

Nano-Mechanical Modeling of Thermoelastic Behavior of AA6061/Silicon Oxide Nanoparticulate Metal Matrix Composites

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Abstract: *The aim of the present work was to estimate non-linear thermoelastic behavior of three-phase AA6061/silicon oxide nanoparticle metal matrix composites. The RVE models were used to analyze thermo-elastic behavior using finite element analysis. The AA6061/silicon oxide metal matrix nanocomposites have lost the elastic modulus at high temperatures.*

Keywords: AA6061, silicon oxide, RVE model, nano-mechanical modeling, thermoelastic, finite element analysis.

1. Introduction

Even though MMCs possess various advantages, they still have limitations of thermal fatigue, thermo-chemical compatibility, and possess lower transverse creep resistance [1]. Silicon carbide [2-8] and alumina [9-13] are being used as reinforcement particulates in most of the metal matrix composites. Also found in the literature about the usage of silicon nitride, carbon and alumina trihydrate to manufacture metal matrix composites [14-16]. Fused silica is an excellent thermal insulator and has essentially zero thermal expansion. It has good chemical resistance to molten metal but is limited by its very low strength. It is used for a number of refractory and glass applications as well as for missiles. 6061Al alloy is a precipitation hardening aluminum alloy, containing magnesium and silicon as its major alloying elements. 6061-T6 aluminum is commonly used in aircraft construction. Although primarily used in private rather than commercial aircraft, its strength-to-weight ratio is very high, making it ideal for large parts that need to be very light, such as the plane's fuselage and wings. Temperature fluctuations may cause dimensional changes, because the elastic modulus is not a constant, but a function of temperature [17]. Modeling and prediction of the overall elastic-plastic response and local damage mechanisms in heterogeneous materials in general and particle-reinforced composites in particular, is a very complex problem. Finite element method (FEM) is applied to estimate the local response of the material using unit cell reinforced by a single particle subjected to periodic and symmetric boundary conditions [18, 19].

The significance of the present work was to evaluate the nonlinear thermoelastic behavior of AA6061/SiO₂ nanoparticulate metal matrix composites. The RVE models were used to analyze the AA6061/SiO₂ nanoparticulate metal matrix composites with interphase between them using finite element analysis.

2. Materials and Methods

The matrix material was AA6061 aluminum alloy. The reinforcement material was SiO₂ nanoparticles of average size 100nm. The mechanical properties of materials used in

the present work are given in table 1. The volume fractions of SiO₂ nanoparticles were 10% and 20%.

Table 1: Mechanical properties of AA6061 matrix and SiO₂ nanoparticles

Property	AA6061	SiO ₂
Density, g/cc	2.69	2.20
Elastic modulus, GPa	68.9	73.1
Ultimate tensile strength, MPa	310	110
Poisson's ratio	0.33	0.17
CTE, $\mu\text{m/m}^\circ\text{C}$	23.6	0.4
Thermal Conductivity, W/m-K	167.0	1.4
Specific heat, J/kg-K	896	670

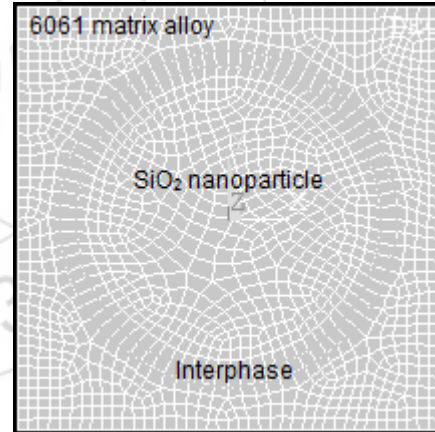


Figure 1: A square RVE containing a nanoparticle.

In this paper, a square RVE (figure 1) was executed to investigate the thermo-elastic tensile behavior AA6061/SiO₂ nanocomposites [19]. The large strain PLANE183 element was used in the matrix and the interphase regions in all the models. In order to model the interphase between nanoparticle and matrix, a CONTACT172 element was used [20]. The maximum contact friction stress of $\sigma_y/\sqrt{3}$ (where, σ_y is the yield stress of the material being deformed) was applied at the contact surface. The basic Coulomb friction model was considered between two contacting surfaces. Both uniform thermal and hydrostatic pressure loads were applied simultaneously on the RVE model.

3. Results and Discussion

The finite element analysis (FEA) was carried out at high temperature environment. The hydrostatic pressure load and uniform temperature were applied on the RVE models to examine thermo-elastic tensile behavior of AA6061/SiO₂ nanoparticulate composites. The volume fractions of SiO₂ nanoparticles in the AA6061 matrix were 10% and 20%.

