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Composite structure modeling and mechanical behavior of particle reinforced metal matrix composites

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ABSTRACT

The present work aims to investigate the relationship between the mechanical behavior and composite structure of silicon carbide (SiC) particle reinforced aluminum matrix composites. On account of newly developed particle size analysis technique, a large number of SiC particles are experimentally measured to provide statistical particular structural information. According to the statistical analysis and physical observations of SiC particles, the composite structures of SiC/Al composites are numerically reproduced in line with their actual microscopic structures, in which a developed structural modeling program can build the randomly dispersions of the particle sizes, the particle shapes, the particle positions and the volume fractions of SiC particles. Elastoplastic material properties, strengthened matrix properties and particle–matrix interfacial behaviors are introduced to simulate the mechanical behavior of SiC/Al composites. Enough fine meshes and reasonable loads and boundaries conditions can efficiently guarantee the computing accuracy and reduce the computing cost. A lot of simulating results of SiC/Al composites are provided and verified with the related experimental results. This work makes an effective attempt to establish the relationship between the actual composite structures and the mechanical behaviors within the particle reinforced metal matrix composites.

1. Introduction

Particle reinforced metal matrix composites (MMCs) have the very large potential to provide ultrahigh mechanical behaviors, for example specific stiffness and specific strength, in the civil and defense applications as well as the automotive and aerospace industries [1]. Considering the materials characteristics and producing process, the composite structures of particle reinforced MMCs largely depend on their reinforced particles [2,3], such as: the particle sizes, the particle shapes, the particle positions and the particle contents in the composites, in which the particle–matrix interfaces are also largely retained and they further affect the mechanical behaviors of particle reinforced MMCs [4]. Therefore, the load-carrying of reinforced ceramic particles, e.g. silicon carbide and aluminum oxide, in metal matrix was very significant [5], and the effect of particle size were as well taken into account on the mechanical behaviors of the MMCs [6,7]. However, it is very difficult to completely use experimental analysis to find the key parameters in the composite structures, which should be improved to optimize the overall tensile behavior of particle reinforced MMCs. This work is well attempted nowadays thorough composite structural modeling, from unit particle models to multiple particles models [8,9], from photograph analysis to direct geometric modeling [10,11], from 2D simple models to 3D complex models [12,13], which can take into account the composite structural characteristics of particle reinforced MMCs. Along with the composites structural modeling of particle reinforced MMCs, the morphologies of particle–matrix interfaces [14,15] were established and the interfacial behaviors, for example widely applied cohesive failure model, were also introduced to perform mechanical behavior of particle reinforced MMCs [16,17]. These structural models of particle reinforced MMCs are based upon experimental observations that can provide useful guidelines to a certain extent for optimum composite structures design. Therefore, a long way still exists to go before the potential of particle reinforced MMCs can be wholly achieved to develop new strong and lightweight materials in both material design and industrial applications.

The present work aims to experimentally and numerically investigate the intrinsic relationship between the mechanical behavior and complex composite structure coupling with particle–matrix interfacial behaviors within the silicon carbide (SiC) particles reinforced aluminum (Al) matrix composites. Based on advanced particle size analysis technique, a large number of SiC particles are experimentally measured to present available SiC particular geometrical information, such as the particle size and particle aspect ratio. In the light of this statistical information of polyhedral SiC reinforced particles, a developed 3D structural modeling program can not only establish the structural models

