Micromechanical and Porosity Studies of Cast AA3003/ Boron Nitride Metal Matrix Composites

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Abstract: In the current work, the AA3003 alloy/BN metal matrix composites were analyzed for tensile properties in the presence of porosity. The results obtained from the finite element analysis of AA3003 alloy/BN composites were in agreement with the experimental result. The, density, tensile strength and elastic modulus of AA3003 alloy/BN composites have decreased in the presence of porosity.

Keywords: Boron nitride, AA3003 alloy, unit cell models, finite element analysis, porosity.

1. INTRODUCTION

Porosity is among the difficulties occurring in cast MMC which has significantly affected the composite mechanical behavior [1-8]. Previous works had related the presence of porosity to the size and volume fraction of reinforcing particles [9-20]. Porosity formation in stir-cast discontinuous reinforced MMC was originated from gas entrapment during vigorous stirring method, air bubbles entering either the slurry or as an air envelope to the particles, water vapor on the surface of the reinforcing particles, hydrogen evolution and solidification shrinkage [21-30]. The effect of porosity on mechanical properties was much focusing on tensile and fatigue properties of MMC. The porosity presence has also affected the yield strength, ductility, Poisson's ratio and ultimate tensile strength of MMC [31-35]. The yield strength and ultimate tensile strength were decreased by increasing porosity content.

The current work presents the effect of porosity, volume fraction of particles and distribution of particles on micromechanical behavior of AA3003 alloy/ boron nitride metal matrix composites. The shape of boron nitride (BN) nanoparticle considered in this work is spherical. Finite element analysis was used to analyze unit cells with and without porosity.

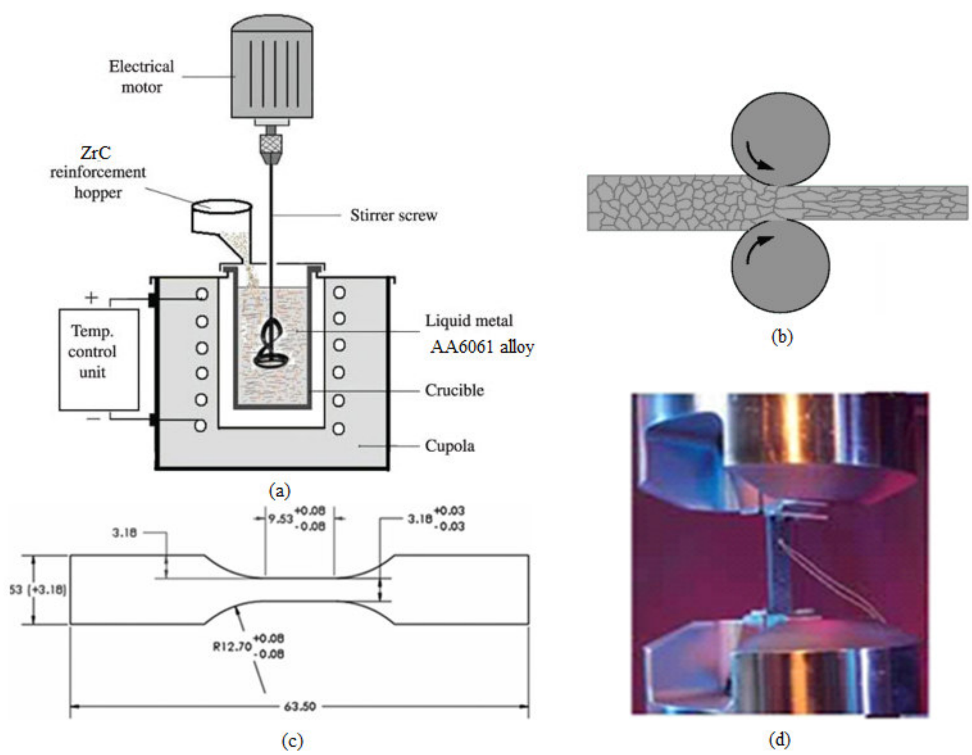

Figure 1: Stir casting process; cold rolling (b); shape and dimensions of tensile specimen (c); and tensile testing on UTM (d).

