Occurrence of Agglomeration and Porosity during High pressure Die Casting of AA8090/Graphite Particulate Metal matrix Composites

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Abstract: *Zirconium carbide nanoparticle reinforced AA8090 metal matrix composite specimens were produced high pressure die casting technique in bottom pouring stir casting. The influence of porosity and clustering on micromechanical properties were evaluated in as-cast condition by finite element method and experimental procedure. Porosity content was significantly linear with increasing percentage of titanium oxide nanoparticles in the clusters. The tensile strength and stiffness of have been decreased with increased porosity and clustering of Graphite nanoparticles.*

Keywords: *AA8090 alloy, zirconium carbide, unit cell, finite element analysis, clustering, porosity.*

1. INTRODUCTION

Metal matrix composites are one of the important innovations in the development of advanced materials. Aluminum graphite particulate MMCs produced by solidification techniques represent a class of inexpensive tailor-made materials for a variety of engineering applications such as automotive components [1], bushes, and bearings [2]. The most economical production of such composites is by stir casting; nevertheless, this is associated with some problems arising mainly from the apparent non-wettability of graphite by liquid aluminum alloys [3, 4] and density differences between the two material. As a result, the introduction and retention of graphite particles in molten aluminum is extremely difficult. Earlier it has been reported that the production method has a strong influence on the mechanical and tribological properties of composites through its effects on the matrix grain size, porosity, the distribution of graphite particles, and the interfacial properties of the Al/graphite composites [5-31]. Defects such as clusters, agglomerates, and segregation of graphite particles play a dominant role in accelerating the fracture process. An inhomogeneous distribution of the particles, inadequate bonding between the metal and graphite particles, and formation of porosity at the graphite/matrix interface could be reduced to some extent by using pressure die-casting [32].

This study was undertaken to fabricate AA8090/graphite nanoparticulate metal matrix composites using stir casting process and high pressure die casting technique. The key idea is to understand the occurrence of porosity and agglomeration of nanoparticles and their effect on the micromechanical properties of AA8090/graphite composites. Also, the composites were modeled with two unit cells consisting of circular graphite nanoparticles to obtain composites with and without clustering and porosity using finite element methods.

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 high pressure die casting technique with pressure at 25 MPa. The test samples were machined to get flat-rectangular specimens 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 present work, a unit cell comprising of nine particles was implemented to analyze the micromechanical behavior AA8090/graphite metal matrix composites at three (10%, 20% and 30%) volume fractions of graphite with and without clustering and porosity. 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. The shape of graphite nanoparticle considered in this work is spherical. The periodic particle distribution was a square array. The tensile stress, elastic modulus and shear modulus are, respectively, normalized with tensile strength, elastic modulus and shear modulus of the matrix alloy.

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:

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

$$k = E_m m_m / E_p m_p$$

where, v_v and v_p are the volume fractions of voids/porosity and nanoparticles in the composite respectively, m_p and m_m are the possion's ratios of the nanoparticles and matrix respectively, d_p is the mean nanoparticle size (diameter) and E_m and E_p 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

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

The lower-bound equation is given by

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

where, $\delta = E_p / E_m$.

3. RESULTS AND DISCUSSION

The density of AA8090/graphite metal matrix composites unchanged as shown in figure 1a with increase of volume fraction of graphite nanoparticles. This is due to fact that the density (2.51g/cc) of graphite nearly equal to that (2.54 g/cc) of AA8090 alloy.

