MANUFACTURING PROCESS OF HYBRID ALUMINUM MATRIX COMPOSITE BY LOW PRESSURE CASTING

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ABSTRACT

Optimization of manufacturing process of carbon fiber/alumina fiber reinforced hybrid composites by using low-pressure casting. The total fraction of fibers in the composite was 10 vol.%, with equal parts of Carbon fibers and alumina fibers (i.e., 5 vol.% each) In additions, carbon fiber and alumina fiber reinforced aluminum composites were fabricated respectively as the compared hybrid composites. Composites was fabricated under the low-pressure casting process by means of the infiltration of molten Al (A1070) into the preform. Carbon fiber and alumina fiber were randomly distribution inside the matrix. Carbon fiber-alumina fiber reinforced aluminum hybrid composite was fabricated the dense materials by using low-pressure casting. Vickers hardness of carbon fiber-alumina fiber reinforced hybrid composite was 32.8Hv. To comparison with aluminum of matrix, vickers hardness of carbon fiber-alumina fiber reinforced hybrid composite was increased 76%. Carbon fiber-alumina fiber reinforced hybrid composite exhibit high TC of 215.8$Wm^{-1}\cdot K^{-1}$.

1 INTRODUCTION

In the thermal management material fields, composite materials with high thermal conductivity (TC) and light weight have been expected to be utilized as heat sink materials for high heat generation parts [1,2]. Recently, the metal matrix composites (MMCs) reinforced with silicon carbide (SiC) have been widely developed as the heat sink materials [3,4]. However, the high volume fraction of SiC reinforcement was required to accomplish the desired thermal conductivity (TC) and coefficient of thermal expansion (CTE) because its TC and CTE are not enough. In addition, the composite materials reinforced with SiC are difficult to machining due to their high hardness property.

On the other hand, carbon fibers (CFs) reinforced aluminum composites possess high thermal and electrical conductivity, extremely low CTE and good mechanical properties. CF and aluminum can be a good combination for heat sink components with high TC, light weight and good workability [5-7]. However, CF has poor wettability with aluminum and the reaction product Al_4C_3 at the fiber–matrix interface by chemical reaction between the CF and Al is inevitable. The formation of Al4C3 on CF surfaces has a negative effect on the TC of the composites, due to its low TC. Many attempts have been made to characterize the Al_4C_3 in both chemical and mechanical fields. It has been known that formation of Al_4C_3 happened at the temperature above 773 K, and Al_4C_3 is formed at the surface of carbon phase and grows toward Al phase with a needle-like shape in nanoscale [8-11]. Alumina fiber reinforced aluminum composites was their relatively low strength when compared to systems such as CF or SiC fiber reinforced aluminum composites. However, alumina fiber, which has a composition of $80Al_2O_3$-$20SiO_2$ (mass %), has good wettability with aluminum and low CTE compared with CF or SiC. Recently, hybrid fiber reinforced aluminum composite attracted a lot of attention [12]. Hybridization of reinforcements has gained significant importance in enhancing the properties of

MMCs [13].

In the present studies, we have introduced carbon fiber/alumina fiber reinforced aluminum hybrid composites using low-pressure casting method. Microstructures of carbon fiber/alumina fiber reinforced aluminum hybrid composites was observed. In addition, Vickers hardness, TC and CTE of composites was evaluated.

2 MATERIALS AND EXPERIMENTAL PROCEDURE

Prior to the fabrication of carbon fiber/alumina reinforced aluminum hybrid composites by the low-pressure casting, the preparation of porous carbon fiber/alumina preform is required. The porous carbon fiber/alumina preform is fabricated by means of bridging silica sol to carbon fiber and alumina fibers with stirring method. Carbon fiber with diameter of 11μm (K13D2U, Mitsubishi Rayon Co., Japan) with high TC and alumina fiber with diameter of 3.5μm (B80L, Denka Co., Japan) with low CTE as reinforcements, SiO_2 sol (ST-ZL, Nissan Chemical Industries, Ltd., Japan) as binder were used to the fabrication of preform. The preform was dried at 403K and sintered at 1433K in Ar. Then the composites were fabricated by low pressure casting method at 1073K in Ar under applied pressure of 0.4MPa. The dimension of the preform is ϕ30×h10mm. And volume fraction of fiber is 10%. The volume ratio of carbon fiber and alumina fiber is 5:5 volume fraction. In additions, carbon fiber and alumina fiber reinforced aluminum composites were fabricated respectively as the compared hybrid composites. Composites was fabricated under the low-pressure casting process by means of the infiltration of molten Al (A1070) into the preform. The microstructure of the composites was observed using a scanning electron microscope (SEM). Hardness was carry out by the Vickers hardness under 300 N. TC was measured by the steady state method (SSM) [14]

