Effect of Thermal-heating on Nanoparticle Fracture Trend in AA2024/c-BN Particle-Reinforced Metal Matrix Composites

[1]M. S. Ramgir and A. Chennakesava Reddy[2]

[1]Research Scholar, Department of Mechanical Engineering, JNTU College of Engineering, Hyderabad, India
[2]Professor, Department of Mechanical Engineering, JNTU College of Engineering, Hyderabad, India

Abstract: *In the present work, the AA2024-BNmetal matrix composites were manufactured at 10% and 30% volume fractions of BN. The composites were subjected to mechanical and thermal loads. The microstructure of AA2024 alloy-BN reveals the fracture of interphase and particle. Only particle fracture was observed above 100^{o}C. Debonding occurs at all temperatures of thermal loading.*

Keywords: *AA2024, boron nitride, phase transformation, RVE model, finite element analysis, interphase fracture.*

1. INTRODUCTION

Good bonding between ceramic reinforcements and their metal matrix is crucial to the strength of metal matrix composites (MMCs). In the past, various research works have been carried out on metal matrix composites prepared from aluminum alloy matrices and reinforced particles such as SiC [1-7], Al_2O_3 [8-13], TiO_2 [13], MgO [14], B_4C [15], ZrC [16], TiB_2 [17-19] and $Al(OH)_3$ [20]. The stress transfer characteristic of nanoparticle reinforced composite materials under various mechanical and thermal loadings is very important for optimum utilization of metal matrix composites.

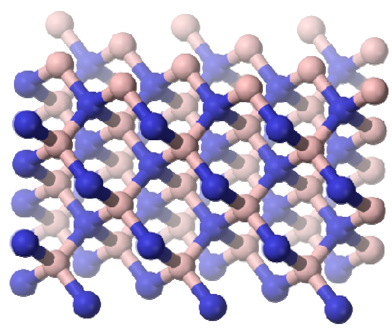

Figure 1: Halite (cubic) structure of c-BN.

Cubic boron nitride has a crystal structure analogous to that of diamond. it is softer than diamond, but its thermal and chemical stability is superior. Under combined loading of thermal and tension, the phase transformation is very important the optimum utilization BN particle based composites. Finite element method (FEM) is capable of identifying the local response of the material. A common practice to estimate the bulk and local responses of composite material is to use a unit cell reinforced by a single fiber, whisker or particle subjected to periodic and symmetric boundary conditions [14]. A lot of research was carried out to assess the interface behavior in particle reinforced metal matrix composites under tensile loading using finite element analysis approach [17].

In the present work, hexagonal boron nitride (c-BN) was used to fabricate AA2024/c-BN composites. The effect of thermo-tensile loading on the fracture in AA2024 alloy/c-BN composites was examined. Both microscopic and micromechanics methods were employed to assess fracture in the composites. ANSYS software was used to computationally simulate thermo-mechanical nonlinear behavior of AA2024 alloy/BN composites to analyze local constituent response including the interface/interphase regions. The results obtained from the numerical simulation were validated with the experimental results.

2. MATERIALS METHODS

The matrix material was AA2024 alloy. The reinforcement material was BN nanoparticles of average size 100nm. AA2024 alloy/ BN composites were fabricated by the stir casting process and low pressure casting technique with argon gas at 3.0 bar.

The composite samples were give solution treatment and cold rolled to the predefined size of tensile specimens. The heat-treated samples were machined to get rectangular specimens (figure 2) for the tensile tests. The tensile specimens were placed in the grips of a Universal Test Machine (UTM) with temperature controlled chamber at a specified grip separation and pulled until failure. The test speed was 2 mm/min. A strain gauge was used to determine elongation. In the current work, a cubical representative volume element (RVE) was implemented to analyze the tensile behavior AA2024/BN nanoparticle composites at two (10% and 30%) volume fractions of BN and at different temperatures. The shape BN nanoparticle considered in this work is spherical. The periodic particle distribution was a square array and corresponding representative volume element (RVE) as shown in figure 3. 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.

