Effects of Interphase and Interface Characteristics on the Tensile Behavior of Boron Nitride/7020 Particle Reinforced Composites Subjected to Thermo-Mechanical Loading

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Abstract: In the current work, the BN/AA7020 alloy metal matrix composites were subjected to mechanical and thermal loads. The results obtained from the finite element analysis of BN/AA7020 alloy composites reveal the interphase separation from the particle and the matrix.

Keywords: Boron nitride, AA7020 alloy, RVE model, finite element analysis, interphase separation, particle fracture.

1. INTRODUCTION

The condition of the interfacial area and interphase region in a nanocomposite can significantly affect its mechanical performance. Adhesion between nanoparticles and the metal matrix can affect mechanical properties of the composite. Decreasing the interfacial strength could cause the interfacial debonding of particles from the matrix and, as a consequence, the tensile strength of the composite could be reduced. Interfacial debonding can also cause shear yielding of the matrix around the particles. The interfacial adhesion strength should not be too low so as to significantly scarify the modulus and other mechanical properties [1]. The use of numerical analysis to gain better performance in composite materials is well established [2-15]. The identification of the mechanical properties of the interphase and its modeling procedure both have a significant impact on the accurate prediction of nanocomposites' tensile properties. A number of efforts have numerically analyzed nanocomposites' tensile behavior using FEM.

In this research, the tensile performance of a Boron Nitride/AA7020 alloy metal matrix composite, including the modulus of elasticity, tensile strength, interface debonding are analyzed using Ansys FEM software. The shape boron nitride nanoparticle considered in this work is spherical. The periodic particle distribution was a square array and corresponding representative volume element (RVE) is showed in figure 1.

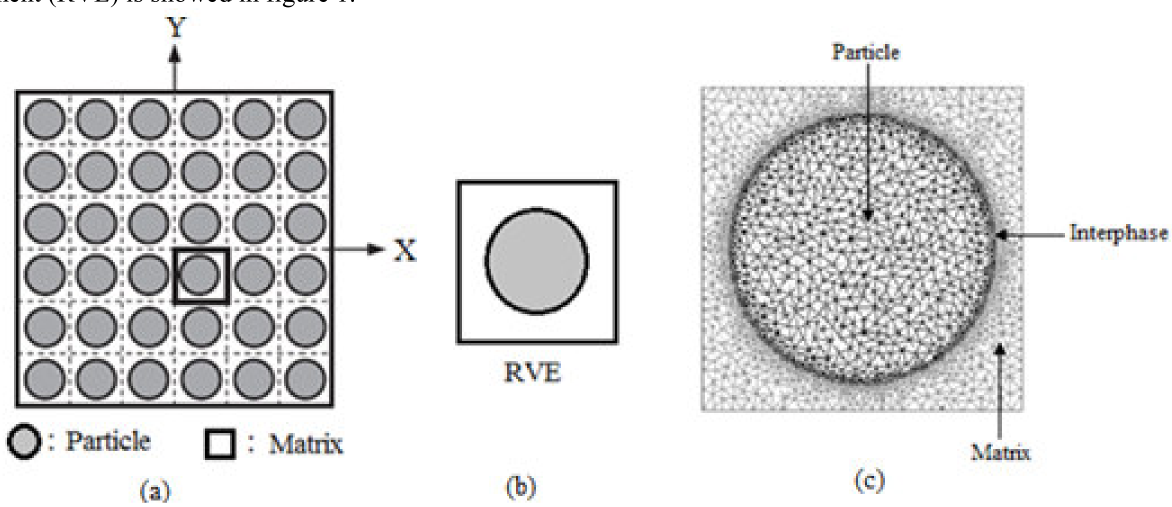

Figure 1: Square array of particles (a); Representative Volume Element (b); and Discretization of RVE (c).

2. MATERIALS METHODS

The matrix material was AA7020 alloy. The reinforcement material was boron nitride (BN) nanoparticles of average size 100nm. The mechanical properties of materials used in the present work are given in table 1. In the current work, a cubical representative volume element (RVE) was implemented to analyze the tensile behavior BN/AA7020 alloy composites at two (10% and 30%) volume fractions of BN and at different temperatures. The large strain PLANE183 element was used in the matrix in all the models. In order to model the adhesion between the matrix and the particle, a CONTACT 172 element was used.