3 RESULTS

3.1 Microstructures

Figure 1 shows BSE images of each composites: (a) carbon fiber reinforced composite (CFC), (b) alumina fiber reinforced composite(AFC) and (c) carbon fiber-alumina fiber reinforced aluminum hybrid composite(CFC/AFC). The fibers of all composites were randomly distribution inside the matrix. However, interfacial layer was observed between fiber and aluminum. It is confirmed by the presence of the γ-Al_2O_3 from diffraction peaks in the XRD pattern (previous study [12]). It suggests that γ-Al_2O_3, can be produced as results of the interfacial reaction between aluminum and SiO_2 binder, $4Al+3SiO_2 \rightarrow \gamma\text{-}Al_2O_3+3Si$, which results in improved interfacial wettability between fiber and aluminum. Relative density of each composites were 96.5%, 98.3% and 97.9% respectively. Alumina reinforced aluminum composite has high relative density when compared to the composite, which has used carbon fiber. That means alumina fiber has good wettability with aluminum. However, the relative density of CFC/AFC was almost similar to that of alumina reinforced aluminum composite. CFC/AFC was fabricated the dense materials by using low-pressure casting.

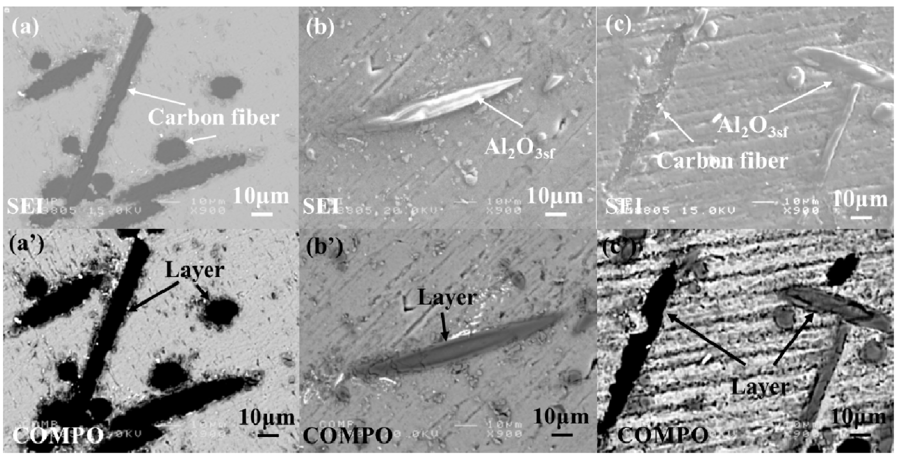

Figure 1: Microstructures of CFC (a), AFC (b) and CFC/AFC (c).

3.2 Vickers hardness

Figure 2 shows the results of vickers hardness of CFC, AFC and CFC/AFC. Vickers hardness of CFC, AFC and CFC/AFC containing 10% volume fraction of fiber were 33.3Hv, 26.2Hv and 32.8Hv respectively. Carbon fiber-alumina fiber reinforced hybrid composite was almost similar to that of the CFC. That means was not decreasing of hardness even if a hybrid of carbon fiber and alumina fiber. To comparison with aluminum of matrix, vickers hardness of CFC/AFC was increased 76%.

