Effect of Particle Spatial Distribution and Clustering on Tensile Behavior of Titanium Oxide/AA5050 Alloy Particle Reinforced Composites

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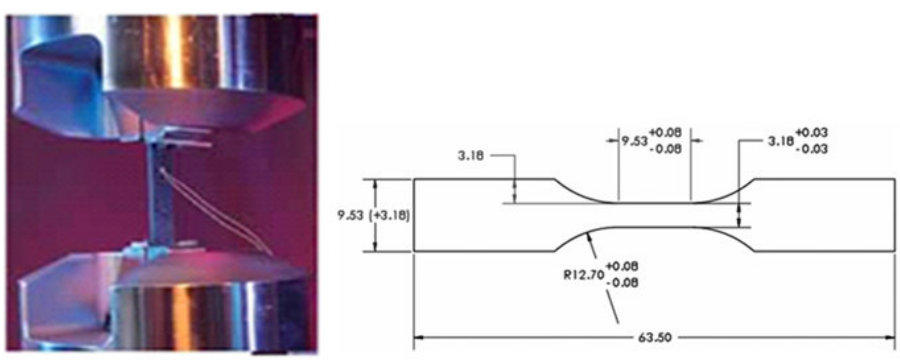
Abstract: *In the current work, the TiO_2/ AA5050 alloy metal matrix composites were fabricated at 10%, 20% and 30% volume fractions of TiO_2. These composites were analyzed with finite element analysis code with and without clustering of TiO_2 particles. The local volume fraction of the reinforcements in the clustering region is found reasonably higher than that of the non-clustering region leading to enhancement of stress in the reinforcement clustering region. The tensile strength and elastic modulus decrease with clustering of TiO_2 particles in AA5050 alloy matrix.*

Keywords: *AA5050, titanium oxide, spherical nanoparticle, unit-cell, finite element analysis, clustering.*

1. INTRODUCTION

The production techniques of metal matrix composites have been well advanced in recent years, such as stir casting method, powder metallurgy, extrusion process and liquid infiltration. However in practice, it is often difficult to obtain a homogeneous distribution of reinforced particles or whiskers. Further, it has been found that the non-uniformity in the reinforcement arrangement can have significant effects on the mechanical properties of the MMCs [1]. Existing experimental and theoretical evidences suggest that the homogeneity of particles arrangement plays a key role in controlling the yield strength, ductility, fatigue and fracture behaviors of metal matrix composites [2]. It is generally agreed that the yield strength and the work hardening increase with increased clustering of reinforcements [3]. Reddy [4] showed experimentally on behavior of brittle matrix and alumina trihydrate particulate composites that damage grows first in the whole composite but localization occurs in a particle-rich zone.

The experimental and numerical analysis of clustering in metal matrix composites is rare. In the present work, the effect of reinforcement clustering on the tensile behavior in cast metal matrix (AA5050 alloy) composites reinforced with TiO_2 particles was investigated. A two-dimensional unit-cell model in the periodic boundary condition [5-18] was developed using finite element method (FEM) to analyze the stress distribution in the clustering and non-clustering regions. The shape of titanium oxide nanoparticle considered in this work is spherical.



(a) (b)

Figure 1: Tensile testing: UTM with temperature controlled chamber and (b) shape and dimensions of tensile specimen.

2. MATERIALS METHODS

The matrix material was AA5050 alloy. The reinforcement material was titanium oxide (TiO_2) nanoparticles of average size 100nm. AA5050alloy/TiO_2 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 1) for the tensile tests. The tensile specimens were placed in the grips of a Universal Test Machine (UTM) 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 unit cell comprising of nine particles was implemented to analyze the tensile behavior TiO_2/AA5050 composites at three (10%, 20% and 30%) volume fractions of TiO_2. 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. The discretization a unit cell without clustering of TiO_2 particles is shown in figure 2a and that with clustering of TiO_2 particles is shown in figure 2b.

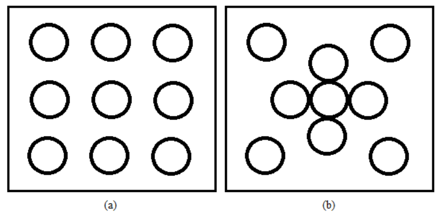


Figure 2: The interphase in a nanoparticle-reinforced composite: (a) without clustering and (b) with clustering.

Considering adhesion, formation of precipitates, particle size, agglomeration, voids/porosity, obstacles to the dislocation, and the interfacial reaction of the particle/matrix, the formula for the strength of composite [19, 20] is stated below:

$$\sigma_c = \left[\sigma_m \left\{\frac{1-(v_p+v_v)^{2/3}}{1-1.5(v_p+v_v)}\right\}\right] e^{m_p(v_p+v_v)} + k d_p^{-1/2} \quad (1)$$

$$k = E_m m_m / E_p m_p$$

where, v_v and v_p are the volume fractions of voids/porosity and nanoparticles in the composite respectively, m_p and m_m are the possion's ratios of the nanoparticles and matrix respectively, d_p is the mean nanoparticle size (diameter) and E_m and E_p is elastic moduli of the matrix and the particle respectively. Elastic modulus (Young's modulus) is a measure of the stiffness of a material and is a quantity used to characterize materials. Elastic modulus is the same in all orientations for isotropic materials. Anisotropy can be seen in many composites.