3.1 Thermo-elastic behavior

The influence of temperature on the elastic and thermo-elastic strains is shown in figure 2. The elastic and thermo-elastic strains increased with increase of temperature. For the composites having 20% SiO₂, the gradient of strain increase was higher as compared to that in the composites containing 10% SiO₂. Figure 3 exhibits the state of elastic and thermo-elastic strains developed in the AA6061/SiO₂ composites. In all the cases, SiO₂ nanoparticles had experienced the compressive strains in the direction normal to the tensile loading. SiO₂ nanoparticles were compressed because their CTE is lower than that of AA6061 matrix.

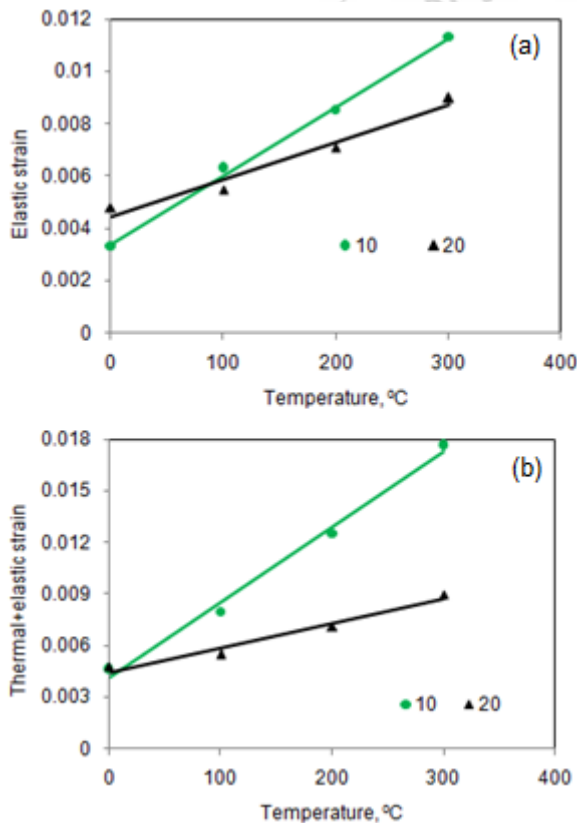


Figure 2: Influence of temperature on elastic and thermo-elastic strains.

The tensile strength decreased with increase of temperature from 0°C to 300°C for both the high volume fractions of 30% SiO₂ in AA6061 alloy matrix (figure 4). However, the tensile strength increased with the increase of temperature for the composites having low volume fraction of 10% SiO₂ from 0°C to 300°C. This might be due to the dominant role of AA6061 matrix extending the yield point and elongation. The raster images of tensile strength are shown in figure 5 for clear understanding the penalty of temperature on the tensile strength.

