Microstructure and Properties of Liquid Metal Processed MgO Reinforced AA8090 Metal Matrix Composites

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Abstract: The AA8090/MgO metal matrix composites were fabricated using stir casting process and analyzed for micromechanical properties in the presence of porosity. The density increased with increase of MgO particles in AA8090 alloy matrix. Development of porosity has reduced the mechanical properties of AA8090/MgO metal matrix composites.

Keywords: Magnesium Oxide, AA8090 alloy, unit cell models, finite element analysis, porosity.

1. INTRODUCTION

In the discontinuously reinforced MMC system, mechanical failure processes occur mainly by the formation and bonding of porosity within the matrix [1-16]. Stir casting method is a relatively low cost liquid processing present to produce metal matrix composites and hence, this processing technique had been utilized in this study. There are several difficulties [17-32] in stir casting that are of concern, which are:

- porosity in the cast MMC,
- difficulty in achieving a uniform distribution of the reinforcement material,
- wettability between the two main substances, and
- chemical reactions between the reinforcement material and matrix alloy.

AA8090 alloy/MgO 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.

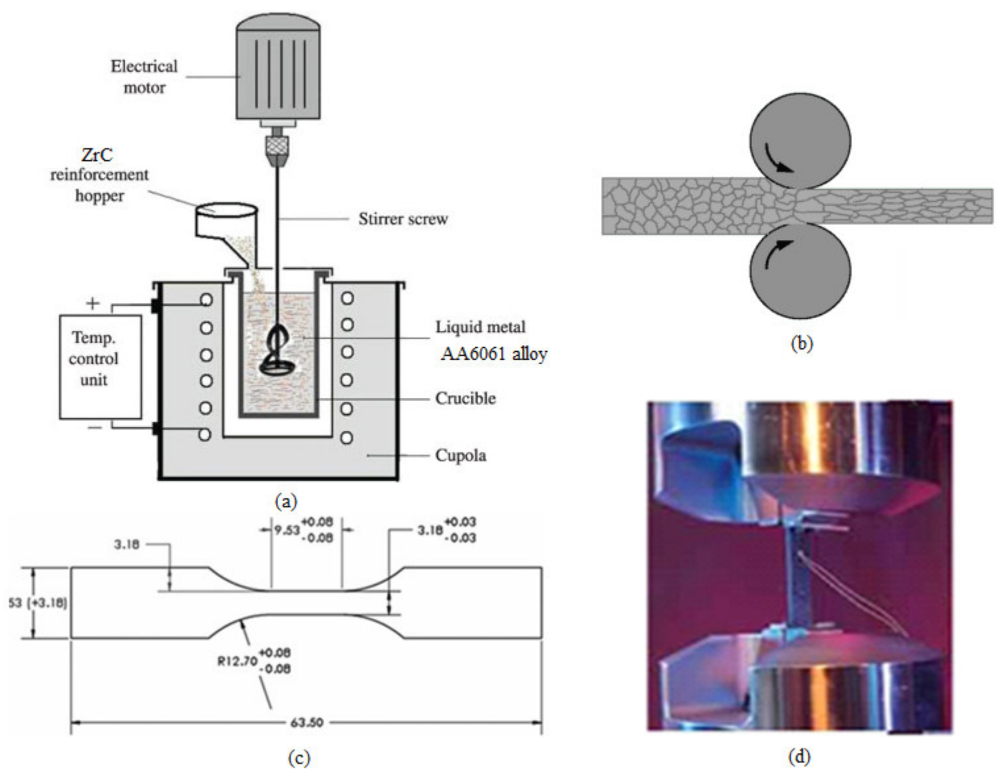

Figure 1: Stir casting process; cold rolling (b); shape and dimensions of tensile specimen (c); and tensile testing on UTM (d).

2. MATERIALS METHODS

The matrix material was AA8090 alloy. The reinforcement material was graphite nanoparticles of average size 100nm. AA8090/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 AA8090/MgO composites at three (10%, 20% and 30%) volume fractions of MgO. 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.

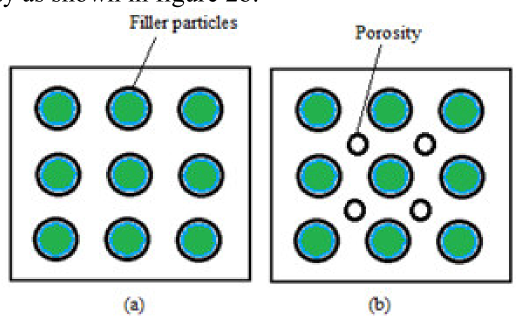

Figure 2: Unit cells: (a) without porosity and (b) with porosity.

