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Effect of High Temperature Diffusion on Microstructure and Mechanical Performance of Si/1199Al Composites

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A dense Sip/1199 composite was prepared by squeeze casting firstly, and high temperature diffusion treatment was employed to transformed irregular Si particles to smooth 3D-structure, then 3D-Si/1199Al composite was obtained. After high temperature diffusion treatment, the independent Si particles in Sip/1199Al composite contact with each other and form 3D-Si/1199Al composite. Si/Al interface is clean, straight and free-from interfacial reaction products in Sip/1199Al composite. However, Si/Al interface change to wavy after high temperature diffusion treatment because of dissolution of Si particles in 3D-Si/1199Al composite. Furthermore, some Si precipitates at Si/Al interface are revealed in 3D-Si/1199Al composite. Moreover, some fine Si phases are also observed in Al matrix in 3D-Si/1199Al composite. Brinell hardness and bending strength of 3D-Si/1199Al composite are higher than Sip/1199Al composite, which results from the smoothed Si/Al interface and Si precipitations. Al matrix deformation in 3D-Si/1199Al composite is less than Sip/1199Al composite, and brittle fracture of 3D-structure is the main failure characteristic in 3D-Si/1199Al composite.

Keywords: *Sip/1199; 3D-structure; Microstructure; Mechanical properties*

1. Introduction

The composites reinforced with special 3D-structure reinforcement are paid appreciate attention for their high fracture strength, excellent wear resistance, controllable electrical and thermal properties [1]. Furthermore, Al matrix composites reinforced with the special 3D-structure reinforcement exhibit high specific strength, high specific stiffness and low thermal expansion properties, and have been identified as potential candidate materials for aerospace, automotive, electronics, machinery manufacture industry [2-7].

It is well established that the microstructure and properties of composite are associated with its matrix, reinforcement and processing. Recent researches indicate that the composites reinforced with special 3D-structure reinforcement could be manufactured by Hot isostatic Pressing [2, 3], Insitu Reactive Synthesis Method [2, 5~11] and Infiltration Technique [2, 4~12].

However, all methods mentioned above are immature in fabrication of inter-penetration metal matrix composites (IPMMCs). Little literatures of each method are reported, and even only ideas are given in some literatures [2].

In this paper, high-purity Si particles were used to reinforce 1199 pure Al by squeeze casting method, and then high temperature diffusion treatment was employed to transformed irregular Si particles to smooth 3D-structure to fabricate 3D-Si/1199Al composite. The effect of high temperature diffusion treatment on microstructure and mechanical properties of Si/1199Al composites were investigated.

2. Experimental

The high pure Si particles with nominal diameter of 10μm were introduced to reinforce pure Al (1199) by squeeze casting method while the reinforcement volume was 65%. High temperature diffusion treatment at 700℃ for 2h in sealed container under 0.2MPa was employed to transformed irregular Si particles to smooth 3D-structure.

Microstructure of Si/1199Al composites were observed by OLYMPUS PMG3 optical microscope (OM) and JEOL200CX transmission electron microscopy (TEM).

The mechanical properties of Si/1199Al composites were evaluated by Brinell hardness (HB) and three-point bending tests. The HB measurement was carried out with a 1mm ball indenter and a load of 30kgf for 30s, average values of HB were tested five times. Three-point bending tests with 30 mm span were carried out at room temperature on an Instron5569 universal electron tension testing system. The specimens were all 4 mm wide, 3 mm thick and 36 mm in length. Fractography analysis was carried out on S-4700 scanning electron microscopy (SEM).

3. Results and discussion

3.1 Microstructure of Si/1199Al composites

Representative morphology of Sip/1199Al composite and 3D-Si/1199Al composite are shown in Fig.1(a) and Fig.1(b), respectively. Si particles with irregular shape edge without any particle clustering distribute uniformly and no apparent porosity or significant casting defects were observed (Fig.1(a)). However, after high temperature diffusion treatment, the former independent Si particles contact with each other and form 3D-Si/1199Al composite (Fig.1(b)).

