Effect of Reinforcement Loading on Porosity and Micromechanical Properties of AA7020/Graphite Metal Matrix Composites

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Abstract: The AA7020/graphite 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 graphite particle reinforced to AA7020 alloy. The density decreased with increase of graphite particles in AA7020 alloy matrix. Development of porosity has reduced the mechanical properties of AA7020/graphite metal matrix composites.

Keywords: Graphite, AA7020 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. Previous works had related the presence of porosity to the size and volume fraction of reinforcing particles, process parameter and mould type [1-10]. Basically, 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 [11-20]. Hydrogen evolution was associated with high hydrogen solubility in most melt metal, at which solidification process caused porosity development from trapped hydrogen. There was a linear correlation between the amount of alumina reinforced and the porosity volume fraction measured [21-30]. This appeared as porosity tends to occur at the matrix reinforcement interfaces. The effect of porosity was reported was much focusing on tensile properties of MMC [31-36].

AA7020 alloy/graphite metal matrix composites were fabricated using stir casting technique. The effects of porosity on micromechanical properties were investigated using experimental practice and finite element analysis. For the finite element analysis, the spherical shaped graphite particles were assumed to analyze unit cells with and without porosity.

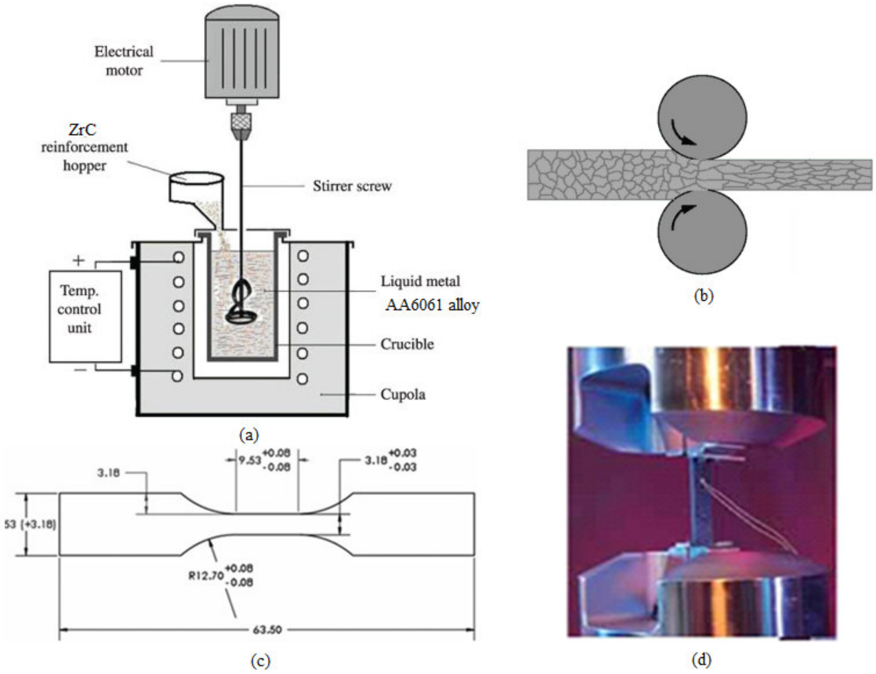

Figure 1: Stir casting process; cold rolling (b); shape and dimensions of tensile specimen (c); and tensile testing on UTM (d).

2. MATERIALS METHODS

The matrix material was AA7020 alloy. The reinforcement material was graphite nanoparticles of average size 100nm. AA7020/graphite metal matrix 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 AA7020/graphite composites at three (10%, 20% and 30%) volume fractions of graphite. 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.

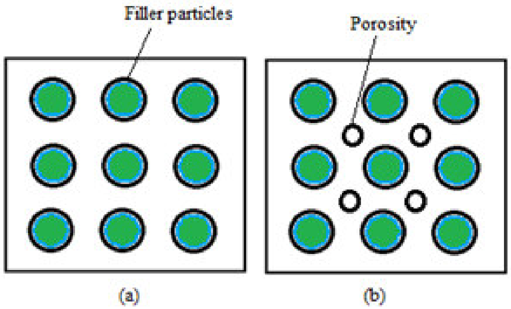

Figure 2: Unit cells: (a) without porosity and (b) with porosity.