Table 1: Mechanical properties of AA7020 matrix and BN nanoparticles

Property	AA7020	BN
Density, g/cc	2.78	2.10
Elastic modulus, GPa	72	100
Coefficient of thermal expansion, 10^{-6} 1/^{o}C	23.1	5.5
Specific heat capacity, J/kg/^{o}C	875	1150
Thermal conductivity, W/m/^{o}C	137	52
Poisson's ratio	0.33	0.27

3. RESULTS AND DISCUSSION

Figure 2a shows the normalized elastic modulus of BN/AA7020 composites at different temperatures. The elastic modulus is normalized with the elastic modulus of AA7020 alloy. The normalized elastic modulus is decreased with increase of temperature. Under thermo-mechanical loading, the stiffness of 30% BN/AA7020 alloy composites is higher than that of 10% BN/AA7020 alloy composites. The normalized stiffness along the normal direction is lower than that along the load direction owing to tensile loading. The normalized shear modulus increases with increase of temperature as shown in figure 2b. The increase of major Poisson's ratio with temperature from 100^{o}C to 300^{o}C indicates the elongation along the load is greater than that along the transverse direction of loading of RVE (figure 2c).

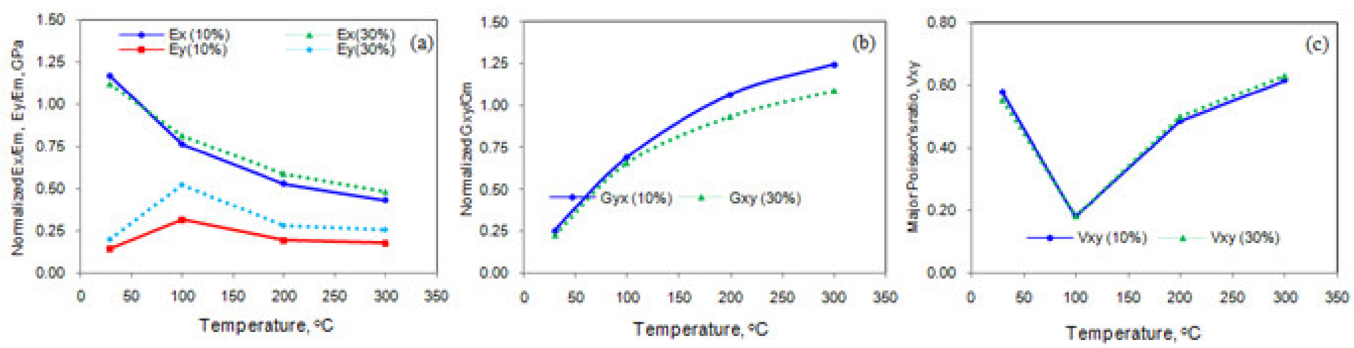

Figure 2: Effect of temperature on micromechanical properties of BN/AA7020 composites.

