Processing of AA4015-Zirconium Oxide Particulate Metal Matrix Composites by Stir Casting Technology

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Abstract: *Particulate metal matrix composites have fascinated interest for application in numerous fields. The current processing methods often produce clustering of nano particles and porosity in the ductile matrix and as a result these composites exhibit extremely low ductility. The purpose of this work was to understand the effect of clustering and porosity on the micromechanical properties of AA4015/ZrO_2 metal matrix composites. The composites were manufactured by stir casting practice and high pressure die casting process at three volume fractions of ZrO_2.Thre results obtained from the finite elements method were compared with those of experimental procedure and empirical computations. Two types of finite element models were proposed with and without clustering and porosity. The microstructures of AA4015/ZrO_2 composites have revealed the increase of porosity content and number of clusters with increased volume fraction of ZrO_2 nanoparticles in AA4015 alloy matrix. The stiffness and tensile strength were not affected by the addition of ZrO_2 particles to AA4015 alloy matrix.*

Keywords: *AA4015 alloy, zirconium oxide, unit cell, finite element analysis, clustering, porosity.*

1. INTRODUCTION

Particulate metal matrix composites have been shown to offer improvements in strength, wear resistance, structural efficiency, reliability and control of physical properties such as density and coefficient of thermal expansion, thereby providing improved engineering performance in comparison to the un-reinforced matrix [1]. In recent years, nano-sized materials have also drawn much interest as reinforcements in metal matrix composites because of their superior properties compared with those of micro-sized particles. One of the major challenges when processing metal matrix composites is clustering of reinforcement particles in the matrix and porosity as they have a strong impact on the properties and the quality of the material. Possible reasons resulting in particle clustering are chemical binding, surface energy reduction or particle segregation [2-15]. Another important issue is that the final stages of solidification of the composite may involve microporosity formation in the hot spots of the composite. Porosity is a major defect found in these fabricated composites, which adversely affects their fatigue properties [16-28].

The aim of this study was on porosity and cluster formation phenomena observed in the metal matrix composites having near-equal stiffness and density properties. In this study, two different models were analyzed with and without porosity and clustering of porosity formation using two-dimensional finite element analysis.

2. MATERIALS METHODS

The matrix material was AA4015 alloy. The reinforcement material was silicon oxide (ZrO_2) nanoparticles of average size 100nm. AA4015/ZrO_2 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 AA4015/ZrO_2 metal matrix composites at three (10%, 20% and 30%) volume fractions of ZrO_2 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 ZrO_2 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

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

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 AA4015/ZrO_2 metal matrix composites decreased as shown in figure 1a with increase of volume fraction of ZrO_2 nanoparticles. This is due to fact that the density (2.20g/cc) of ZrO_2 is higher than that (2.71 g/cc) of AA4015 alloy.