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

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

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:

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

$$k = E_m m_m / E_p m_p$$

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

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

The lower-bound equation is given by

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

where, $\delta = E_p / E_m$.

3. RESULTS AND DISCUSSION

The tensile strength increased with addition of graphite 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 graphite in the AA7020 alloy matrix (figure 3b). The reason could be attributed increasing volume percentages of graphite particles in the matrix. The densities of graphite and AA7020 alloy are, respectively, 2.51 g/cc and 2.78 g/cc. The elastic modulus increased with increase of volume fraction of graphite particles; however it was lower n the presence of porosity (figure 3c). The shear modulus was drastically reduced at volume fraction of graphite particles in the presence of porosity (figure 3d). This is confirmed with the microstructures of the composites shown in figure 4.

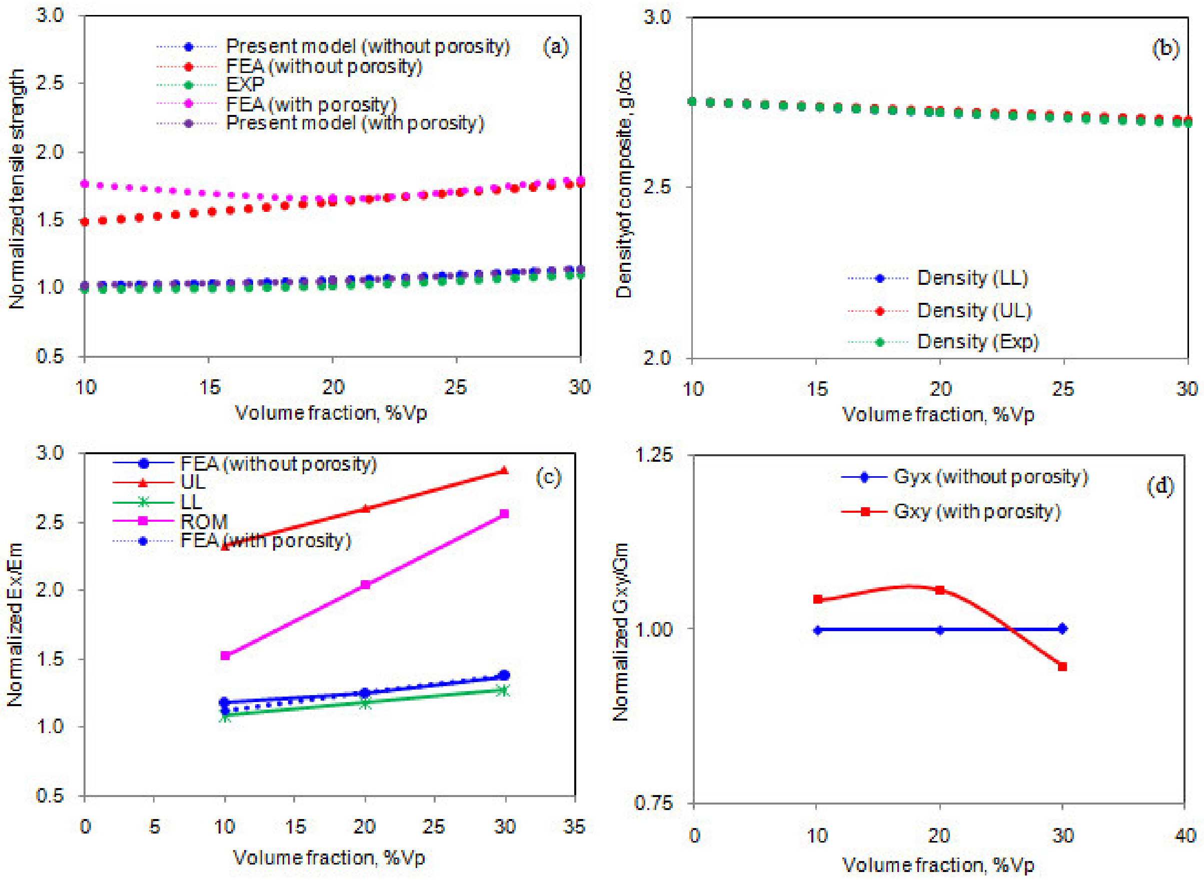

Figure 3: Effect of volume fraction on (a) normalized strength, (b) normalized tensile elastic modulus, (c) normalized shear modulus and (d) density of AA7020/ graphite composites.

