Cohesive Zone interfacial debonding of Silicon Nitride/AA1100 Alloy Metal Matrix Composites Using Finite Element Analysis

[1]S. Sundara Rajan and A. Chennakesava Reddy[2]

[1]Scientist-F, Defence Research and Development Organisation, Hyderabad, India
[2]Assistant Professor, Department of Mechanical Engineering, MJ College of Engineering and Technology, Hyderabad, India
dr_acreddy@yahoo.com

Abstract: Cohesive zone interfacial debonding is analyzed using finite element analysis within silicon nitride/AA1100 alloy metal matrix composite under various particle loading conditions. Square hexagonal array unit cell/rectangular particle RVE models are worked out using two-dimensional finite element methods. The linear kinematics and the linear elastic material models are used the nonlinearity is only due to the cohesive failure of the particle-matrix interface. The debonding has enlarged with increase of volume fraction of silicon nitride.

Keywords: AA1100 alloy, Silicon nitride, rectangular particle, RVE model, finite element analysis, interfacial tractions, debonding.

1. INTRODUCTION

Decohesion (figure 1) between the matrix and particulate in the metal matrix composites is an important failure mechanism. Interfacial failure, resulting in debonding, of the particle from the matrix, is often the first mode of failure to occur [1-5]. Micromechanics models are attractive as they give rise to closed-form or semi-analytic solutions. Numerical simulation is performed on a sample region of the heterogeneous material, which is small enough to be computationally tractable. This calculation region is the base cell of a periodically repeating microstructure. The simplest possible base cell contains a single inclusion and thus represents an ordered particle distribution [6-15]. In the limit, the region of calculation becomes a Representative Volume Element (RVE).

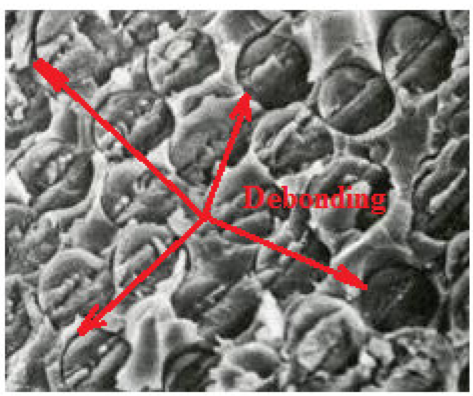

Figure 1: Decohesion in a metal matrix composite.

The effect of damage due to particle debonding on the constitutive response of particulate reinforced composites is investigated using the finite element implementation of the mathematical theory of homogenization. The particle debonding process is modeled using a bilinear cohesive law which relates cohesive tractions to displacement jumps along the particle-matrix interface. The analysis is performed in plane strain with linear kinematics. RVE model is of hexagonal square array consisting periodical distribution of silicon nitride particulates in the AA1100 alloy matrix.

2. MATERIALS AND METHODS

The volume fractions of silicon nitride particulate reinforcement were 10%, 20%, and 30% in the matrix AA1100 alloy. The periodic model for the representative volume element (RVE) scheme is shown in figure 2. The perfect adhesion was assumed between Silicon nitride particle and AA1100 alloy matrix. PLANE183 element was used for the matrix and the nanoparticle. The interface between particle and matrix was modeled using a CONTACT-172 element.

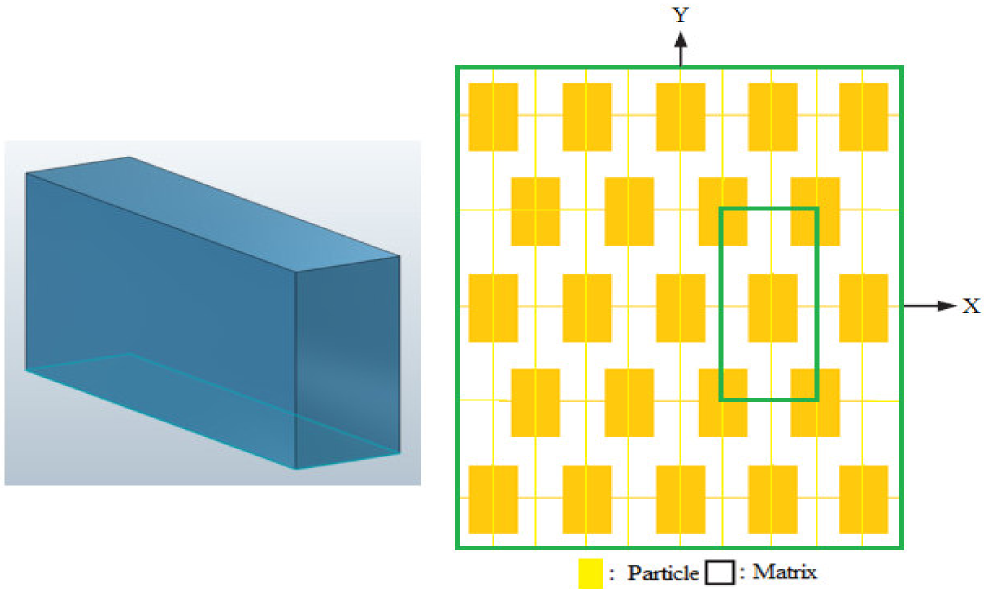

Figure 2: The RVE model: (a) particle distribution and (b) RVE scheme.

