Modeling of Interphases in SiO_2/AA8090 alloy Particle -Reinforced Composites under Thermo-Mechanical Loading Using Finite Element Method

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Abstract: In the present work, the SiO_2/AA8090 alloy metal matrix composites were subjected to mechanical and thermal loads. The results obtained from the finite element analysis of SiO_2/AA8090 alloy composites reveal the interphase separation from the particle and the matrix.

Keywords: Silicon oxide, AA8090 alloy, RVE model, finite element analysis, interphase separation.

1. INTRODUCTION

Of particular importance on the overall mechanical properties of a composite is the interphase which is a three dimensional region immediately surrounding the inclusion. The bonding between the matrix and the inclusion occurs across this region and the stiffness properties of this region differ from that of the matrix and the inclusion. Earlier modeling the mechanical properties of composite materials ignored the effects of an interphase and are considered as two phase composites. The shear modulus of a two phase composite consisting of isotropic spherical inclusions surrounded by an isotropic matrix has been derived [1, 2]. Idealized models using the unit cell or representative volume element concept are usually employed in micromechanics analysis. Many finite element models based on the two-dimensional elasticity theory have been developed to study the micromechanical properties of fiber-reinforced composites under transverse loading and with the presence of an interphase, for example, in [3-6], and most recently in [7-20].

In this paper, detailed two-dimensional models for the interphases in particle-reinforced composite materials have been developed based on the elasticity theory to study their micromechanical behaviors under thermo-mechanical loading. This two-dimensional model of the interphases can provide more accurate interface stresses and therefore a more accurate account on the micromechanical behaviors of fiber-reinforced composites. An interphase region of finite size is considered surround each inclusion as shown in figure 1. The properties of the interphase are assumed to vary as a function of the radial distance from the centre of the inclusion. These functions are assumed to be smooth, bounded and continuous. The radius of the inclusion is assumed to have length a and the thickness of the interphase is $(b-a)$. The inclusion and interphase together are modeled as forming a new effective spherical particle of radius b.

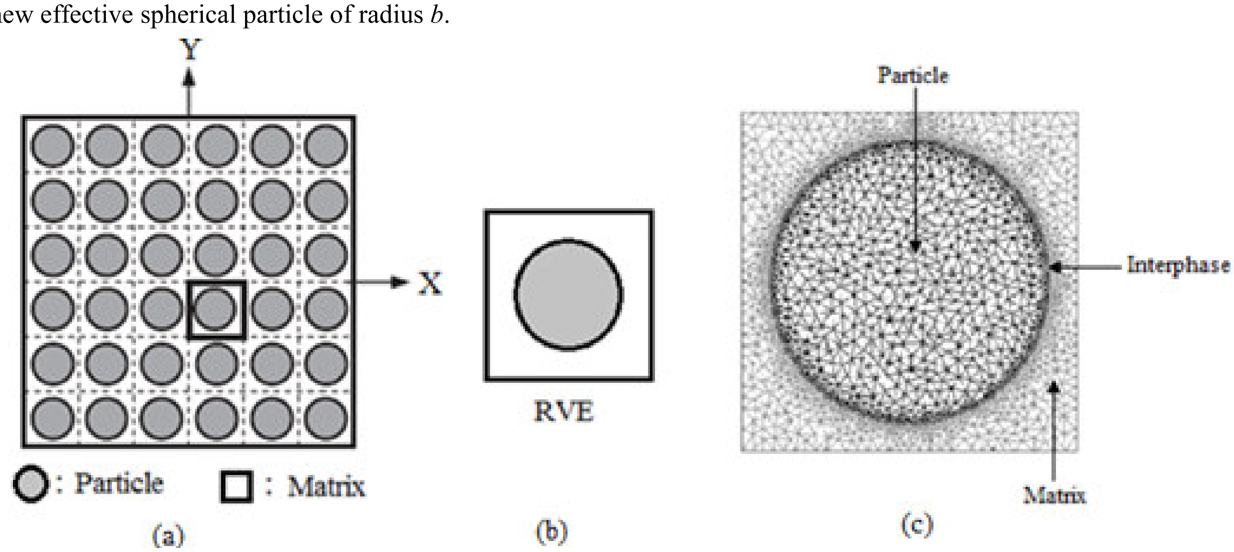

Figure 1: Square array of particles (a); Representative Volume Element (b); and Discretization of RVE (c).

2. MATERIALS METHODS

The matrix material was AA8090 alloy. The reinforcement material was silicon oxide (SiO_2) nanoparticles of average size 100nm. The mechanical properties of materials used in the present work are given in table 1. In the current work, a cubical representative volume element (RVE) was implemented to analyze the tensile behavior SiO_2/AA8090 alloy composites at two (10% and 30%) volume fractions of SiO_2 and at different temperatures. 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.