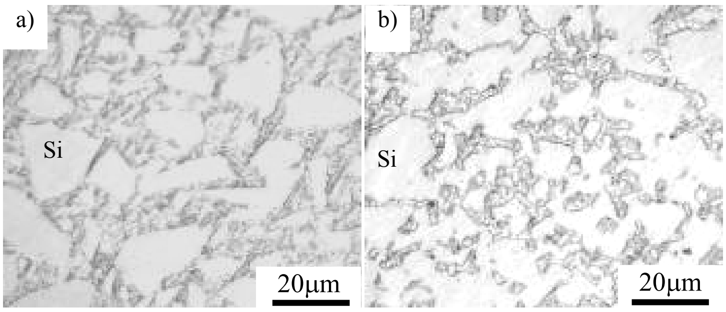

Fig.1 Representative morphology of Si/1199Al composites
a) Sip/1199Al composite; b) 3D-Si/1199Al composite

Fig.2 shows the TEM observation of Si/1199 composites. The interface is an important factor which will affect the properties of composites. Si/Al interface is clean, straight and free-from interfacial reaction products in Sip/1199Al composite (Fig.2 (a)). However, Si/Al interface change to wavy after high temperature diffusion treatment because of dissolution of Si particles in 3D-Si/1199Al composite (Fig.2 (b)). Furthermore, some Si precipitates at Si/Al interface are revealed in 3D-Si/1199Al composite (Fig.2 (b)). Moreover, some fine Si phases are also observed in Al matrix in 3D-Si/1199Al composite (Fig.2(c)). These Si precipitates come from original Si particles and improve the bonding strength of Si/Al interface, which lead to higher strength of 3D-Si/1199Al composite than Sip/1199Al composite.

3.2 Mechanical properties of Si/1199Al composite

The Brinell hardness of 3D-Si/1199Al composite is HB250, improved HB11 than Sip/Al composite, as shown in Fig.3(a). During high temperature diffusion treatment, the former independent Si particles evolve to 3D-structure (Fig.1), and then the pressure are undertaken by the overall 3D-structure rather than some independent Si particles, which improve the hardness values of 3D-Si/1199Al composite. Furthermore, the fine Si precipitates in Al matrix also improve the mechanical properties of matrix (Fig.2(c)), which is also beneficial to mechanical properties of 3D-Si/1199Al composite.

Bending properties of Si/1199Al composites are shown in Fig.3(b). The bending strength of 3D-Si/1199Al composite improves 13.9MPa to 247.3MPa after high temperature diffusion treatment. However, the treatment shows little effect on Young's modulus on the composites, improving 4GPa to 87GPa. It is because that the Young's modulus is characteristic of materials, both heat treatment and microstructure have little effect on it for composite. Fig.4 shows the fractography of Si/1199Al composites. Al matrix deformation in 3D-Si/1199Al composite is less than Sip/1199Al composite, and brittle fracture of 3D-structure is the main failure characteristic in 3D-Si/1199Al composite.

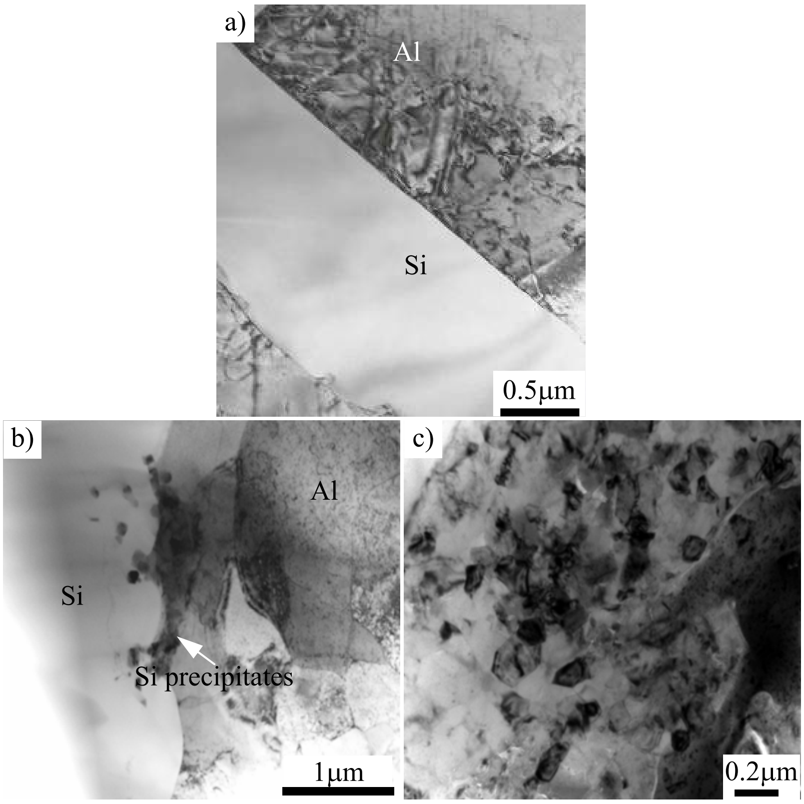

Fig.2 TEM observation of Si/1199Al composites
a) Si/Al interface of Sip/1199Al composite; b) Si/Al interface of 3D-Si/1199Al composite;
c) Si precipitates in Al matrix of 3D-Si/1199Al composite

