Evaluation of Nanoparticle Fracture in MgO Reinforced Aluminum matrix composites

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Abstract: *In the present work, the AA1100-MgO metal matrix composites were manufactured at 10% and 30% volume fractions of MgO. The composites were subjected to mechanical and thermal loads. The microstructure of AA1100 alloy-MgO reveals the fracture of particle. The particle fracture was initiated at 100^{o}C due to combined thermal and tensile loading.*

Keywords: *AA1100, magnesium oxide, RVE model, finite element analysis, particle fracture.*

1. INTRODUCTION

The metal matrix composites (MMCs) being of very high interest for the aerospace industry, particularly to build up thermal-structural components, it is important to have available technique which are easy and simple to conduct for characterization of the mechanical strength of the material. 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 [8-12], TiO_2 [13], MgO [14], TiN [15], B_4C [16, 17], TiB_2 [18-20], $Al(OH)_3$ [21] and graphite [22]. 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 [23]. The characteristics of low density and low thermal expansion of ceramics assume a great deal of importance in most applications. Magnesium oxide (MgO) is also is also known as magnesia. MgO doping has been shown to effectively inhibit grain growth in ceramics and improve their fracture toughness by transforming the mechanism of crack growth at nanoscale. Magnesium oxide is used as an oxide barrier in spin-tunneling devices. MgO is thermally stable up to about 700 K.

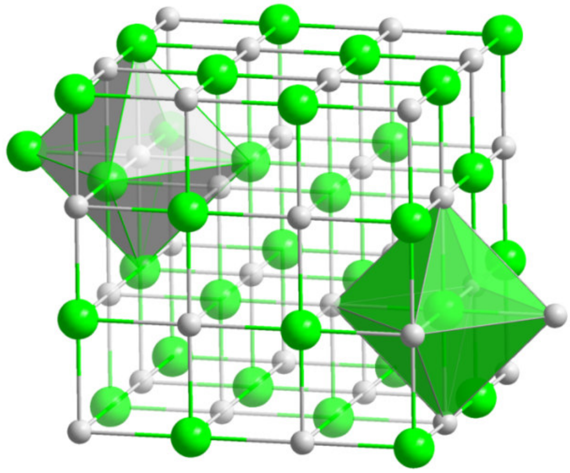

Figure 1: Halite (cubic) structure of MgO.

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. 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 [14-20]. In the present work, cubic magnesium oxide (MgO) was used to fabricate AA1100/MgO composites. The effect of thermo-tensile loading on the fracture in AA1100 alloy/MgO 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 AA1100 alloy/MgO 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 AA1100 alloy. The reinforcement material was MgO nanoparticles of average size 100nm. AA1100 alloy/ MgO 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 AA8090/BN nanoparticle composites at two (10% and 30%) volume fractions of MgO and at different temperatures. The shape MgO 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.

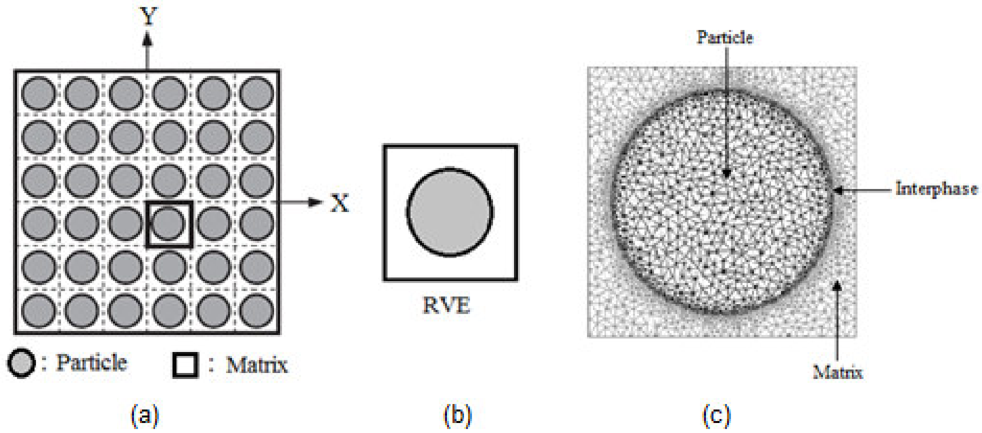

Figure 2: Square array of particles (a), Representative Volume Element (b) and Discretization of RVE (c).