Table 1: Mechanical properties of AA8090 matrix and SiO_2 nanoparticles

Property	AA8090	SiO_2
Density, g/cc	2.54	2.20
Elastic modulus, GPa	77.0	73.1
Coefficient of thermal expansion, 10^{-6} 1/°C	21.4	5.5
Specific heat capacity, J/kg/°C	930	703
Thermal conductivity, W/m/°C	95.3	1.4
Poisson's ratio	0.33	0.17

3. RESULTS AND DISCUSSION

Figure 2a shows the normalized elastic modulus of SiO_2/AA8090 composites at different temperatures. The elastic modulus is normalized with the elastic modulus of AA8090 alloy. The normalized elastic modulus is decreased with increase of temperature. Under thermo-mechanical loading, the stiffness of 30% SiO_2/AA8090 alloy composites is higher than that of 10% SiO_2/AA8090 alloy composites. The normalized stiffness along the normal direction is lower than that along the load direction owing to tensile loading except at 100°C in 30% SiO_2/AA8090 alloy composites. The normalized shear modulus is constant with increase of temperature as shown in figure 2b. The increase of major Poisson's ratio with temperature from 100°C to 300°C indicates the elongation along the load is greater than that along the transverse direction of loading of RVE (figure 2c). The fall of Poisson's ratio at 100°C is not clear.

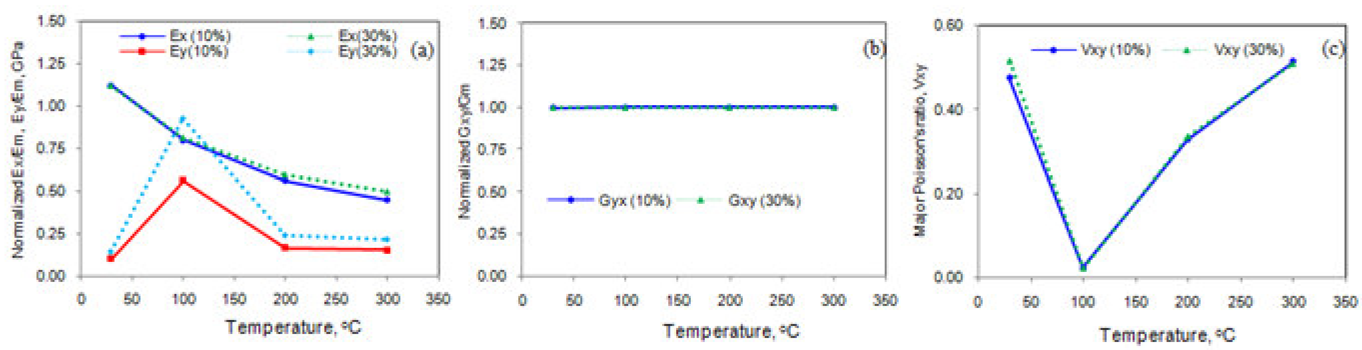

Figure 2: Effect of temperature on micromechanical properties of SiO_2/AA8090 composites.

If the particle deforms in an elastic manner (according to Hooke's law) then,

$$\tau = \frac{n}{2}\sigma_p \quad (1)$$

where σ_p is the particle stress. For the interfacial debonding/yielding to occur, the interfacial shear stress reaches its shear strength:

$$\tau = \tau_{max} \quad (2)$$

For particle/matrix interfacial debonding can occur if the following condition is satisfied:

$$\tau_{max} < \frac{n\sigma_p}{2} \quad (3)$$

It is observed from figure 3a that the interphase separation occurs between SiO_2 nanoparticle and AA8090 alloy matrix as the condition in Eq.(3) is satisfied. If particle fracture occurs when the stress in the particle reaches its ultimate tensile strength, $\sigma_{p,uts}$, then setting the boundary condition at

$$\sigma_p = \sigma_{p,\,uts} \quad (4)$$

The relationship between the strength of the particle and the interfacial shear stress is such that if

$$\sigma_{P,uts} < \frac{2\tau}{n} \quad (5)$$

Then the particle will fracture. From the figure 3b, it is observed that the SiO_2 nanoparticle was not fractured as the condition in Eq. (5) is not satisfied. The von Mises stress as a function of temperature is illustrated in figure 4. The von Mises stresses induced at the interface are higher than that induced in the nanoparticle. Hence, the interphase separation has occurred between the particle and the matrix.