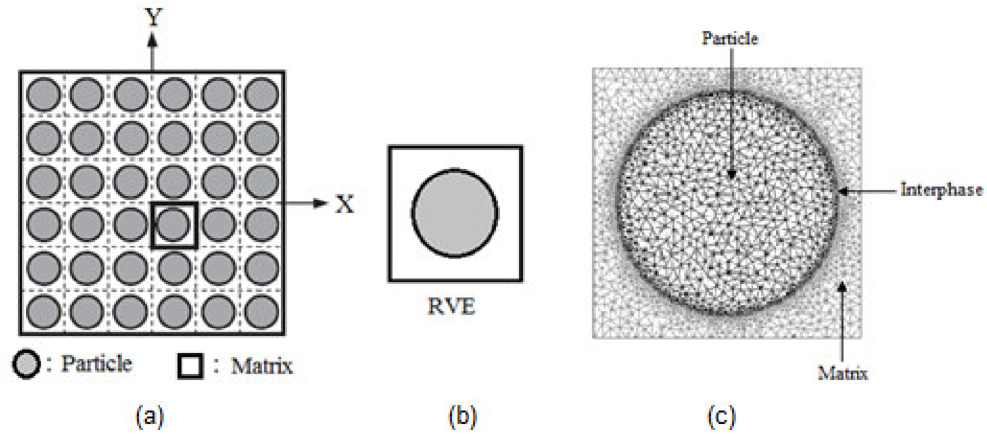

Figure 3: Square array of particles (a), Representative Volume Element (b) and Discretization of RVE (c).

3. RESULTS AND DISCUSSION

3.1 Thermo-Mechanical Behavior

Figure 7 represents micromechanical properties of AA2024/BN composites. The elastic modulus is normalized with the elastic modulus of AA2024alloy. The normalized stiffness of the composites decreases with increase of temperature. The stiffness of AA2024 alloy/30% BN composites is higher than that of AA2024 alloy/10% BN composites (figure 7a). The normalized stiffness along the normal direction is lower than that along the load direction. There is discrepancy of stiffness along normal to load direction at 100^{o}C. The reason is unknown. The normalized shear modulus is constant with increase of temperature for AA2024 alloy/BN composites (figure 7b). The major Poisson's ratio decreases initially from room temperature to 100^{o}C and later on it increases with temperature (figure 7c).

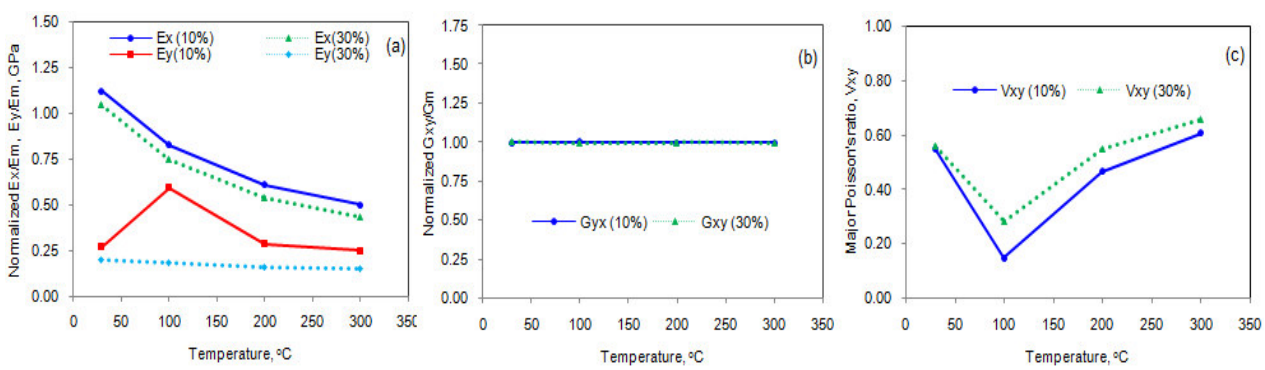

Figure 7: Effect of temperature on micromechanical properties of AA2024/BN composites.

3.2 Fracture Analysis

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

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

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

$$\sigma_p = \sigma_{p,\,uts} \qquad (2)$$

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

$$\sigma_{P,uts} < \frac{2\tau}{n} \qquad (3)$$

Then the particle will fracture. From the figure 8a, it is observed that the BN nanoparticle was fractured as the condition in Eq. (3) is satisfied above 100°C for the composites AA2024/BN. This is due to CTE and stiffness mismatches between BN nano-particles and AA2024 alloy matrix. For the interfacial debonding/yielding to occur, the interfacial shear stress reaches its shear strength [21]:

$$\tau = \tau_{max} \qquad (4)$$

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

$$\tau_{max} < \frac{n\sigma_p}{2} \qquad (5)$$

It is observed from figure 8b that the interphase debonding occurs between BN nanoparticle and AA2024 alloy matrix as the condition in Eq.(5) is satisfied at all temperatures for the composites AA2024/BN composites. The debonding phenomenon is high in the composites comprising of 10% BN.