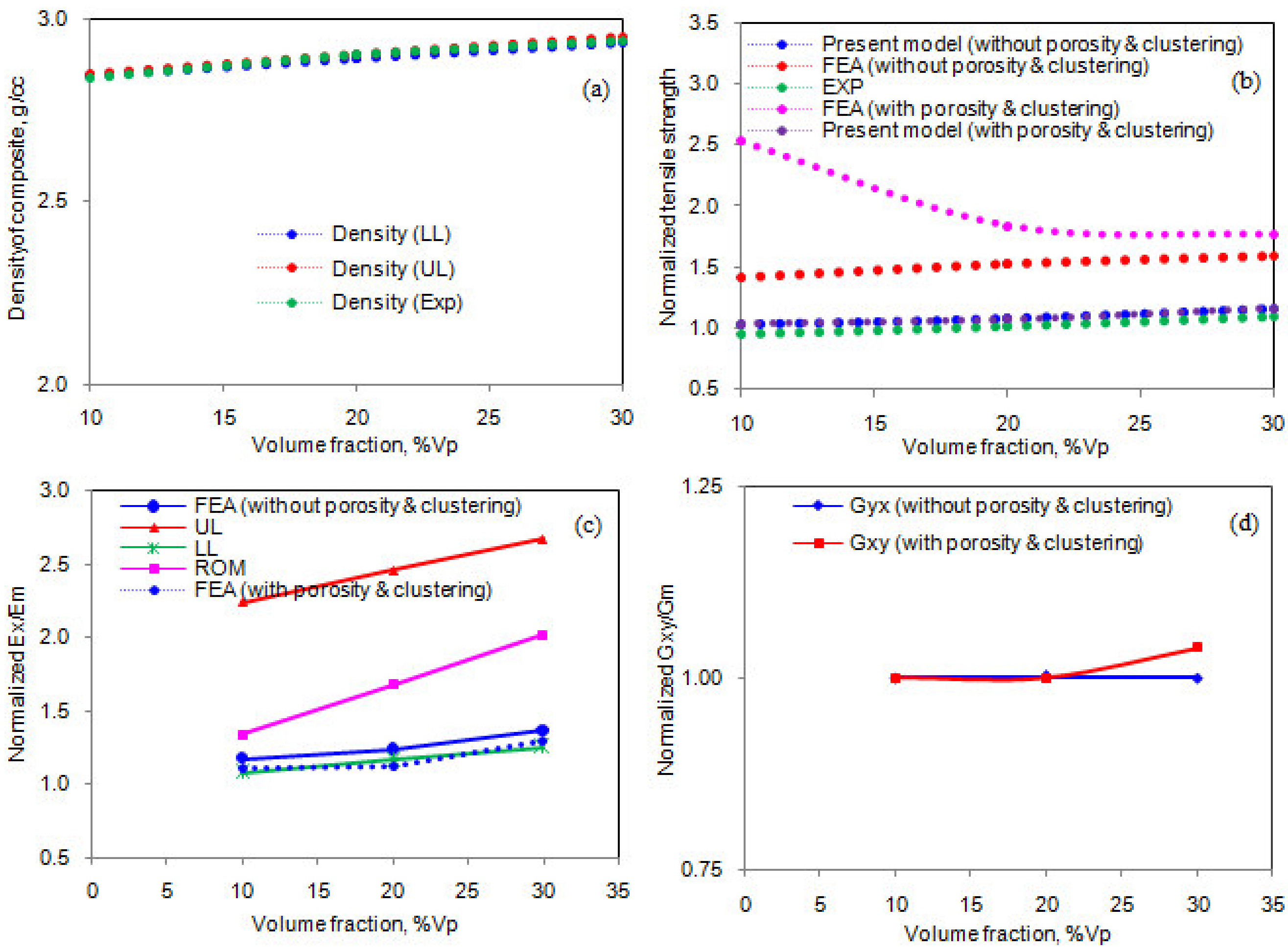

Figure 1: Effect of volume fraction on (a) density (b) normalized tensile stress, (c) normalized tensile elastic modulus and (d) normalized shear modulus of AA4015/ZrO_2 composites.

Addition of ZrO_2 nanoparticles to AA4015 alloy matrix did not make any improvement in the tensile strength (figure 1b), stiffness (figure 1c) and shear modulus (figure 1d) without porosity and clustering. The volume fraction of clusters and porosity voids increase with increase in volume fraction ZrO_2 nanoparticles in AA4015 alloy matrix as shown in figure 2. The tensile strength decreased owing to porosity and clustering in AA4015/ZrO_2 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.

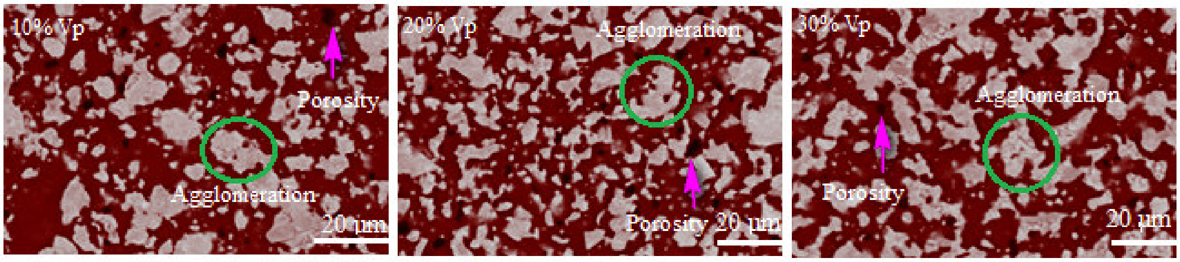

Figure 2: Porosity and clustering in AA4015/ZrO_2 metal matrix composites cast by high pressure die casting technique.

