Interfacial Criterion for Debonding of Titanium Boride/AA4015 Metal Matrix Composites

[1]Y. S. A. Kumar and A. Chennakesava Reddy[2]

[1]Research scholar, Department of Mechanical Engineering, JNTUH College of Engineering and Technology, Hyderabad, India
[2]Assistant Professor, Department of Mechanical Engineering, JNTUH College of Engineering and Technology, Hyderabad, India
dr_acreddy@yahoo.com

Abstract: Square array unit cell/octagonal particle RVE models are used for micromechanical modeling of titanium boride/AA4015 alloy metal matrix composites. The analysis is carried out employing two-dimensional finite element methods under plane strain conditions. Debonding at particle-matrix interfaces is calculated through interfacial tractions for different volume fractions.

Keywords: AA4015 alloy, titanium boride, RVE model, finite element analysis, interfacial tractions, debonding, octagonal particle.

1. INTRODUCTION

Compared with conventional materials, particle reinforced nanocomposites exhibits low density, high strength to weight ratio and high stiffness to weight ratio, high toughness with improved creep resistance and wear resistance. Combining high stiffened nanoparticles to the low modulus polymer matrix, improves the load carrying capacity [1-7]. The impact of shape and size of reinforcement on the mechanical properties of composite material can be estimated through micromechanics using finite element method. Micromechanical research of the past two decades has produced a number of models of interface decohesion in heterogeneous materials such as metal matrix composites, which often represents the main source of distributed damage in composite materials [8-19].

The goal of this paper is to estimate debonding and stress bridging based on the elastic moduli, major Poisson's ratio and interfacial tractions of titanium boride/AA4015 alloy metal matrix composites. Finite element analysis (FEA) of TiB_2/AA4015 alloy metal matrix composites was executed RVE models comprising of square array cell/octagonal particle.

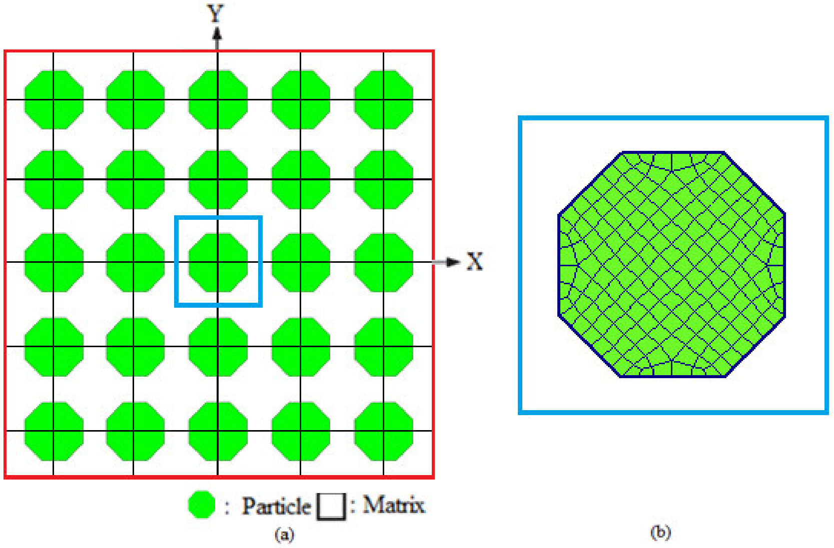

Figure 1: The RVE model: (a) particle distribution and (b) RVE scheme.

2. MATERIALS AND METHODS

The matrix material was AA4015 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 AA4015 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:

$$\bar{\sigma} = \bar{C}\bar{\varepsilon} \tag{1}$$

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:

$$\begin{Bmatrix} \bar{\sigma}_x \\ \bar{\sigma}_y \\ \bar{\tau}_{xy} \end{Bmatrix} = \begin{bmatrix} \bar{C}_{11} & \bar{C}_{12} & 0 \\ \bar{C}_{21} & \bar{C}_{22} & 0 \\ 0 & 0 & \bar{C}_{33} \end{bmatrix} \times \begin{Bmatrix} \bar{\varepsilon}_x \\ \bar{\varepsilon}_y \\ \bar{\gamma}_{xy} \end{Bmatrix} \tag{2}$$

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

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

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

3. RESULTS AND DISCUSSION

Figure 2a exhibits a slender increase in moduli with increasing volume fraction of titanium boride in the matrix AA4015 alloy. Figure 2b indicates nearly constant major Poisson's ratio for three volume fractions if titanium boride. Figure 2c indicates a fluctuation in the shear modulus as volume fraction increases from 10%Vp to 30%Vp.

