Thermo-compressive Loading on Micromechanical Behaviour of Si_3N_4/8090 Al Alloy Nanocomposites

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Abstract— **Aluminium 8090 alloy is chiefly used as advanced materials for aerospace technology and to minimize the weight of army weaponry and defense systems Silicon nitride (Si_3N_4) nanoparticles are characterized by resistance to oxidation at high temperatures, wear and corrosion resistance. The aim of the current work was to investigate the influence of combined thermo-compressive loading on the behaviour of Si_3N_4/8090 metal matrix composites. A numerical analysis was carried out using ANSYS code. The major conclusion of the current work was that the interphase between the nanoparticles ant matrix 8090 Al alloy was ruptured at 300^{0}C due to thermal mismatch between Si_3N_4 and 8090 Al alloy.**

Keywords- 8090 Al alloy; silicon nitride, compressive loading; numerical analysis.

I. Introduction

A composite material is a material system composed of mixture or combination of two or more nano, micro constituents with an interface separating them that differ in form and chemical composition and are essentially insoluble in each other [1-14]. The discrete constituent is called the reinforcement and the continuous phase is called the matrix. Metal matrix composites recently are drawing interests of the researchers because of the ability to alter their physical properties like density, thermal expansion [15-20], thermal diffusivity and mechanical properties like tensile and compressive behaviour, creep, tribological behaviour [21-28], etc. by varying the filler phase.

Aluminum 8090 alloy is a lithium-based wrought alloy. Addition of lithium to aluminum helps to reduce density and increase stiffness. Aluminum 8090 alloy is chiefly used as advanced materials for aerospace technology and to minimize the weight of army weaponry and defense systems. Silicon nitride (Si_3N_4) nanoparticles are spherical high surface area particles. Nanoscale Silicon nitride particles are typically 10 - 100 nanometers (nm) with specific surface area (SSA) in the 25 - 75 m^2/g range. Silicon nitride (Si_3N_4) nanoparticles are characterized by resistance to oxidation at high temperatures, wear and corrosion resistance. These particles are not soluble in water and are able to withstand both hot and cold shocks. This paper describes the micromechanical behaviour subjected to both temperature and tensile loading to investigate thermal stability of Si_3N_4/8090-aluminium alloy composites.

II. Materials and Methods

8090-aluminium (Al) alloy and silicon nitride were used, respectively, for matrix and reinforcement. ANSYS software was employed for the numerical analysis of RVE (representative volume element) models of Si_3N_4/8090Al alloy metal matrix nanocomposites. Nano-silicon nitride modulus: 28420 ~ 46060Mpa; bending strength: 147MPa; compressive strength: 490MPa (reaction sintering). The silicon nitride nanoparticles were assumed to be spherical in the present study. The volume fraction of Si_3N_4 nanoparticles was 20%. The plane strain boundary conditions were imposed on RVE models for the numerical analysis [29-36]. The reinforcement and the matrix were discretised with plane 183 element. The interphase was discretised with contact 172 element. The operating temperatures were 0^{0}C, 100ºC. 200ºC and 300ºC. The RVE models were numerically tested for the compressive yield strength of the 8090 Al alloy at different temperatures. The numerical results were validated with experimentally tested samples of the Si_3N_4/8090 Al alloy nanocomposites.

III. Results and Discussion

The average diameter of Si_3N_4 nanoparticle was 80 nm. The effect of temperature and structural loading on the linear dimension of RVE cell along the loading direction is shown in figure 1 and normal to the load direction is shown in figure 2. It is observed that the dimension along the loading direction increases with increasing temperature of the RVE cell. At zero degree of thermal loading the composite has experienced only compressive deformation. The combined effect of thermal expansion and structural contraction due compressive loading has been observed along the loading direction. Normal to loading direction the thermal expansion dominates the structural elongation. Hence, the deformation of the composite perpendicular to the loading direction was comparatively high.