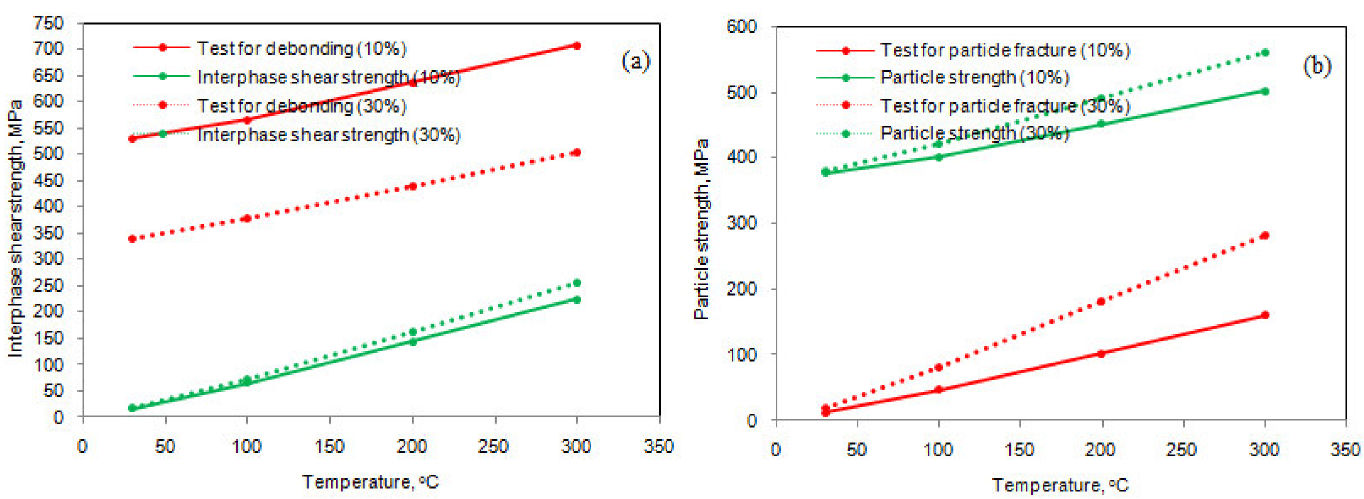

Figure 3: Criterion for interfacial debonding (a) and for particle fracture (b).

If the particle deforms in an elastic manner (according to Hooke's law) then,

$$\tau = \frac{n}{2}\sigma_p \qquad (1)$$

where σ_p is the particle stress. For the interfacial debonding/yielding to occur, the interfacial shear stress reaches its shear strength:

$$\tau = \tau_{max} \qquad (2)$$

For particle/matrix interfacial debonding can occur if the following condition is satisfied:

$$\tau_{max} < \frac{n\sigma_p}{2} \qquad (3)$$

The interphase separation occurs between BN nanoparticle and AA7020 alloy matrix as the condition in Eq.(3) is satisfied. If particle fracture occurs when the stress in the particle reaches its ultimate tensile strength, $\sigma_{p,uts}$, then setting the boundary condition at

$$\sigma_p = \sigma_{p,\, uts} \qquad (4)$$

The relationship between the strength of the particle and the interfacial shear stress is such that if

$$\sigma_{P,uts} < \frac{2\tau}{n} \qquad (5)$$

Then the particle will fracture. From the figure 3b, it is observed that the BN nanoparticle was not fractured as the condition in Eq. (5) is not satisfied. The von Mises stress as a function of temperature is illustrated in figure 4. The von Mises stresses induced at the interface are higher than that induced in the nanoparticle. Hence, the interphase separation has occurred between the particle and the matrix.

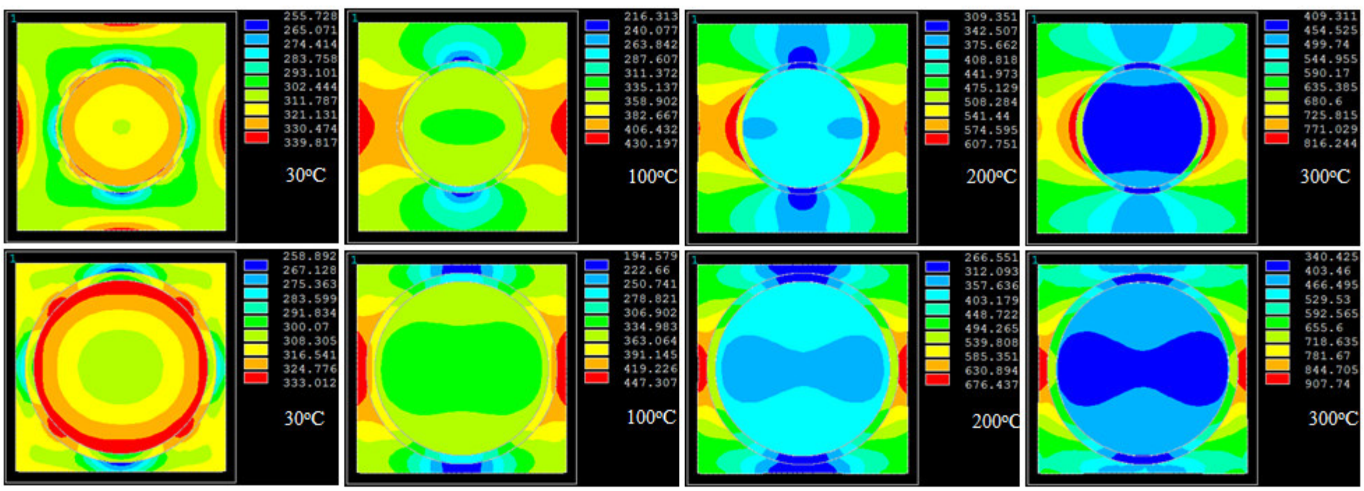

Figure 4: Images of von Mises stresses obtained from FEA: (a) 10% BN/AA7020 alloy and (b) 30% BN/AA7020 alloy composites.

