Microstructural and Numerical Evaluation of Porosity and Clustering Control over Micromechanical Properties of Cast Titanium Nitride Reinforced AA5050 Alloy

[1]A. C. S. Kumar and A. Chennakesava Reddy[2]

[1, 2]Professor, Department of Mechanical Engineering, JNT University, Hyderabad, India
dr_acreddy@yahoo.com

Abstract: *This study on porosity and clustering of nanoparticles in cast metal matrix composites was particular to nano titanium nitride particles reinforced AA5050 alloy. Stir casting process and high pressure die casting technique with three different volume factions were applied to cast the specimens to evaluate the influence of porosity and clustering of nanoparticles. The finite element method was employed to estimate the micromechanical properties with and without porosity and clustering using unit cells. Clustering of nanoparticles at vol.30% of TiN influenced porosity formation among the reinforced nanoparticles. The stiffness and tensile strength were decreased by the addition of TiN nanoparticles to AA5050alloy matrix with porosity and clustering of nanoparticles.*
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Keywords: *AA5050 alloy, titanium nitride, unit cell, finite element analysis, clustering, porosity.*

1. INTRODUCTION

The metal matrix composites provide a combination of the metallic properties of the matrix (high toughness) with the ceramic properties of the reinforcement (high strength and high modulus) to give a material greater strength and stiffness, higher temperature capabilities and more excellent wear resistance than a similar monolithic material [1]. Particles aggregations or clusters and poor wettability are the main processing problems in as cast composites. Particle clusters act as crack or decohesion nucleation sites at stresses lower than the matrix yield strength, causing the metal matrix composites to fail at unpredictable low stress levels. This is often attributed to the stress concentration in the reinforcement clusters, which may lead to preferential nucleation and propagation of damage in the clusters [2-7]. It was reported in [7] that the preferential site for crack propagation is the regions of higher particle volume fractions. Porosity formation has always been associated to casting; among the preferred processing method in producing metal matrix composites. However, the formation was basically caused by the casting parameters and reinforced particles mixed up with the matrix material. Previous works had discussed much on the effects of stirring speeds, volume fraction and shape of reinforcement particles on porosity formation in cast metal matrix composites [8-32].

The experimental and numerical analysis for porosity and clustering of particles in the metal matrix composites is rare. A two-dimensional unit-cell model in the periodic boundary condition was developed using finite element method (FEM) to analyze the stress distribution in the clustering, porosity and non-clustering and non-porosity regions which could lead to microcrack initiation in cast AA5050 alloy/titanium nitride metal matrix composites.

2. MATERIALS METHODS

The matrix material was AA5050 alloy. The reinforcement material was titanium nitride (TiN) nanoparticles of average size 100nm. AA5050/TiN metal matrix composites were fabricated by the stir casting process and high pressure die casting technique with pressure at 25 MPa. The test samples were machined to get flat-rectangular specimens 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 present work, a unit cell comprising of nine particles was implemented to analyze the micromechanical behavior AA5050/TiN metal matrix composites at three (10%, 20% and 30%) volume fractions of TiN with and without clustering and porosity. 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 shape of SiO_2 nanoparticle considered in this work is spherical. The periodic particle distribution was a square array. The tensile stress, elastic modulus and shear modulus are, respectively, normalized with tensile strength, elastic modulus and shear modulus of the matrix alloy.

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 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, $\delta = E_p/E_m$.

3. RESULTS AND DISCUSSION

The density of AA5050/TiN metal matrix composites increased as shown in figure 1a with increase of volume fraction of TiN nanoparticles. This is due to fact that the density (5.22g/cc) of TiN is higher than that (2.69 g/cc) of AA5050 alloy.