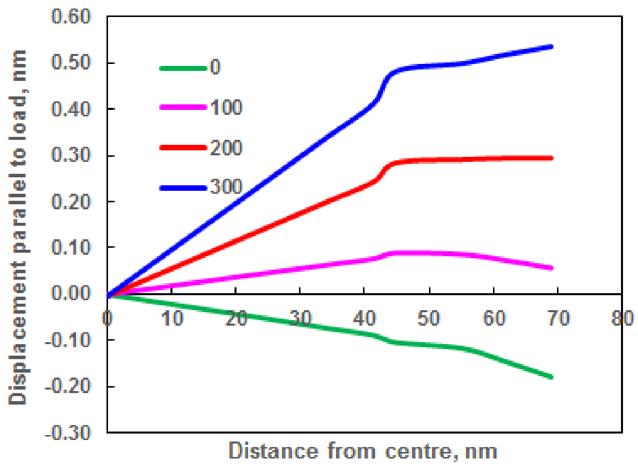

Figure 1. Effect of temperature on deformation of Si_3N_4/8090 Al alloy nanocomposites along load direction.

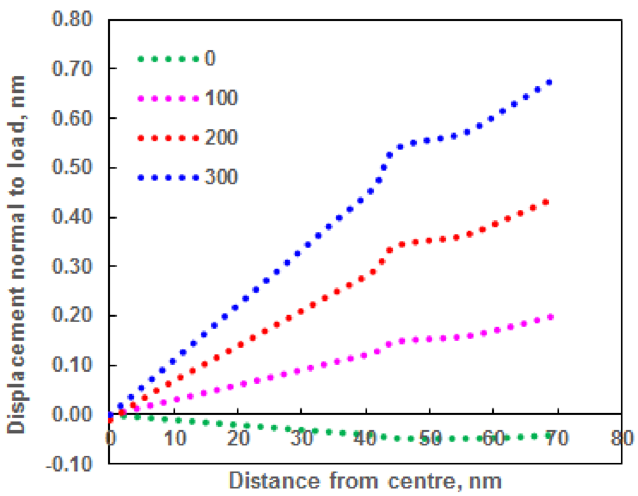

Figure 2. Effect of temperature on deformation of Si_3N_4/8090 Al alloy nanocomposites normal to load direction.

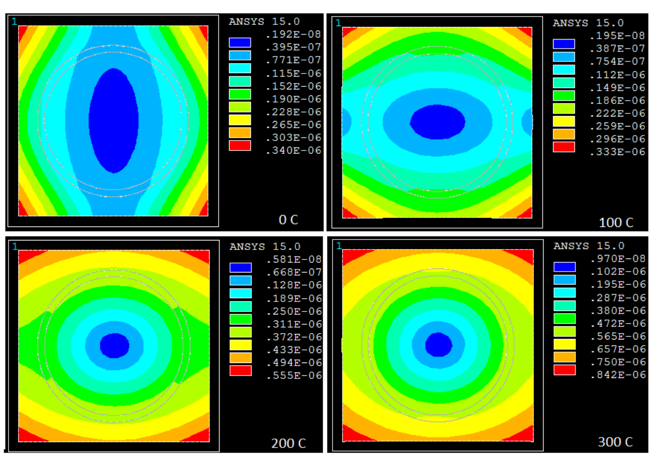

Figure 3. Effect of temperature on resultant deformation of Si_3N_4/8090 Al alloy nanocomposites.

The resultant deformation of Si_3N_4/8090 composites was elongated along loading direction at 100^{0}C, 200^{0}C and 300^{0}C except at 0^{0}C which was contracted along loading direction as seen from figure 3.

The influence of temperature on strains induced parallel and normal to the loading direction is shown in figure 4 and 5. The strain increases with an increase in temperature in the regions of Si_3N_4 nanoparticle in the directions parallel and normal to the loading. The strains in the nanoparticle are tensile in the parallel direction of compressive loading above 200^{0}C, while they are compressive in the normal direction of loading below 100^{0}C. However, the strains induced in the nanoparticle are tensile in the direction normal to the loading at all temperatures. The strains induced in 8090 matrix material are compressive at all temperatures in the direction parallel to the loading; while they are tensile in the direction perpendicular to the loading.