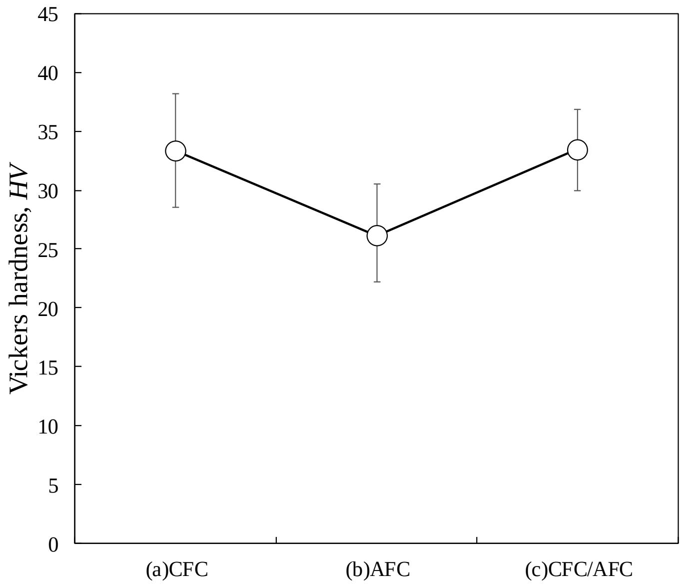

Figure 2: Results of vickers hardness of (a) CFC (b) AFC and (c) CFC/AFC.

3.3 Thermal conductivity

Figure 3 shows the results of thermal conductivity of CFC, AFC and CFC/AFC, which were 245.8, 215.8, and 132.8 $W \cdot m^{-1} \cdot K^{-1}$ respectively. The CFC exhibit high TC of 245.8$Wm^{-1} \cdot K^{-1}$. The CFC (TC of carbon fiber: 800 $W \cdot m^{-1} \cdot K^{-1}$, fiber aspect ratio: 230, ∅11 μm) exhibited the highest thermal conductivity. The CFC/AFC exhibit high TC of 215.8$Wm^{-1} \cdot K^{-1}$. However, the TC of the AFC was only 12% lower than that of carbon-only composite. In contrast, the TC of the AFC was 46% lower than the CSF-Al composite. The smaller loss in the CSF/ASF-Al composite's TC can be attributed to the high TC and aspect ratio of the carbon fiber.

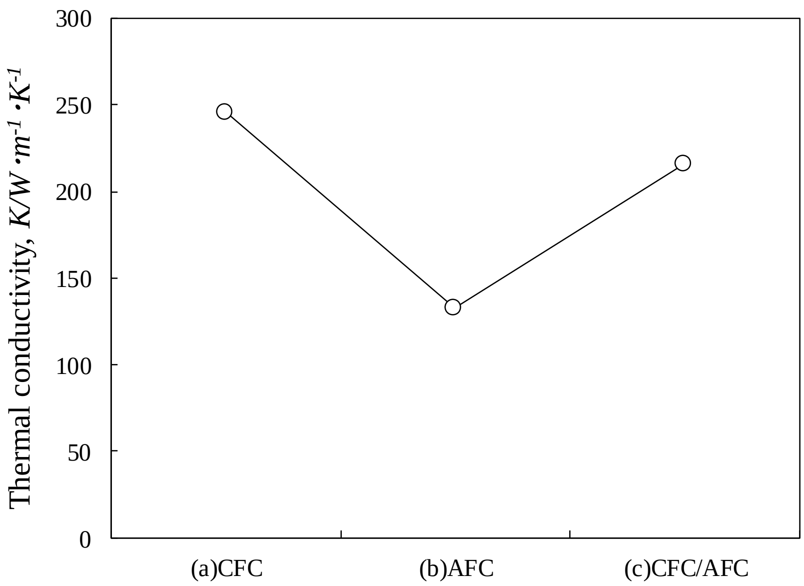

Figure 3: Results of thermal conductivity of CFC, AFC and CFC/AFC.

4 CONCLUSIONS

A low-pressure infiltration casting method for fabricating a CFC/AFC was developed. The significant results are summarized below.

Carbon fibers and Alumina fibers were randomly distribution inside the matrix. A dense carbon fiber-alumina fiber reinforced hybrid composite (over 98% relative density) was fabricated using low-pressure casting. The surfaces of the carbon fibers and alumina fibers were almost completely covered with an oxide layer. The oxide layer suggests that γ-Al_2O_3 could be produced as a result of the interfacial reaction between aluminum and the SiO_2 binder, i.e., $4Al + 3SiO_2 \rightarrow \gamma\text{-}Al_2O_3 + 3\ Si$, which improved the interfacial wettability between the fiber and matrix. The Vickers hardness of the CFC/AFC was 31 Hv, which was 76 % higher than that the aluminum matrix. The CFC/AFC with 5 vol.% carbon fiber and 5 vol.% alumina fiber exhibited high TC of 215.8 $W \cdot m^{-1} \cdot K^{-1}$.

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