

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

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Abstract: In the present work, the AA2024-BN metal 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°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], Al₂O₃ [8-13], TiO₂ [13], MgO [14], B₄C [15], ZrC [16], TiB₂ [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.

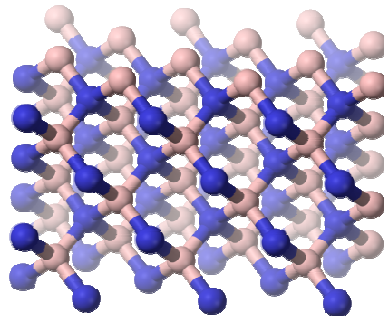


Figure 1: Halite (cubic) structure of c-BN.

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 for the optimum utilization of BN particle-based composites. The 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 the 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.

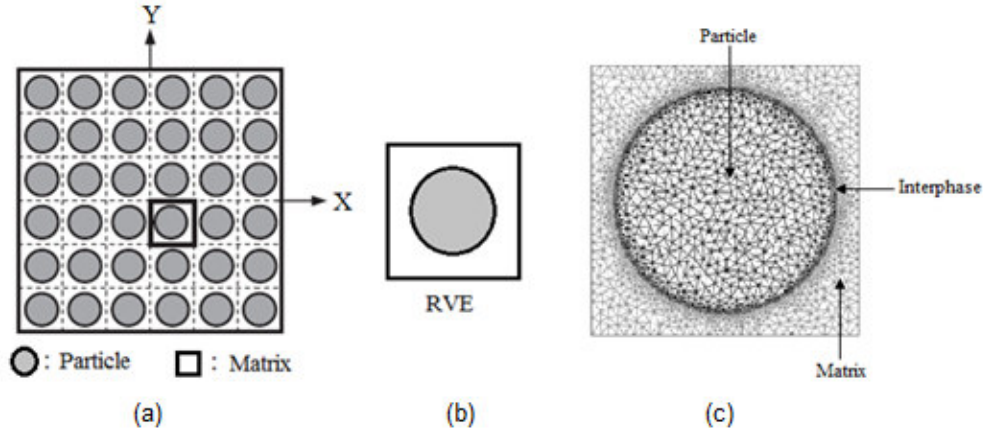


Figure 3: Square array of particles (a), Representative Volume Element (b) and Discretization of RVE (c).

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 AA2024 alloy. 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°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°C and later on it increases with temperature (figure 7c).

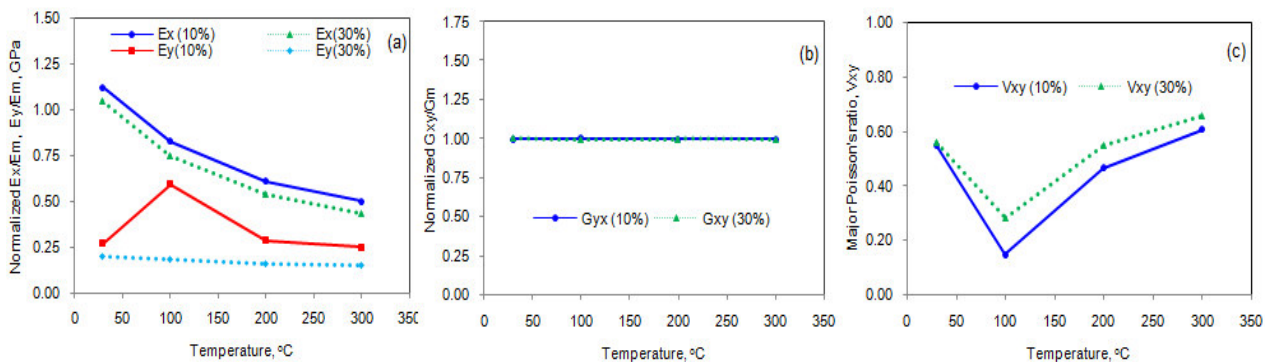


Figure 7: Effect of temperature on micromechanical properties of AA2024/BN composites.

3.2 Fracture Analysis

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

$$\tau = \frac{n}{2} \sigma_p \tag{1}$$

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

$$\sigma_p = \sigma_{p, uts} \tag{2}$$

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

$$\sigma_{p, uts} < \frac{2\tau}{n} \tag{3}$$

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 nanoparticles and AA2024 alloy matrix. For the interfacial debonding/yielding to occur, the interfacial shear stress reaches its shear strength [21]:

$$\tau = \tau_{max} \tag{4}$$

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

$$\tau_{max} < \frac{n\sigma_p}{2} \tag{5}$$

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.