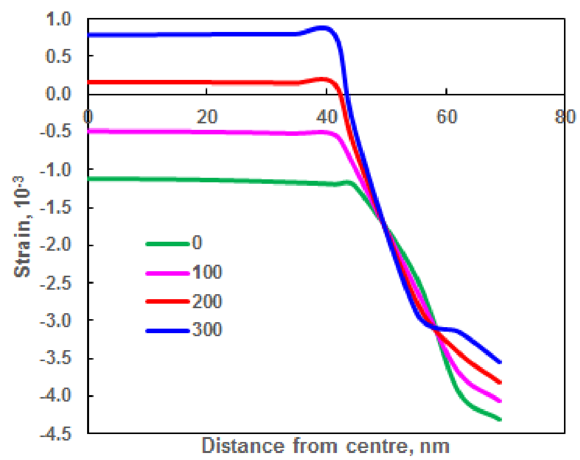

Figure 4. Effect of temperature on strains induced in Si_3N_4/8090 Al alloy nanocomposites along load direction.

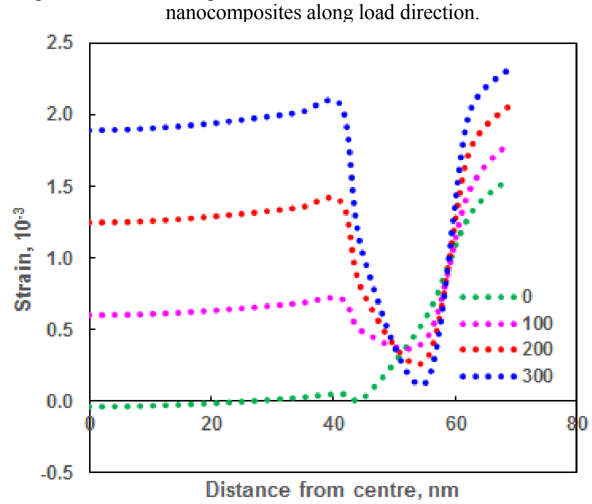

Figure 5. Effect of temperature on strains induced in Si_3N_4/8090 Al alloy nanocomposites along normal direction to loading.

The Poisson's ratio of the Si3N4 nanoparticle is positive above 200^{0}C and it is negative at 100^{0}C. The Poisson's ratio is very small at 0^{0}C as shown in figure 6. The Poisson's ratio in the matrix region is negative at all temperatures.

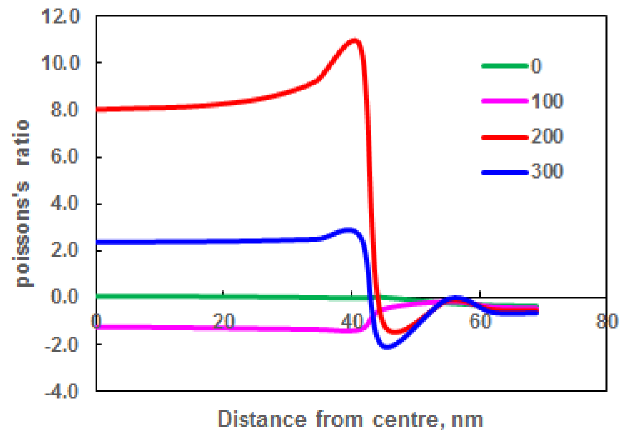

Figure 6. Effect of temperature on Poisson's ratio of Si_3N_4/8090 Al alloy nanocomposites.

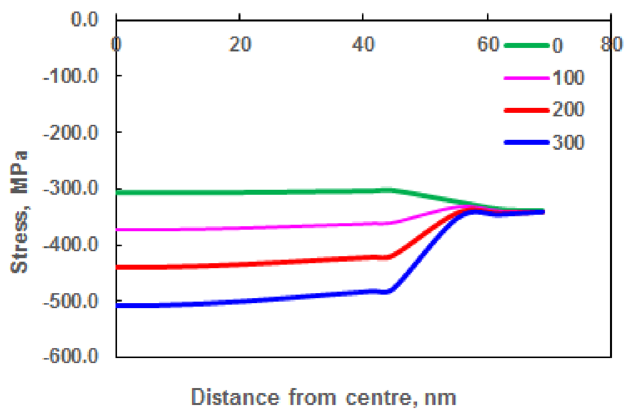

Figure 7. Effect of temperature on stresses induced in Si_3N_4/8090 Al alloy nanocomposites along load direction.

