Effect of Thermo-Tensile Loading on Micromechanical Behavior of AA6061 Alloy-Titanium Carbide Composites

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Abstract: *In the present work, the AA6061/TiC metal matrix composites were manufactured at 10% and 30% volume fractions of TiC. The composites were subjected to combined thermal and tensile loading. The microstructure of AA6061 alloy/TiC reveals the fracture of interphase and particle.*

Keywords: *AA6061, titanium carbide, spherical nanoparticle, RVE model, finite element analysis, interphase fracture.*

1. INTRODUCTION

Particulate reinforced composites constitute a large portion of growing demand of industrial applications. In the past, various studies have been carried out on metal matrix composites. SiC [1-7], Al_2O_3 [8-13], TiO_2 [13], MgO [14], B_4C [15], ZrC [16], TiB_2 [17-19] and $Al(OH)_3$ [22] are the most commonly used particulates to reinforce in the aluminum alloy matrices. Thermo-Mechanical loading of particulate reinforced metal matrix composites leads to the initiation and propagation of widespread microstructural damage, often starting with interphasial failure, followed by fracture of the matrix and/or particles in the particle reinforced metal matrix composites. A two dimensional generalized plane strain model is accurate enough to analyze unidirectional metal matrix composites subjected to thermal and transverse shear loading [21]. It has been observed that thermal residual stresses only reduce the initiation of yielding behavior stress within the composite. 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, 17].

The microhardness of titanium carbide exceeds those of other transition metal carbides. Titanium carbide has high thermodynamic stability melts, melting temperature and corrosion resistance and a low density. Titanium carbide (TiC) works as extensively as any fine-particle filler material to broaden the performance envelope of tailored friction-reducing polymeric bearing and wear materials for non-metallic component-parts. It has ability to enhance the desirable properties in finished products made from metal-matrix composites. The TiC nanopowder needs to avoid direct sunshine. Moisture will result for agglomerations (figure 1).

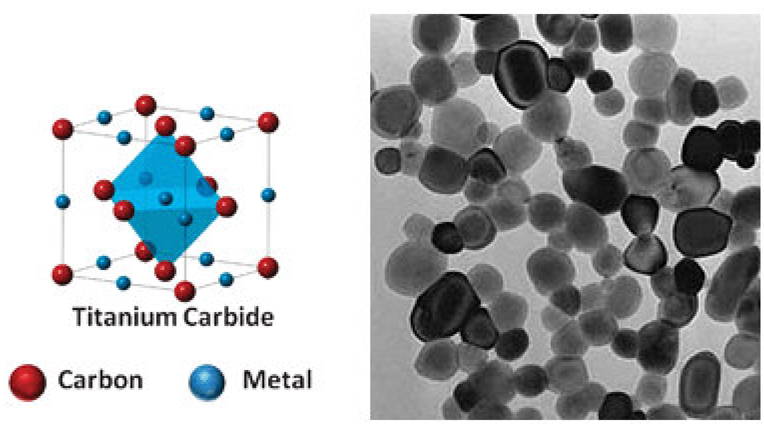

Figure 1: TiC nanopowder.

In the present work, the effect of thermo-mechanical loading on the fracture in AA6061 alloy/TiC 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 AA6061 alloy/TiC 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 AA6061 alloy. The reinforcement material was TiC nanoparticles of average size 100nm. The mechanical properties of materials used in the present work are given in table 1.

Table 1: Mechanical properties of AA6061 matrix and SiO_2 nanoparticles

Property	AA6061	TiC
Density, g/cc	2.70	4.93
Elastic modulus, GPa	68.90	400.00
Coefficient of thermal expansion, 10^{-6} 1/°C	23.60	6.8
Specific heat capacity, J/kg/°C	896.00	565.00
Thermal conductivity, W/m/°C	167.00	330.00
Poisson's ratio	0.33	0.19

