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

**[1]Essa Zitoun and A. Chennakesava Reddy[2]**

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

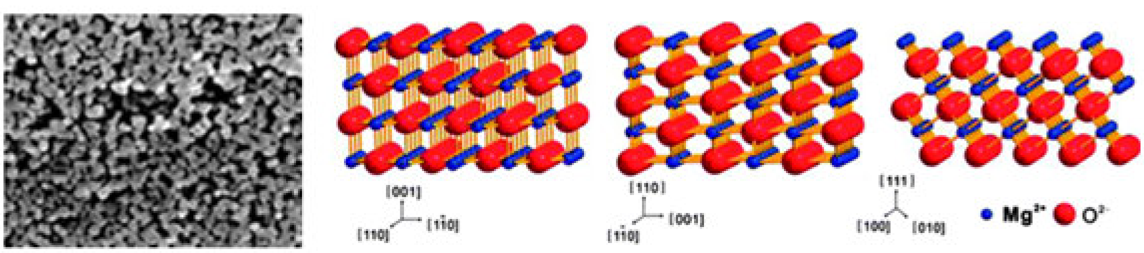

**Figure 1:** MgO particles and crystal structure.

## 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.

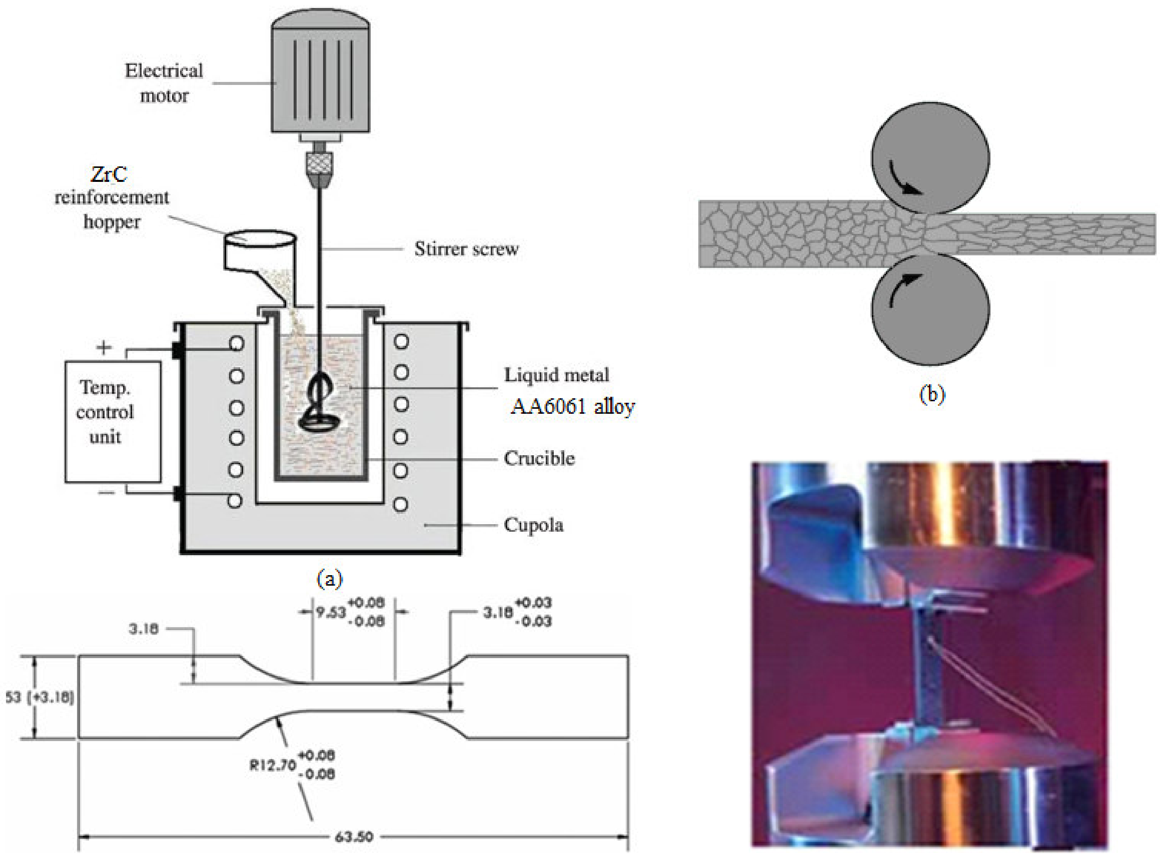


**Figure 2:** Stir casting process; cold rolling (b); shape and dimensions of tensile specimen (c); and tensile testing on UTM (d).

