Fabrication and Properties of AA7020-TiN Composites under Combined Loading of Temperature and Tension

[1]Y. S. A. Kumar and A. Chennakesava Reddy

[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
dr_acreddy@yahoo.com

Abstract: *In the present work, the AA7020-TiN metal matrix composites were manufactured at 10% and 30% volume fractions of TiN. ANSYS software was used to computationally simulate thermo-mechanical nonlinear behavior of AA7020 alloy/TiN composites to analyze local constituent response including the interface/interphase regions. The composites were subjected to mechanical and thermal loads. The tendency of debonding and particle fracture was increased with volume fraction of TiN in AA7020 alloy matrix.*

Keywords: *AA7020, titanium nitride, phase transformation, RVE model, finite element analysis, interphase fracture.*

1. INTRODUCTION

Extensive research work is being carried out for the past two decades to develop wide range of metal matrix composites (MMCs) as alternatives to the conventional engineering alloys and the same has showed tremendous promise and phenomenal growth. The particulate reinforced MMCs are of more interest due to simple preparation techniques, lower cost and more isotropic properties [1-7]. In addition , it is also shown that the properties of MMCs are controlled by the size and volume fraction of the reinforcement phases as well as by the nature of the matrix - reinforced interface. A fine and thermally stable ceramic particulates distributed uniformly in the matrix has led to the optimum set of mechanical properties. 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 [8-19]. The characteristics of low density and low thermal expansion of ceramics assume a great deal of importance in most applications.

TiN will oxidize at 800 °C in a normal atmosphere. It is chemically stable at room temperature and is attacked by hot concentrated acids. It is chemically stable at 20 °C, according to laboratory tests, but can be slowly attacked by concentrated acid solutions with rising temperatures [20]. Bulk ceramic objects can be fabricated by packing powdered metallic titanium into the desired shape, compressing it to the proper density, then igniting it in an atmosphere of pure nitrogen. The heat released by the chemical reaction between the metal and gas is sufficient to sinter the nitride reaction product into a hard, finished item.

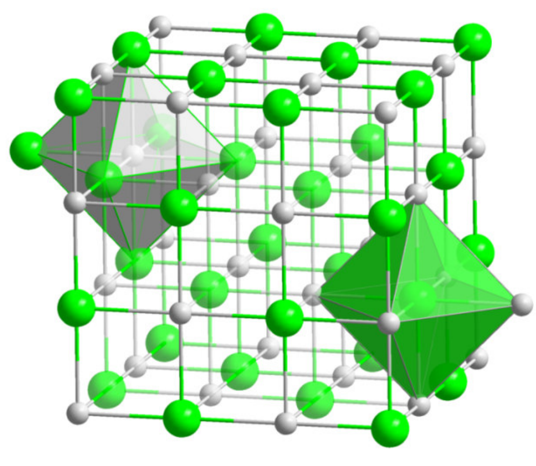

Figure 1: Halite (cubic) structure of TiN.

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 [23]. 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 titanium nitride (TiN) was used to fabricate AA7020/TiN composites. The effect of thermo-tensile loading on the fracture in AA7020 alloy/TiN composites was examined. Micromechanics methods was employed to assess fracture in the composites. ANSYS software was used to computationally simulate thermo-mechanical nonlinear behavior of AA7020 alloy/TiN 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 AA7020 alloy. The reinforcement material was BN nanoparticles of average size 100nm. AA7020 alloy/ TiN 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 AA7020/TIN nanoparticle composites at two (10% and 30%) volume fractions of TiN 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.