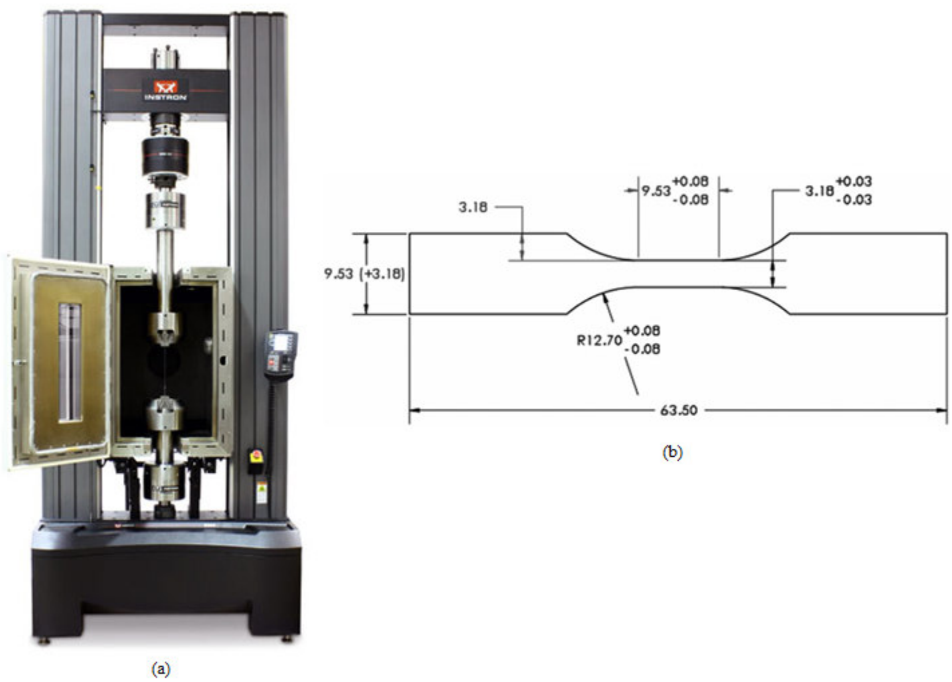

Figure 2: Tensile testing: UTM with temperature controlled chamber and (b) shape and dimensions of tensile specimen.

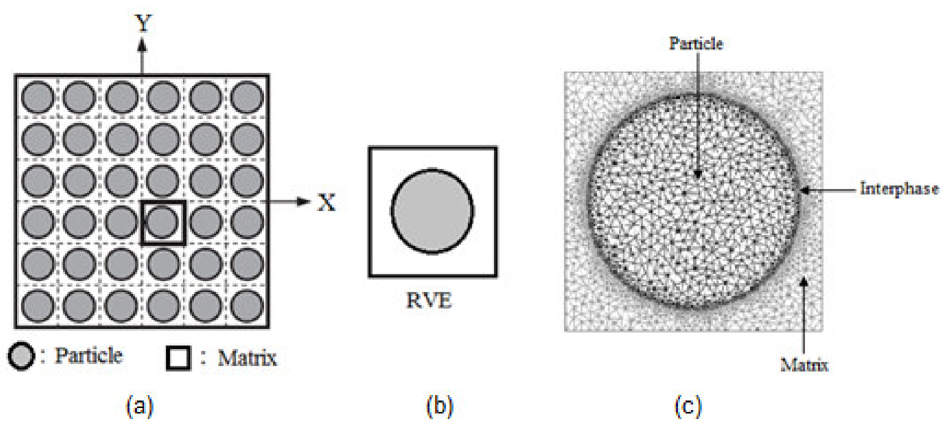

Figure 3: Square array of TiC nanoparticles (a), Representative volume element (b), and Discretization of RVE (c).

AA6061 alloy/ TiC 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 flat-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 (figure 2). The test speed was 1 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 AA6061/TiC nanoparticle composites at two (10% and 30%) volume fractions of TiC and at different temperatures. The shape TiC 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.

3. RESULTS AND DISCUSSION

The results obtained from the numerical simulation were verified with experimental results. The microstructures of AA6061 alloy/TiC composites were revealed for nanoparticle debonding and fracture.