3. RESULTS AND DISCUSSION

3.1 Thermo-Mechanical Behavior

Figure 3 represents micromechanical properties of AA1100/MgO composites. The elastic modulus is normalized with the elastic modulus of AA1100 alloy. The normalized stiffness of the composites decreases with increase of temperature. The stiffness of AA1100 alloy/10% MgO composites is higher than that of AA1100 alloy/30% MgO composites (figure 3a). The normalized stiffness along the normal direction is lower than that along the load direction. The normalized shear modulus increases with increase of temperature for AA1100 alloy/MgO composites (figure 3b). The major Poisson's ratio decreases initially from room temperature to 100^{o}C and later on it increases with temperature (figure 3c).

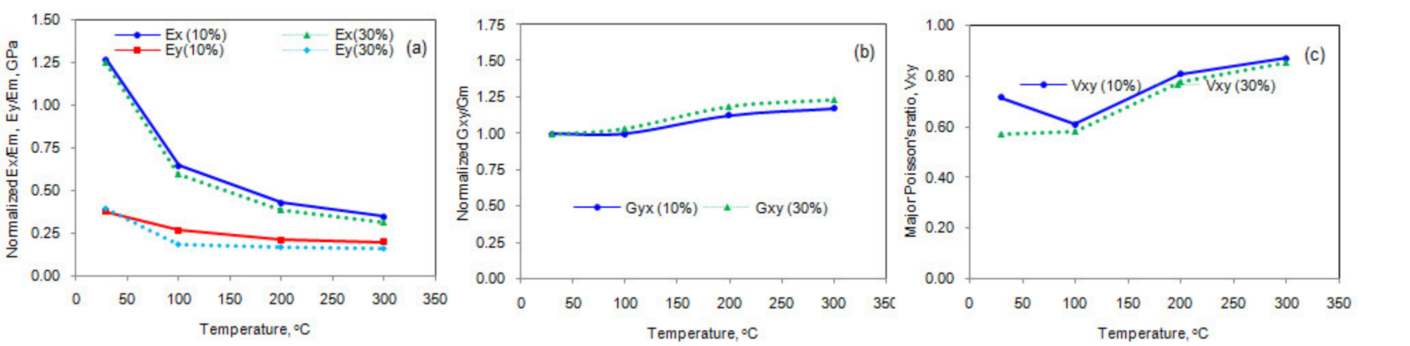

Figure 3: Effect of temperature on micromechanical properties of AA1100/MgO composites.

3.2 Fracture Analysis

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

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

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

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

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

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

Then the particle will fracture. From the figure 4a, it is observed that the MgO nanoparticle was fractured as the condition in Eq. (3) is satisfied above 150°C for the composites AA1100/30%MgO and above 225°C for the composites AA1100/10%MgO. This is due to CTE and stiffness mismatches between MgO nanoparticles and AA1100 alloy matrix. For the interfacial debonding/yielding to occur, the interfacial shear stress reaches its shear strength:

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

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

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

It is observed from figure 4b that the interphase debonding occurs between MgO nanoparticle and AA1100 alloy matrix as the condition in Eq.(5) is satisfied at all temperatures for AA1100/30%MgO composites and above 75°C for AA1100/10%MgO composites. The debonding phenomenon is high in the composites comprising of 10% MgO.

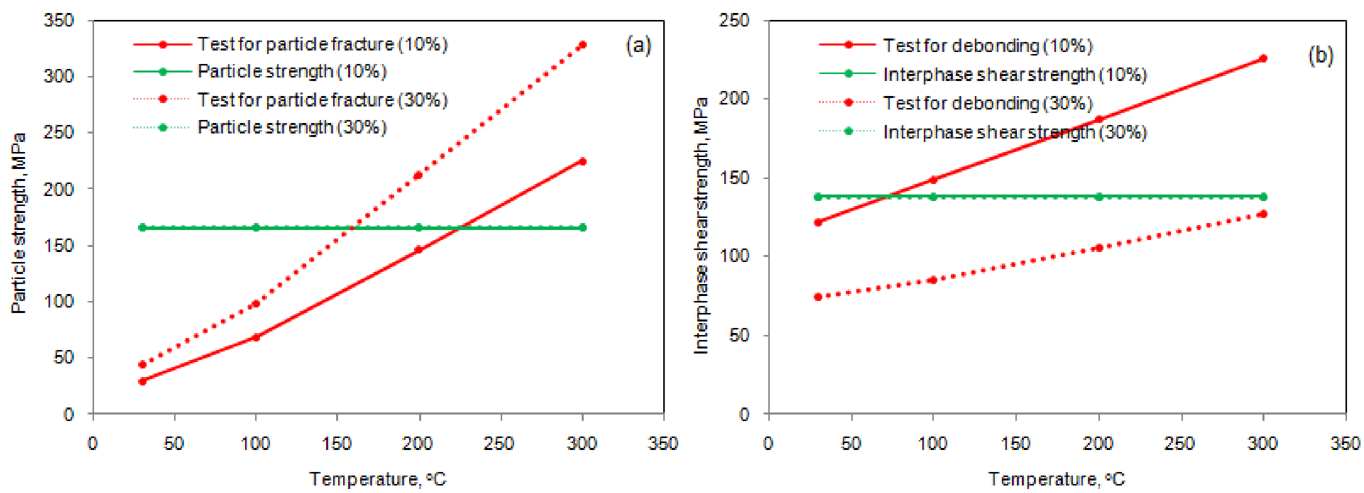

Figure 4: Criterion for interfacial for (a) particle fracture and (b) debonding.

