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Simulations of deformation and damage processes of SiCp/Al composites during tension

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The deformation, damage and failure behaviors of 17 vol.% SiCp/2009Al composite were studied by microscopic finite element (FE) models based on a representative volume element (RVE) and a unit cell. The RVE having a 3D realistic microstructure was constructed via computational modeling technique, in which an interface phase with an average thickness of 50 nm was generated for assessing the effects of interfacial properties. Modeling results showed that the RVE based FE model was more accurate than the unit cell based one. Based on the RVE, the predicted stress-strain curve and the fracture morphology agreed well with the experimental results. Furthermore, lower interface strength resulted in lower flow stress and ductile damage of interface phase, thereby leading to decreased elongation. It was revealed that the stress concentration factor of SiC was ~2.0: the average stress in SiC particles reached ~1200 MPa, while that of the composite reached ~600 MPa.

1. Introduction

Particle reinforced metal matrix composites (PRMMCs) possess high stiffness and strength, improved resistances to fatigue, wear and creep compared to unreinforced metals, which makes them the ideal structural materials for aerospace and defense applications. In-depth understanding of the deformation and fracture behaviors of PRMMCs is critical in the development of those materials [1–3]. In the past several decades, experiments and numerical simulations have been used to study the mechanical behaviors of PRMMCs [4–10].

Experimental methods are convincing to investigate the microstructure and macroscopic properties of PRMMCs [11–14]. For instance, Lloyd [15] examined the relationship between the particle size and particle fracture of SiCp/6061Al composites based on experimental observations. He found that few SiC particles cracked during tensile test when the particle size was below 10 μm. Guo et al. [16] used micro-pillars containing a slanted 4H-SiC(0001)/Al interface to study the interfacial properties of PRMMCs during uniaxial compression. The interfacial shear strength was found to be 133 ± 26 MPa. Due to the complex stress state in actual deformation and fracture process, the behavior of interface of PRMMCs is still difficult to characterize using conventional experimental methods.

Alternatively, numerical methods, especially the finite element (FE) methods, have been extensively used. For instance, many 2D FE models [17,18] have been used to predict the deformation and fracture properties of PRMMCs. However, traditional 2D models (of plane-stress or plane-strain types) have low accuracy to characterize the distribution of equivalent plastic strain [19]. In addition, Williams et al. [20] showed that 3D model containing spherical or ellipsoid particles cannot reproduce the stress evolution in PRMMCs accurately. Recently, 3D realistic models are receiving increasing attention in simulation investigations of metal matrix composites (MMCs).

Many approaches are developed to construct 3D realistic microstructure models [19,21,22], including serial sectioning, X-ray tomography and computer modeling techniques. Serial sectioning technique [23], as a conventional method, is time consuming and requires lots of labor works. Besides, one dimension of the resulted geometrical model is usually smaller than the other two dimensions [19]. X-ray tomography technique can construct 3D real microstructure models quickly. However, the resolution is usually 1–2 μm [22,24,25], which is difficult to determine fine details of small particles, such as sharp particle edges and corners. Compared to serial sectioning and X-ray tomography tech-

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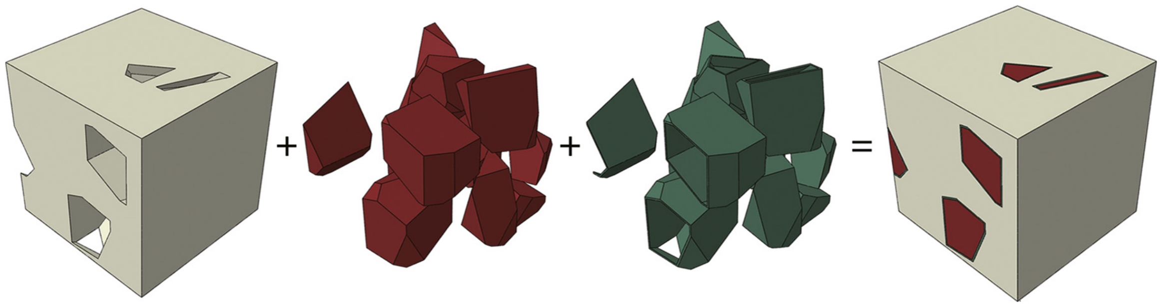

Fig. 1. Realistic microstructure based RVE model of 17 vol.% SiCp/Al composite with a size factor of 5.