2. MATERIALS METHODS

The matrix material was AA3003 alloy. The reinforcement material was BN nanoparticles of average size 100nm. AA3003 alloy/BN 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 AA3003 alloy/BN composites at three (10%, 20% and 30%) volume fractions of BN. 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.

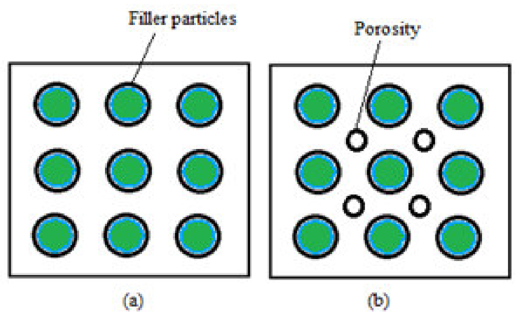

Figure 2: Unit cells: (a) without porosity and (b) with porosity.

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

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

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:

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

$$k = E_m m_m / E_p m_p$$

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

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

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

Adding BN particles to AA3003 alloy matrix, the tensile strength was increased without porosity AA3003 alloy/BN 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. This is owing to the ignorance of clustering of BN particles in AA3003 alloy matrix.

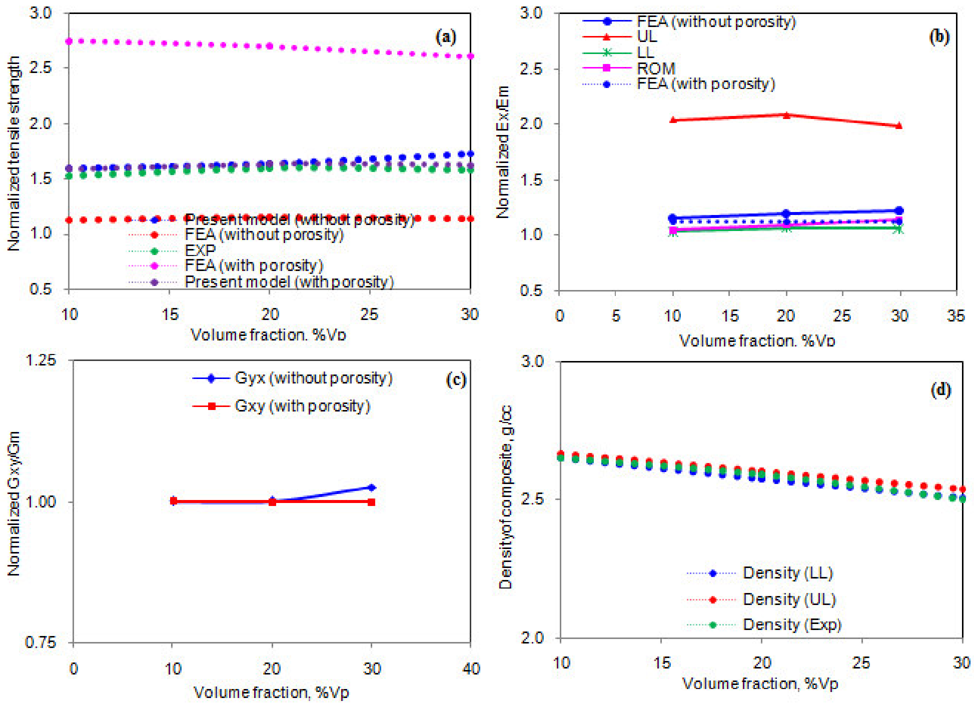

Figure 3: Effect of volume fraction on (a) normalized strength, (b) normalized tensile elastic modulus, (c) normalized shear modulus and (d) density of AA3003 alloy/BN composites.

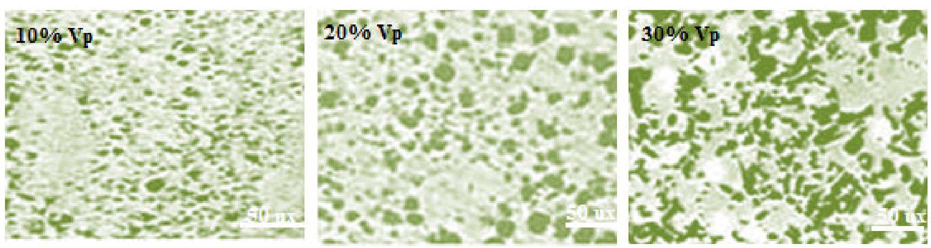

Figure 4: Microstructure showing porosity and distribution of 10%, 20% and 30% BN nanoparticles in AA3003 alloy matrix.