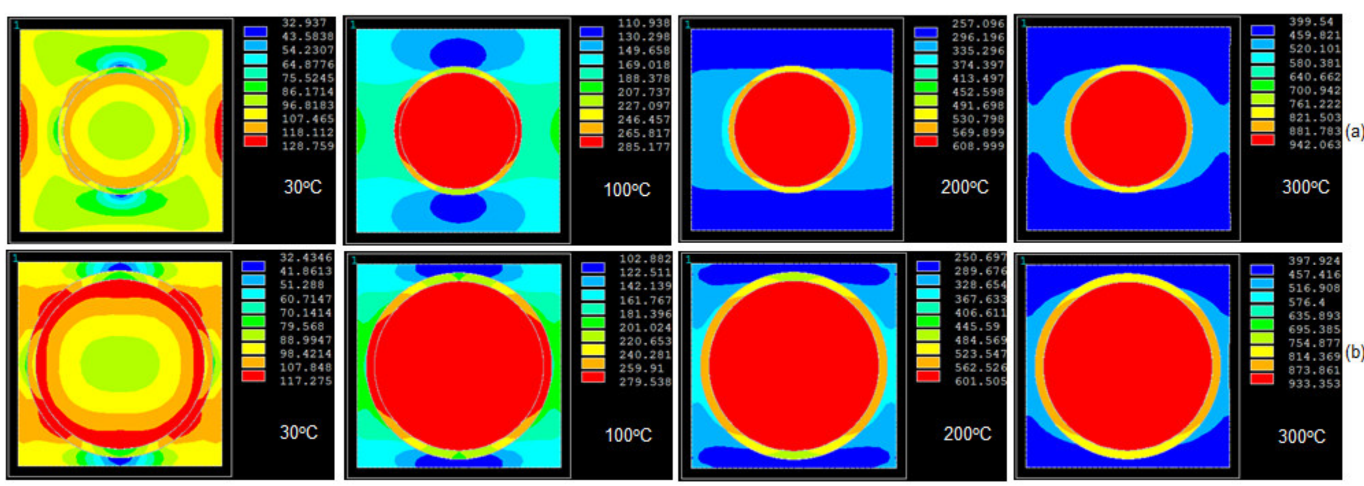

Figure 5: Images of von Mises stresses obtained from FEA: (a) AA8090/10% BN and (b) AA8090/30% BN composites.

At room temperature the von Mises stress induced at the interface are higher than that induced in the nanoparticle (figure 5). Above room temperature, the MgO particle has experienced very high von Mises stress. Hence, the MgO nanoparticle has occurred as a result of thermal and tensile loading. The microstructure shown in figure 6 confirms the occurrence of particle in the composites.

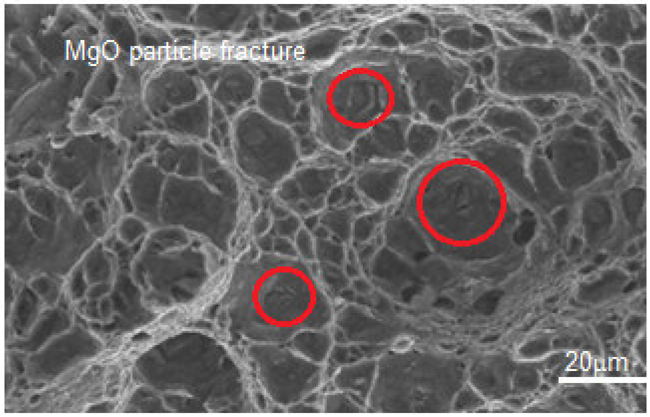

Figure 6: MgO particle fracture in AA1100/30MgO at 300°C.

4. CONCLUSION

The von Mises stress is very high in MgO nanoparticles as that compared in the AA1100 alloy matrix. The particle fracture was observed above 100°C temperature loading in AA1100/MgO composites. The microstructure obtained from the experimental samples confirms the fracture of MgO particles and AA1100 alloy matrix.

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