3.1 Thermo-Mechanical Behavior

Figure 4a represents the normalized stiffness of AA6061/TiC composites as a function of temperature. The elastic modulus was normalized with the elastic modulus of AA6061 alloy. The stiffness of the composites decreases with increase of temperature. The stiffness of AA6061 alloy/10% TiC composites is higher than that of AA6061 alloy/30% TiC composites with respect to increase of temperature. The normalized stiffness along the normal direction is lower than that along the load direction. The normalized shear modulus increases with volume fraction of TiC and temperature (figure 4b). Initially, the major Poisson's ratio decreases from 30°C to 100°C and later on it increases with temperature from 100°C to 300°C (figure 4c).

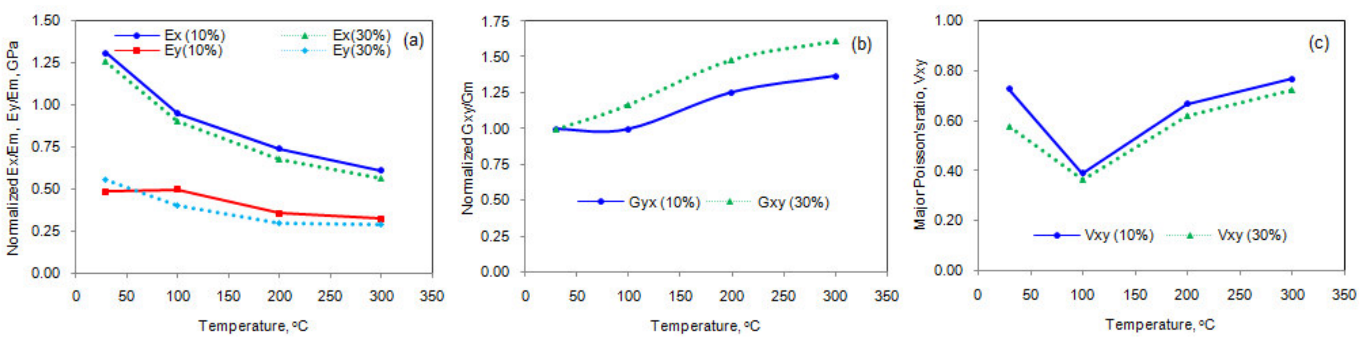

Figure 4: Effect of temperature on micromechanical properties of AA6061/TiC composites.

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

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

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. 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 5a that the interphase debonding has occurred between TiC nanoparticle and AA6061 alloy matrix as the condition in Eq.(5) is satisfied for AA6061/TiC composites. The particle fracture was not occurred in AA6061/10% TiC composites at 30°C of thermal loading (figure 5b); while it was fractured above 100°C due to thermal shock. The particle fracture was occurred in AA6061/30% ZrC composites at temperatures of thermal loading (figure 5b) as the condition in Eq. (3) is satisfied. This might be due to combined effect of thermal shock as well as heavy load transfer from the matrix to the nanoparticle.

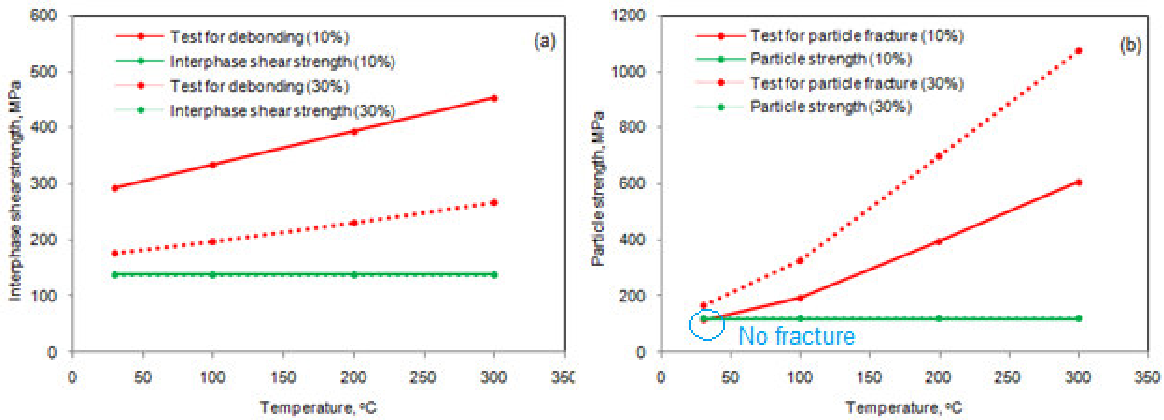

Figure 5: Debonding and nanoparticle fracture in AA6061 alloy/TiC composites.

