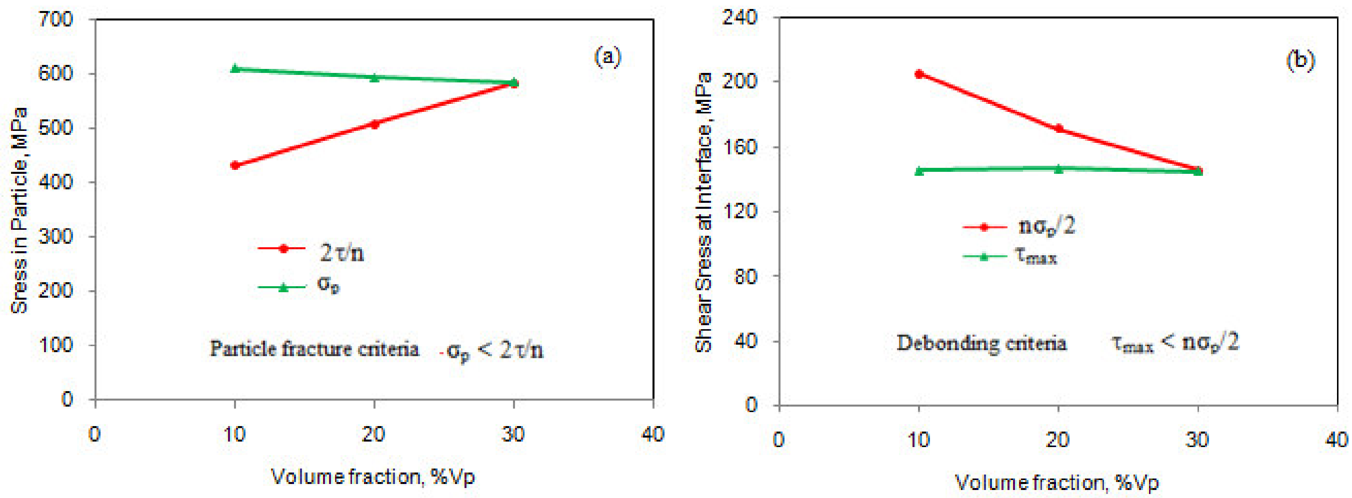

Figure 3: Fracture criteria of: (a) particulate and (b) interface.