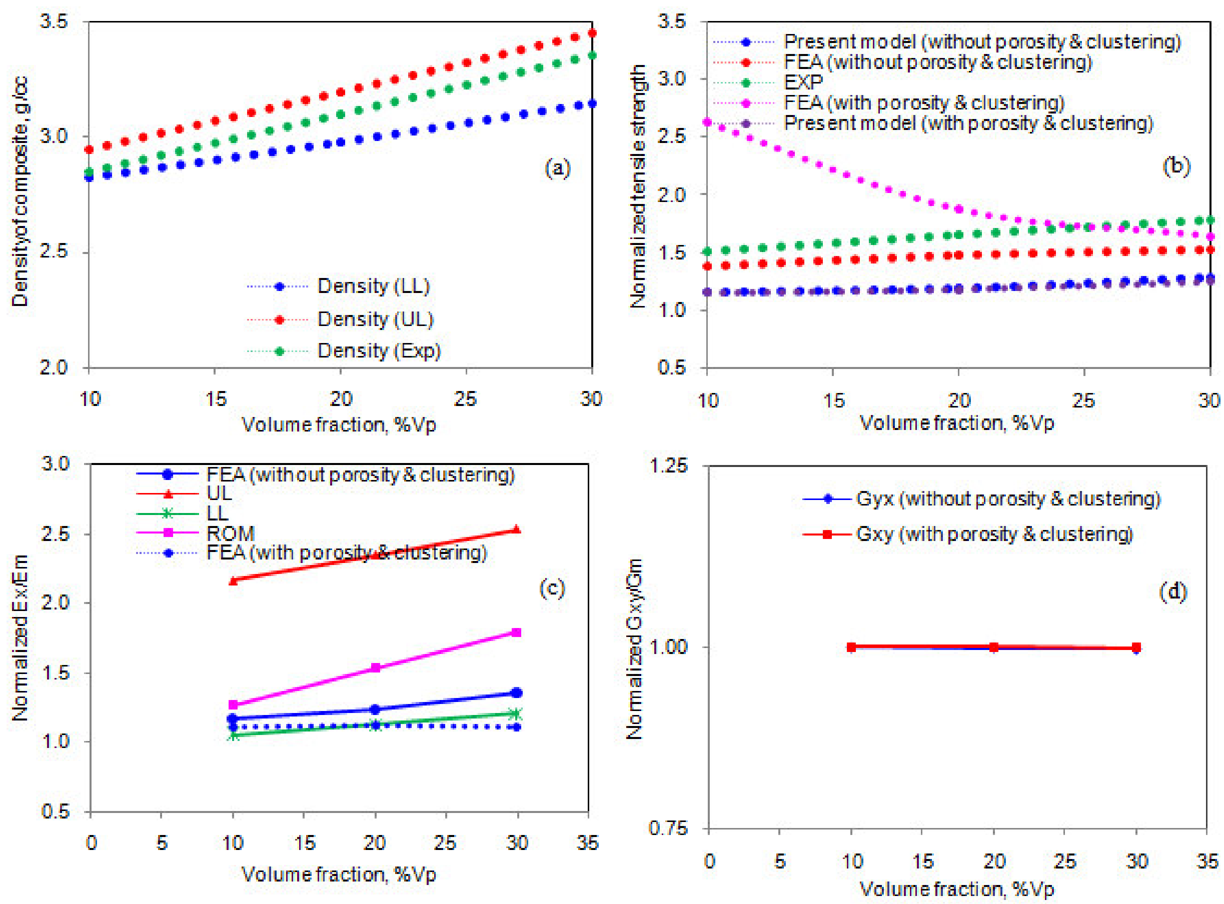

Figure 1: Effect of volume fraction on (a) density (b) normalized tensile stress, (c) normalized tensile elastic modulus and (d) normalized shear modulus of AA5050/TiN composites.

The tensile strength (figure 1b), stiffness (figure 1c) have increased with increase in volume fraction of TiN nanoparticles while the shear modulus (figure 1d) has decreased without porosity and clustering in the composites. The volume fraction of clusters and porosity voids increase with increase in volume fraction TiN nanoparticles in AA5050 alloy matrix as shown in figure 2. The decrease in tensile strength and elastic modulus is due to porosity and clustering in AA5050/TiN metal matrix composites. As a result of stress concentrations at voids and clustered regions, the tensile stresses obtained from the finite element analysis (FEA) were higher than those obtained from the mathematical expression mentioned in Eq.(1) and the experimental procedure.

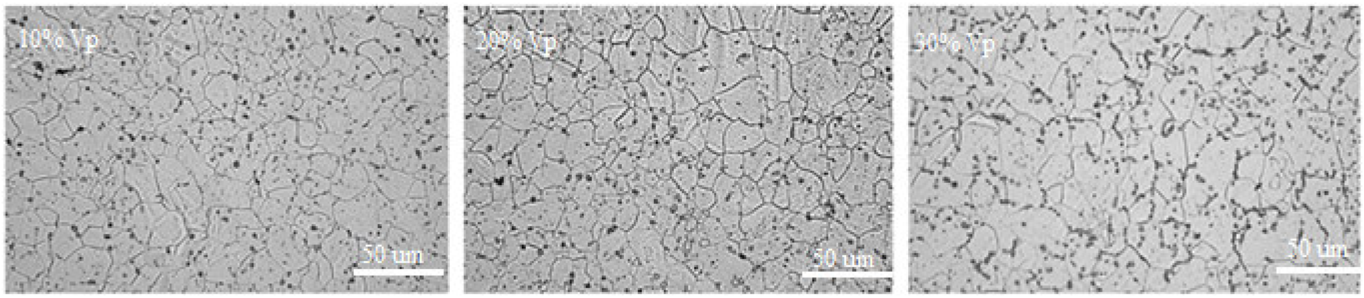

Figure 2: Porosity and clustering in AA5050/TiN metal matrix composites cast by high pressure die casting technique.

