High Pressure Die Casting Process on Micromechanical Properties of AA2024/Boron Carbide Metal Matrix Composites

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Abstract: The AA2024/boron carbide metal matrix composites were fabricated using stir casting process and analyzed for tensile properties in the presence of porosity. Porosity was measured with different volume percents of boron carbide particle reinforced to AA2024 alloy. The density decreased with increase of boron carbide particles in AA2024 alloy matrix. Development of porosity has reduced the mechanical properties of AA2024/ boron carbide metal matrix composites.

Keywords: Boron carbide, AA2024 alloy, unit cell models, finite element analysis, porosity.

1. INTRODUCTION

While metal matrix composites have the ability to augment the strength and stiffness of the alloy, there are drawbacks that must be taken into consideration when using them in design. The use of boron carbide in the structural ceramics field, however, has been severely limited because of the brittleness associated with the material [1]. The unique combination of low specific gravity, high elastic modulus, and high hardness in boron carbide has led to its development for use as ceramic armor for the protection against a variety of ballistic threats in helicopters or vests for personnel. Different methods have been adopted for fabrication of metal matrix composites [2-15]. Among them, the conventional foundry based processes are more favorable in obtaining near net shape components at high production rates and low costs. In recent years, the stir casting technique has attracted the interest of many researchers [16-25]. The numerous voids and high porosity of the material create additional stress concentrations. There is often an appreciable degree of porosity and microscopic cracks inherent to ceramics, which also contribute to the brittleness [26-32].

AA2024 alloy/boron carbide metal matrix composites were fabricated using stir casting and high pressure die casting techniques. The effects of porosity on micromechanical properties were investigated using experimental practice and finite element analysis. For the finite element analysis, the spherical shaped boron carbide particles were assumed to analyze unit cells with and without porosity.

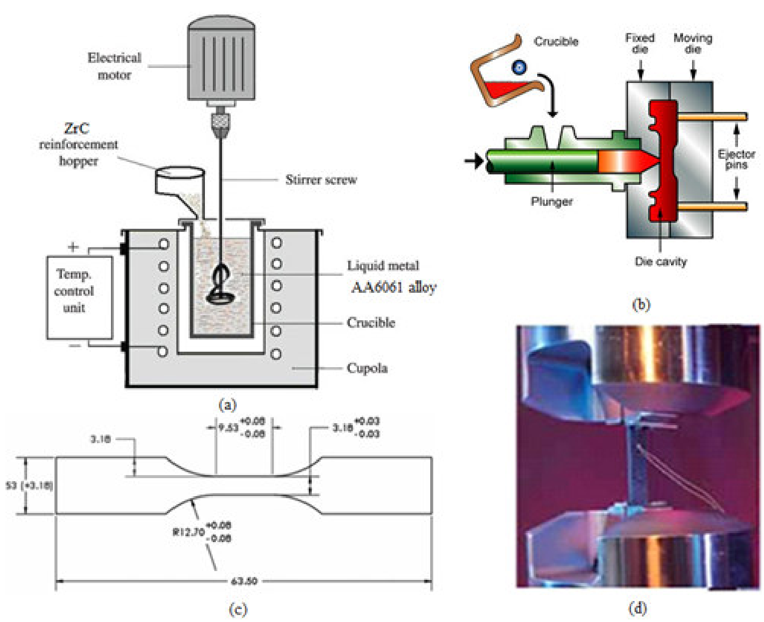

Figure 1: Stir casting process; cold rolling (b); shape and dimensions of tensile specimen (c); and tensile testing on UTM (d).

2. MATERIALS METHODS

The matrix material was AA2024 alloy. The reinforcement material was boron carbide nanoparticles of average size 100nm. AA2024/ boron carbide metal matrix composites were fabricated by the stir casting process and high pressure die casting technique at 15MPa. 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 AA2024/boron carbide composites at three (10%, 20% and 30%) volume fractions of boron carbide. 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.

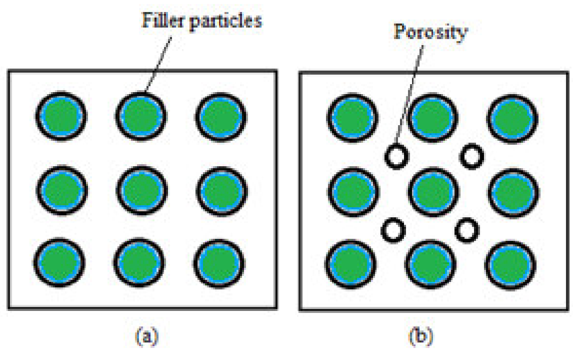

Figure 2: Unit cells: (a) without porosity and (b) with porosity.

