Stir Casting Process on Porosity Development and Micromechanical Properties of AA5050/Titanium Oxide Metal Matrix Composites

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Abstract: The AA5050/TiO_2 alloy metal matrix composites were fabricated using stir casting process and analyzed for tensile properties in the presence of porosity. The density increased with increase of TiO_2 in AA5050 alloy matrix. The tensile strength and elastic modulus of AA5050/TiO_2 composites have decreased due to porosity in the composites.

Keywords: Titanium oxide, AA5050 alloy, unit cell models, finite element analysis, porosity.

1. INTRODUCTION

The inspiration for research in metal matrix composites development is its attractive properties and higher performance potentials over traditional metals and alloys [1-7]. Among metallic matrices, aluminum based matrix remains the most explored metal matrix material for the development of metal matrix composites [8-14]. Porosity of the composite material occurs in the region of the composite matrix metal of the isolated area that solidified as the last [15-23]. The choice of the composite processing route is dictated by the volume fraction of the SiC reinforcement in the composite [24-31]. For instance, the stir casting route is more suitable for low volume fractions < 20%, whilst the infiltration routes are more appropriate for high volume fraction of the reinforcement > 40%. The gases that dissolved during stirring of molten metal would lead to formation of porosities on solidification [32-38].

The aim of this study was to fabricate AA5050 alloy-Titanium oxide metal matrix composite using stir casting technique to disperse the reinforcement material through the matrix molten metal. The effects of porosity on micromechanical properties were investigated. The shape of titanium oxide (TiO_2) nanoparticle considered in this work is spherical. Finite element analysis was used to analyze unit cells with and without porosity.

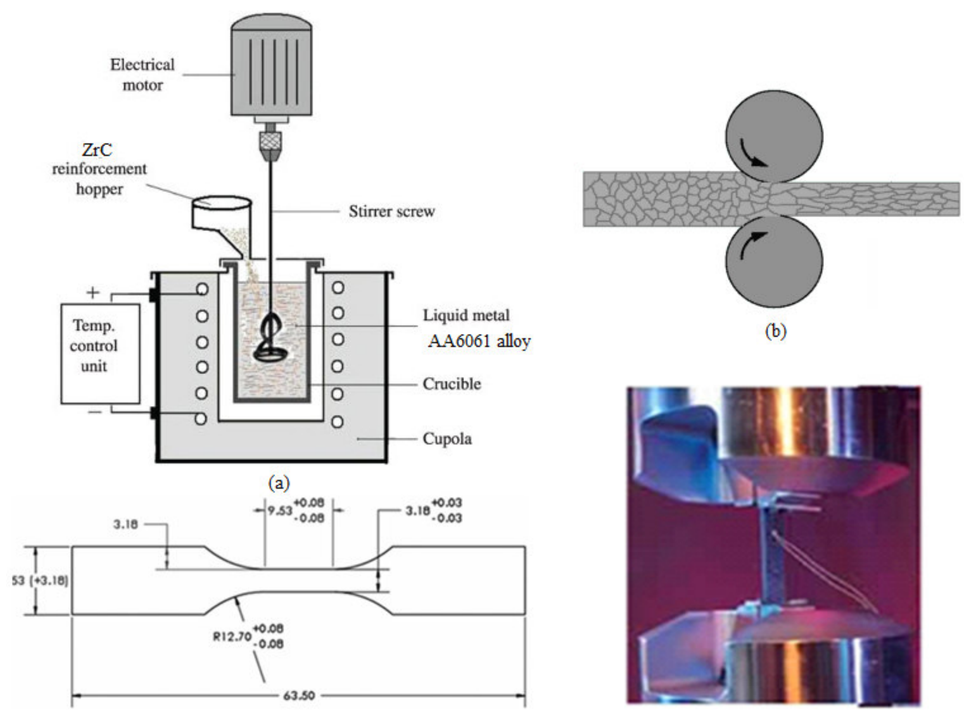

Figure 1: Stir casting process; cold rolling (b); shape and dimensions of tensile specimen (c); and tensile testing on UTM (d).

2. MATERIALS METHODS

The matrix material was AA5050 alloy. The reinforcement material was TiN nanoparticles of average size 100nm. AA5050 alloy/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 AA5050/ TiO_2 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 with reference to application of finite element method for several metal matrix composites. The finite element analysis was carried out on a unit cell without porosity as shown in figure 2a and that with porosity as shown in figure 2b.

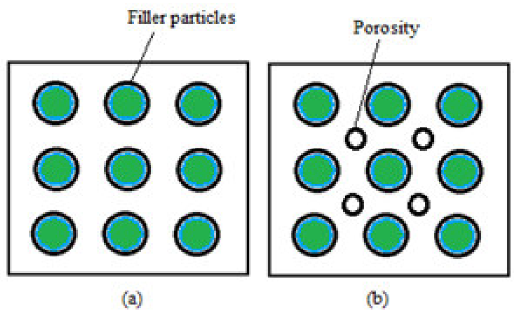

Figure 2: Unit cells: (a) without porosity and (b) with porosity.