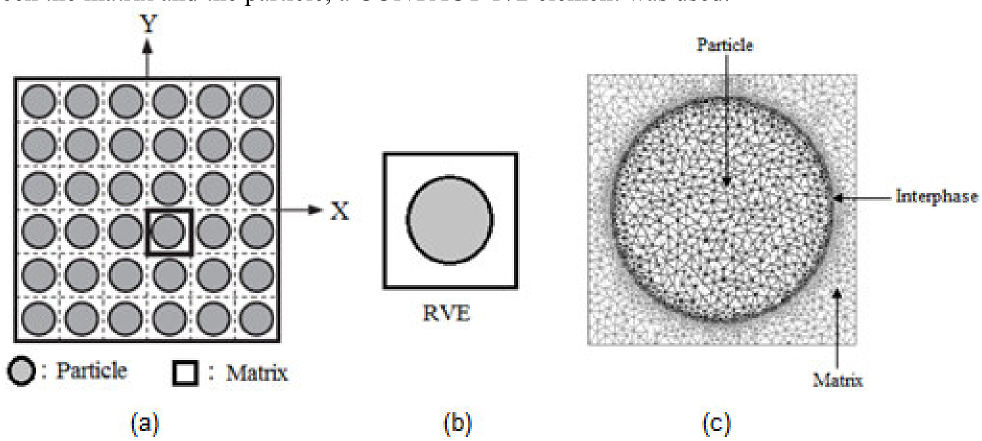

Figure 3: Square array of particles (a), Representative Volume Element (b) and Discretization of RVE (c).

3. RESULTS AND DISCUSSION

3.1 Thermo-Mechanical Behavior

Figure 7 represents micromechanical properties of AA7020/TiN composites. The elastic modulus is normalized with the elastic modulus of AA7020 alloy. The normalized stiffness of the composites decreases with increase of temperature. The stiffness of AA7020 alloy/30% TiN composites is higher than that of AA7020 alloy/10% TIN 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 AA7020 alloy/TiN 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).

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

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

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 TiN nanoparticle was fractured as the condition in Eq.(3) is satisfied above room temperature for the composites AA7020/TiN. This is due to CTE and stiffness mismatches between BN nanoparticles and AA7020 alloy matrix. For the interfacial debonding/yielding to occur, the interfacial shear stress reaches its shear strength:

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

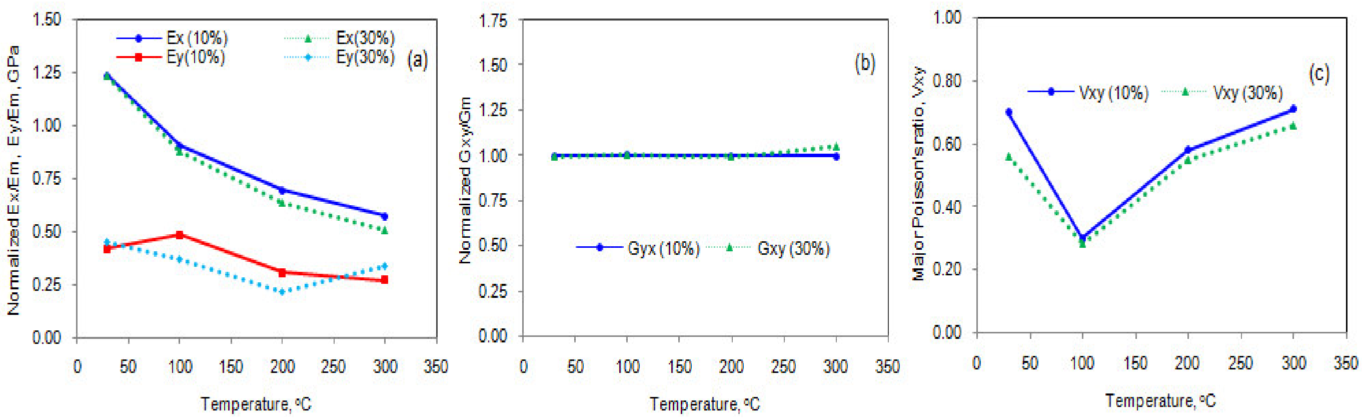

Figure 7: Effect of temperature on micromechanical properties of AA7020/TiN composites.

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 TiN nanoparticle and 7020 alloy matrix as the condition in Eq.(5) is satisfied at all temperatures for the composites AA7020/TiN composites. The debonding phenomenon is high in the composites comprising of 30% TiN.