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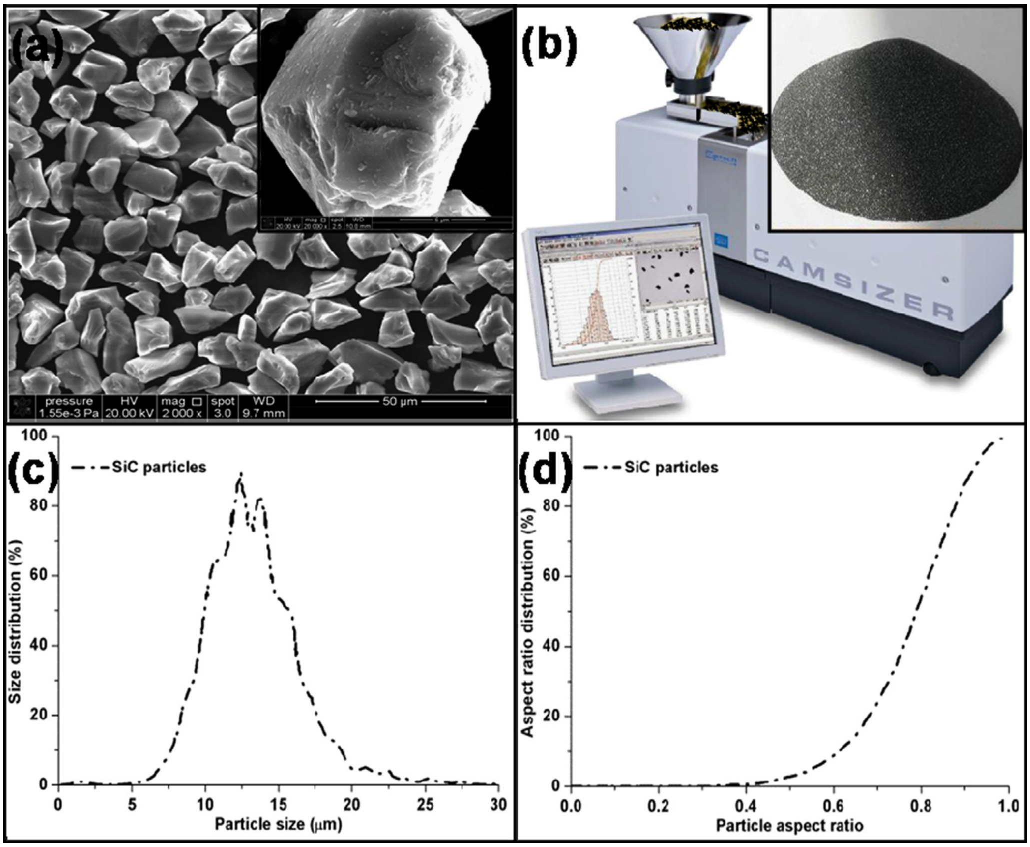

Fig. 1. Geometrical information of SiC particles: (a) microscopic characteristics, (b) particle size analysis, (c) particle size and (d) particle aspect ratio.

close to reality of SiC particles, but also reproduce the composite structures in line with the actual ones of particle reinforced MMCs. In these created structural models, the random dispersions of the sizes, the shapes, the positions and the contents of SiC particles can be realized according to the actual structural characteristics of SiC/Al composites. For numerically performing the mechanical behaviors of SiC/Al composites, elastoplastic mechanical properties with particle–matrix interfacial behaviors (adhesion, cohesive and frictions interfaces) are applied, and reasonable loads and boundary conditions are conducted. Both experimental and numerical results indicate that the volume fraction of SiC particles and particle–matrix interfacial behaviors play the significant role in the enhancement of mechanical behaviors of SiC/Al composites.

2. Materials and experimental procedure

2.1. Microscopic structural characteristics of SiC particles

Commercial black silicon carbide particles owning hexagonal crystal structure and polyhedral morphologies were supplied as reinforced materials. Fig. 1(a) shows the microscopic structural observations of SiC particles in Scanning Electron Microscope (SEM 515, PHILIPS Co. Ltd., Netherlands), in which the particle morphologies are relatively irregular. In Fig. 1(b), a rather large number of SiC particles were measured to present the statistical geometric information in a device Camisizer XT (Laboratory in Shanghai, Retsch Co. Lt, China), in which a single injection with simultaneous particle size analysis can be well processed to guarantee the high resolution and accuracy. After the dynamic particle size analysis, Fig. 1(c) and (d) provides the important structural parameters: the particle size and the particle aspect ratio of SiC particles respectively, which will determine the composite structures of produced SiC/Al composites and then be used to model the microscopic composite structures of SiC/Al composites.

2.2. Production of SiC/Al composites and experimental testing

In this study, commercial α-SiC particles with an average particle size ~13 μm were used as the reinforced materials (seen in Fig. 1(c)), and 7A04 Al alloy with chemical components: Zn: 5.0–7.0, Mg: 1.8–2.8, Cu: 1.4–2.0, Mn: 0.2–0.6, Cr: 0.1–0.25 and Al: rest in weight percent was applied as the metal matrix. SiC/Al composites with different volume fractions of SiC particles were produced by a stir casting technique and then were extruded at high temperature to generate fine enough grains and to make the reinforced particles uniformly dispersed, shown in Fig. 2(a). Fig. 2(b) provides the microscopic structural characteristics of produced SiC/Al composites, in which the dispersions of the particle shapes and particle positions of SiC particles are relatively uniform. Fig. 2(c) presents a further magnified particle–matrix zone in SiC/Al composites, where two basic particle shapes: triangle shape and quadrangle shape can be extracted for the composite structural reproduction in the next part. Meanwhile, Fig. 2(d) presents a reproduced composite structural model of 14 vol% SiC/Al composite with the model size of 100 μm × 100 μm × 20 μm.

Uniaxial tensile specimens of SiC/Al composites with the diameter 5 mm and gauge length 25 mm were machined from the final extruded composites products. Experimental tensile tests of SiC/Al composites with varying volume fraction of SiC particles were performed using universal testing machine (AUTO-GRAPH