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 $\overline{C}$ 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):

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

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

3. RESULTS AND DISCUSSION

The tensile elastic modulus, E_x increases with increase of volume fraction of silicon nitride in AA1100 alloy matrix as shown in figure 3a.In contrast, the compressive elastic modulus, E_y and shear modulus, Gxy diminish with augment in the volume fraction of silicon nitride. The major Poisson's ratio increases with increase of volume fraction of silicon nitride for SiN_4/AA1100 alloy metal matrix composites (figure 3b). Figure 4 shows von Mises stresses induced in a unit cell of square hexagonal array RVE under tensile stress. The maximum von Mises stress occurs at edges and vertices of the rectangular particulate. The stress bridging enhances with increase in the volume fraction of silicon nitride.

In this work, the linear kinematics and the linear elastic material models are used the nonlinearity is only due to the cohesive failure of the particle-matrix interface. The stiffness mismatch between the Silicon nitride particle and the AA1100 alloy matrix is 247 MPa. The analysis is performed in two dimensions using a plane strain assumption. The two surfaces of the cohesive element begin to separate, with a constant initial stiffness. Once the interface strength is reached to its maximum, the interface becomes weaker with increasing separation, until achieving the critical separation, at which point failure is complete and the interface can no longer sustain tractions. When the interfacial normal traction, t_n becomes zero the interface can no longer withstand the loading transfer capability from the matrix to the particle but resulting the occurrence of debonding due to tensile loading (figure 5a). When the interfacial tangential traction, t_t becomes zero the interface debonding is due to shear as shown in figure 5b. The resultant effect of normal and tangential traction is the incidence of debonding as shown in figure 3. The level of debonding (c > b > a) increases with increase of volume fraction owing to more transfer of load from the matrix to the particle.

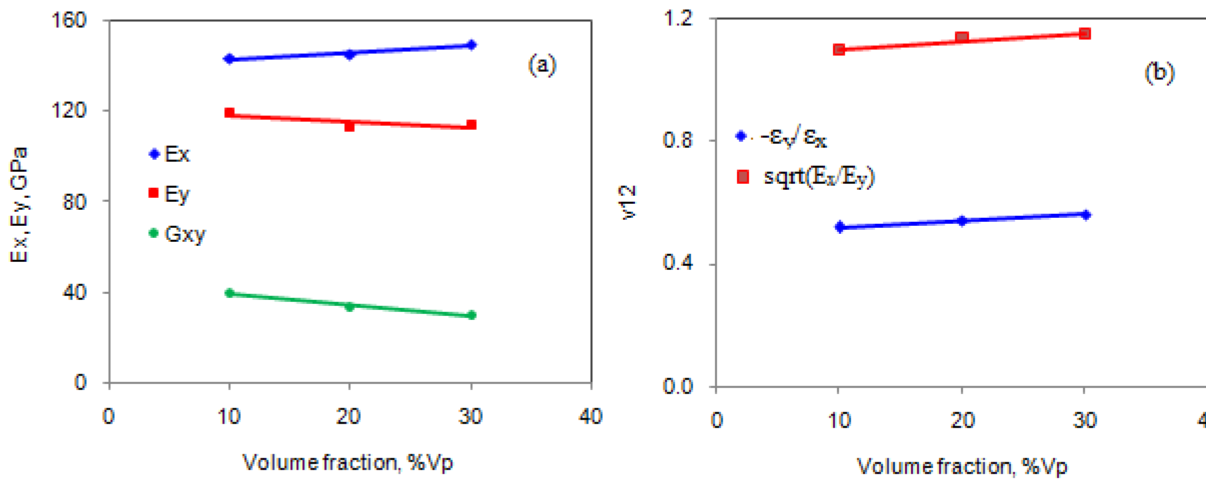

Figure 3: Effect of volume fraction on effective material properties.

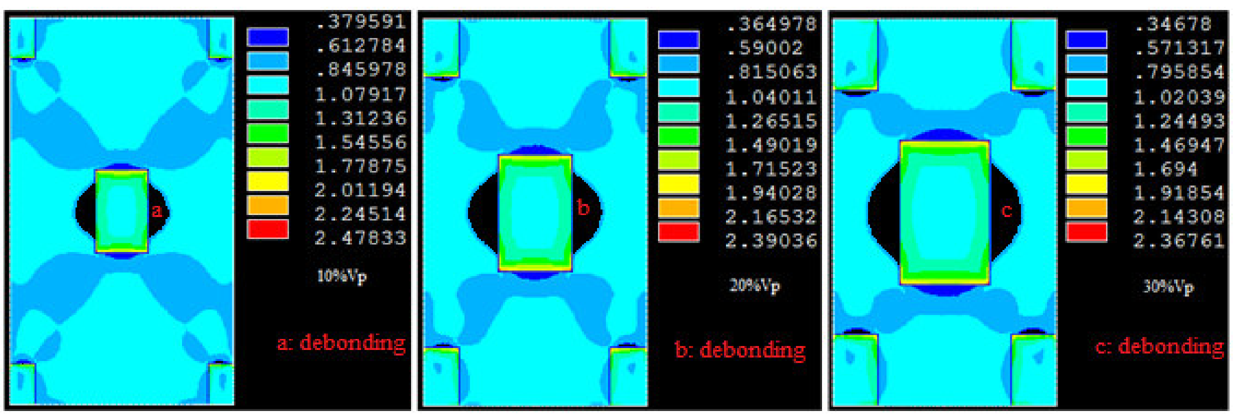

Figure 4: Stress concentrations in Si_3N_4/AA1100 alloy metal matrix composites.