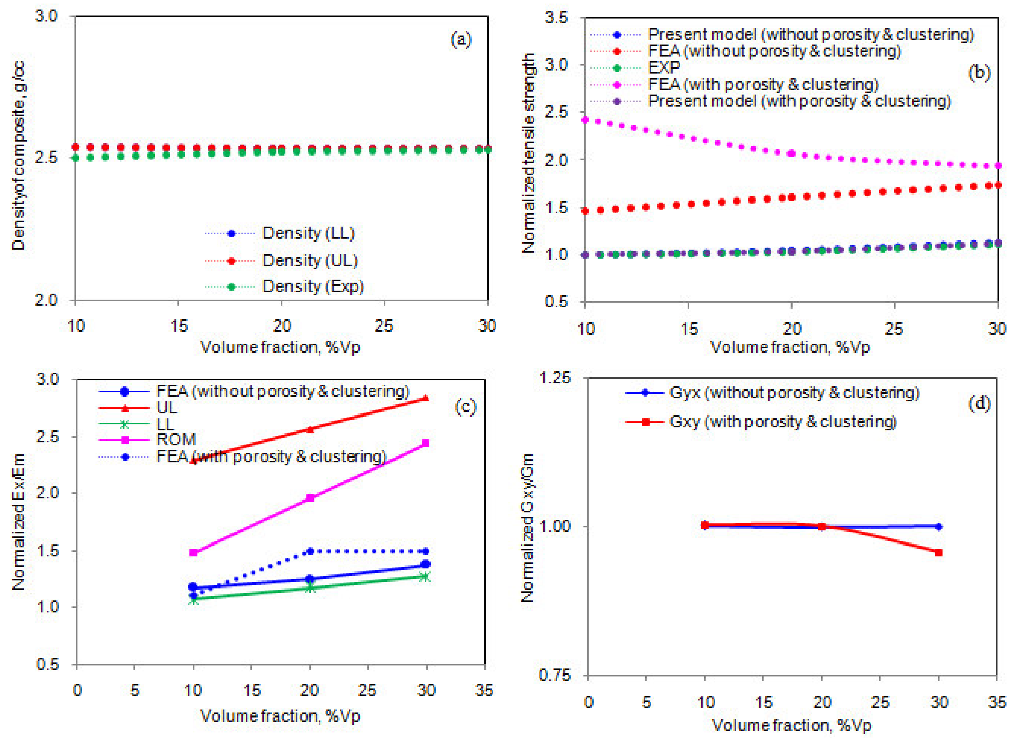

Figure 1: Effect of volume fraction on (a) density (b) normalized tensile stress, (c) normalized tensile elastic modulus and (d) normalized shear modulus of AA8090/graphite composites.

Reinforcing of graphite nanoparticles into AA8090 alloy matrix increased the tensile strength (figure 1b) and stiffness (figure 1c) without porosity and clustering. The shear modulus (figure 1d) was unaffected by the quantity of graphite loading in the AA8090 alloy matrix. As shown in figure 2, the graphite nanoparticles were randomly distributed in AA8090 alloy matrix. The volume fraction of clusters and porosity increased with increase in volume fraction graphite nanoparticles in AA8090 alloy matrix as shown in figure 3. Also, the porosity increased with increase of nanoparticles in a cluster. This can be attributed to high pressure die casting technique. The tensile strength decreased on account of porosity and clustering in AA8090/graphite metal matrix composites. As a result of stress concentrations at voids and clustered regions, the tensile stresses obtained from the finite element analysis (FEA) were higher than those obtained from the mathematical expression mentioned in Eq.(1) and the experimental procedure.

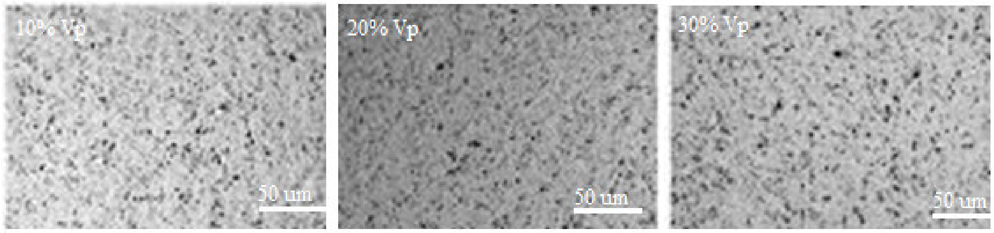

Figure 2: Influence of high pressure die casting process on distribution of nanoparticles.