The von Mises stress induced in the nanoparticle and at the interphase is higher than that induced in the matrix (figure 6). Hence, the fracture of interfacial interphase and nanoparticle was occurred. The microstructure shown in figure 7 confirms the occurrence of interphase and particle fractures in the composites.

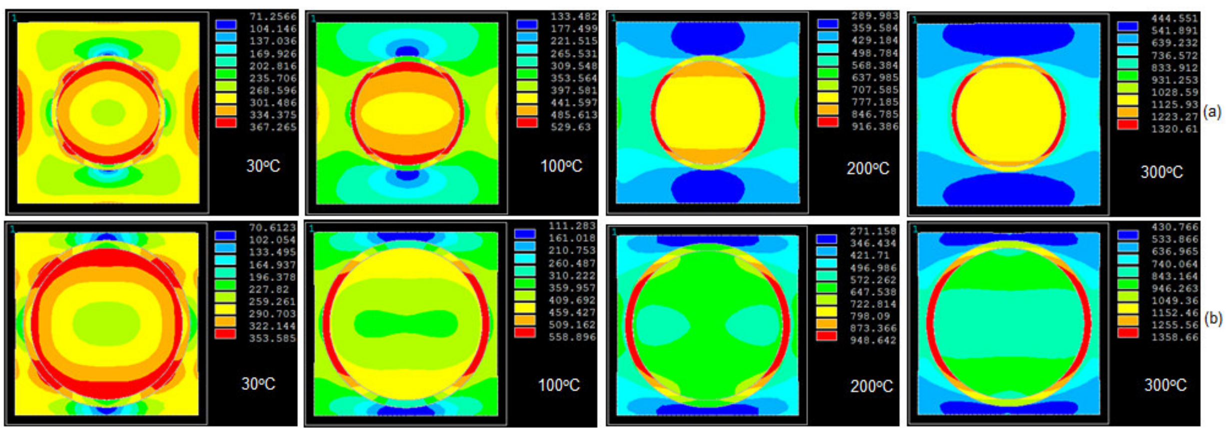

Figure 6: Images of von Mises stresses obtained from FEA: (a) AA6061/10% TiC and (b) AA6061/30% TiC composites.

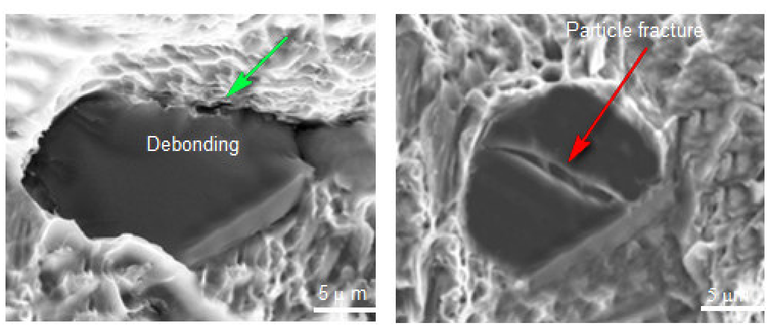

Figure 7: SEM images of (a) interfacial debonding and (b) and particle fracture.

4. CONCLUSION

The shear stress is high at the interface resulting to interphase debonding in AA6061/TiC composites. The particle fracture was very high in AA6061/30% TiC composites. The microstructure obtained from the experimental samples confirms the fracture of interphase between the TiC particles and AA6061 alloy matrix and TiC nanoparticle fracture.

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