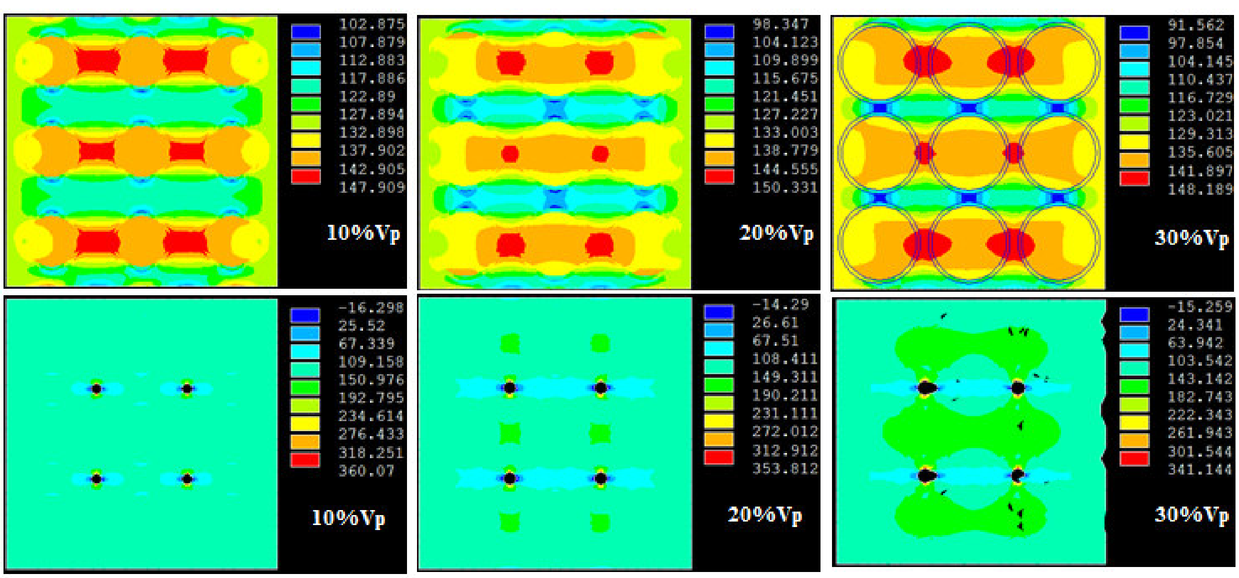

Figure 5: Images of tensile stresses obtained from FEA: (a) without porosity and (b) with porosity.

The normalized elastic modulus increased with increase of volume fraction of BN particles in AA3003 alloy matrix without porosity; while it decreased with increase of volume fraction of clustered BN particles in AA3003 alloy matrix with porosity (figure 3b). The normalized shear modulus was constant with increase of volume fraction of BN in the AA3003 alloy matrix without porosity (figure 3c); but it increased in the composites having porosity. The density variation in various composites is shown in figure 3d. The density decreased with increase of volume fraction of BN in the AA3003 alloy matrix. This is confirmed with the microstructures of the composites shown in figure 4.

Without porosity in the composites, the tensile stress increased with increase of volume fraction of BN in AA3003 alloy matrix. With an assumption of constant porosity in all the composites, 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. This is attributed to the development of the stress concentrations in the vicinity of the porosity. On the other hand, the tensile stress decreased with increase of volume fraction of BN. This trend is in agreement with the results obtained from experimental procedure and mathematical computation. The fracture of matrix material is seen in the composites having 30% BN.

4. CONCLUSIONS

The density of AA3003/BN alloy has been decreased with increase of BN particles in AA3003 alloy matrix having voids. 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. The elastic modulus and tensile stress decreased with porosity in the composites.

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