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

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

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:

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

$$k = E_m m_m / E_p m_p$$

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 AA8090/MgO composites decreased with porosity in the composites (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 MgO in the AA8090 alloy matrix (figure 3b). The reason could be attributed increasing volume percentages of MgO particles in the matrix. The densities of MgO and AA8090 alloy are, respectively, 3.50 g/cc and 2.71 g/cc. The elastic modulus increased with increase of volume fraction of MgO particles; however it was lower n the presence of porosity (figure 3c). The shear modulus was nearly constant except for low volume fraction of MgO particles (figure 3d).

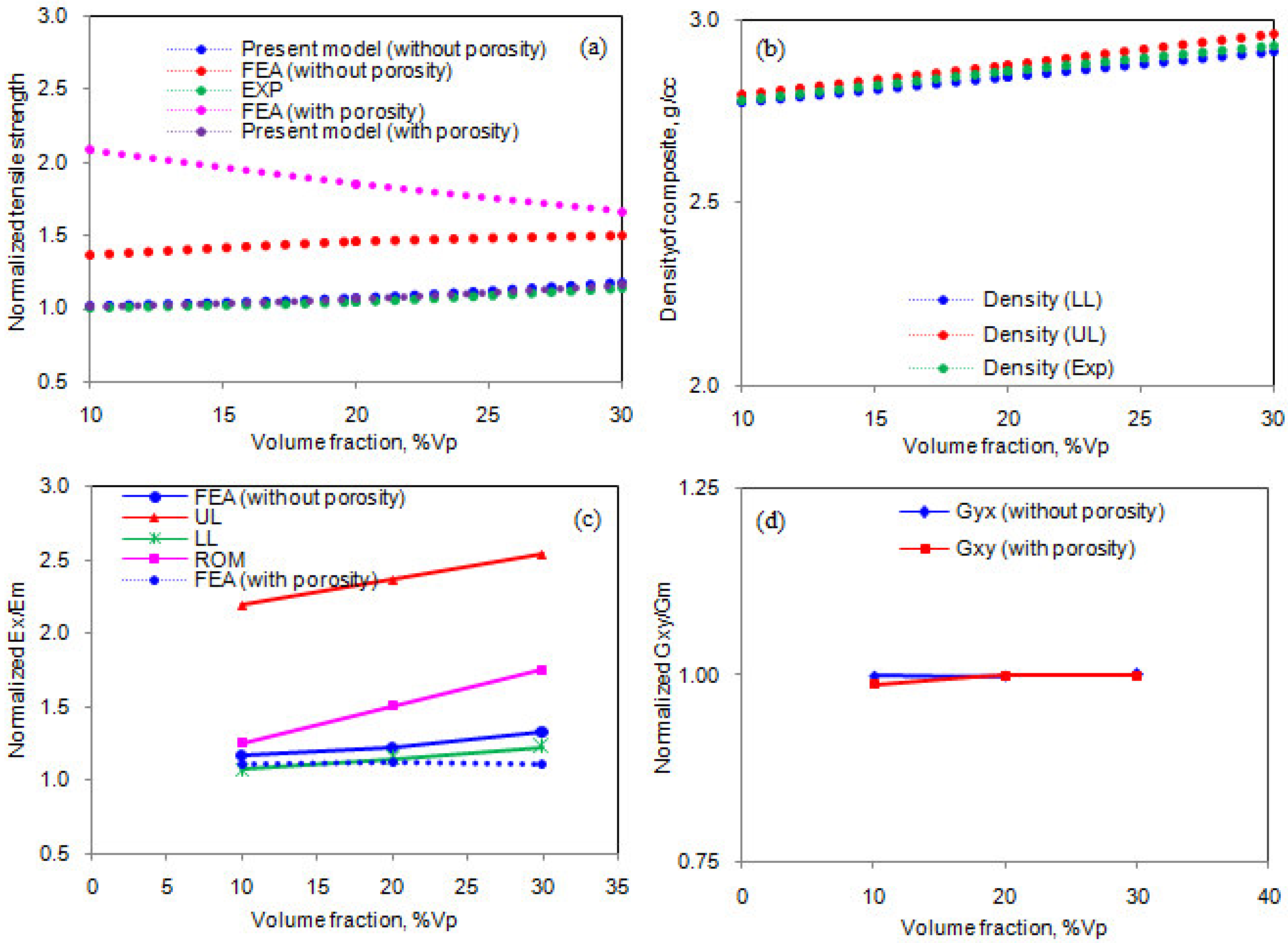

Figure 3: Effect of volume fraction on (a) normalized strength, (b) normalized tensile elastic modulus, (c) normalized shear modulus and (d) density of AA8090/ MgO composites.