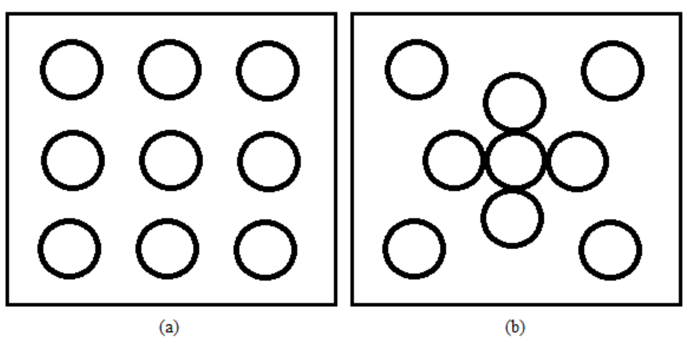


**Figure 3:** The interphase in a nanoparticle-reinforced composite: (a) without clustering and (b) with clustering.

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:

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

$$k = E_m m_m / E_p m_p$$

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, $\delta = E_p / E_m$ .

The transverse modulus is given by

$$E_t = \frac{E_m E_p}{E_m + E_p(1-v_p^{2/3})/v_p^{2/3}} + E_m\left(1 - v_p^{2/3} - v_v^{2/3}\right) \quad (4)$$

## 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.

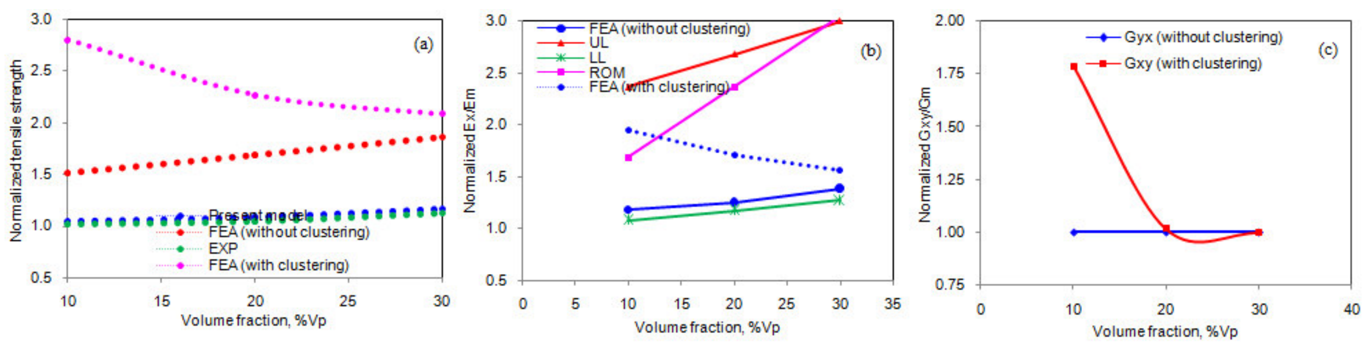


**Figure 4:** Effect of volume fraction on (a) normalized strength, (b) normalized tensile elastic modulus and (c) normalized shear modulus of MgO/AA8090 composites.