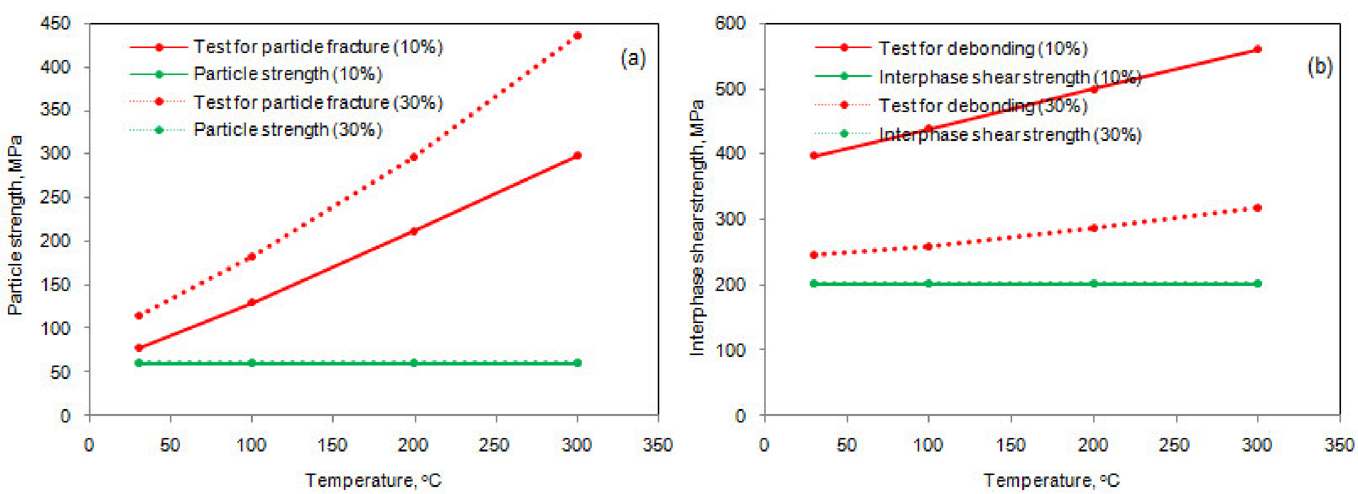

Figure 8: Criterion for interfacial for (a) particle fracture and (b) debonding.

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 TiN nanoparticles due to thermal shock.

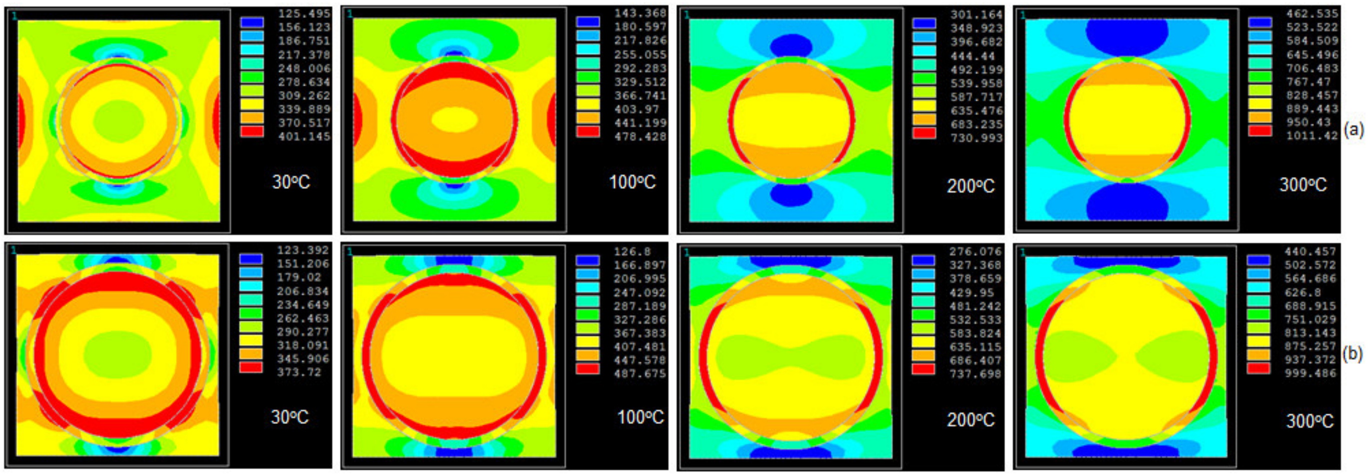

Figure 9: Images of von Mises stresses obtained from FEA: (a) AA7020/10% TiN and (b) A7020/30% TiN composites.

4. CONCLUSION

The shear stress is high at the interface resulting to interphase debonding in AA7020/ TiN composites. The particle fracture and debonding were observed above room temperature loading in AA7020/TiN composites. The tendency of debonding and particle fracture was increased with volume fraction of TiN in AA7020 alloy matrix.

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