High pressure Die Casting of AA7020/Zirconium Carbide Particulate Metal matrix Composites

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Abstract: *Zirconium carbide nanoparticle reinforced AA7020 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 ZrC nanoparticles.*

Keywords: *AA7020 alloy, zirconium carbide, unit cell, finite element analysis, clustering, porosity.*

1. INTRODUCTION

Metal matrix composites reinforced with nano-particles are being investigated worldwide in recent years, owing to their promising properties suitable for a large number of functional and structural applications. The nanoparticles are prone to form clusters, losing their capability to be homogeneously dispersed throughout the matrix for an optimal exploitation of the strengthening potential. In the composite processing, the complete elimination of porosity is either difficult or impossible [1, 2]. Porosity is among the dominant factors causing failure of discontinuous reinforced metal matrix composites in the tensile tests [3-10]. The commonly encountered spherical pores or gas porosity are observed to create stress concentrations and thus lead to failure. The ductility and toughness of most metal based composites are influenced by the formation of voids and the balance between reinforcing particles sharing the load [11-20]. The large amount of porosity associated with oxides is often surrounded by either individual or clusters of reinforcement particles, which significantly decreases the mechanical properties of particulate metal matrix composites [21-27]. Also, it was reported that the presence of nanoparticulates led to a higher level of porosity and more irregular pores with bigger pore size in the nanocomposites [34]. Thus, it is necessary to account for the effects of porosity on the mechanical properties of nanocomposites.

The objective of this study was, therefore, to fabricate AA7020/zirconium carbide metal matrix composites by varying the zirconium carbide (ZrC) volume fractions of 10%, 20% and 30% using stir casting process and high pressure die casting technique. The composites were also modeled with two unit cells consisting of circular ZrC nanoparticles to obtain composites with and without clustering and porosity using finite element methods.

2. MATERIALS METHODS

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

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

$$k = E_m m_m / E_p m_p$$

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

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

The lower-bound equation is given by

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

where, $\delta = E_p / E_m$.

3. RESULTS AND DISCUSSION

The density of AA7020/ZrC metal matrix composites increased as shown in figure 1a with increase of volume fraction of ZrC nanoparticles. This is due to fact that the density (6.73g/cc) of ZrC is higher than that (2.78 g/cc) of AA7020 alloy.

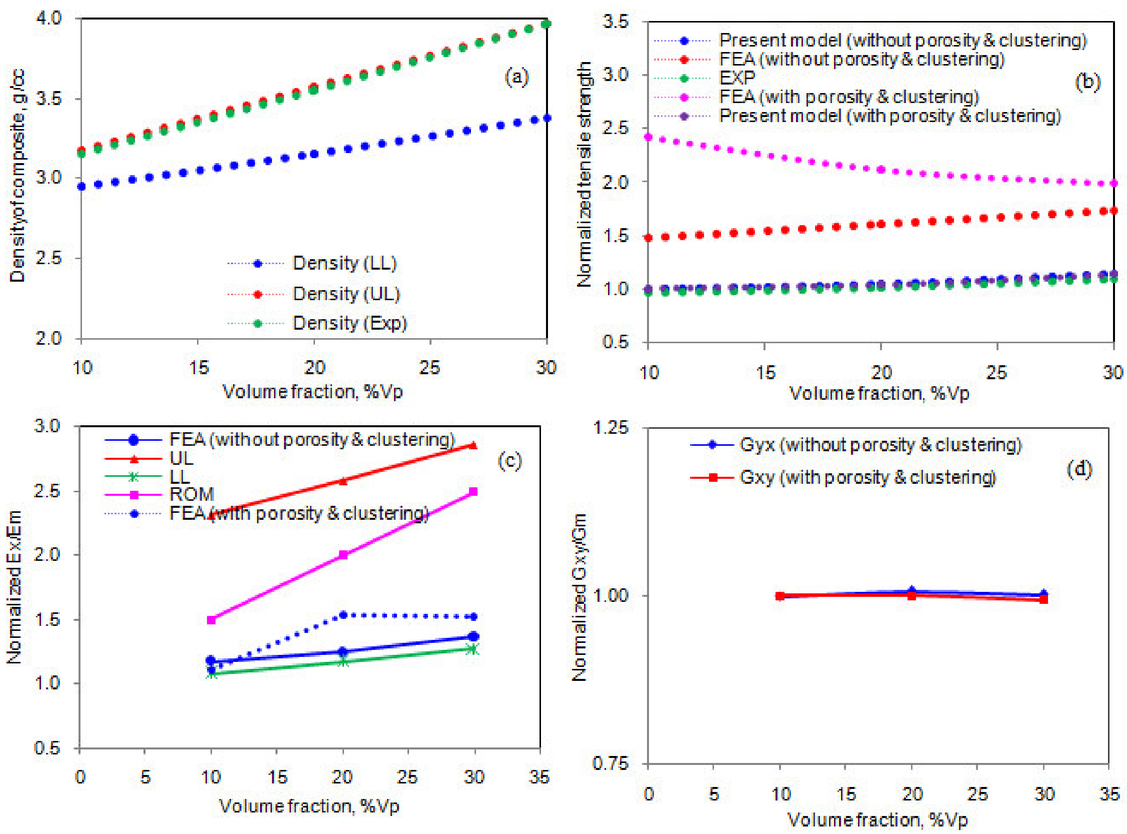

Figure 1: Effect of volume fraction on (a) density (b) normalized tensile stress, (c) normalized tensile elastic modulus and (d) normalized shear modulus of AA7020/ZrC composites.