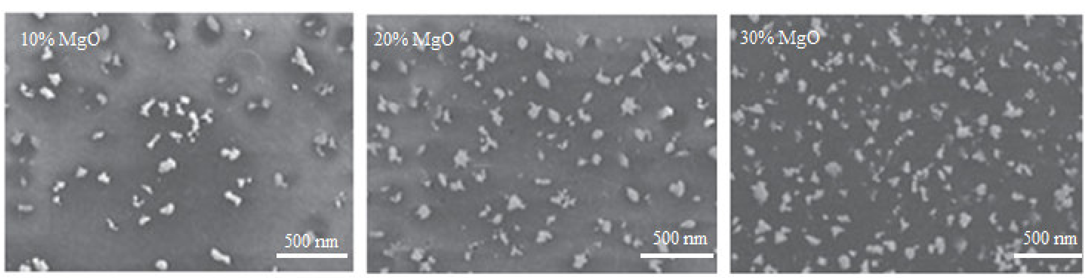


**Figure 5:** Microstructure showing distribution of 10%, 20% and 30% MgO nanoparticles in AA8090 alloy matrix.

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.

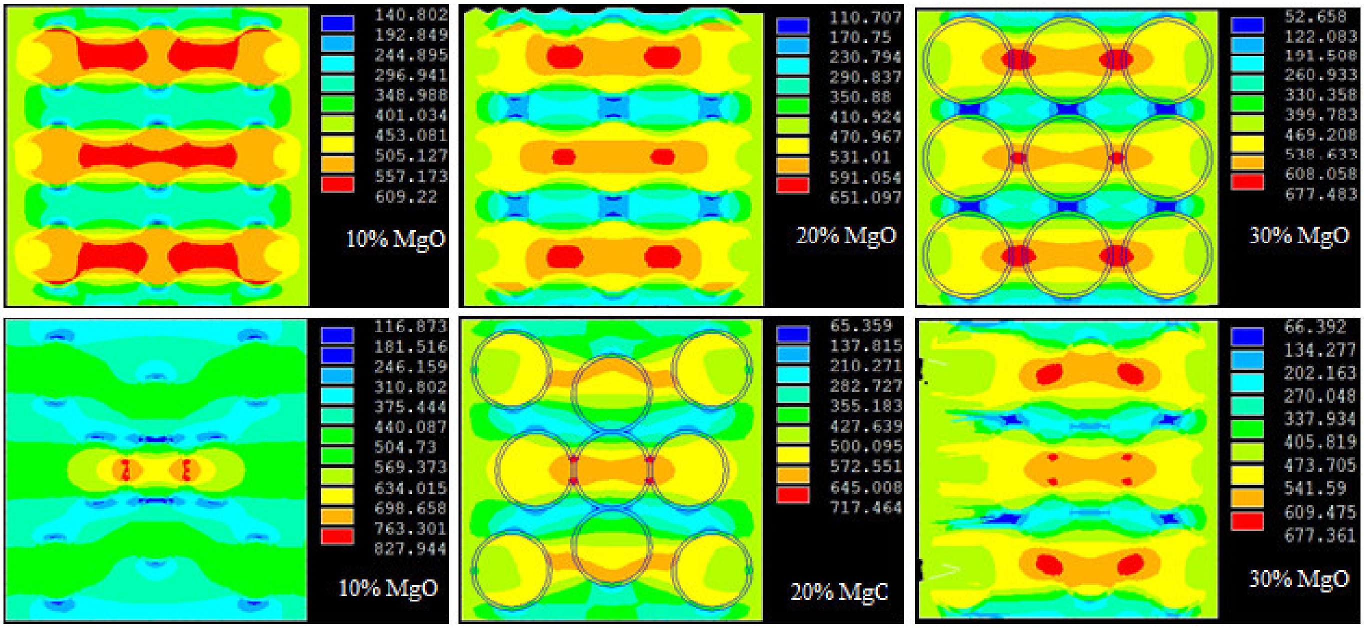


**Figure 6:** Images of tensile stresses obtained from FEA: (a) without clustering and (b) with clustering.

## 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

1. P.M. Ajayan, L.S. Schadler And P.V. Braun, Nanocomposite Science and Technology. Wiley-VCH,Weinheim, 2003.
2. P.K. Rohatgi, F.M. Yarandi, and Y. Liu: Cast Reinforced Metal Composites, ASM International Conference Proceedings, S.G. Fishman and A.K. Dhingra, eds., ASM International, Metals Park, OH, 1988, pp. 249-55.
3. A. Chennakesava Reddy, Studies on fracture behavior of brittle matrix and alumina trihydrate particulate composites, Indian Journal of Engineering & Materials Sciences, 9, 2002, pp.365-368, 2002.
4. A. Chennakesava Reddy, Assessment of Debonding and Particulate Fracture Occurrences in Circular Silicon Nitride Particulate/AA5050 Alloy Metal Matrix Composites , National Conference on Materials and Manufacturing Processes, Hyderabad, India, 27-28 February 1998, pp. 104-109.
5. A. Chennakesava Reddy, Local Stress Differential for Particulate Fracture in AA2024/Titanium Carbide Nanoparticulate Metal Matrix Composites, National Conference on Materials and Manufacturing Processes, Hyderabad, India, 27-28 February 1998, pp. 127-131.
6. A. Chennakesava Reddy, Micromechanical Modelling of Interfacial Debonding in AA1100/Graphite Nanoparticulate Reinforced Metal Matrix Composites, 2nd International Conference on Composite Materials and Characterization, Nagpur, India, 9-10 April 1999, pp. 249-253.
7. A. Chennakesava Reddy, Cohesive Zone Finite Element Analysis to Envisage Interface Debonding in AA7020/Titanium Oxide Nanoparticulate Metal Matrix Composites, 2nd International Conference on Composite Materials and Characterization, Nagpur, India, 9-10 April 1999, pp. 204-209.
8. A. Chennakesava Reddy, Micromechanical and fracture behaviors of Ellipsoidal Graphite Reinforced AA2024 Alloy Matrix Composites, 2nd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 10-11 March 2000, pp. 96-103.
9. A. Chennakesava Reddy, Constitutive Behavior of AA5050/MgO Metal Matrix Composites with Interface Debonding: the Finite Element Method for Uniaxial Tension, 2nd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 10-11 March 2000, pp. 121-127.