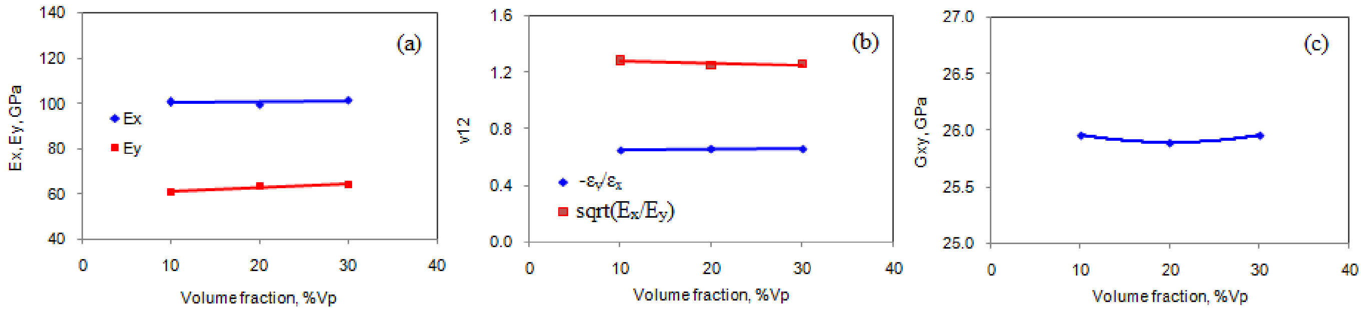

Figure 2: Effect of volume fraction on effective material properties.

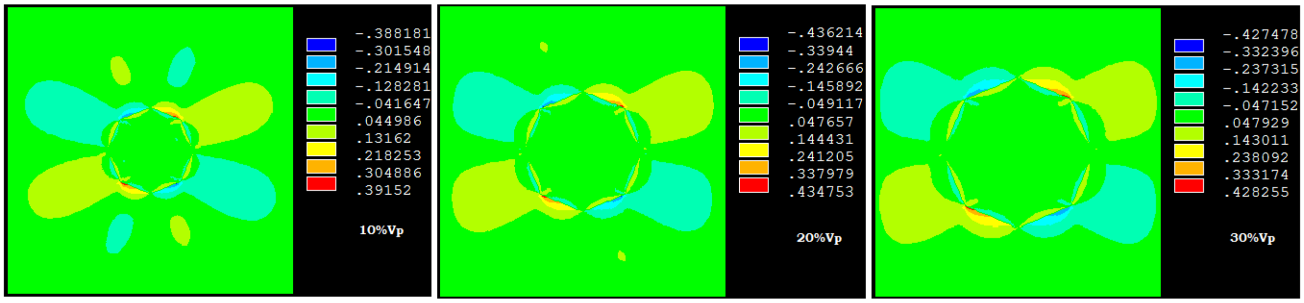

Figure 3: Stress concentrations in TiB_2/AA4015 alloy metal matrix composites.

Figure 3 shows shear stress induced in a unit cell of square array under tensile stress. The shear stress is of same magnitude in the titanium boride and AA4015 alloy matrix for three volume fractions except at the interface region between the matrix and the particle. For the interfacial normal traction, t_n, the angle between maximum amplitude to minimum amplitude is 150° (figure 4a). For the interfacial tangential traction, t_t, the angle between minimum amplitude to maximum amplitude is 90° (figure 4b). Both normal and normal tractions become zero at 75° from the axis of tensile loading. For the normal traction to fall from maximum to zero the angle of normal traction is 75°, while the angle of tangential traction is 45° to rise tangential traction from minimum to zero. It is also observed that the tangential zone is shorter than the compressed zone around the interface between the particle and the matrix. The debonding area is clearly visible at the interface along the tensile loading in figure 3.

