Carbon nanofiber–copper composite powder prepared by electrodeposition

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Abstract

Carbon nanofiber–copper composite powder is prepared by an electrodeposition process using a copper plating bath containing homogeneously dispersed carbon nanofibers. Particles of the composite with a spiky ball structure are accumulated on the plating electrode during the initial stage of electroplating, and can be separated easily to give a powder carbon nanofiber–copper composite. The particle size can be controlled by selecting appropriate electroplating conditions.

Keywords: Carbon nanofiber; Copper; Composite; Electrodeposition; Powder; Polyacrylic acid

1. Introduction

Carbon nanotubes and nanofibers [1,2] have excellent mechanical characteristics such as high tensile strength and high elastic modulus, and also have high thermal and electric conductivity. Research into practical applications of carbon nanotubes and nanofibers has been actively pursued, and metal composites of such nano-sized materials are promising new materials offering innovative functions. Powder carbon nanofiber–metal composites represent promising raw materials for powder metallurgy, such as powder rolling, powder flame spraying, and powder forging.

The present authors have been investigating the development of a new method for fabrication of powder composites of carbon nanofiber and metal. The technique presented here is an electroplating technique. It has been reported that composite materials such as Ni–Al2O3 [3], Ni–TiO2 [4], Cr–graphite [5], and Cu–Al2O3 [6] can be obtained via the electroplating technique. The present authors have used a similar technique to obtain the Cu–carbon nanofiber powder composite.

2. Experimental

Carbon nanofibers were commercially available carbon nanofibers (Showa Denko Co. Ltd.), vapor-grown carbon nanofibers (VGCFs), obtained via catalyst assisted CVD [7], and heat treated at 2800 °C in Ar for 30 min, which corresponds to the multi-walled carbon nanotube. Carbon nanofibers were typically 100–200 nm in diameter and 20 μm in length. A sulfuric acid bath (0.85 M CuSO4·5H2O + 0.55 M H2SO4) was used as the basic plating bath. VGCFs did not disperse uniformly in the basic bath, and Cu-VGCF composite could not be obtained by electrodeposition. A homogeneous dispersion of VGCFs was achieved by the addition of polyacrylic acid (mean molecular weight 5000; PA5000, Wako Junyaku Kogyo Co. Ltd.) to the basic bath as a dispersing agent with stirrer agitation. The composition of the composite plating bath was 0.85 M CuSO4·5H2O + 0.55
M H₂SO₄ + 2 g dm⁻³ VGCFs + 2 × 10⁻⁵ M PA5000. Plating was performed at 25 °C with aeration under galvanostatic conditions. A commercially available electrolytic cell (Model I, Yamamoto-Ms Co. Ltd) with internal dimensions of 65 × 65 × 95 mm was employed for electrodeposition. The volume of the plating bath was 250 cm³. A pure copper plate (JIS C1201P) or stainless-steel plate (JIS SUS304) with an exposed surface area of 10 cm² (3 × 3.33 cm) was used as the substrate. A copper plate containing phosphorus (JIS H3250) was used as the anode. The appearance of the electrodeposited materials were observed by field-emission scanning electron microscopy (FE-SEM).

3. Results and discussion

Electrodeposits with various morphologies were obtained from the plating bath under various conditions. Spherical copper deposits with many tendril- or spike-like carbon nanofibers were obtained during the initial stage of electroplating. Fig. 1 shows SEM photographs of electrodeposits formed at various total electrical charges. Current density was 5 A dm⁻². At a total electrical charge of 1 C cm⁻², the spiky Cu-VGCF composite particles did not form, but VGCFs had begun to become incorporated into the deposited Cu film (Figs. 1(a), (d)). At 5 C cm⁻², spherical Cu particles of 2–3 μm in diameter containing VGCFs were obtained. The diameter and VGCF content of the particles increases with total electrical charge up to 15 C cm⁻², beyond which spiky Cu-VGCF composite particles were obtained in closely packed arrangement to form a film.

The growth process is shown schematically in Fig. 2. At low charge, carbon nanofibers are incorporated into the deposited Cu film (Fig. 2(a)). As the fibers have high electrical conductivity in the axial direction, Cu will deposited on both the substrate and the protruding end of fiber (Fig. 2(b)). As deposition proceeds, fibers become incorporated into the deposited Cu to give the closely packed spiky ball structure (Fig. 2(c)).

The Cu-VGCF particles were then readily separated from the electrode by blowing with compressed air or ultrasonication in water or acetone to obtain a powder composite. Fig. 3 shows the appearance of the powder produced at 5 A dm⁻² and 15 C cm⁻² and separated by ultrasonication in acetone. The particles were of relatively uniform size (2–6 μm), and the carbon nanoparticles were well dispersed in the Cu matrix.
nanofibers were securely incorporated into the Cu particles. The same results were obtained even if copper or stainless-steel substrate was used.

4. Conclusion

Powder composites of copper and carbon nanofibers were successfully prepared by electrodeposition using a copper plating bath with homogeneously dispersed VGCFs. VGCFs were tightly incorporated into the deposited Cu as spiky or tendril-like structures surrounding individual Cu grains, and the resulting composite could be readily separated from the electrode by ultrasonication in water or acetone to afford a powder Cu-VGCF composite.

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References