10. B. Kotiveera Chari, A. Chennakesava Reddy, Finite Element Modeling and Experimental Validation of Interphase Debonding and Particle Fracture in Titanium Carbide/AA1100 Alloy, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 156-161.

11. B. Kotiveera Chari, A. Chennakesava Reddy, Interphase Cracking in Titanium Nitride/2024 Alloy Particle-Reinforced Metal-Matrix Composites, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 162-167.
12. V. V. Satyanarayana, A. Chennakesava Reddy, Computation of Interphase Separation and Particle Fracture of Titanium Oxide/3003 Particle Reinforced Composites: The Role of Thermo-Mechanical Loading, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 168-173.
13. V. V. Satyanarayana, A. Chennakesava Reddy, Micromechanical Modeling of Reinforcement Fracture in Zirconium Carbide/4015 Particle-Reinforced Metal-Matrix Composites , 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 174-178.
14. A. Chennakesava Reddy, Two dimensional (2D) RVE-Based Modeling of Interphase Separation and Particle Fracture in Graphite/5050 Particle Reinforced Composites, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 179-183.
15. A. Chennakesava Reddy, Simulation of MgO/AA6061 Particulate-Reinforced Composites Taking Account of CTE Mismatch Effects and Interphase Separation, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 184-187.
16. Ch. Rajanna, A. Chennakesava Reddy, Effects of Interphase and Interface Characteristics on the Tensile Behavior of Boron Nitride/7020 Particle Reinforced Composites Subjected to Thermo-Mechanical Loading, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 188-191.
17. Ch. Rajanna, A. Chennakesava Reddy, Modeling of Interphases in SiO2/AA8090 alloy Particle -Reinforced Composites under Thermo-Mechanical Loading Using Finite Element Method, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 22-25 February 2002, pp. 192-195.
18. A. Chennakesava Reddy, Effect of CTE and Stiffness Mismatches on Interphase and Particle Fractures of Zirconium Carbide /AA5050 Alloy Particle-Reinforced Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 257-262.
19. A. Chennakesava Reddy, Behavioral Characteristics of Graphite /AA6061 Alloy Particle-Reinforced Metal Matrix Composites, 3rd International Conference on Composite Materials and Characterization, Chennai, India, 11-12 May 2001, pp. 263-269.