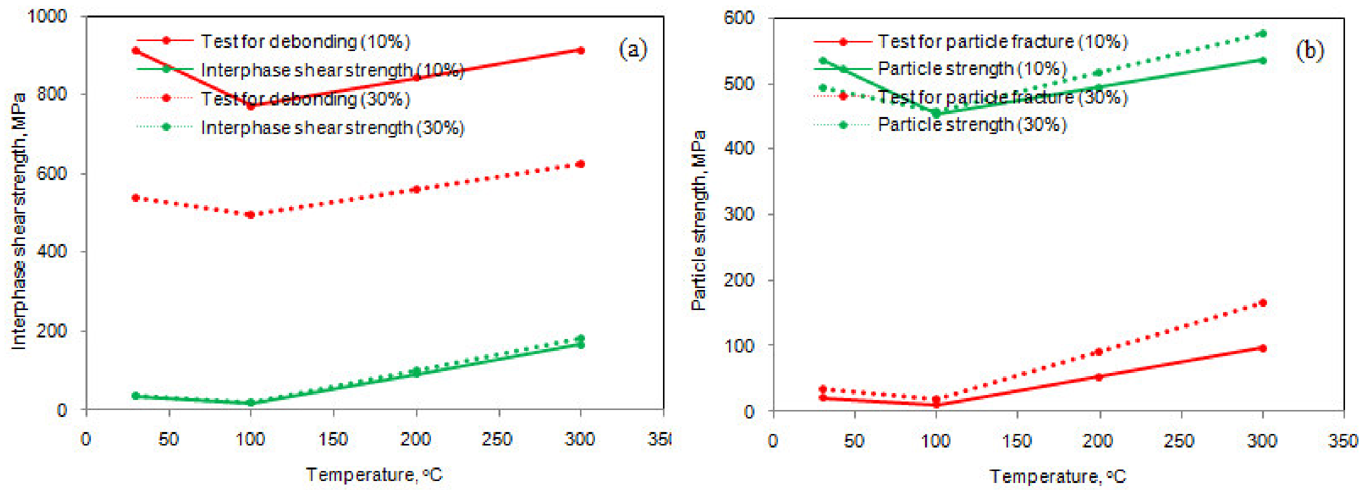

Figure 3: Criterion for interfacial debonding (a) and for particle fracture (b).

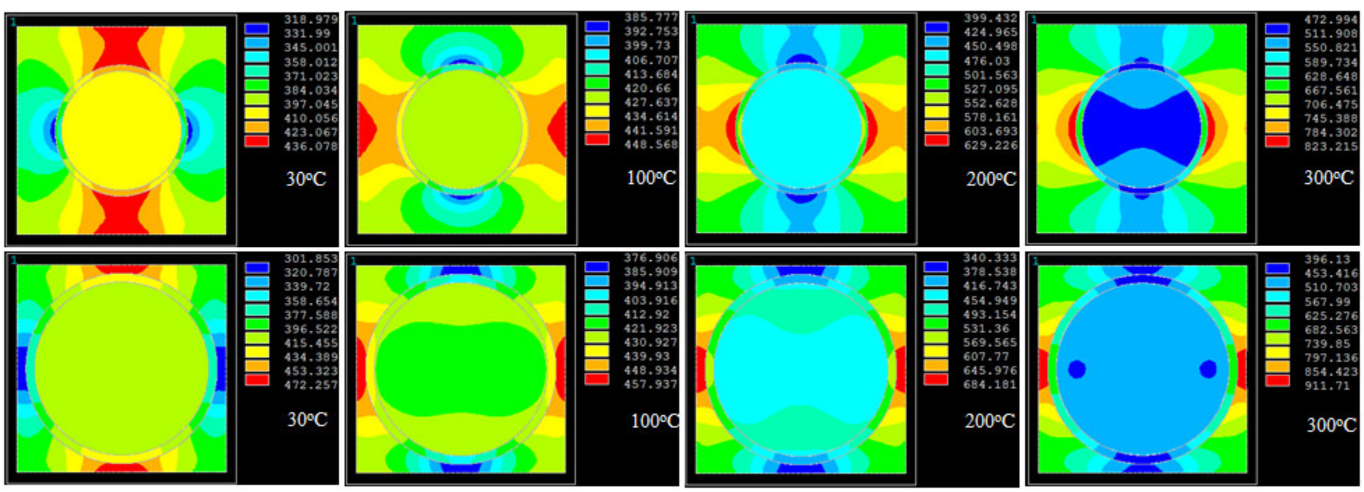

Figure 4: Images of von Mises stresses obtained from FEA: (a) 10% SiO_2/AA8090 alloy and (b) 30% SiO_2/AA8090 alloy composites.

4. CONCLUSION

The shear stress is high at the interface resulting to interphase separation from the particle and the matrix. The interphase separation has occurred between the particle and the matrix. The particle fracture has not occurred in SiO_2/AA8090 composites.

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