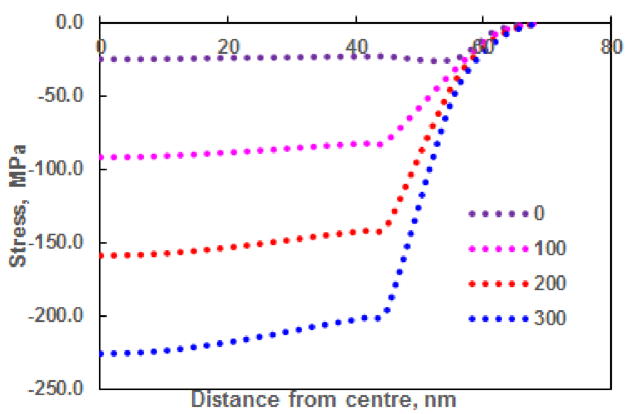

Figure 8. Effect of temperature on stresses induced in Si_3N_4/8090 Al alloy nanocomposites along normal to load direction.

The compressive stresses induced in the Si_3N_4 nanoparticle increase with increase in the temperature as shown in figure 7 and 8. It is clearly understood that the load transfer take place from the matrix to the reinforced nanoparticle via interphase. The compressive strength of Si_3N^4 nanoparticle is 490 MPa. The Si_3N_4 nanoparticle is safe at all temperature under compressive load applied. It is observed that the interface and the matrix material is likely to fracture at 300^{0}C. The same observation can be from the stress-strain diagrams shown in figures 9 and 10.

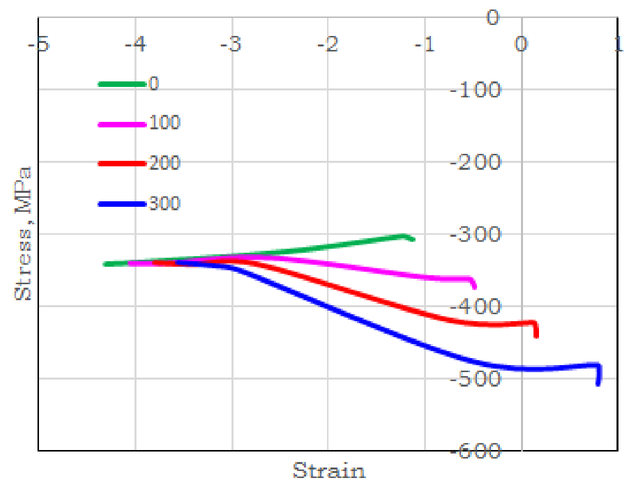

Figure 9. Stress-strain diagram of Si_3N_4/8090 Al alloy nanocomposites along load direction.

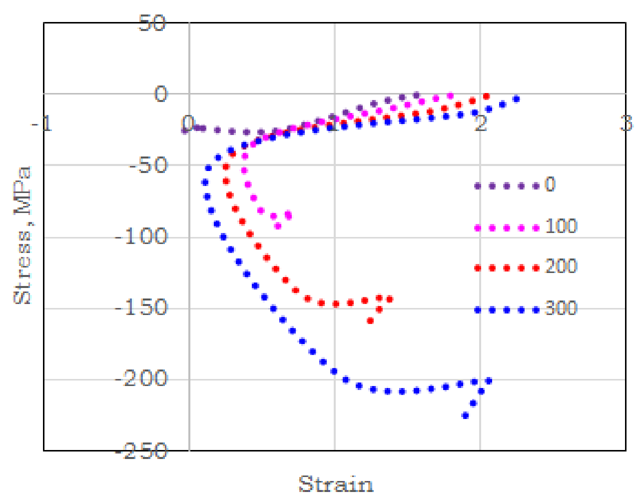

Figure 10. Stress-strain diagram of Si_3N_4/8090 Al alloy nanocomposites along norma to load direction.

The elastic modulus of Si_3N_4 nanoparticle is in the range of 28419 – 46060 MPa. The elastic modulus developed in the nano particle is well below the acceptable range at all tempertures as shown in figures 11 and 12. But the interpahse has compressed and ruptured at 300^{0}C. The same phnomena can be observed in the raster images for von Mises stresses of the composites as shown in figures 13 and in the SEM image shown in figure 14.

