Effect of Particulate Volume Fraction on Particulate Cracking in AA5050/Zirconium Oxide Nanoparticulate Metal Matrix Composites

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Abstract: *Hexagonal array unit cell/2-D hexagonal particulate RVE models were used to attribute interface debonding and particulate fracture on account of volume fraction of zirconium oxide. The particulate metal matrix composites are zirconium oxide/AA5050 alloy at different volume fractions of zirconium oxide. Particulate fracture was observed in the composites consisting of 30%Vp of zirconium oxide.*

Keywords: AA5050*, zirconium oxide, hexagonal particle, RVE model, finite element analysis, debonding, particulate fracture.*

1. INTRODUCTION

The ceramic particle-reinforced metal matrix composite (PMMC) has been widely paid great attention to on its high strength. In last about twenty years, a lot of researches on the mechanical properties of the PMMC have been done. In experimental researches, the size effect of the strength increase with particle size decrease has been reported. Cell model and finite element calculations have been used to study the mechanical behaviors of the particle-reinforced metal matrix composite [1-10].

In the present research, the micromechanical behaviors of the AA5050/zirconium oxide nanoparticulate-reinforced composites were modeled using the plane strain theory and the cell model. In the analysis, the two cases of interfacial debonding and particulate fracture were studied. Representative volume elements (RVEs) models were taken from the periodic 2-D hexagonal particulates in a hexagonal array distribution.

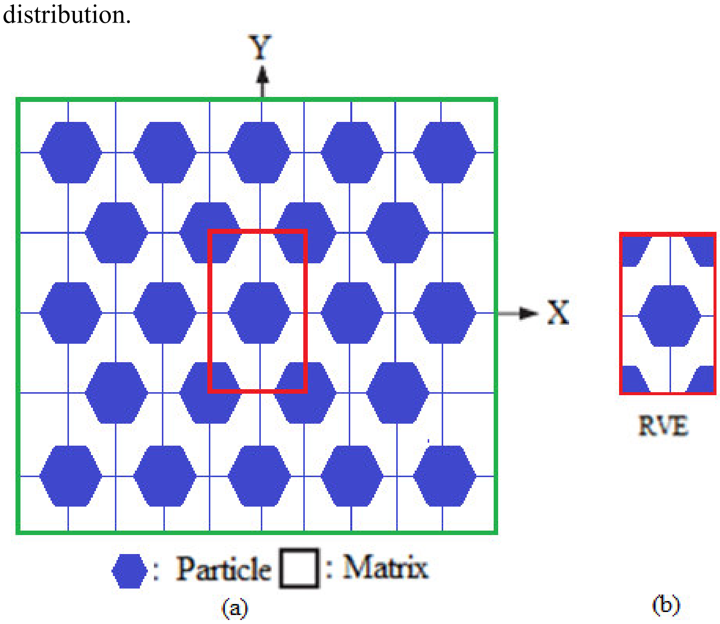

Figure 1: The RVE model: (a) particle distribution and (b) RVE scheme.

2. MATERIALS AND METHODS

The volume fractions of zirconium oxide used in the present work were 10%, 20%, and 30% ZrO_2. The matrix material was AA5050 alloy. The periodic model for the representative volume element (RVE) scheme was constructed from 2-D hexagonal particulates in a hexagonal array particulate distribution. The perfect adhesion was assumed between zirconium oxide particulate and AA5050 alloy matrix. PLANE183 element was used for the matrix and the nanoparticulate. The interface between particulate and matrix was modeled using CONTACT -172 elements.

If particle fracture occurs when the stress in the particle reaches its ultimate tensile strength, $\sigma_{p,uts}$, then setting the boundary condition at

$$\sigma_p = \sigma_{p,\,uts} \quad (1)$$

and substituting into Eq.(1) gives a relationship between the strength of the particle and the interfacial shear stress such that if

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

Then the particle will fracture. Similarly if interfacial debonding/yielding is considered to occur when the interfacial shear stress reaches its shear strength

$$\tau = \tau_{max} \quad (3)$$

Then by substituting Eq. (5) into Eq.(1) a boundary condition for particle/matrix interfacial fracture can be established whereby,

$$\tau_{max} < \frac{n\sigma_p}{2} \quad (4)$$

This approach suggests that the outcome of a matrix crack impinging on an embedded particle depends on the balance between the particle strength and the shear strength of the interface.

