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Characterization of fiber-reinforced metal matrix composites fabricated by low-pressure infiltration process

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Abstract

The physical and mechanical properties of randomly oriented fiber-reinforced metal matrix composites (FRMMCs) fabricated by LPI process were examined. SiC particles and SiC fibers were used as reinforcement, while Al–4 mass% Cu alloy, Al–7 Si mass% alloy and AZ91 alloy were used as matrix. A mixture consisting of aluminum particles, SiC particles and SiC fibers was prepared as a preform to control the distribution of SiC fibers in FRMMC. Randomly oriented FRMMC specimens were fabricated by infiltrating the molten matrix alloy into the preform by pressing the melt surface with a low pressure of Ar gas. FRMMC specimens showed a high performance in thermal cycling test as well as an excellent wear resistance. The Vickers hardness of FRMMC specimens was almost constant on the different sections and the physical and mechanical properties were found to be isotropic.

Keywords: Low-pressure infiltration process; Fiber-reinforced metal matrix composite; Microstructure control; Vickers hardness; Wear resistance; Thermal expansion

1. Introduction

In recent years, the demand for metal matrix composites (MMCs) with excellent mechanical and physical properties has increased with the development of high-performance transportation machines. Development of an efficient fabrication process for MMCs is required in order to meet the demand. Hitherto, various kinds of processes for the fabrication of MMCs have been proposed. Among them, the casting processes are recognized to be the most advantageous because of their high productivity and formability. High-pressure infiltration is one of the casting processes used for the fabrication of MMCs, but it has some disadvantages such as high cost arising from the preparation of preforms and large scale facilities for high pressure infiltration. On the other hand, low-pressure infiltration process (LPI process), developed by the present authors, can fabricate particle reinforced MMCs (PRMMCs) with an infiltration pressure of about 0.2 MPa by using mixed particles consisting of reinforcement particles and metal particles [1,2]. The distribution and volume fraction of the reinforcement particles in PRMMC can be controlled accurately in the LPI process. The SiC_P/Al–Cu composites fabricated by the LPI process exhibit a good thermal expansion behavior due to a reaction layer resulting from a moderate reaction between the alloy melt and SiC particles during the infiltration process [3]. These results indicate that the LPI process is a suitable fabrication process for MMCs. Furthermore, the present authors have revealed that fiber orientation and distribution in fiber-reinforced MMCs (FRMMC) can be controlled by using a preform consisting of metal particles and reinforcement fibers [4] and found an optimum condition to fabricate the randomly oriented FRMMC [5]. In the present work, mechanical and physical properties of randomly oriented FRMMCs fabricated by the LPI process were examined.

2. Experimental procedure

Al–4 mass% Cu alloy, Al–7 mass% Si alloy and Mg–9 mass% Al–1 mass% Zn alloy (AZ91 alloy) were used as matrix. SiC fibers (14 μm in diameter and 1 mm in length) were used as reinforcement. The pure aluminum particles (10 μm and 150 μm in diameter) were employed to control the volume fraction and the orientation of SiC fibers in the FRMMC. In the fabrication of hybrid MMC reinforced with SiC fibers and particles, mixed particles consisting of SiC particles (100 μm in diameter) and pure aluminum particles were used. The volume fraction of SiC

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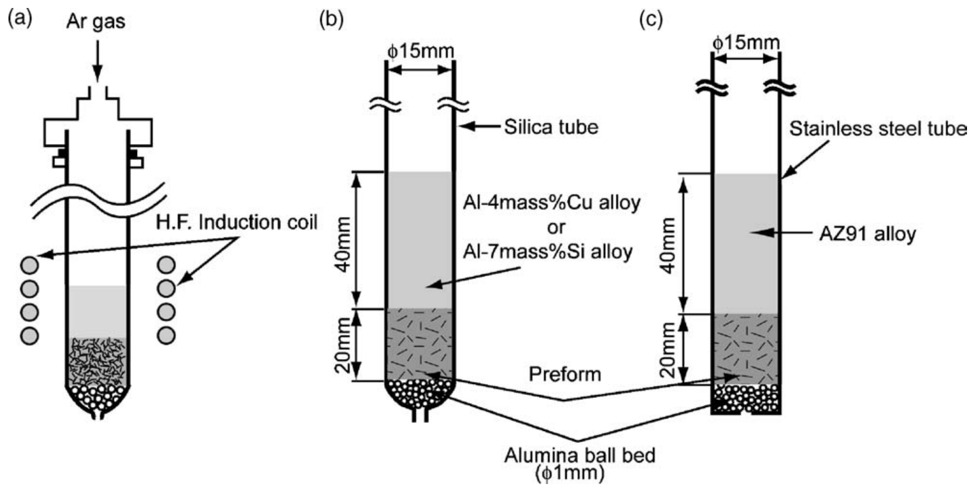