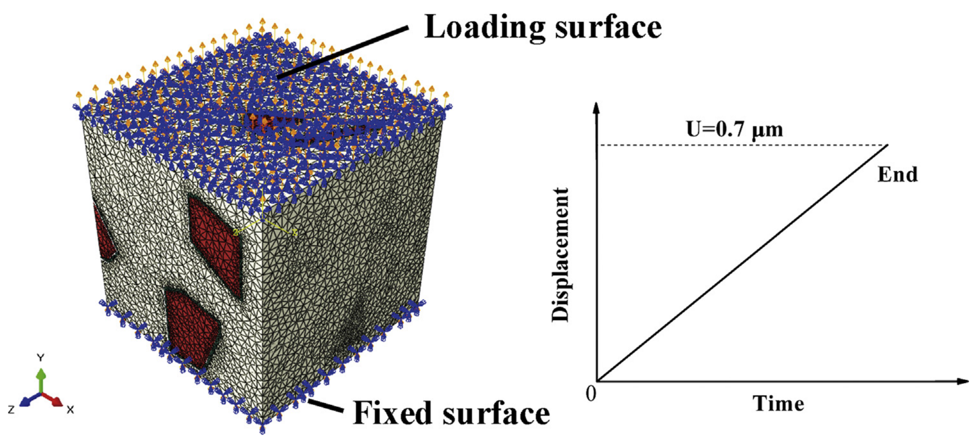

Fig. 2. Applied loading conditions of 3-D FE model in y direction.

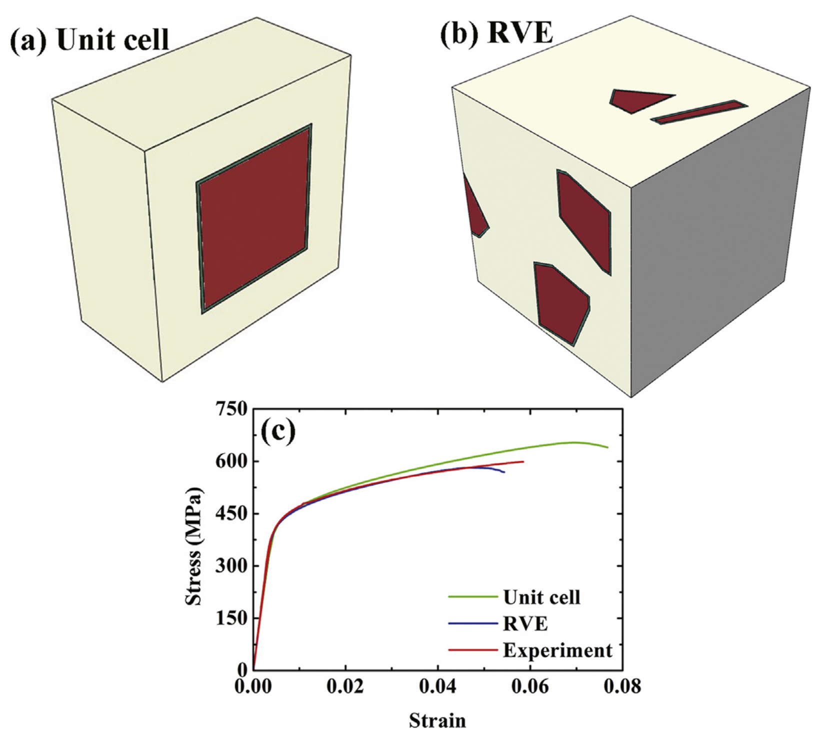

Fig. 3. (a) Unit cell model, (b) RVE model and (c) tensile strain-stress responses of 17 vol.% SiCp/Al composite.

niques, computer modeling technique is more efficient and exhibits adjustable resolution for describing real microstructures.

Several studies have been conducted on the mechanical behaviors of PRMMCs based on 3D realistic models [22,26]. The characterization of interfacial properties is a concerned problem in these studies. Cohesive zone method is commonly applied in modelling composite interface [27]. However, in the cohesive zone method, the fracture surface coincides with the cohesive element boundary, which limits its application and accuracy [28]. Zhang et al. [26] used the cohesive zone models in Abaqus. Since

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