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

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

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:

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

$$k = E_m m_m / E_p m_p$$

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

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

The lower-bound equation is given by

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

where, $\delta = E_p / E_m$.

3. RESULTS AND DISCUSSION

The tensile strength increased with addition of B_4C particles without porosity in the 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 decreased with increase of volume fraction of B_4C in the AA2024 alloy matrix (figure 3b). The reason could be attributed increasing volume fraction and shape of B_4C particles in the matrix. The density (2.51 g/cc) of B_4C is lower than that (2.71 g/cc) of AA2024 alloy. The elastic modulus increased with increase of volume fraction of B_4C particles; however it was lower in the presence of porosity (figure 3c). The shear modulus was nearly constant (figure 3d).

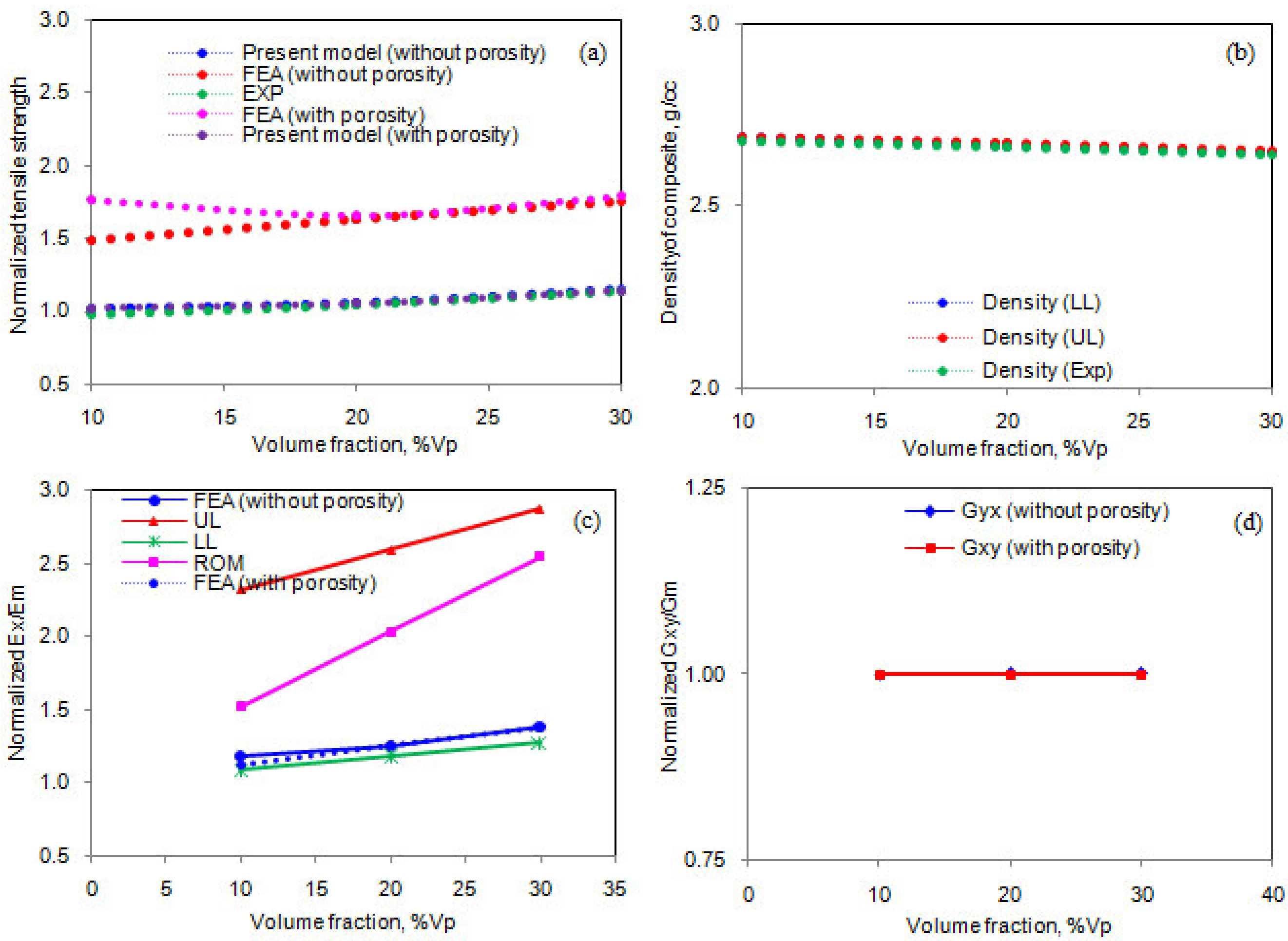

Figure 3: Effect of volume fraction on (a) normalized strength, (b) normalized tensile elastic modulus, (c) normalized shear modulus and (d) density of AA2024/ B_4C composites.