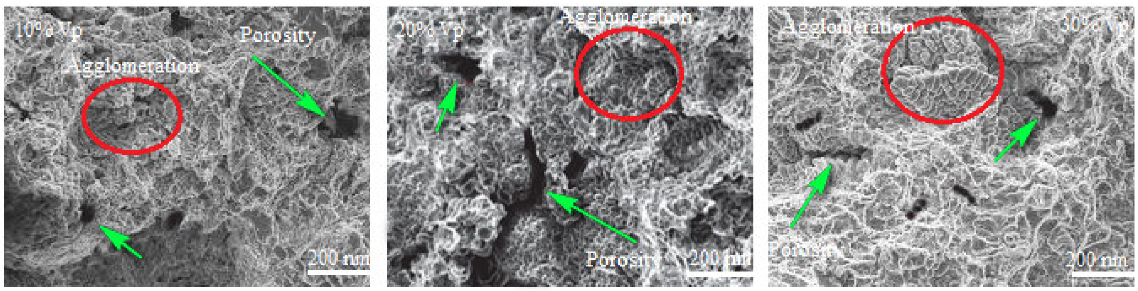

Figure 3: Influence of high pressure die casting process on porosity and clustering of nanoparticles.

Without porosity and clustering in the composites, the stress intensity was gradually decreased with increase in the volume fraction of graphite in AA8090 alloy matrix (figure 4a). With porosity and clustering in the composites, the stress intensities were high in the composites. However, the stress intensity decreased abruptly with increase of graphite nanoparticles in AA8090 alloy matrix (figure 4b).

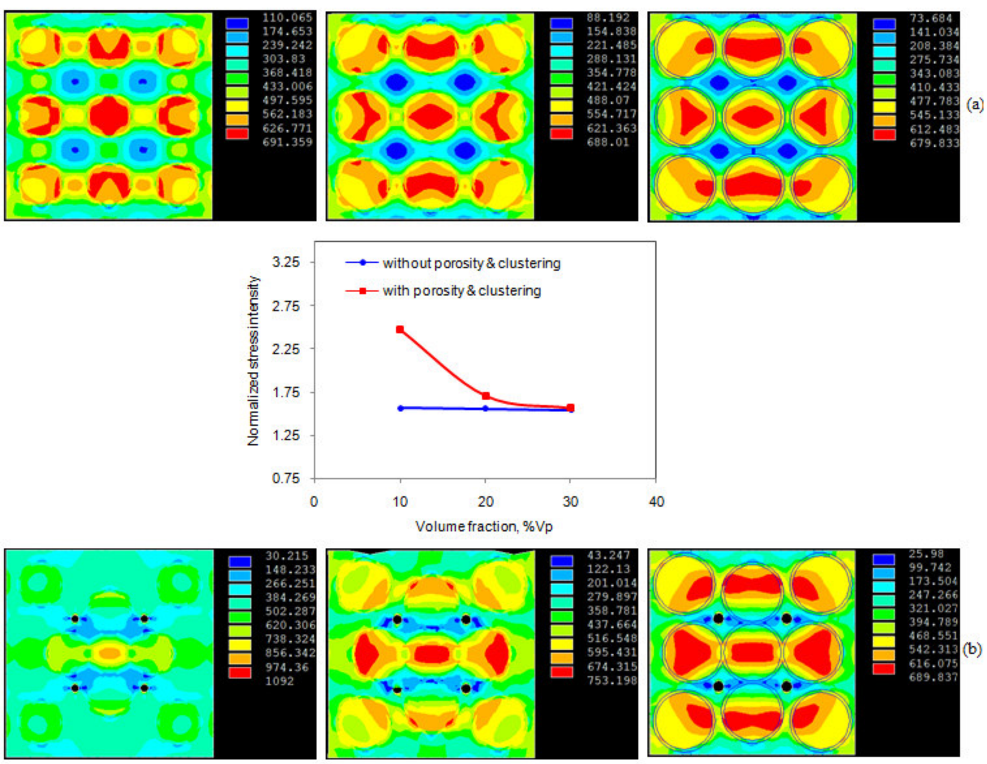

Figure 5: Images of stress intensities obtained from FEA: (a) without clustering and porosity and (b) with clustering and porosity.

4. CONCLUSION

In AA8090/graphite metal matrix composites, the porosity and clustering have been increased with increase of graphite nanoparticles in the clusters. Increase in volume fraction of graphite nanoparticles has reduced the tensile strength and stiffness of AA8090/graphite metal matrix composites. The stress intensity has been found decreased abruptly with the increase of volume fraction of graphite in the AA8090 alloy matrix.

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