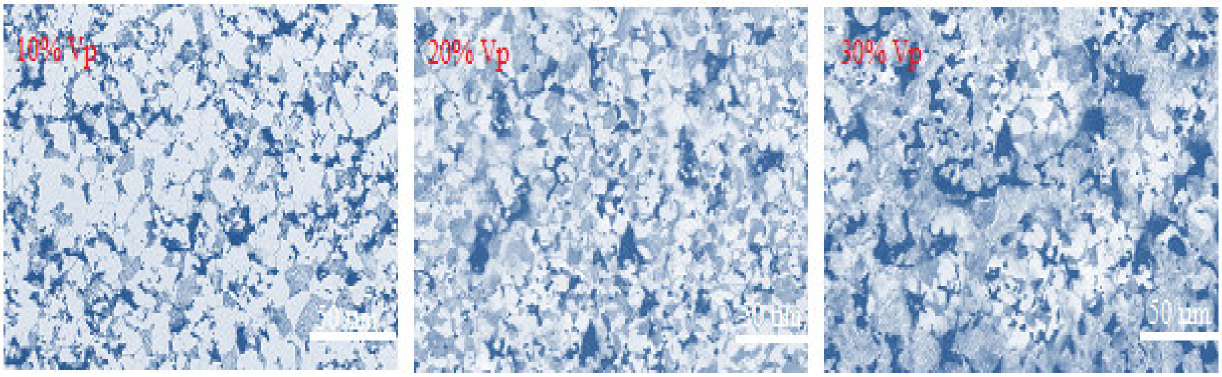

Figure 4: Microstructure showing porosity and distribution of 10%, 20% and 30% graphite nanoparticles in AA7020 alloy matrix.

Without porosity in the composites, the tensile stress increased with increase of volume fraction of graphite in AA7020 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 graphite particles.

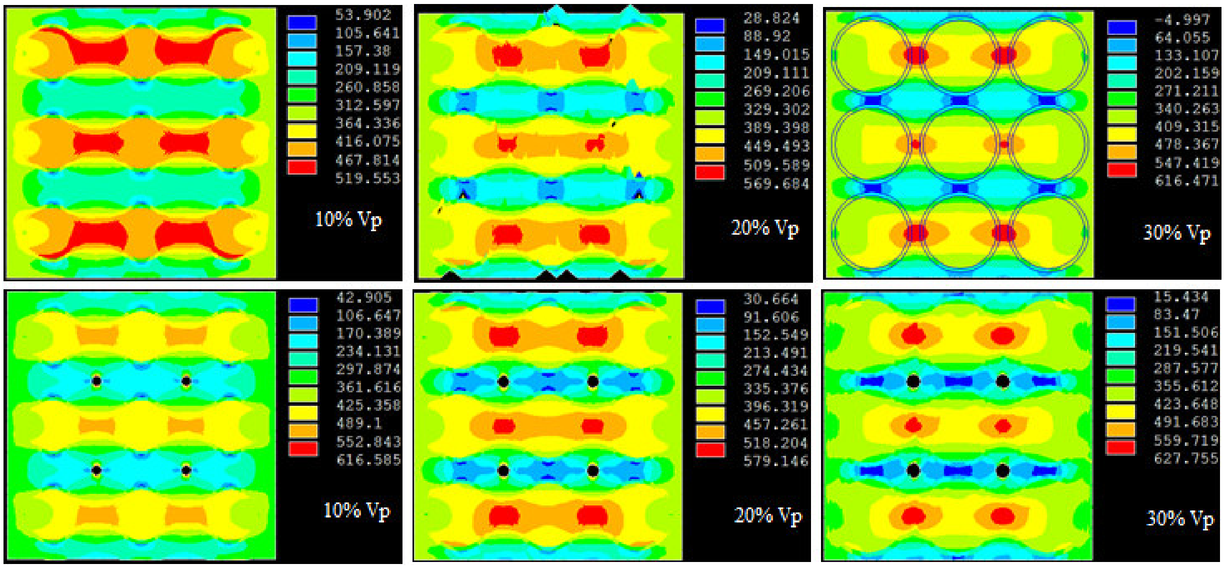

Figure 5: Images of tensile stresses obtained from FEA: (a) without porosity and (b) with porosity.

4. CONCLUSIONS

Porosity content reduces significantly the tensile properties with increasing percentage of graphite particles in AA7020 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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