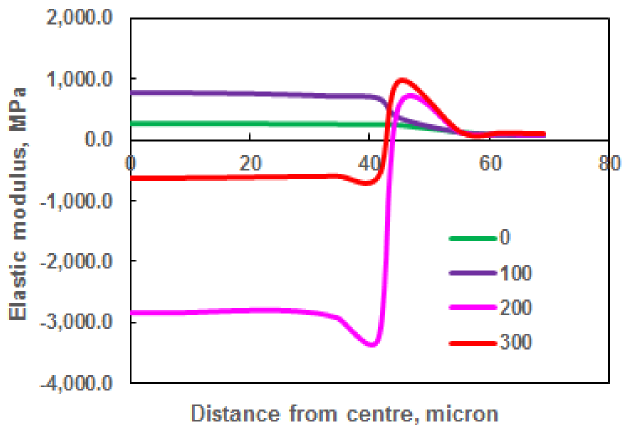

Figure 11. Elastic modulu of Si_3N_4/8090 Al alloy nanocomposites along load direction.

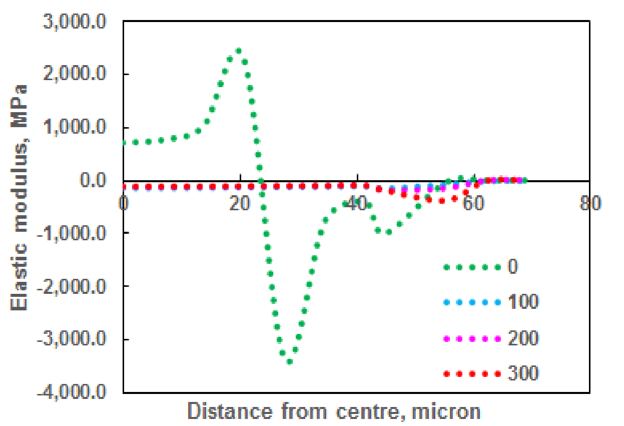

Figure 12. Elastic modulus of Si_3N_4/8090 Al alloy nanocomposites along norma to load direction.

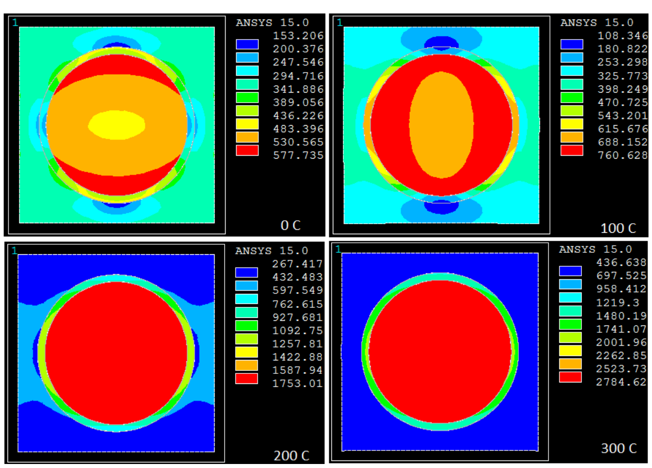

Figure 13. Raster images of von Mises stresses.

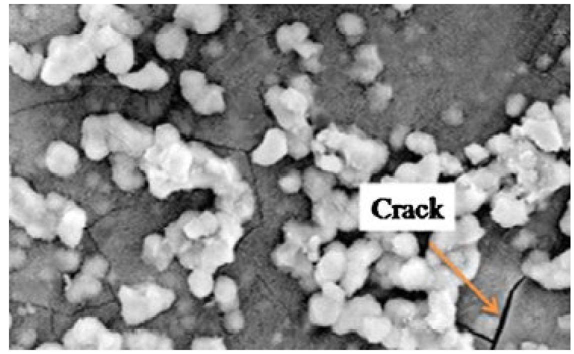

Figure 14. SEM image illustrating the fracture of interphase.

IV. Conclusion

The thermo-compressive induced micromechanics of Si_3N_4/8090 Al alloy have been computed numerically using ANSYS code. The critical conclusion of this work is that the intherphae are likely fracture at high temperautres along with applied stuctural loading. The elastic modulus developed in the nano particle is well below the acceptable range of 28419 – 46060 MPa at all tempertures.

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