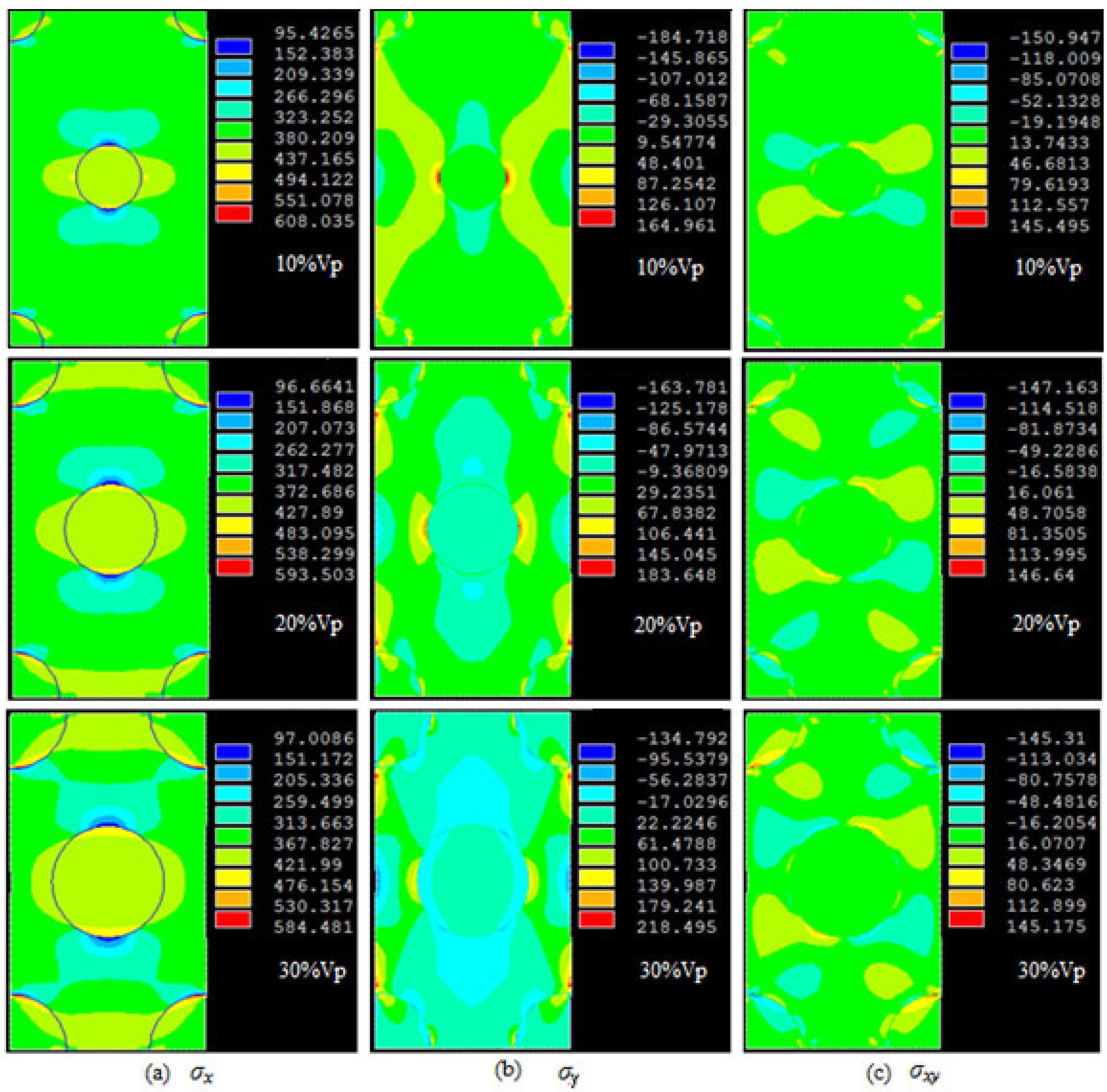

Figure 4: Results obtained from finite element analysis: (a) tensile stress, (b) compressive stress and (c) shear stress.

4. CONCLUSION

The interface debonding and silicon nitride particulate fractures took place at volume fraction of 30% SiN in the composite. The debonding was in the direction of the tensile loading. The elastic moduli mismatch between AA7020 alloy and silicon nitride is about 245 GPa.

REFERENCES

1. D.L. McDanels and C.A. Hoffman, "Microstructure and orientation effects on properties of discontinuous Silicon Carbide/ Aluminum Composites" NASA Tech. Pap. 2303, Cleveland, OH, 1984, pp 1-29.
2. S. Sundara Rajan and A. Chennakesava Reddy, Assessment of Tensile Behavior of Boron Carbide/AA2024 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, March 1997, pp.160-163.
3. P. Martin Jebaraj and A. Chennakesava Reddy, Prediction of Micro-stresses and interfacial Tractions in Boron Carbide/AA6061 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, March 1997, pp. 183-185.
4. B. Kotiveera Chari and A. Chennakesava Reddy, Computation of Micro-stresses and interfacial Tractions in Boron Carbide/AA7020 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, March 1997, pp. 186-188.
5. J.Q.Jiang, R.S.Tan, A.B.Ma, "Dry sliding wear behaviour of Al_2O_3-Al composite produced by centrifugal force infiltration", Material Science and Technology, Vol. 12, 1996, pp 483-488.
6. P. Martin Jebaraj, A. Chennakesava Reddy, Effect of Interfacial Debonding on Stiffness of Titanium Boride/AA5050 Alloy Metal Matrix Composites, 1st National Conference on Modern Materials and Manufacturing , Pune, 19-20 December, 1997.
7. S. Sundara Rajan, A. Chennakesava Reddy, Micromechanical modeling of Titanium Boride/AA7020 Alloy Metal Matrix Composites in Finite Element Analysis using RVE Model, 1st National Conference on Modern Materials and Manufacturing, Pune, 19-20 December, 1997.
8. P. Martin Jebaraj, A. Chennakesava Reddy, Effect of Interfacial Tractions of Rectangular Titanium Boride Particulate/AA8090 Alloy Metal Matrix Composites , 1st National Conference on Modern Materials and Manufacturing, Pune, 19-20 December, 1997.
9. S. Sundara Rajan, A. Chennakesava Reddy, Cohesive Zone interfacial debonding of Silicon Nitride/AA1100 Alloy Metal Matrix Composites Using Finite Element Analysis , 1st National Conference on Modern Materials and Manufacturing, Pune, 19-20 December, 1997.
10. S. Sundara Rajan, A. Chennakesava Reddy, Simulation of Micromechanics for interfacial debonding in Silicon Nitride/AA2024 Alloy Metal Matrix Composites , 1st National Conference on Modern Materials and Manufacturing, Pune, 19-20 December, 1997.
11. P. Martin Jebaraj, A. Chennakesava Reddy, Finite Element Analysis for Assessment of Dislocation and Debonding Events in Silicon Nitride/AA3003 Alloy Metal Matrix Composites, 1st National Conference on Modern Materials and Manufacturing, Pune, 19-20 December, 1997.
12. A. Chennakesava Reddy, Evaluation of Debonding and Dislocation Occurrences in Rhombus Silicon Nitride Particulate/AA4015 Alloy Metal Matrix Composites, 1st National Conference on Modern Materials and Manufacturing, Pune, India, 19-20 December, 278-282, 1997.