4. CONCLUSION

The normalized elastic modulus is decreased with increase of temperature. The shear stress is high at the interface resulting to interphase separation from the particle and the matrix. The interphase separation has occurred between the particle and the matrix.

REFERENCES

1. S. Ahmed, F. Jones, A review of particulate reinforcement theories for polymer composites, Materials Science Journal, 25, 1990, pp. 4933-4942.
2. 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 1997, pp. 278-282.
3. A. Chennakesava Reddy, Interfacial Debonding Analysis in Terms of Interfacial Tractions for Titanium Boride/AA3003 Alloy Metal Matrix Composites, 1st National Conference on Modern Materials and Manufacturing , Pune, 19-20 December, 1997.
4. A. Chennakesava Reddy, Assessment of Debonding and Particulate Fracture Occurrences in Circular Silicon Nitride Particulate/AA5050 Alloy Metal Matrix Composites , National Conference on Materials and Manufacturing Processes, Hyderabad, India, 27-28 February 1998, pp. 104-109.
5. A. Chennakesava Reddy, Local Stress Differential for Particulate Fracture in AA2024/Titanium Carbide Nanoparticulate Metal Matrix Composites, National Conference on Materials and Manufacturing Processes, Hyderabad, India, 27-28 February 1998, pp. 127-131.

6. A. Chennakesava Reddy, Micromechanical Modelling of Interfacial Debonding in AA1100/Graphite Nanoparticulate Reinforced Metal Matrix Composites, 2nd International Conference on Composite Materials and Characterization, Nagpur, India, 9-10 April 1999, pp. 249-253.
7. A. Chennakesava Reddy, Cohesive Zone Finite Element Analysis to Envisage Interface Debonding in AA7020/Titanium Oxide Nano-particulate Metal Matrix Composites, 2nd International Conference on Composite Materials and Characterization, Nagpur, India, 9-10 April 1999, pp. 204-209.
8. H. B. Niranjan, A. Chennakesava Reddy, Computational Modeling of Interfacial Debonding in Fused Silica/AA7020 Alloy Particle-Reinforced Metal Matrix Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 222-227.
9. H. B. Niranjan, A. Chennakesava Reddy, Nanoscale Characterization of Interfacial Debonding and Matrix Damage in Titanium Carbide/AA8090 Alloy Particle-Reinforced Metal Matrix Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 228-233.
10. S. Sundara Rajan, A. Chennakesava Reddy, Assessment of Temperature Induced Fracture in Boron Nitride/AA1100 Alloy Particle-Reinforced Metal Matrix Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 234-239.
11. S. Sundara Rajan, A. Chennakesava Reddy, Estimation of Fracture in Zirconia/AA2024 Alloy Particle-Reinforced Composites Subjected to Thermo-Mechanical Loading, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 240-245.
12. P. M. Jebaraj, A. Chennakesava Reddy, Finite Element Predictions for the Thermoelastic Properties and Interphase Fracture of Titanium Nitride /AA3003 Alloy Particle-Reinforced Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 246-251.
13. P. M. Jebaraj, A. Chennakesava Reddy, Effect of Thermo-Mechanical Loading on Interphase and Particle Fractures of Titanium Oxide /AA4015 Alloy Particle-Reinforced Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 252-256.
14. A. Chennakesava Reddy, Effect of CTE and Stiffness Mismatches on Interphase and Particle Fractures of Zirconium Carbide /AA5050 Alloy Particle-Reinforced Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 257-262.
15. A. Chennakesava Reddy, Behavioral Characteristics of Graphite /AA6061 Alloy Particle-Reinforced Metal Matrix Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 263-269.