3. RESULTS AND DISCUSSION

The effect of volume fraction of zirconium oxide (ZrO_2) on the elastic moduli, E_x, E_y and G_{xy} is shown figure 2a. The tensile modulus increased with an increase in the volume fraction of zirconium oxide, while minor decrease of E_y and G_{xy} were noticed with the increase of ZrO_2 in the composites. The major Poisson's ratio increased with increase of volume fractions of ZrO_2 (figure 2b). The reasons could be attributed the mismatchs of elastic moduli of AA5050 alloy matrix and ZrO_2 particulates. The elastic moduli of AA5050 alloy matrix and ZrO_2 particulates are, respectively 68.9 GPa and 250 GPa.

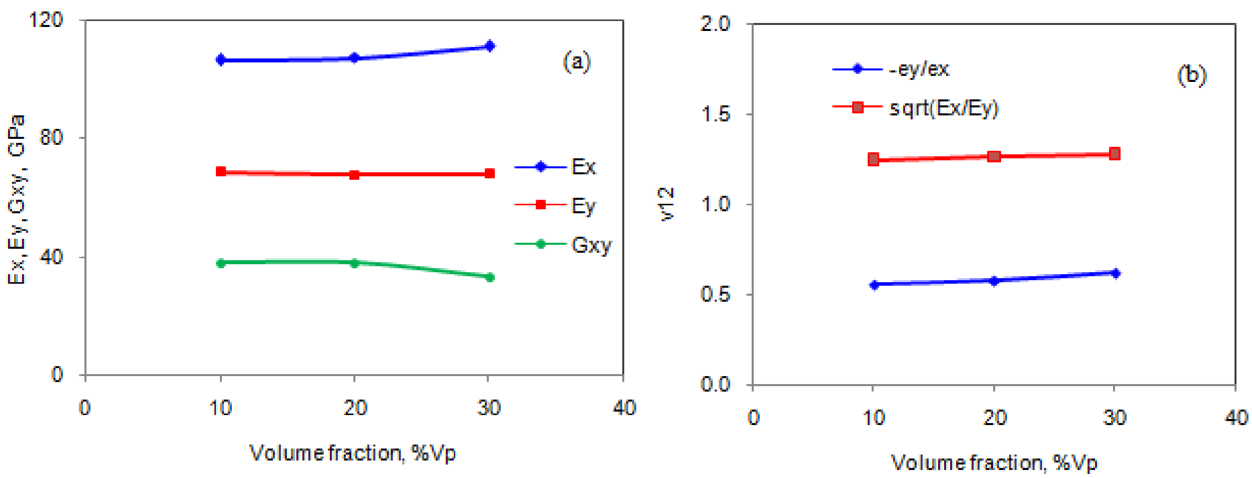

Figure 2: Effect of volume fraction on effective material properties.

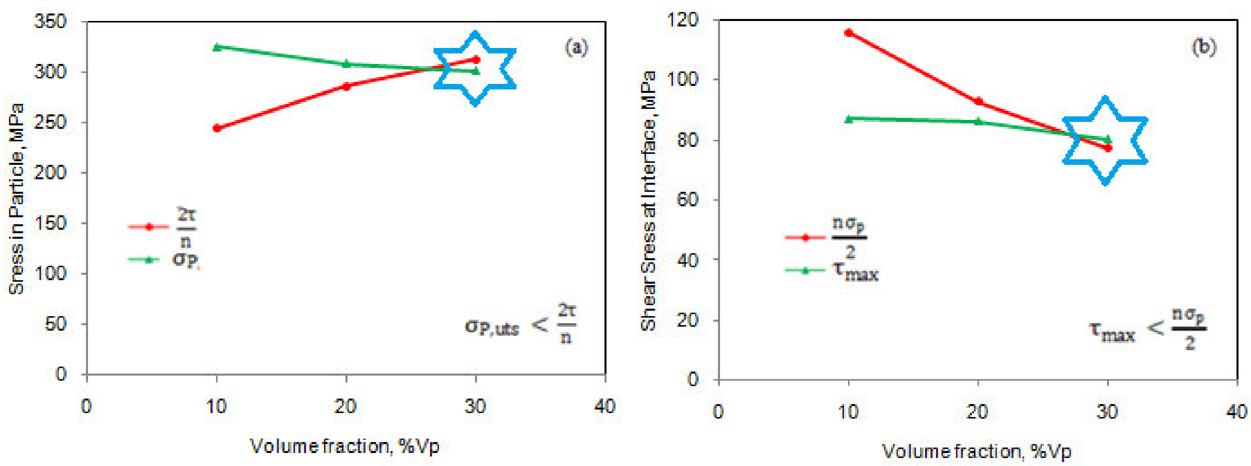

Figure 3: Fracture criteria of: (a) particulate fracture and (b) interface debonding.

