Unit Cell Models for Clustering of Particles embedded in MgO Particle/AA8090 Alloy Metal Matrix Composites

1Essa Zitoun and A. Chennakesava Reddy2

1Research Scholar, Department of Mechanical Engineering, College of Engineering, Osmania University, Hyderabad, India.
2Associate Professor, Department of Mechanical Engineering, Vasavi College of Engineering, Hyderabad, India

dr_acreddy@yahoo.com

Abstract: In the present work, MgO/AA8090 alloy metal matrix composites were fabricated at 10%, 20% and 30% volume fractions of MgO. These composites were also analyzed with finite element analysis software with and without clustering of MgO particles. The number of MgO particles per cluster increases with increase in volume fraction of MgO particles. In the clustering regions, the stress induced was found to be high. The tensile strength and elastic modulus decrease with clustering of MgO particles in AA8090 alloy matrix; however, the shear modulus has been unchanged.

Keywords: AA8090, magnesium oxide, spherical nanoparticle, unit-cell, finite element analysis, clustering.

1. INTRODUCTION

Nano-particle reinforced aluminum matrix composites are attractive engineering materials for many automotive and aerospace applications because they exhibit numerous desirable mechanical and thermal properties, such as high specific strength, hardness, stiffness, and resistance to creep and thermal degradation [1]. Since these conventional fabrication techniques involve adding exogenous reinforcing particles to the metal alloy, they suffer from several drawbacks including contamination, interfacial reactions between the particles and the alloy matrix, and clustering of the particles due to their poor wettability by the matrix alloy [2, 3].

Aim of this paper is to predict the influence of clustering of magnesium oxide particles in AA8090 alloy matrix on micromechanical behavior. The shape of magnesium oxide (MgO) nanoparticle considered in this work is spherical and it has isotropic behavior. A two-dimensional unit-cell model with periodic boundary conditions was developed using finite element method (FEM) to analyze the stress distribution in the clustering and non-clustering regions.

![MgO particles and crystal structure.](image)

Figure 1: MgO particles and crystal structure.

2. MATERIALS METHODS

The matrix material was AA8090 alloy. The reinforcement material was MgO nanoparticles (figure 1) of average size 100nm. MgO/AA8090 alloy 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 2) 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 MgO/AA8090 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 [4-17]. The finite element analysis was carried out on a unit cell without clustering of MgO particles is shown in figure 3a and that with clustering of MgO particles is shown in figure 3b.
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 [18, 19] is stated below:

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

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 posssion’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
The lower-bound equation is given by
\[
\frac{E_c}{E_m} = \left( \frac{1-v_p^{2/3}}{1-v_p^{2/3}+v_e} \right) + \frac{1+(\delta-1)v_p^{2/3}}{1+(\delta-1)(v_p^{2/3}-v_p)}
\] (2)

The lower-bound equation is given by
\[
\frac{E_c}{E_m} = 1 + \frac{v_p-v_p}{\delta/(\delta-1)-(v_p+v_p)^{1/3}}
\] (3)
where, \( \delta = E_p/E_m \).

The transverse modulus is given by
\[
E_t = \frac{E_m E_p}{E_m + E_p(1-v_p^{2/3}/v_p^{2/3}) + E_m(1-v_p^{2/3} - v_p^{2/3})}
\] (4)

3. RESULTS AND DISCUSSION

Figure 4a shows the normalized tensile strengths of the composites as a function of volume fractions of MgO particles. Adding the reinforcement to the matrix alloy increased tensile strength without clustering MgO particles. However, due to the effect of the reinforcement clusters the tensile strength decreased with increase of MgO content in AA8090 alloy matrix. The tensile stresses obtained from the finite element analysis (FEA) are higher than those obtained from the mathematical expression mentioned in Eq.(1) and the experimental procedure as shown in figure 4a.

Figure 4: Effect of volume fraction on (a) normalized strength, (b) normalized tensile elastic modulus and (c) normalized shear modulus of MgO/AA8090 composites.

Figure 5: Microstructure showing distribution of 10%, 20% and 30% MgO nanoparticles in AA8090 alloy matrix.

The MgO particles distributions in various composites are shown in figure 5. For the composite with a volume fraction of 10 vol.%, the MgO particles were randomly distributed with less number of clusters (figure 5a). For the composites with higher reinforcement contents (≥ 20 vol.%), although the distributions of the MgO particles were uniformly distributed, number of clusters are high. The number of MgO particles per a cluster in 30% MgO/AA8090 alloy composites is higher than that in 20% MgO/AA8090 alloy composites. The cluster density (i.e., the number of MgO particles per cluster) increases with increase in volume fraction of MgO particles (figure 5c). The normalized elastic modulus increases with increase of volume fraction of non-clustered MgO particles in AA8090 alloy matrix; while it decreases with increase of volume fraction of clustered MgO particles in AA8090 alloy matrix (figure 4b). The normalized shear modulus is constant with increase of volume fraction of MgO with or without clustering of particles (figure 4c).

In all the models (figure 6), MgO particles-AA8090 alloy interface edges experience higher stresses. This is attributed to the fact of the stress concentration in the vicinity of the reinforcement. It indicates clearly that the tensile stress increases with
increase of volume fraction of MgO particles without clustering; whereas it decreases with volume fractions with clustering of MgO particles in AA8090 alloy matrix.

4. CONCLUSION

MgO/AA8090 alloy composites were analyzed following two different schemes: (i) uniform distribution of MgO particles without clustering and (ii) clustering of MgO particles. The stresses developed in the clustering regions are higher than those developed in other sides of the clustering regions. The tensile stress and elastic modulus decrease with the clustering of particles in MgO/AA8090 composites; but shear modulus remains unchanged.

REFERENCES