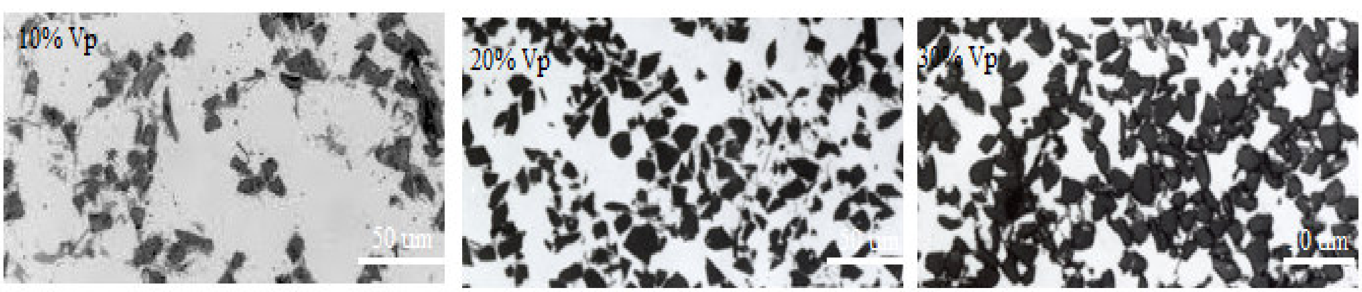

Figure 4: Microstructure showing porosity and distribution of 10%, 20% and 30% graphite nanoparticles in AA8090 alloy matrix.

Not only porosity but also clustering of MgO particles were observed in the composites (figure 4). The porosity was developed in the matrix alloy. Without porosity in the composites, the tensile stress increased with increase of volume fraction of MgO in AA8090 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 MgO particles.

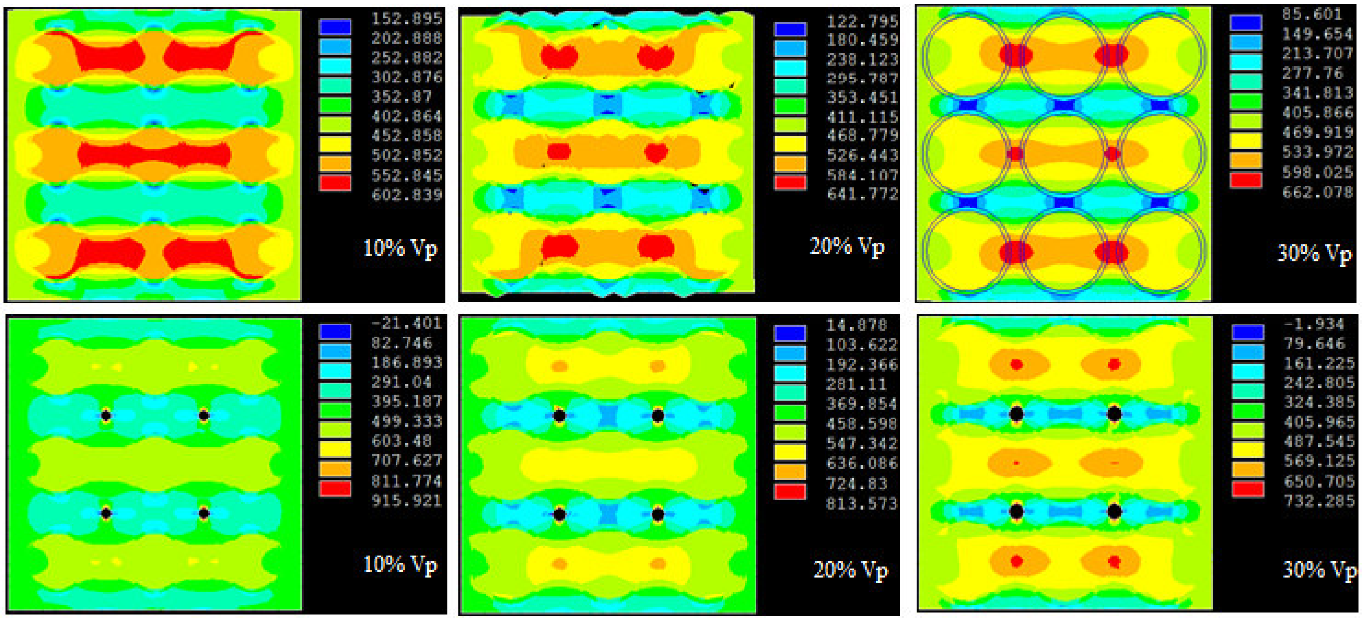

Figure 5: Images of tensile stresses obtained from FEA: (a) without porosity and (b) with porosity.

4. CONCLUSIONS

Porosity and clustering of MgO particles are noticed in AA8090/MgO composites. In the presence of porosity and clustering, 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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