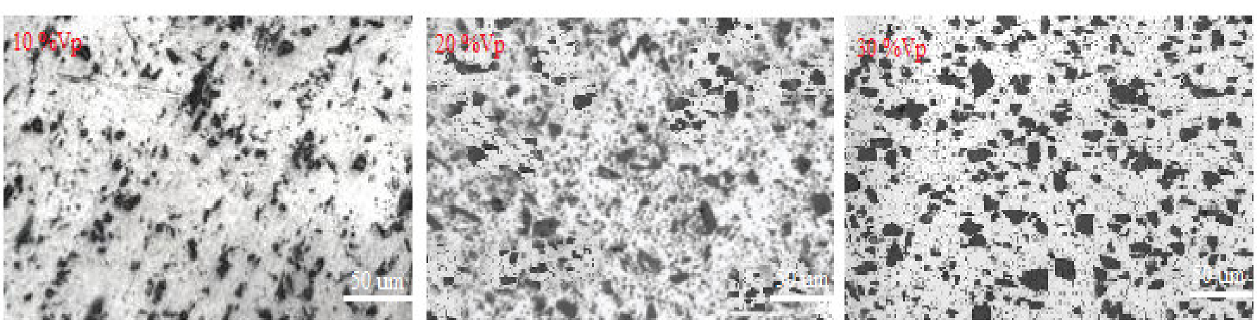

Figure 4: Microstructure showing porosity and distribution of 10%, 20% and 30% B_4C nanoparticles in AA2024 alloy matrix.

The microstructure shown in figure 4 reveals the porosity and clustering of particles. Without porosity in the composites, the tensile stress increased with increase of volume fraction of B_4C in AA2024 alloy matrix (figure 5a). 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 especially in the composites having high volume fraction of B_4C particles.

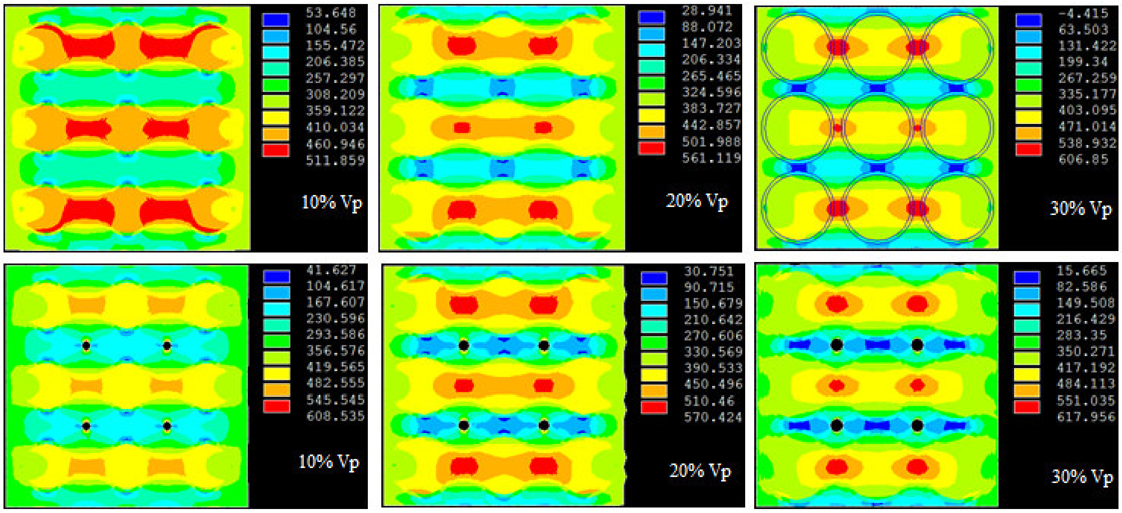

Figure 5: Images of tensile stresses obtained from FEA: (a) without porosity and (b) with porosity.

4. CONCLUSIONS

Porosity content reduces significantly the tensile properties with increasing percentage of B_4C particles in AA2024 alloy 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 reducing the plastic deformation of matrix.

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