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Enhanced Mechanical Strength of Nickel–Copper-coated Carbon Fiber/Magnesium Alloy Composites Fabricated Using Powder Metallurgy

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Carbon fibers could be deposited uniformly with duplex coatings of nickel (the internal layer) and copper (the external layer) using an electroplating process. The thickness of Ni and Cu coatings was about 1–2 µm. Furthermore alloying between Ni and Cu films and alloying between Cu and base Mg alloy occurred respectively after hot pressing (673 K, 2.5 MPa). In particular the strain to failure of magnesium composites with Ni–Cu-coated carbon fibers was 0.7% higher than that (1.81%) of magnesium composites with untreated carbon fibers.

Carbon fiber reinforced metal (CFRM) matrix composites have been extensively used in a wide range of industrial applications because of their outstanding mechanical and/or physical properties.[1,2] However, weak bonding between carbon fiber and base metal or alloy gives these composites poor mechanical properties. In particular, in the Al–C fiber composites, the existence of reaction products such as Al_4C_3 at the interface is a drawback associated with metal matrix composites (MMCs) synthesized via liquid-state processing.[3] It has been widely reported that the formation of this brittle compound at the interface has an adverse affect on the mechanical properties of the MMCs.[4] Also, the carbon fibers are not wetted and not dispersed well in the melted aluminum.[5] To improve the wetting and dispersion between carbon fibers and base metal/alloy, two techniques regarding metal nanoplating[6] and powder metallurgy[7] with hot pressing were applied to prepare CFRM matrix composites in this study. Accordingly, the primary aim of the present study is to synthesize magnesium alloy composite materials reinforced with carbon fibers having high mechanical strength.

In this study, magnesium alloy AZ91D (supplied by Sakai Ovex Co., Ltd., 100–200 µm) powders and Ni–Cu-coated carbon fibers (provided by TohoTenax Co., Ltd., $7\,\mu m^{\phi} \times 50\,mm^{l}$) were used as the matrix material and the reinforcing fibers, respectively. AZ91D alloy has high modulus and tensile strength and has been used as the matrix material in synthesizing MMCs. The Ni and Cu coatings were deposited on carbon fibers by electroplating. After surface acid treatment with hydrochloric acid (0.1 M), the carbon fibers were designed to successively pass through two plating baths of Ni and Cu. Namely, the carbon fibers can be coated with duplex coatings of nickel (the internal layer) and copper (the external layer), that is denoted by Cu–Ni–C. The Ni and Cu plating bath was prepared using $20\,g\,dm^{-3}$ aqueous nickel(II) sulfate hexahydrate (Nacalai Tesque Inc.), $20\,g\,dm^{-3}$ aqueous cupper(II) sulfate pentahydrate (Nacalai Tesque Inc.), $30\,g\,dm^{-3}$ aqueous trisodium citrate dehydrate (Nacalai Tesque Inc.), and sodium ammonium solution (Kanto Chemical Co., Inc.) as a pH adjuster. Then sodium phosphinate monohydrate (Nacalai Tesque Inc.) was used as a reducing agent. The electroplating was controlled at 55 °C and pH 5.0 with $0.5\,A\,dm^{-2}$ of current density. Finally, the substrate was rinsed carefully with ion-exchanged water and dried in a 70 °C air chamber after filtering. After Cu–Ni–Carbon fibers were acquired, they were blended 2 wt % with Mg alloy particles in a ball mill for 2 h. The blended powder mixture (2 g) was compacted to a billet ($20 \times 60 \times 1\,mm^3$) at a pressure of 2.5 MPa and 673 K for 1 h under 10% H_2–90% N_2. Namely, the magnesium matrix composites were synthesized under hot-pressing using powder metallurgy. Surface and cross-section morphology of Cu–Ni–Carbon fibers reinforced magnesium matrix composites were observed using SEM–EPMA (S-2400; Hitachi Ltd.). The tensile strength of composite fibers was investigated using a MTS 4482 (Instron Corp.).

Figure 1 shows SEM image (a) and mapping images ((b) Ni, (c) Cu, and (d) C) of Ni–Cu composite film coated on carbon fiber in a cross section of magnesium composite fiber. It was found that the Ni and Cu films of 1.5 µm thickness, respectively, covered uniformly on the carbon fibers as shown in Ni and Cu mapping images. Comparing with casting preparation method, the coated metal films existed stably on carbon fibers without any diffusion to outer base Mg alloy.

To investigate the metal plating films between carbon fiber and base Mg alloy in detail, line and point mapping analyses of the plating films were observed as shown in Figure 2. From the result of (a) line analysis of SEM–EPMA, alloying between Ni

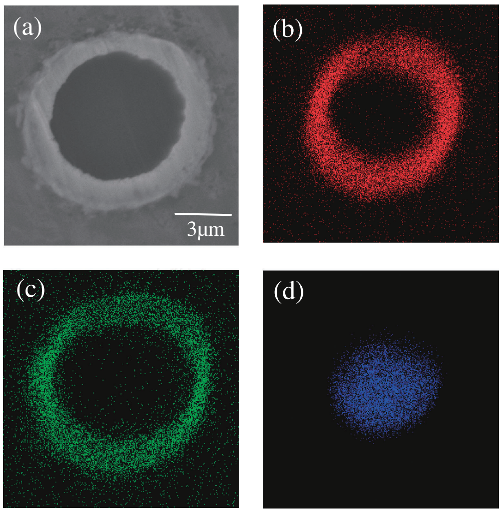

Figure 1. SEM image (a) and mapping images ((b) Ni, (c) Cu, and (d) C) of Cu–Ni duplex layers coated on carbon fiber in cross-section of magnesium composite matrix.