Reinforcing of ZrC nanoparticles into AA7020 alloy matrix increased the tensile strength (figure 1b) and stiffness (figure 1c) without porosity and clustering. The shear modulus (figure 1d) was decreased by the quantity of ZrC loading in the AA7020 alloy matrix. The volume fraction of clusters and porosity increased with increase in volume fraction ZrC nanoparticles in AA7020 alloy matrix as shown in figure 2. Also the porosity increased with increase of nanoparticles in a cluster. This can be attributed to high pressure die casting technique. The nanoparticles were forced closure because of the applied pressure during die casting process. Consequently, the cluster density was increased. The tensile strength decreased owing to porosity and clustering in AA7020/ZrC 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.

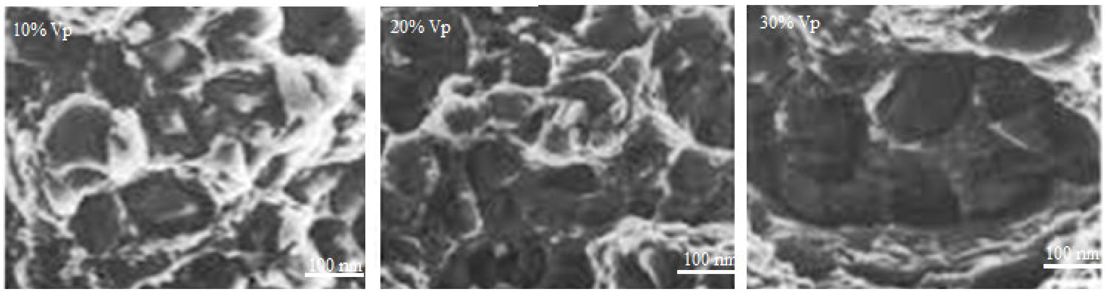

Figure 2: Influence of high pressure die casting process on clustering and porosity.

Without porosity and clustering in the composites, the stress intensity was gradually decreased with increase in the volume fraction of ZrC in AA7020 alloy matrix (figure 3a). With porosity and clustering in the composites, the stress intensities were high in the composites. However, the stress intensity decreased steeply with increase of ZrC nanoparticles in AA7020 alloy matrix (figure 2b).

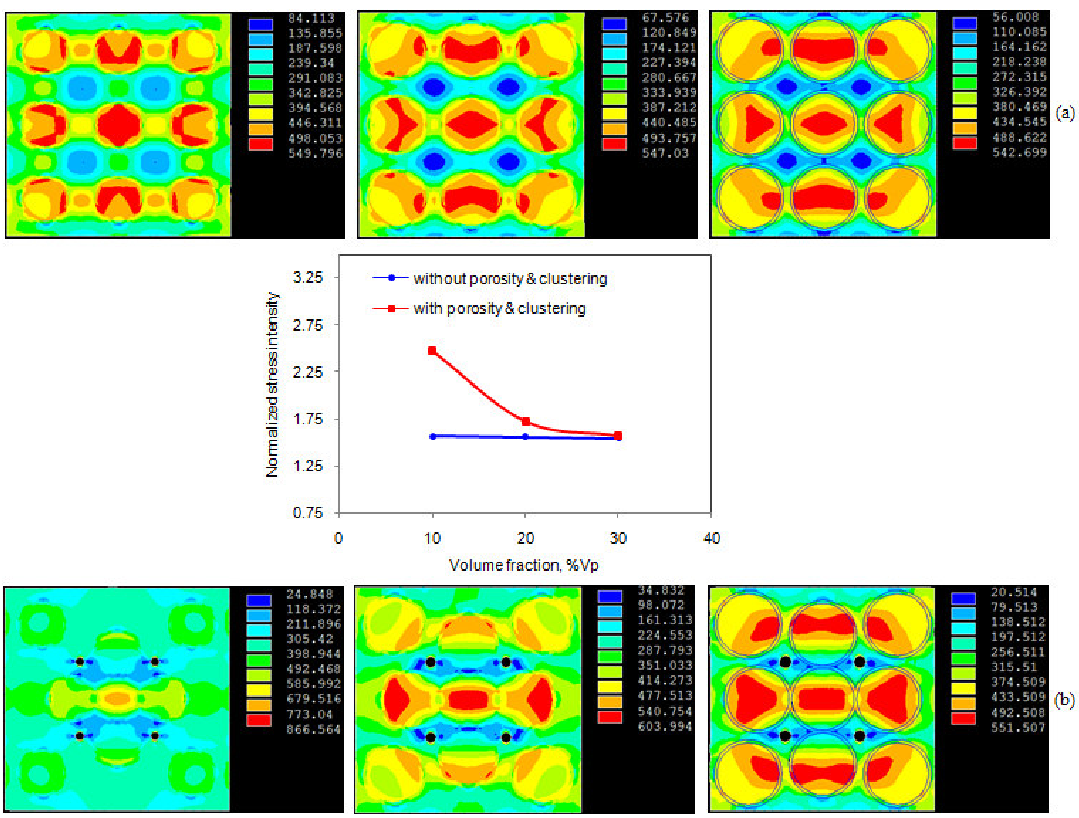

Figure 5: Images of stress intensities obtained from FEA: (a) without clustering and porosity and (b) with clustering and porosity.

4. CONCLUSION

In AA7020/ZrC metal matrix composites, the porosity and clustering have been increased with increase of ZrC nanoparticles in the clusters. Increase in volume fraction of ZrC nanoparticles has reduced the tensile strength and stiffness of AA7020/ZrC metal matrix composites. The stress intensity has been found decreased with the increase of volume fraction of ZrC in the AA7020 alloy matrix.

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