Density of the composite is calculated from 'Rule of Mixture' as follows:

$$\left(\frac{v_p}{\rho_p}+\frac{1-v_p}{\rho_m}\right) \leq \rho_c \leq (1-v_p)\rho_m \quad (1)$$

where v_p is the volume fraction of particles and ρ_c, ρ_p, and ρ_m are densities of composite, particles and matrix, respectively.

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:

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

$$k = E_m m_m / E_p m_p$$

where, vv and vp are the volume fractions of voids/porosity and nanoparticles in the composite respectively, mp and mm are the possion's ratios of the nanoparticles and matrix respectively, dp is the mean nanoparticle size (diameter) and Em and Ep 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

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

The lower-bound equation is given by

$$\frac{E_c}{E_m} = 1 + \frac{v_p-v_p}{\delta/(\delta-1)-(v_p+v_v)^{1/3}} \quad (4)$$

where, $\delta = E_p / E_m$.

3. RESULTS AND DISCUSSION

The tensile strength was increased due to addition of TiO_2 particles without porosity AA5050/ TiO_2 metal matrix composites; it decreased with porosity (figure 3a). The tensile stresses obtained from the finite element analysis (FEA) were higher than those obtained from the mathematical expression mentioned in Eq.(2) and the experimental procedure as shown in figure 3a. The density increased with increase of volume fraction of TiO_2 in the AA5050 alloy matrix (figure 3b). Porosity and clustering of TiO_2 particles are observed in the microstructures of the composites shown in figure 4.

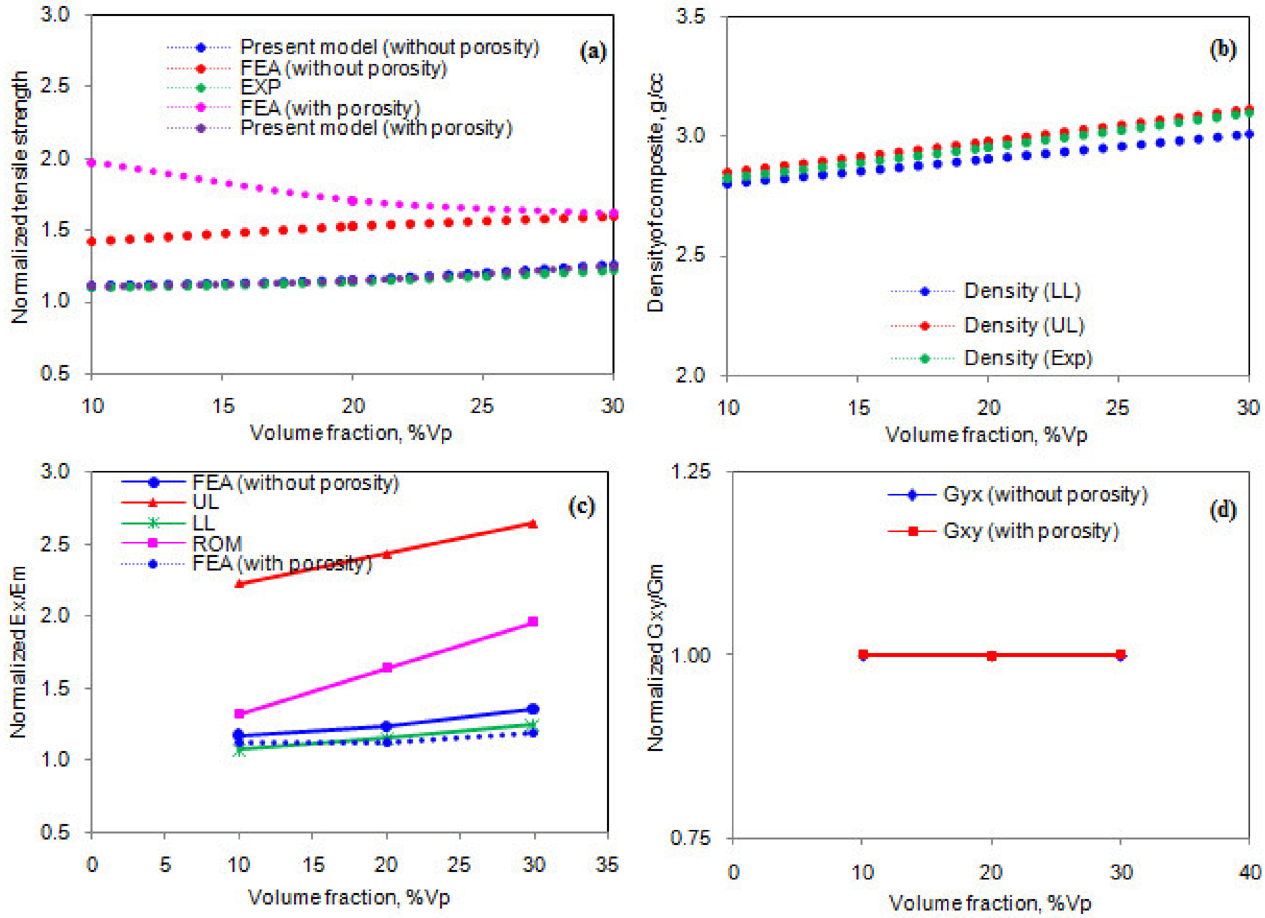

Figure 3: Effect of volume fraction on (a) normalized strength, (b) normalized tensile elastic modulus, (c) normalized shear modulus and (d) density of AA5050/ TiO_2 composites.