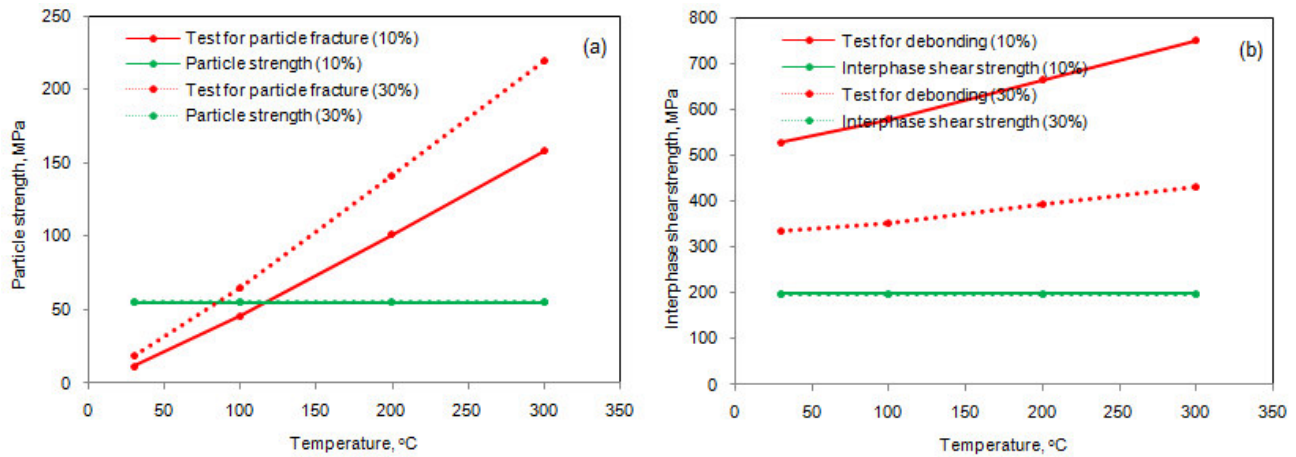


Figure 8: Criterion for interfacial for (a) particle fracture and (b) debonding.

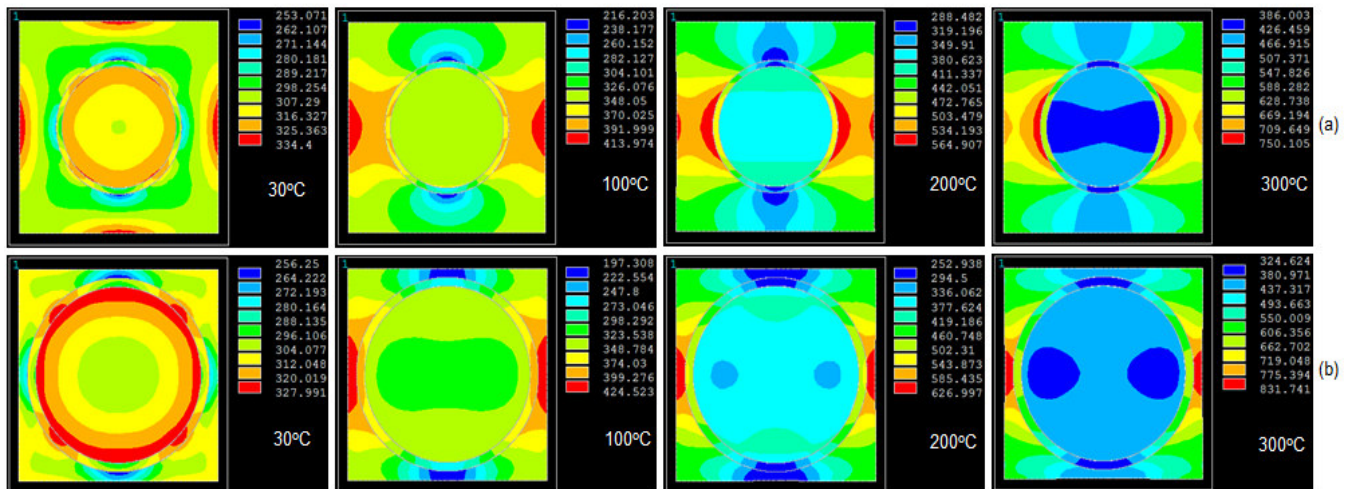


Figure 9: Images of von Mises stresses obtained from FEA: (a) AA2024/10% BN and (b) AA2024/30% BN composites.

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°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 debonding occurred above room temperature.

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