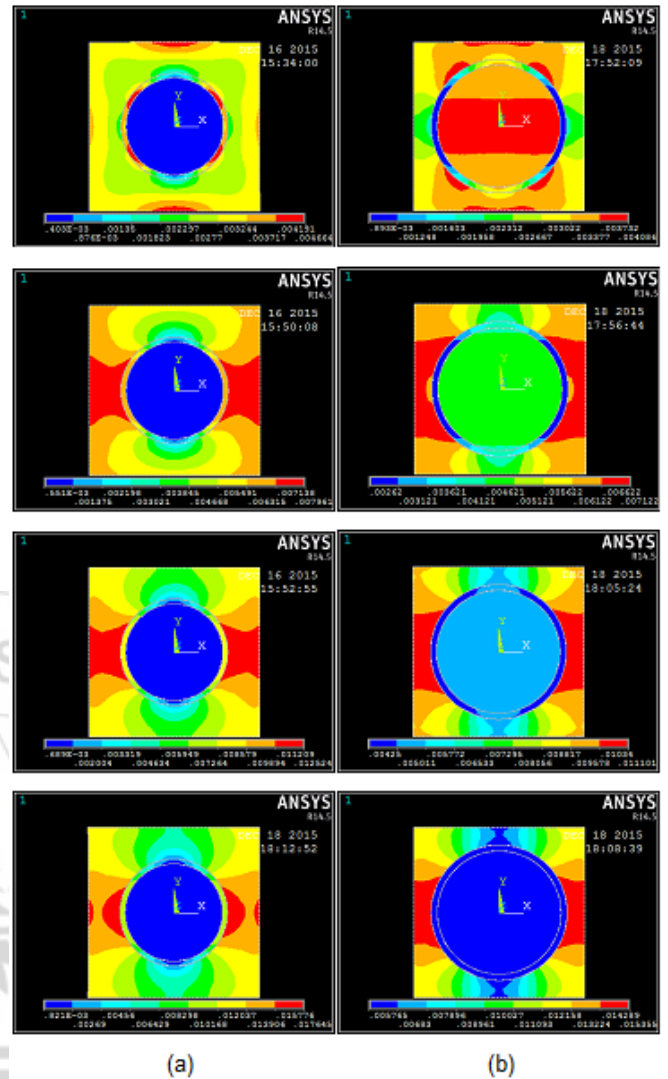


Figure 3: Thermo-elastic strains developed in composites with (a) 10% Vp and (b) SiO₂ nanoparticles.

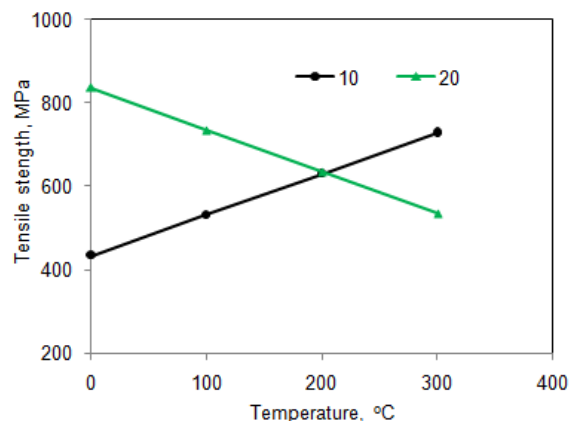


Figure 4: Effect of temperature and volume fraction of SiO₂ on tensile strength.

The effect of temperature and volume fraction of SiO₂ nanoparticles on elastic modulus is shown in figure 6. It was observed that the effective elastic modulus of the composite increased with higher particle volume fraction and decreased with the increase of temperature.

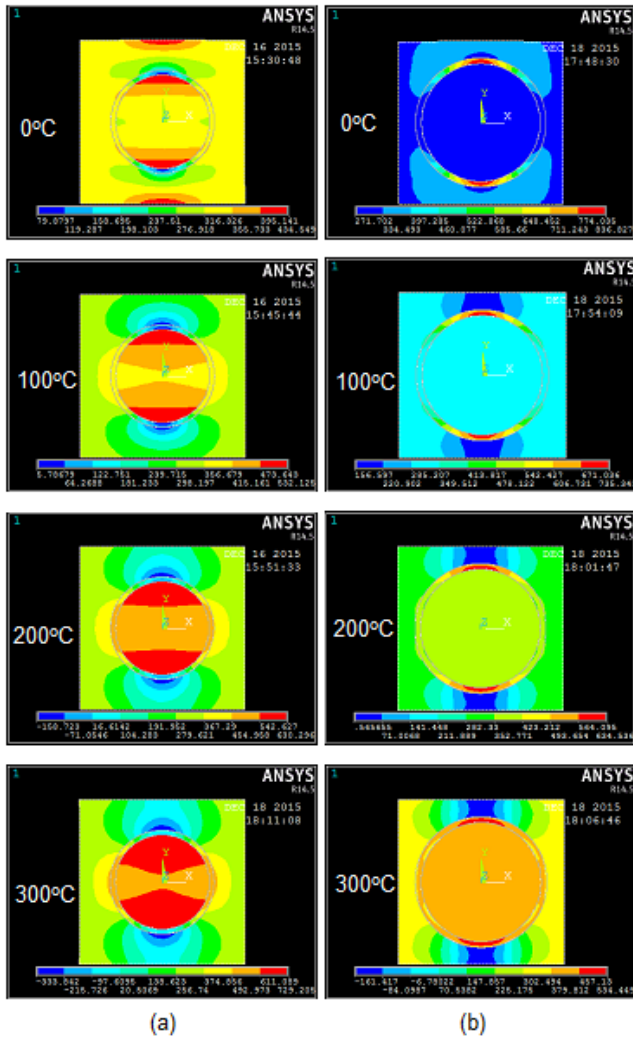


Figure 5: Tensile strength induced in composites with (a) 10% and (b) with 30% Vp nanoparticles.