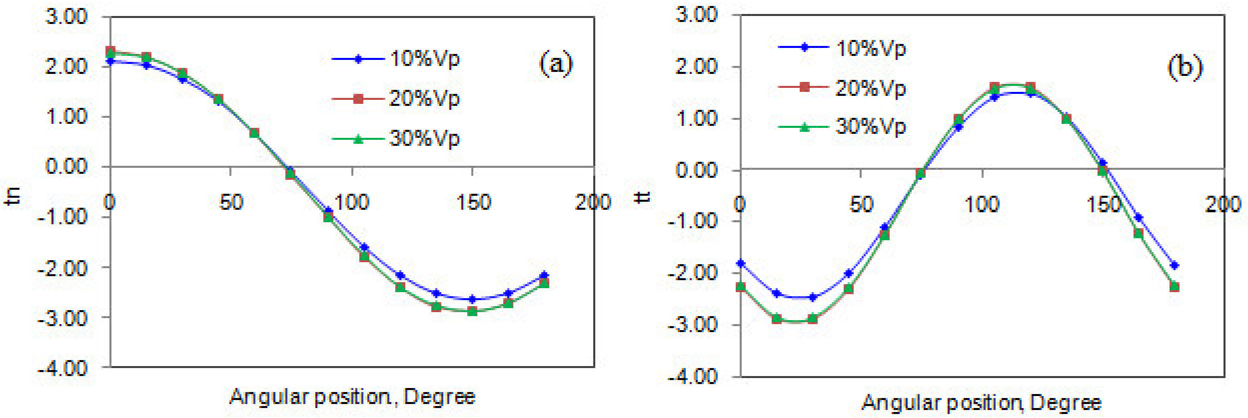

Figure 5: Interfacial tractions along the angle due to tensile loading: (a) normal and (b) tangential.

4. CONCLUSION

The shear stress is of same magnitude in the titanium boride and AA4015 alloy matrix for three volume fractions. For the octagonal particulate in AA4015 alloy matrix, the angle of traction between maximum amplitude to minimum amplitude is 150^o for the normal interfacial traction and it is 90^o for the interfacial tangential traction between minimum amplitude to maximum amplitude. The possibility of debonding is along the direction of tensile loading.

REFERENCES

1. A. Chennakesava Reddy, Fracture behavior of brittle matrix and alumina trihydrate particulate composites, Indian Journal of Engineering & Materials Sciences, 9, 2002, pp.365-368.
2. A. Chennakesava Reddy, S. Sundararajan, Influences of ageing, inclusions and voids on the ductile fracture mechanism of commercial Al-alloys, Journal of Bulletin of Material Sciences, Springer India, 28, 2005, pp. 75-79.
3. A. Chennakesava Reddy and Essa Zitoun, Matrix al-alloys for alumina particle reinforced metal matrix composites, Indian Foundry Journal, 55, 2009, pp.12-16.
4. A. Chennakesava Reddy, Mechanical properties and fracture behavior of 6061/SiCp Metal Matrix Composites Fabricated by Low Pressure Die Casting Process, Journal of Manufacturing Technology Research, 1, 2009, pp.273-286.
5. A. Chennakesava Reddy and B. Kotiveerachari, Effect of aging condition on structure and the properties of Al-alloy / SiC composite, International Journal of Engineering and Technology, 2, 2010, pp.462-465.
6. A. Chennakesava Reddy, Tensile properties and fracture behavior of 6063/SiCP metal matrix composites fabricated by investment casting process, International Journal of Mechanical Engineering and Materials Sciences, 3, 2010, pp.73-78.
7. A. Chennakesava Reddy and Essa Zitoun, Tensile behavior 0f 6063/Al_2O_3 particulate metal matrix composites fabricated by investment casting process, International Journal of Applied Engineering Research, 1, 2010, pp.542-552.
8. A. Chennakesava Reddy, Stir Casting Process on Porosity Development and Micromechanical Properties of AA5050/Titanium Oxide Metal Matrix Composites, 5th National Conference on Materials and Manufacturing Processes, Hyderabad, 9-10 June 2006, pp. 144-148.
9. A. Chennakesava Reddy, Effect of Porosity Formation during Synthesis of Cast AA4015/Titanium Nitride Particle-Metal Matrix Composites, 5th National Conference on Materials and Manufacturing Processes, Hyderabad, 9-10 June 2006, pp. 139-143.
10. A. Chennakesava Reddy, Role of Porosity and Clustering on Performance of AA1100/Boron Carbide Particle-Reinforced Metal Matrix Composites, 6th International Conference on Composite Materials and Characterization, Hyderabad, 8-9 June 2007, pp. 122-127.
11. A. Chennakesava Reddy, Effect of Clustering Induced Porosity on Micromechanical Properties of AA6061/Titanium Oxide Particulate Metal matrix Composites, 6th International Conference on Composite Materials and Characterization, Hyderabad, 8-9 June 2007, pp. 149-154.
12. B. Kotiveera Chari, A. Chennakesava Reddy, Bottom-Up Pouring and its Effect on Porosity and Clustering in Casting of AA1100/Silicon Nitride Particle-Reinforced Metal Matrix Composites, 6th National Conference on Materials and Manufacturing Processes, Hyderabad, 8-9 August 2008, pp. 110-114.
13. Essa Zitoun, A. Chennakesava Reddy, Microstructure-Property Relationship of AA3003/Boron Nitride Particle-Reinforced Metal Matrix Composites Cast by Bottom-Up Pouring, 6th National Conference on Materials and Manufacturing Processes, Hyderabad, 8-9 August 2008, pp. 115-119.
14. A. Chennakesava Reddy, Wear and Mechanical Behavior of Bottom-Up Poured AA4015/Graphite Particle-Reinforced Metal Matrix Composites, 6th National Conference on Materials and Manufacturing Processes, Hyderabad, 8-9 August 2008, pp. 120-126.
15. S. Pitchi Reddy, A. Chennakesava Reddy, Effect of Needle-like Brittle Intermetallic Phases on Fracture Behavior of Bottom-up Poured AA5050/Titanium Carbide Particle-Reinforced Metal Matrix Composites, 6th National Conference on Materials and Manufacturing Processes, Hyderabad, 8-9 August 2008, pp. 127-132.