The upper-bound equation is given by

$$\frac{E_c}{E_m} = \left(\frac{1-v_v^{2/3}}{1-v_v^{2/3}+v_v}\right) + \frac{1+(\delta-1)v_p^{2/3}}{1+(\delta-1)(v_p^{2/3}-v_p)} \quad (2)$$

The lower-bound equation is given by

$$\frac{E_c}{E_m} = 1 + \frac{v_p - v_p}{\delta/(\delta-1)-(v_p+v_v)^{1/3}} \quad (3)$$

where, $\delta = E_p / E_m$.

The transverse modulus is given by

$$E_t = \frac{E_m E_p}{E_m + E_p(1-v_p^{2/3})/v_p^{2/3}} + E_m(1 - v_p^{2/3} - v_v^{2/3}) \quad (4)$$

3. RESULTS AND DISCUSSION

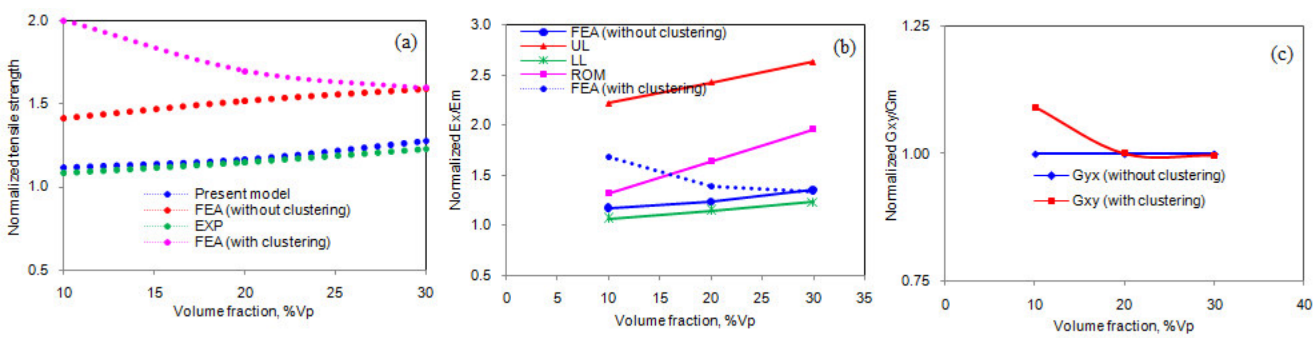


Figure 3: Effect of volume fraction on (a) normalized strength, (b) normalized tensile elastic modulus and (c) normalized shear modulus of TiO_2/AA5050 composites.

The tensile stresses induced in the composites were normalized with tensile strength of AA5050 alloy matrix. The tensile stresses obtained from the finite element analysis (FEA) are higher than those obtained from the mathematical expression mentioned in Eq.(1) and the experimental procedure as shown in figure 3a. For the case without clustering of TiO_2 particles, the tensile stress increases with increase of volume fraction of TiO_2 in AA5050 alloy matrix. However, the tensile stress decreases in the case of clustering of TiO_2 particles. The clustering effect might be occurred due to the elastic-plastic interaction between the reinforcing particles and matrix. Furthermore, the local volume fraction of the reinforcements in the clustering region is found reasonably higher than that of the non-clustering region which could lead to enhance stress in the reinforcement clustering region. The optical micrograph as shown in figure 4 reveals random distribution of 20% TiO_2 and 30% TiO_2 (30% Vp) particles in AA5050 alloy matrix. The clustering of particles is also seen in the microstructure illustrated in figure 4. The local volume fractions of the reinforcement in the clustering regions were found to be 30%, 50% and 70% in the composites having 10%, 20% and 30% volume fractions of TiO_2.

The normalized elastic modulus increases with increase of volume fraction of non-clustered TiO_2 particles in AA5050 alloy matrix; while it decreases with increase of volume fraction of clustered TiO_2 particles in AA5050 alloy matrix (figure 3b). The normalized shear modulus is constant with increase of volume fraction of TiO_2 without clustering of particles (figure 3c); whereas it decreases with increase of volume fraction of TiO_2 with clustering of particles.