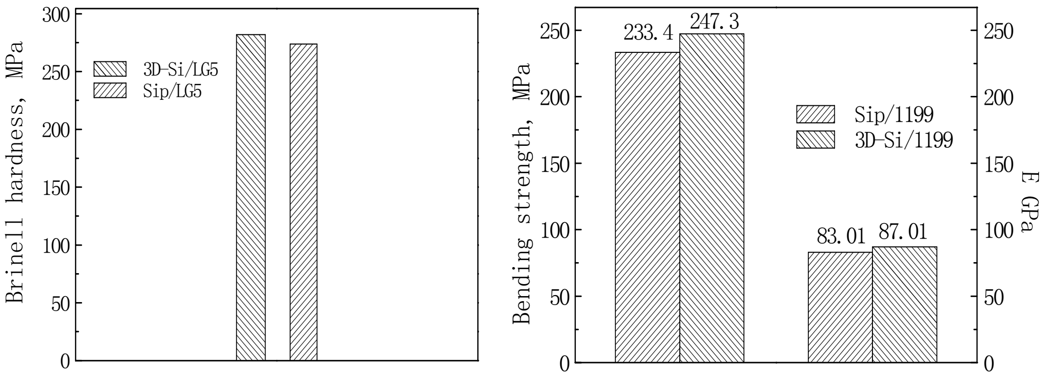

Fig.3 Mechanical properties of Si/1199Al composites
a) Brinell hardness; b) Bending properties

As shown in Fig.2(a), Si/Al interface is clean, straight and free-from interfacial reaction products in Sip/1199Al composite. The bonding of these interface depend on mechanical bond and friction force between Si particles and Al matrix. Furthermore, the Si particles could only tranfer load and their acute edges are beneficial for generation and growth of cracks.

However, after high temperature diffusion treatment, Si/Al interface is smoother and some Si phases precipitate at the interface (Fig.2(b)). The smoothed Si/Al interface and Si precipitations improve the interfacial bonding. The former acute edges of Si particles are smoothed via passivation, spheroidization and dissolution (Fig.1(b)), which decrease stress concentration. Furthermore, other than load transfer effect of particles, the 3D-structure could undertake the load. The 3D-structure could also inhibit cracks growth. Study of Hong on TiB2/(Cu,Ni) interpenetrating phase composites and research of Gao on NiAl/TiC composite indicate that two interpenetrating phases are beneficial to composite mechanical properties. Moreover, the fine Si precipitates in Al matrix also improve the mechanical properties of matrix (Fig.2(c)), which is also beneficial to mechanical properties of 3D-Si/1199Al composite.

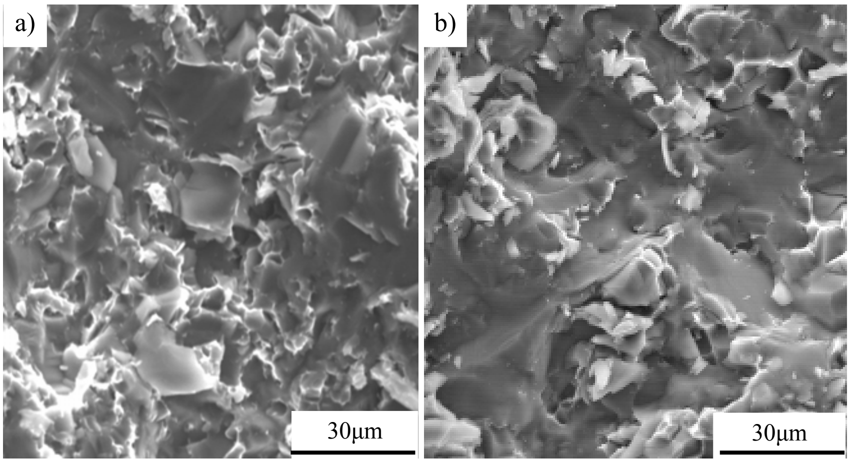

Fig.4 SEM fractographics of Si/1199Al composites
a) Sip/1199Al composite; b) 3D-Si/1199Al composite

4. Conclusions

(1)After high temperature diffusion treatment, the independent Si particles in Sip/1199Al composite contact with each other and form 3D-Si/1199Al composite.

(2) Si/Al interface is smoothed after high temperature diffusion treatment, and fine Si precipitates are observed at Si/Al interface and Al matrix.

(3) Young’s modulus of 3D-Si/1199Al composite is 4.8% higher than Sip/1199Al composite. The value is similar to the difference in the HB value (4.4%) and the bending strength (6.0%)

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