Without porosity and clustering in the composites, the stress intensity remains constant with increase in the volume fraction of ZrO_2 in AA2024 alloy matrix (figure 3a). With porosity and clustering in the composites, the stress intensities were high in the composites. But, for vol.20% of ZrO_2, the stress intensity is lower than that of other two volume fractions (figure 2b).

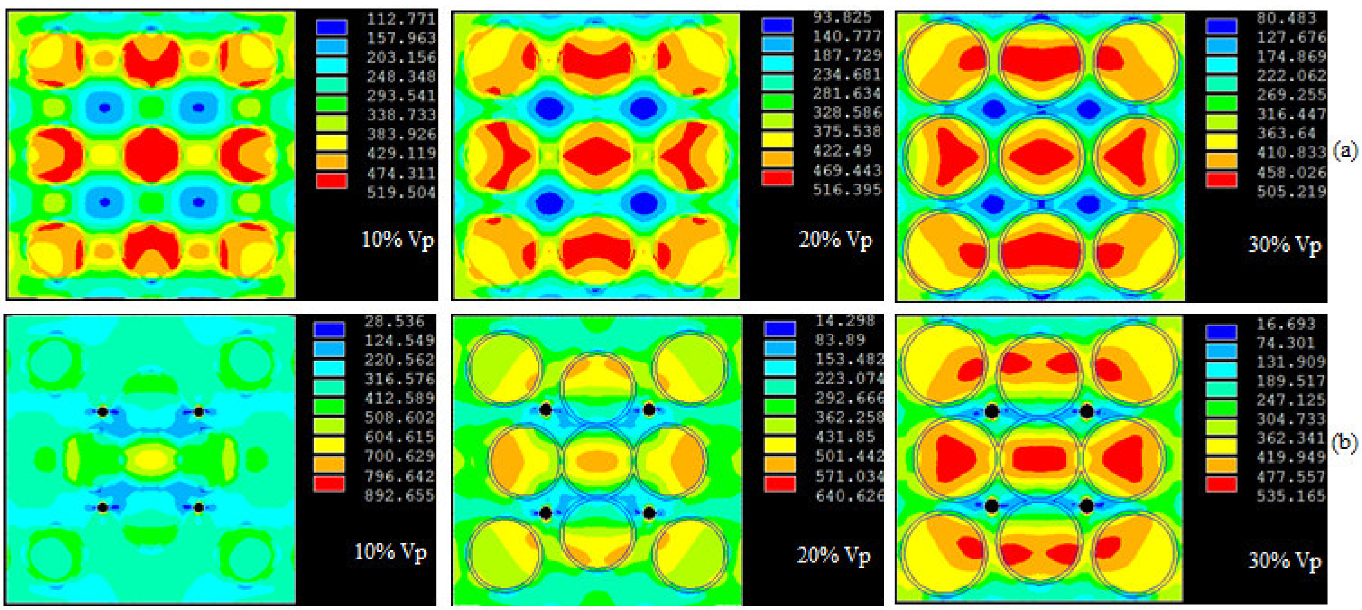

Figure 3: Images of stress intensities obtained from FEA: (a) without clustering and porosity and (b) with clustering and porosity.

4. CONCLUSION

In AA4015/ZrO_2 metal matrix composites, the increase in volume fraction of ZrO_2 nanoparticles did not make any appreciable enhancement of stiffness and tensile strength. The clustering and porosity decreased with the increase of volume fraction of SiO_2 in the AA4015 alloy matrix.

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