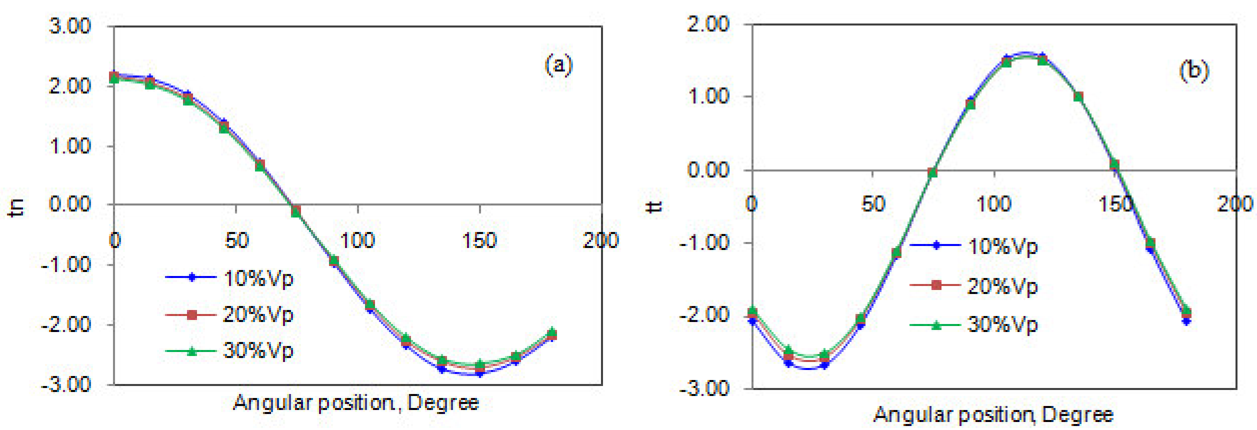

Figure 5: Interfacial tractions along the angle due to tensile loading: (a) normal and (b) tangential.

4. CONCLUSION

In this work, the linear kinematics and the linear elastic material models are used the nonlinearity is only due to the cohesive failure of the particle-matrix interface. The degree of debonding increases with increase of volume fraction owing to more transfer of load from the matrix to the particle.

REFERENCES

1. Y. Benveniste, J. Aboudi. A continuum model for fiber reinforced materials with debonding, International Journal of Solids and Structures, vol. 20, 1984, pp.935–951.
2. D. H. Chen, S. Nakamichi. Stress intensity factors for an interface crack along an elliptical inclusions, International Journal of Fracture, vol. 82, 1996, pp. 31–152.
3. R. Pyrz. Correlation of microstructure variability and local stress field in two-phase materials, Materials Science and Engineering A, no. 177, 1994, pp.253–259.
4. R. M. Christensen. A critical evaluation for a class of micro-mechanics models. Journal of Mechanics of Physics and Solids, vol. 38, no. 3, 1990, pp. 379–404.
5. T. Mori and K. Tanaka. Average stress in matrix and average elastic energy of materials with misfitting inclusions. Acta Metallurgica, vol. 21, 1973, pp.571–574.
6. S. Sundara Rajan and A. Chennakesava Reddy, Evaluation of Tensile Behavior of Boron Carbide/AA1100 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, March 1997, pp.156-159.
7. 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.
8. P. Martin Jebaraj and A. Chennakesava Reddy, Prediction of Tensile Behavior of Boron Carbide/AA3003 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, March 1997, pp.164-166.
9. A. Chennakesava Reddy, Effect of Particle Loading on Microealstic Behavior and interfacial Tractions of Boron Carbide/AA4015 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, March 1997, pp. 176-179.
10. Kotiveera Chari and A. Chennakesava Reddy, Estimation of Micro-stresses and Interfacial Tractions in Boron Carbide/AA5050 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, March 1997, pp. 180-182.
11. 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.
12. 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.
13. H. B. Niranjan and A. Chennakesava Reddy, Valuation of Micro-stresses and interfacial Tractions in Boron Carbide/AA8090 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, March 1997, pp. 189-191.
14. H. B. Niranjan and A. Chennakesava Reddy, Determination of Micro-stresses and interfacial Tractions in Titanium Boride/AA1100 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, March 1997, pp. 192-194.
15. A. Chennakesava Reddy, Reckoning of Micro-stresses and interfacial Tractions in Titanium Boride/AA2024 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, March 1997, pp. 195-197.