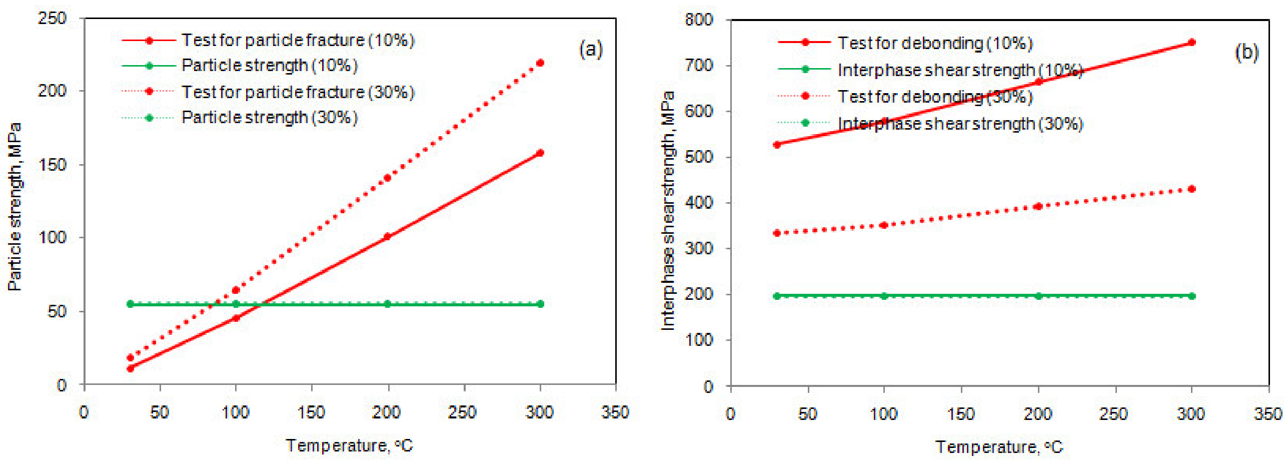

Figure 8: Criterion for interfacial for (a) particle fracture and (b) debonding.

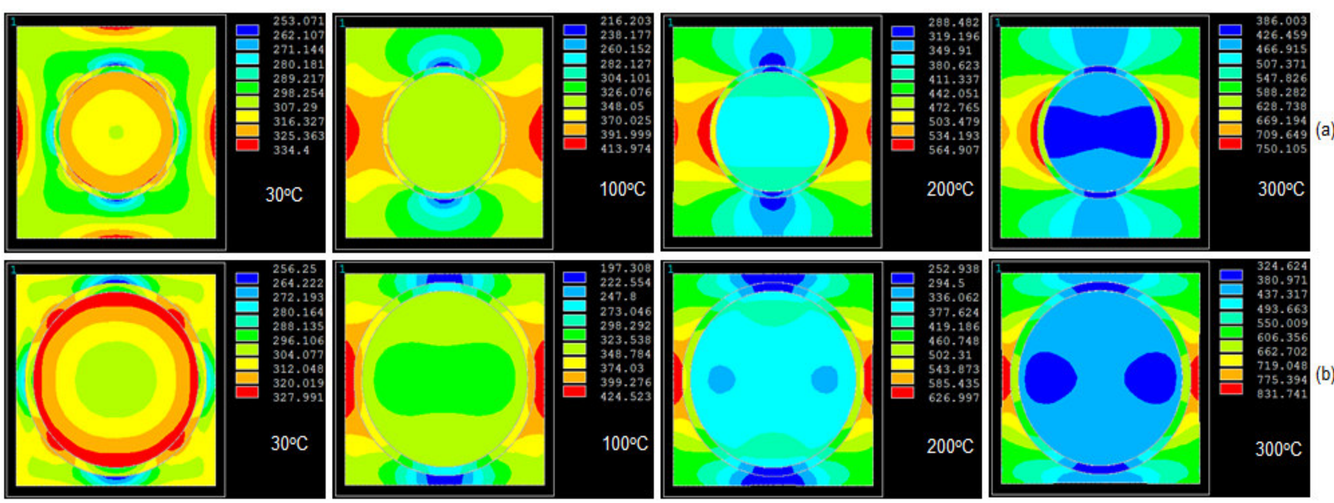

Figure 9: Images of von Mises stresses obtained from FEA: (a) AA2024/10% BN and (b) AA2024/30% BN composites.