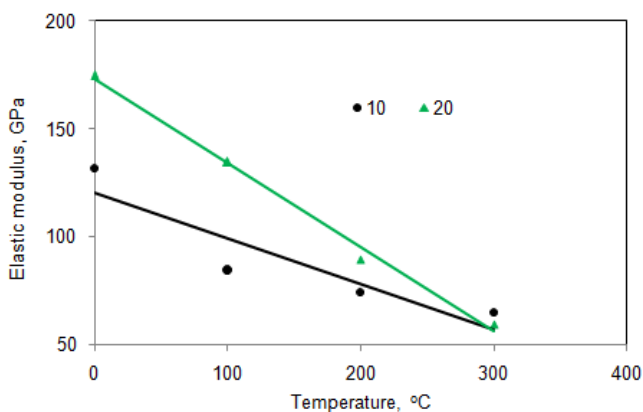


Figure 6: Effect of temperature and volume fraction of SiO₂ nanoparticles on the elastic modulus.

4.2 Fracture Behavior

The von Mises stress increased with the increase of temperature increased from 0°C to 300°C (figure 7) for the composites. Within the nanoparticle various contours were also observed due to CTE mismatch between SiO₂ nanoparticle and AA6061 matrix. It was also noticed that the maximum stress field in the vicinity of interphase (figure 8). This implies a potential early debonding. As the temperature increased ductile mode of failure was witnessed in the

composites. Some structural changes were also locally occurred in the SiO₂ nanoparticle.

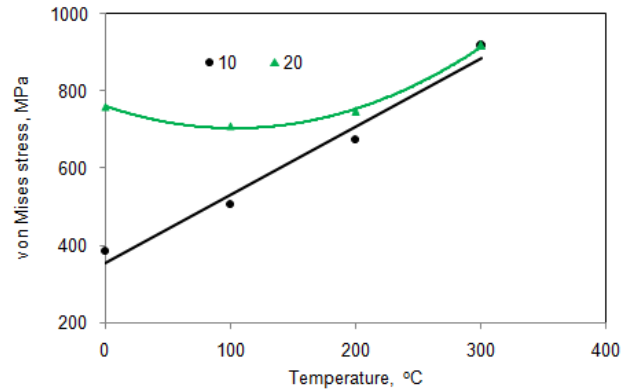


Figure 7: Effect of temperature and volume fraction of SiO₂ nanoparticles the von Mises stress.

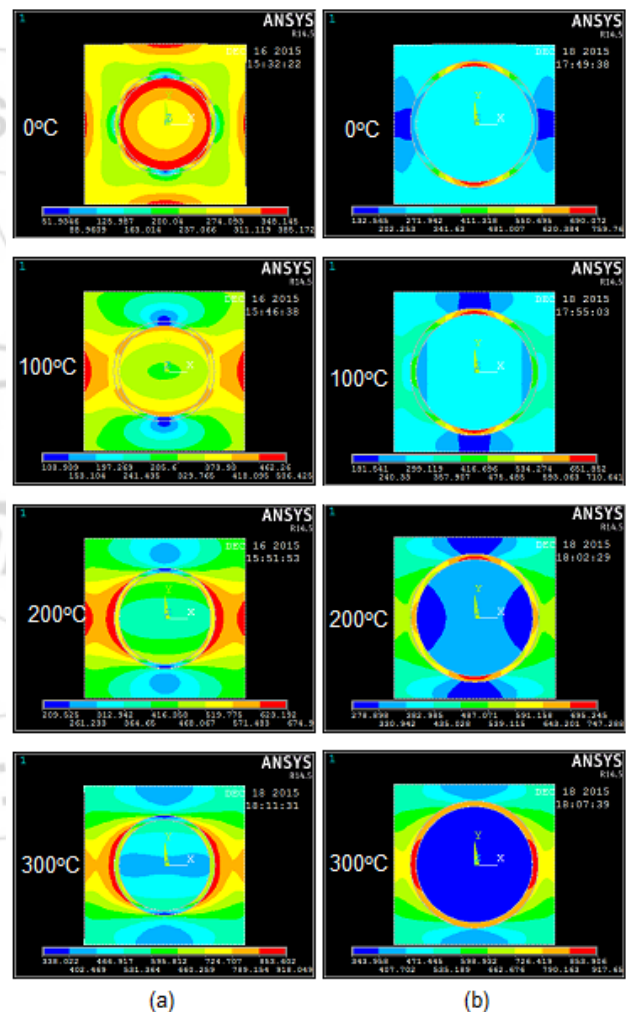


Figure 8: von Mises stress induced in composites with (a) 10% and (b) with 30% Vp nanoparticles.

4. Conclusions

The thermo-elastic strain increased with increase in the temperature of AA6061/SiO₂ metal matrix composites. As the temperature increased, the maximum stress has occurred in the interphase region between the matrix AA6061 and SiO₂. The elastic modulus of the composite decreased with high volume fraction of SiO₂ and decreased with the increase of temperature.

5. Acknowledgement

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