Effect of graphite powder as a forming filler on the mechanical properties of SiCp/Al composites by pressure infiltration

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Abstract: (38vol% SiCp + 2vol% Al2O3f)/2024 Al composites were fabricated by pressure infiltration. Graphite powder was introduced as a forming filler in preform preparation, and the effects of the powder size on the microstructures and mechanical properties of the final composites were investigated. The results showed that the composite with 15 μm graphite powder as a forming filler had the maximum tensile strength of 506 MPa, maximum yield strength of 489 MPa, and maximum elongation of 1.2%, which decreased to 490 MPa, 430 MPa, and 0.4%, respectively, on increasing the graphite powder size from 15 to 60 μm. The composite with 60 μm graphite powder showed the highest elastic modulus, and the value decreased from 129 to 113 GPa on decreasing the graphite powder size from 60 to 15 μm. The differences between these properties are related to the different microstructures of the corresponding composites, which determine their failure modes.

Keywords: metal matrix composites; aluminum; silicon carbide; graphite; preparation; pressure infiltration; mechanical properties

1. Introduction

SiCp/Al composites have drawn much attention in the past decade because of their good mechanical properties and thermophysical properties [1–5]. More importantly, the properties of SiCp/Al composites can be tailored to meet various needs by adjusting the size and volume fraction of the SiC reinforcement in the Al matrix. For example, SiCp/Al composites with 1vol% to 20vol% SiC have high strength and stiffness and can be used as structural materials instead of Al alloys. In addition, they have good wear resistance properties when the volume fraction of SiC is 20vol% to 40vol%, and they have been widely used as wear-resistant materials instead of casting iron. Composites in which the volume fraction of the SiC reinforcement ranges from 55% to 70% are good electronic packaging materials because of their high thermal conductivity and low coefficients of thermal expansion. There are many methods to fabricate SiCp/Al composites with various volume fractions, such as powder metallurgy [2], stir casting [6], infiltration [5], and spray forming [7]. Among these methods, the infiltration process has been widely discussed because it can be used to realize near net shape forming of SiCp/Al parts with complex shapes. Infiltration technology is usually composed of two steps [8]: a porous preform of reinforcements is first prepared, following which the molten matrix alloys infiltrate into the preform with or without pressure. Porous preforms are more easily prepared if the volume fraction of the reinforcements falls between the relative apparent density and the relative tap density. However, when the volume fraction is lower than the relative apparent density of the reinforcement powder, cracks and deformation flaws can easily occur within the preform because of the lack of reinforcement particles to support each other or to maintain the shape of the preform. In our study, a new method is proposed to avoid these difficulties: the addition of two auxiliary additives during preform preparation. One additive is a low-temperature (about 700°C) sintering additive of Al(H2PO4)3, and the other is graphite powder. When preparing the porous preform, those two additives are mixed with the reinforcement powders and organic forming agent and then form a green body under pressure. During the subsequent sintering procedure, the organic forming agent decomposes at 300 to 500°C, following which the sintering additive strengthens...
the preform by bonding the adjacent powders as the temperature increases to 700°C. The graphite powders in the preform are finally burnt by calcination in air at 800 to 900°C; cracking and deformation do not occur in the preform because a certain amount of strength is conferred by the sintering aids. In the end, a preform with a certain strength and porosity can be made. It should be noted that the size of the graphite powder could affect the size of pores within the preform and the distribution of the Al matrix in the composites. This means that the size of the graphite powder can influence the properties of the composite because of the varied distributions of the matrices. In this paper, the effect of graphite powder size on the mechanical properties of SiCp/Al composites will be investigated to determine the optimal size of graphite powder.

2. Experimental procedures

2.1. Materials preparation

2024 Al alloys were used as the matrices of the composites. The reinforcement phases were mainly composed of 38vol% green α-SiCp with an average size of 14 μm and 2vol% Al2O3f fibers with diameters of 4 to 5 μm. Resol phenolic resin was used as the forming binder for the reinforcement particles. The content of aluminum dihydrogen phosphate (Al(H2PO4)3) as a sintering aid was 1vol% of the mixture of SiC particles and Al2O3 fibers. The average sizes of the graphite particles were 15 μm (named G1), 40 μm (named G2), and 60 μm (named G3). The micro-morphologies of the mixtures of 38vol% SiCp and 2vol% Al2O3f, as well as the graphite particles (G1), are shown in Fig. 1.

Firstly, the mixtures consisting of 38vol% SiCp, 2vol% Al2O3f, 1vol% Al(H2PO4)3, 13vol% graphite with three sizes, and 46vol% resol were pressed into a green body with a diameter of 60 mm and a thickness of 10 mm under a pressure of 20 MPa and at a temperature of 200°C. Then the green body was calcined from 200 to 1000°C for 40 min to remove resol and graphite. Thus, a porous preform was formed. Subsequently, the preform was preheated at 560°C and infiltrated by molten 2024 Al alloy under a pressure of 1 to 15 MPa. In the end, Al composites with 38vol% SiCp + 2vol% Al2O3f were successfully prepared. To improve their properties, all the composites were subjected to T6 heat treatment (495°C for 90 min quenching + 190°C for 12 h aging precipitation).

2.2. Property measurements

An electronic universal testing machine (CSS-44200) was used to perform the tensile tests, including ultimate tensile strength, 0.2% offset yield strength, and elastic modulus. The load was measured by a 5000 kg load cell, and the deformation of the specimen was measured by a 2.54 cm extensometer. The specimens were loaded at a constant cross-head speed of $10^{-3}$ cm·s$^{-1}$ until failure. The microstructures of the composites were observed by SEM (LEO-1450).

3. Results and discussion

3.1. Optical microstructures of the composites with three sizes of graphite powder

No pores could be found in the microstructures, and the relative densities of all the infiltrated composites were higher than 99.5%. In addition, when comparing the three composites, the distribution of SiCp particles in the Al matrix was more uniform when the size of the graphite powder was smaller. It is obvious that the local area and dimensions (indicated by red circles in Fig. 2) of the matrix are the largest for the composite with 60 μm graphite particles, and the diameters of the red circles range from 40 to 60 μm, which is nearly equal to the size of the raw graphite particles. Similarly, the diameter (30 to 40 μm) of the local matrix of the composite with 40 μm graphite particles is similar to the size of the raw graphite particles. For the composite with 15 μm graphite particles, the distribution of SiCp is nearly uniform and there is no obvious matrix of a large size in the composites.