The particulate fracture was detected in the composites having 30% ZrO_2 as shown in figure 3a. The ZrO_2 particulate fracture was cropped up as the condition $\sigma_p \le 2\tau/n$ is satisfied at 30% ZrO_2. Other than, the condition $\tau_{max} < n\sigma_p/2$ is satisfied for the occurrence of debonding in the composites including 10% and 20% ZrO_2 (figure 3b). The strain energy density increased in the AA5050 alloy matrix with an increase in the volume fraction of BN (figure 4). Also, the strain energy density increased at the interface with an increase in the volume fraction of ZrO_2 from 10%Vp to 20% Vp. Nevertheless, the strain energy density decreased at 30% of ZrO_2 in the composites. This represents the debonding tendency at the interface between AA5050 alloy matrix and ZrO_2 nanoparticulates below 20% Vp of ZrO_2. The decreased strain energy density attributes to the fracture of ZrO_2 nanoparticulates. The strain energy density in the ZrO_2 nanoparticulates was lower than that developed in the matrix and at the interface. The spectrum of strain densities are shown in localized regions of ZrO_2 nanoparticulates (figure 5).

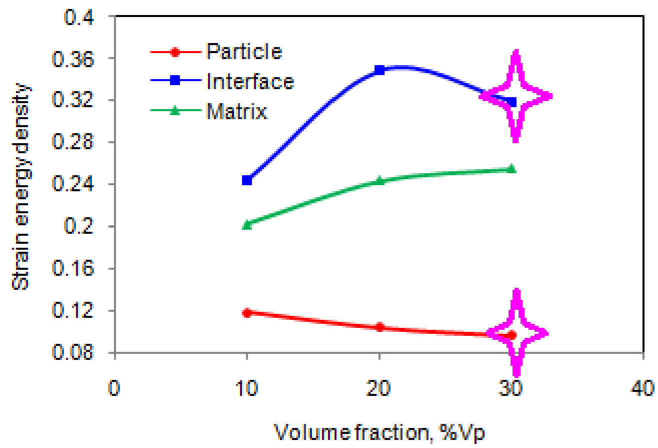

Figure 4: Effect of volume fraction on strain energy density.

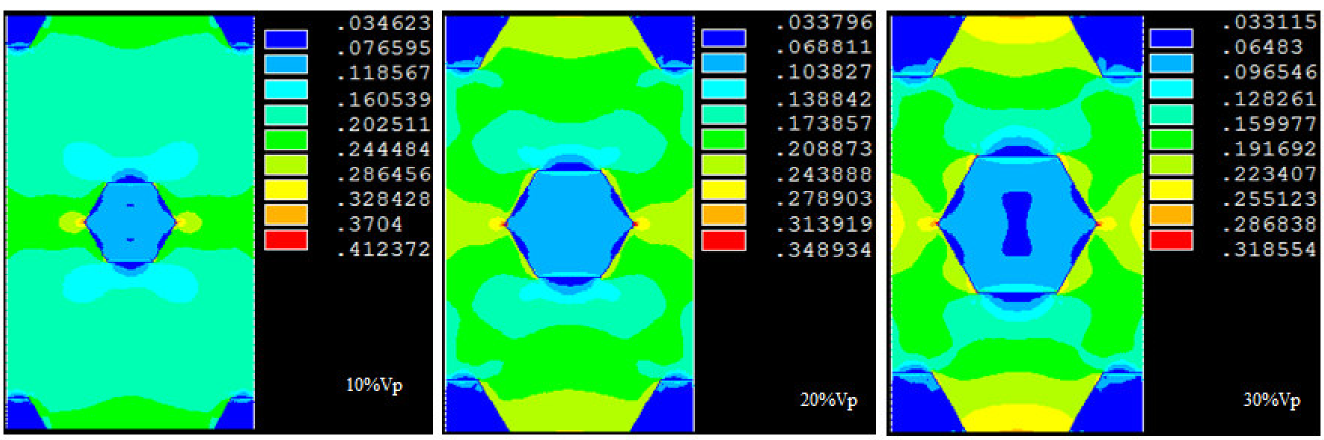

Figure 5: Results obtained from finite element analysis: stress energy densities.

4. CONCLUSION

The interface debonding occurred in the composites containing 10% and 20% volume fractions of ZrO_2; otherwise, ZrO_2 nanoparticulate damage had occurred at 30% Vp of ZrO_2. The strain energy density was very low at the ease of particulate fracture.

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