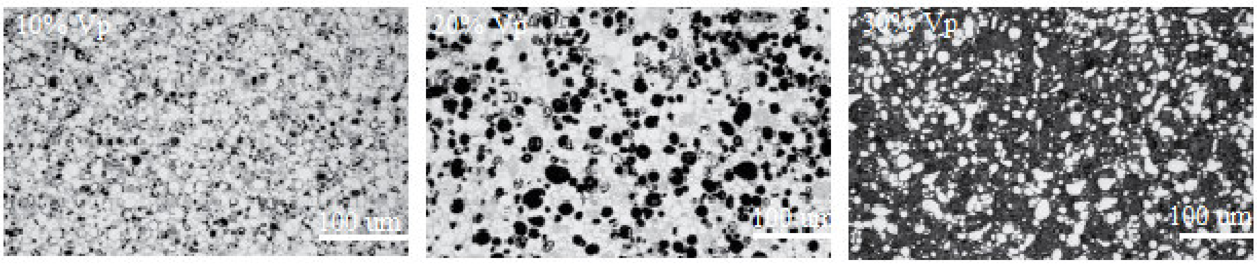


Figure 3: Microstructure showing distribution of 10%, 20% and 30% TiO_2 nanoparticles in AA5050 alloy matrix.

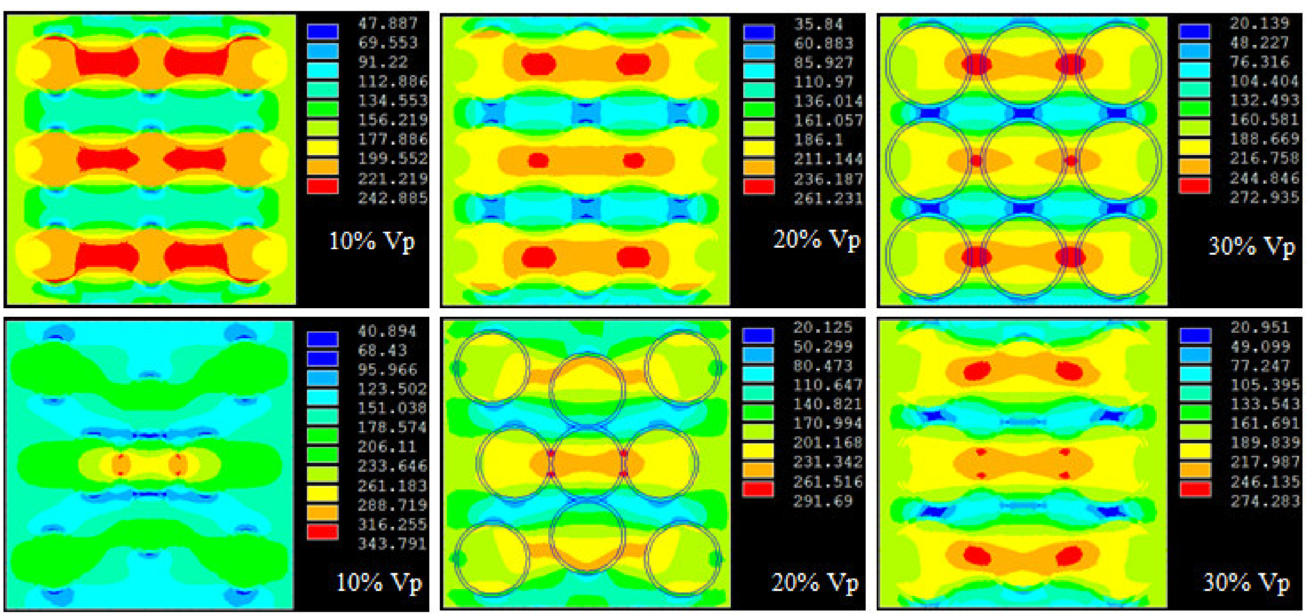


Figure 4: Images of tensile stresses obtained from FEA: (a) without clustering and (b) with clustering.

In all the models (figure 4), the TiO_2 particles-AA5050 alloy interface edges experience higher stresses. This is attributed to the fact of the stress concentration in the vicinity of the reinforcement. Furthermore, the maximum stress concentration at the particle-matrix interface located in the clustering regions. The stresses developed in the clustering regions are reasonably higher than the stresses developed in other sides of the clustering regions. The TiO_2 particles deform elastically within the plastically deforming AA5050 alloy matrix. Once the particles existed very close to one another, the elastic-plastic interaction occurs between the TiO_2 particles and AA5050 alloy matrix, results the higher stress concentration at this location and cracks likely to initiate in this place. Therefore, the reinforcement clustering region where TiO_2 particles exist very close to one another is highly vulnerable for crack initiation.

4. CONCLUSION

TiO_2/AA5050 alloy composites were analyzed following two different schemes: (i) uniform distribution of TiO_2 particles without clustering and (ii) clustering of TiO_2 particles. The local volume fraction of the reinforcements in the clustering region is found reasonably higher than that of the non-clustering region leading to enhancement of stress in the reinforcement clustering region. The stresses developed in the clustering regions are higher than those developed in other sides of the clustering regions. The tensile stress, shear stress and elastic modulus decrease with the clustering of particles TiO_2/ AA5050 composites.

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