The von Mises stress induced at the interface are higher than that induced in the nanoparticle (figure 9). Hence, the interfacial interphase fracture was occurred between the particle and the matrix. The particle fracture was occurred in all the composites as the von Mises stress exceeds the ultimate tensile strength of BN nanoparticles due to thermal shock.

4. CONCLUSION

The shear stress is high at the interface resulting to interphase debonding in AA2024/ BN composites. The particle fracture was observed above 100^{o}C of temperature loading in AA2024/BN composites. The microstructure obtained from the experimental samples confirms the fracture of interphase between the BN particles and AA2024 alloy matrix and particle fracture. The de-bonding occurred above room temperature.

REFERENCES

1. 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.
2. A. Chennakesava Reddy, Tensile properties and fracture behavior of 6063/SiC_P metal matrix composites fabricated by investment casting process, International Journal of Mechanical Engineering and Materials Sciences, 3, 2010, pp.73-78.
3. 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.
4. A. Chennakesava Reddy and B. Kotiveerachari, Influence of microstructural changes caused by ageing on wear behaviour of Al6061/SiC composites, Journal of Metallurgy & Materials Science, 53, 2011, pp. 31-39.
5. A. Chennakesava Reddy, Tensile fracture behavior of 7072/SiCp metal matrix composites fabricated by gravity die casting process, Materials Technology: Advanced Performance Materials, 26, 2011, pp. 257-262.
6. A. Chennakesava Reddy, Influence of strain rate and temperature on superplastic behavior of sinter forged Al6061/SiC metal matrix composites, International Journal of Engineering Research & Technology, 4, 2011, pp.189-198.
7. A. Chennakesava Reddy , Evaluation of mechanical behavior of Al-alloy/SiC metal matrix composites with respect to their constituents using Taguchi techniques, i-manager's Journal of Mechanical Engineering, 1, 2011, pp.31-41.
8. A. Chennakesava Reddy and Essa Zitoun, Matrix al-alloys for alumina particle reinforced metal matrix composites, Indian Foundry Journal, 55, 2009, pp.12-16.
9. A. Chennakesava Reddy and Essa Zitoun, Tensile behavior of 6063/Al_2O_3 particulate metal matrix composites fabricated by investment casting process, International Journal of Applied Engineering Research, 1, 2010, pp.542-552.
10. A. Chennakesava Reddy and Essa Zitoun, Tensile properties and fracture behavior of 6061/Al_2O_3 metal matrix composites fabricated by low pressure die casting process, International Journal of Materials Sciences, 6, 2011, pp.147-157.
11. A. Chennakesava Reddy, Strengthening mechanisms and fracture behavior of 7072Al/Al_2O_3 metal matrix composites, International Journal of Engineering Science and Technology, 3, 2011, pp.6090-6100.
12. A. Chennakesava Reddy, Evaluation of mechanical behavior of Al-alloy/Al_2O_3 metal matrix composites with respect to their constituents using Taguchi, International Journal of Emerging Technologies and Applications in Engineering Technology and Sciences, 4, 2011, pp. 26-30.
13. 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, 205-210.
14. A. S. Goud, A. Chennakesava Reddy, Evaluation of Nanoparticle Fracture in MgO Reinforced Aluminum matrix composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10 December 2011, pp. 320-324.
15. M. S. Ramgir, A. Chennakesava Reddy, Control of B_4C Reinforced Particulates on Dry Wear Resistance of AA2024/B4C Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10 December 2011, pp. 336-340.
16. M. Mastanaiah, A. Chennakesava Reddy, Abrasive Wear of AA3003/ZrC Composites, 3rd International Conference on Modern Materials and Manufacturing , New Delhi, 9-10 December 2011, pp. 347-351.
17. A. S. Goud, A. Chennakesava Reddy, Interface Failure Analysis of TiB_2 Reinforced Aluminum Alloy Matrix Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10 December 2011, pp. 325-328.
18. V. K. Reddy, A. Chennakesava Reddy, Mathematical Models for Dry Wear of H18 Heat Treated AA1100/TiB_2 Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10 December 2011, pp. 341-346.
19. R. G. Math,A. Chennakesava Reddy, Unlubricated Sliding of AA4015/TiB_2 Metal Matrix Composites, 3rd International Conference on Modern Materials and Manufacturing, New Delhi, 9-10 December 2011, pp. 352-356.
20. A. Chennakesava Reddy, Fracture behavior of brittle matrix and alumina trihydrate particulate composites, Indian Journal of Engineering & Materials Sciences, 9, 2002, pp.365-368.
21. 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, 28, 2005, pp. 75-79.