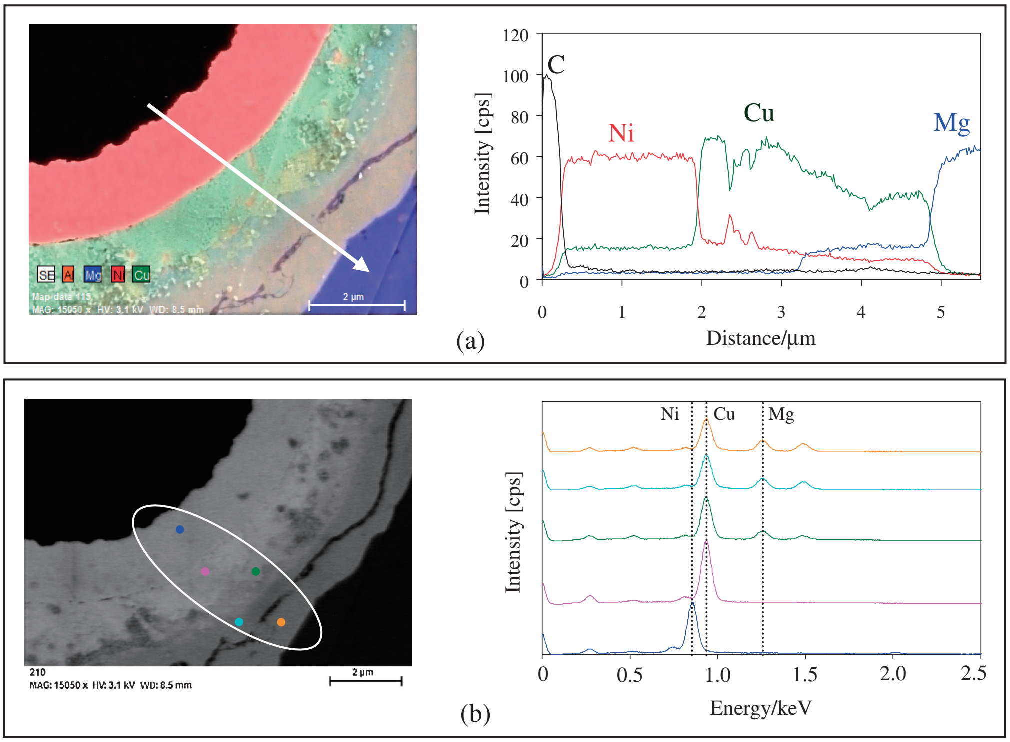

Figure 2. Line (a) and point (b) analyses of SEM–EPMA for the plating layers between carbon fiber and base Mg alloy.

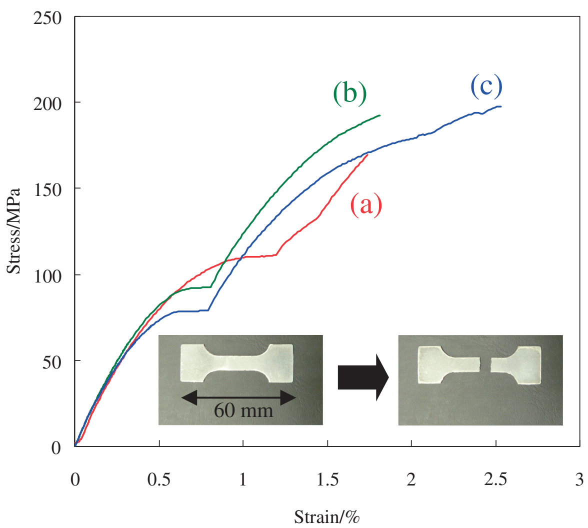

Figure 3. Stress–strain curves from tensile testing of (a) only Mg alloy, (b) untreated carbon fiber reinforced magnesium alloy composite, and (c) Ni–Cu-coated carbon fiber reinforced magnesium alloy composite.

and Cu layers and alloying between Cu and outer Mg alloy were confirmed. Also the result of (b) point analysis showed the same result. Especially alloying between Cu and Mg alloy was more advanced, and it may be a formation of Cu_2Mg or Cu_3Mg_2 alloy.[8] These alloying degrees may affect the mechanical strength of composite fibers. The effects of Ni–Cu metals between carbon fiber and base Mg alloy on the mechanical strength of CFRM matrix composites are focused on in this paper.

The stress–strain curves for only magnesium alloy (a) and magnesium matrix composites containing untreated (b) or Ni–Cu-coated (c) carbon fibers are shown in Figure 3. Ultimate tensile strength (UTS) values of samples (b) and (c) with carbon fibers were 192 and 198 MPa, respectively, higher than that (169 MPa) of sample (c). Namely, carbon fibers play a role to improve the tensile strength of Mg alloy composites. Comparing with samples (b) and (c), the effects of metal plating between carbon fiber and base Mg alloy on tensile strength did not change so much. However, regarding the strain to failure, sample (c) with Ni–Cu-coated carbon fibers was much higher 0.7% than sample (a) with untreated carbon fibers and sample (b).

Consequently, Ni–Cu plating films formed on carbon fiber improved the strain to failure of carbon fiber reinforced magnesium matrix composites. It may be reasoned that the Ni–Cu plating films can increase the adhesion between carbon fiber and base Mg alloy.

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