Fig. 1. Schematic drawing of (a) apparatus for low-pressure infiltration experiment; (b) sample set-up for SiC_f/Al–Cu alloy composite, and SiC_f/Al–Si alloy composite; and (c) sample set-up for SiC_f/AZ91 alloy composite.

fibers in the FRMMC was set to be 10 vol.%. The mixture consisting of SiC fibers, the aluminum particles and organic binder was formed in a cylindrical shaped preform and was fired at 773 K to remove the binder. Then the preform was placed in the low-pressure infiltration apparatus shown in Fig. 1(a). In the case of the fabrication of SiC_f/Al–Cu alloy composite and SiC_f/Al–Si alloy composite, a silica tube of 15 mm in diameter was used as a container that had a small nozzle at the bottom to release the air inside the tube. A coarse alumina particle layer (particle size: 1 mm) was placed at the bottom of the silica tube as a bed layer, then the preform and matrix alloy were piled up in order in the silica tube as shown in Fig. 1(b). In the case of the fabrication of SiC_f/AZ91 alloy composite, a stainless steel tube of 15 mm in diameter was used as a container as shown in Fig. 1(c). The upper matrix alloy was melted by H.F. induction heating, then the alloy melt was forced to infiltrate into the preform by applying an argon gas pressure on the melt surface. The infiltration pressure was 0.25 MPa and pressing was stopped when a small amount of the alloy melt flowed out through the nozzle. The dimension of the FRMMC specimens produced is Ø 15 mm × 20 mm. The microstructure and solute distribution on the horizontal section of the FRMMC specimens were examined with optical microscopy and EDX-SEM. The fiber orientation in the specimens was examined by image analysis. To evaluate the bonding strength of the interface between reinforcement and matrix, thermal cycling test was carried out from room temperature to 473 K using thermodilatometric analysis (TDA). Vickers hardness was measured using AKASHI AVK hardness tester with 98 N load in order to examine the anisotropy in mechanical properties of the FRMMC specimens. Wear testing was carried out in dry condition using a pin-on-disk type wear testing machine with 9.8 N load. A schematic illustration of the wear testing machine is shown in Fig. 2. The weight loss of the specimen was measured every 1 min during wear testing.

3. Results and discussion

3.1. Microstructure of randomly oriented fiber-reinforced MMC

In previous work, the authors have developed a fabrication process to control the orientation and distribution of reinforcement fibers in FRMMC [4,5], where the mixture of large alu-

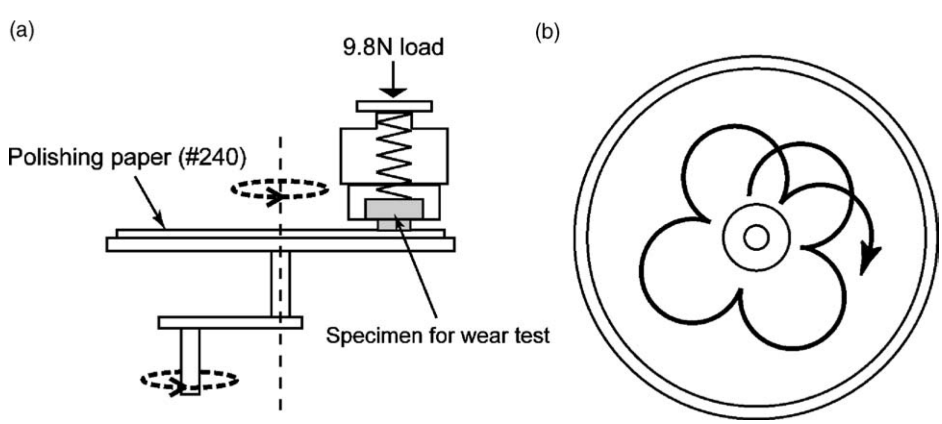

Fig. 2. Schematic illustration of (a) pin-on-disk type wear testing machine and (b) locus of a specimen on abrasive during wear test.