16. A. Chennakesava Reddy, Sliding Wear and Micromechanical Behavior of AA1100/Titanium Oxide Metal Matrix Composites Cast by Bottom-Up Pouring, 7th International Conference on Composite Materials and Characterization, Bangalore, 11-12 December 2009, pp. 205-210
17. S. Pitchi Reddy, A. Chennakesava Reddy, Synthesis and Characterization of Zirconium Carbide Nanoparticles Reinforced AA2024 Alloy Matrix Composites Cast by Bottom-Up Pouring, 7th International Conference on Composite Materials and Characterization, Bangalore, 11-12 December 2009, pp. 211-215.
18. Essa Zitoun, A. Chennakesava Reddy, Analysis of Micromechanical Behavior of AA3003 Alloy - Graphite Metal Matrix Composites Cast by Bottom-Up Pouring with Regard to Agglomeration and Porosity, 7th International Conference on Composite Materials and Characterization, Bangalore, 11-12 December 2009, pp. 216-220.
19. P. Rami Reddy, A. Chennakesava Reddy, Processing of AA4015-Zirconium Oxide Particulate Metal Matrix Composites by Stir Casting Technology, 7th International Conference on Composite Materials and Characterization, Bangalore, 11-12 December 2009, pp. 221-224.
20. J. Aboudi. Micromechanical analysis of composites by the method of cells. Applied Mechanics Review, 42:193-221, July 1989.
21. C. A. Bigelow, W. S. Johnson, and R. A. Naik. A comparison of various micromechanics models for metal matrix composites. In J. N. Reddy and J. L. Teply, editors, Mechanics of Composite Materials and Structures, number 100 in Applied Mechanics Division, pages 21-32, La Jolla, CA, July 1989. The Applied Mechanics Division, ASME.
22. M. P. Divakar and A. Fafitis. Micromechanics-based constitutive model for interface shear. Journal of Engineering Mechanics, 118, 1992, pp.1317-1337.
23. R. L. Foye. An evaluation of various engineering estimates of the transverse properties of unidirectional composites. In Proceedings of the Tenth National SAMPE Symposium-Advanced Fibrous Reinforced Composites, November 1966.
24. Tvergaard, V. Model studies of fibre breakage and debonding in a metal reinforced by short fibers. J. Mech. Phys. Solids 41, 1993, pp. 1309–1326.