Without porosity and clustering in the composites, the stress intensity remains constant with increase in the volume fraction of TiN in AA5050 alloy matrix (figure 3a). With porosity and clustering in the composites, the stress intensities were high in the composites. But, the stress intensity decreases with increase in volume fraction of TiN (figure 2b).

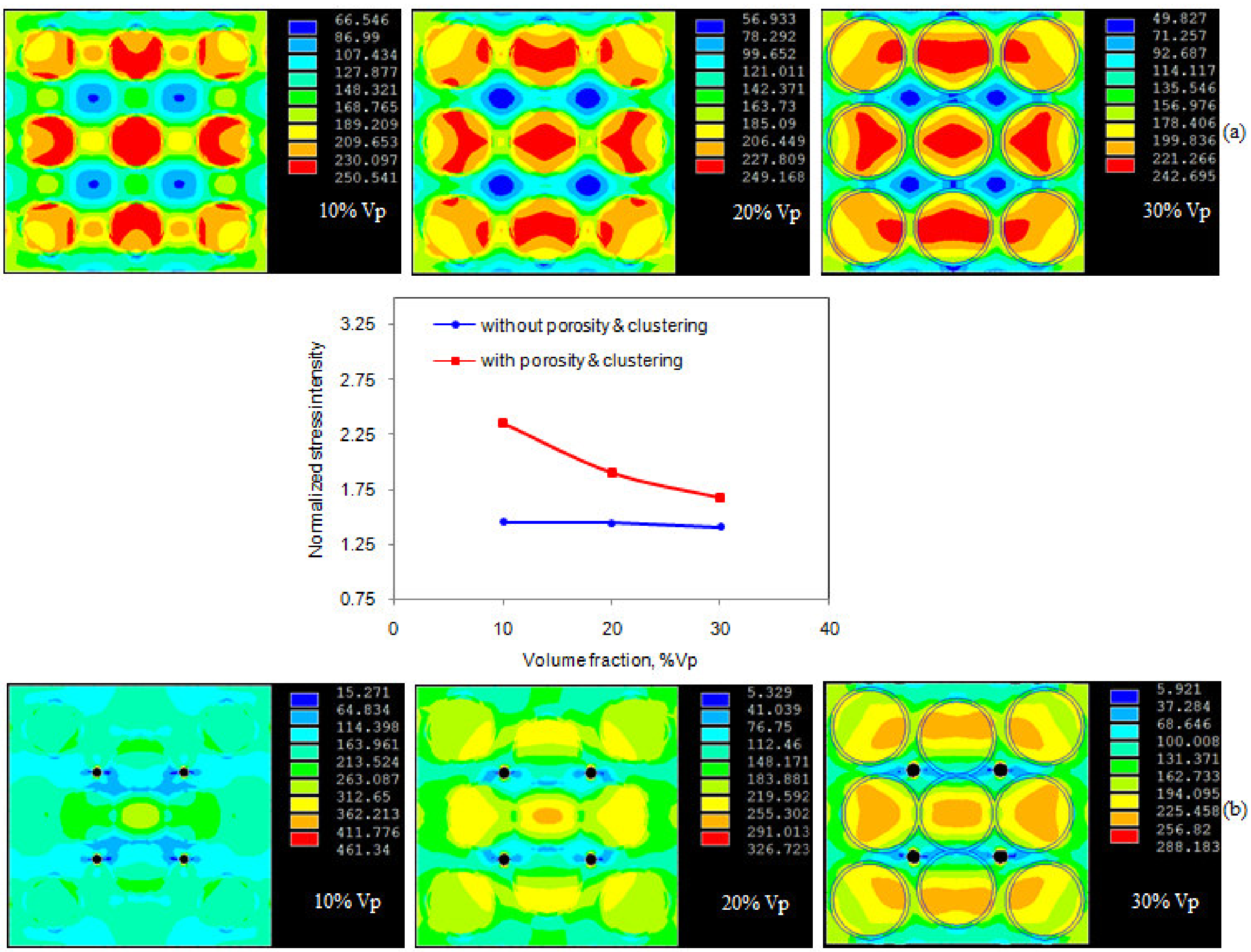

Figure 3: Images of stress intensities obtained from FEA: (a) without clustering and porosity and (b) with clustering and porosity.

4. CONCLUSION

In AA5050/TiN metal matrix composites, the increase in volume fraction of TiN nanoparticles made an appreciable enhancement of stiffness and tensile strength. In the presence of clustering and porosity, the tensile strength and stiffness decreased with the increase of volume fraction of TiN in the AA5050 alloy matrix.

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