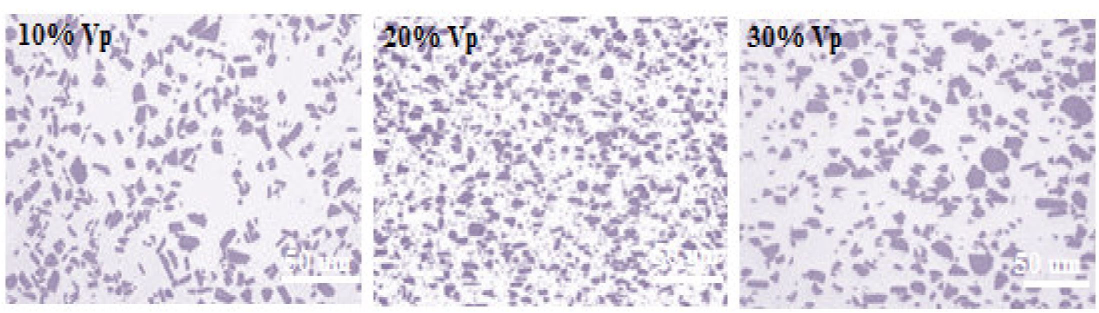

Figure 4: Microstructure showing porosity and distribution of 10%, 20% and 30% TiO_2 nanoparticles in AA5050 alloy matrix.

The normalized elastic modulus increased with increase of volume fraction of TiO_2 particles in AA5050 alloy matrix without porosity. The normalized shear modulus was constant with increase of volume fraction of TiO_2 in the AA5050 alloy matrix with or without porosity (figure 3d). Without porosity in the composites, the tensile stress increased with increase of volume fraction of TiO_2 in AA5050 alloy matrix. The tensile stress was exceeded the allowable stress in the composites with porosity for the same load as that applied on the composites without porosity as shown in figure 5b. This is attributed to the development of the stress concentrations in the vicinity of the porosity.

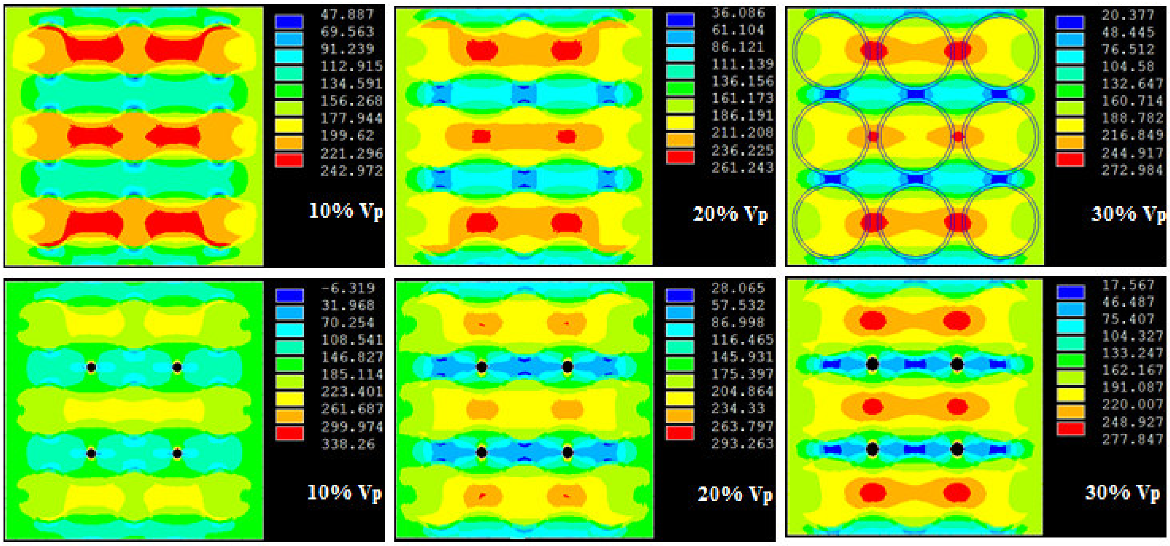

Figure 5: Images of tensile stresses obtained from FEA: (a) without porosity and (b) with porosity.

4. CONCLUSIONS

The density of AA5050/ TiO_2 alloy has been increased with increase of TiO_2 particles in AA5050 alloy matrix containing porosity in the matrix. In the presence of voids, the tensile stresses developed in the composites have exceeded the allowable stress for the same load applied on all the composite specimens.

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