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Full Length Article

Magnetic thermal dissipations of FeCo hollow fibers filled in composite sheets under alternating magnetic field

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ABSTRACT

To evaluate the heat elevation of FeCo hollow fibers filled in magnetic composite sheet, we synthesized the FeCo hollow fiber by using electroless plating method. The synthesized FeCo hollow fibers (50 wt.%) were mixed with thermoplastic polyurethane (TPU). FeCo hollow fiber in composite sheet exhibited the representative α-FeCo peak by XRD. The magnetization and coercivity of FeCo hollow fibers were 176.5 Am^2/kg and 6.2 kA/m, respectively. In order to measure the heat elevation, the alternating magnetic field (AMF) was applied to magnetic composites sheets from 7.1 kA/m to 11.1 kA/m at 190 kHz and the frequency was applied from 190 kHz to 355 kHz at 8.3 kA/m, respectively. The elevated temperatures and the specific loss power (SLP) values exhibited about 76 °C from the initial temperature of 26 °C and about 25.3 W/g for the AMF of 8.3 kA/m and frequency of 355 kHz.

1. Introduction

High magnetic moment is one of very important factors for the applications of electronic devices, bio-sensing and biomedical usage: high density recording, induction core, electromagnetic interference (EMI) materials, magnetic resonance imaging (MRI) contrast agent and drug delivery etc. Especially, FeCo is well known material as one of high magnetic moment materials [1–6]. Therefore, some researchers have been synthesized and reported the coated FeCo on basal materials [7–9].

When the magnetic particles were exposed by an alternating magnetic field (AMF), the magnetic materials will be heated. The elevated heat resulted from the magnetic loss which is caused by a combination of eddy currents, hysteresis losses, and relaxation losses. The eddy current loss arises when the skin depth is less than that of thickness and diameter of particles, which is defined by the frequency, conductivity and permeability of materials. However, the eddy current loss can be negligible in a nanometer sized-particles within a few hundred kHz region. For the agglomerated single domain particles or multi-domain magnetic particles, the magnetic loss could be mainly caused by the hysteresis loss due to the reversal magnetization and inter-particle interaction although the dispersed superparamagnetic nanoparticles is mainly generated by Neel relaxation due to the magnetic spins in single-domain [10–13]. The total losses of the magnetic particles are governed by the strength of the AMF and their operating frequencies as well as the intrinsic magnetic properties [14]. In recent, some researchers have been tried to employ the composite sheet filled with magnetic particles as well as magnetic colloids to healing of skin infections including hyperthermia-aided immunotherapy [13,15–19]. The magnetic fillers dispersed in polymer matrix have an advantage of easily usage to healing and wound area with an immovable magnetic particles while the magnetic nanoparticles should be movable in human body in human body. Thus it can be allowed a repeated localized heat treatment. Therefore, we synthesized the FeCo hollow fibers filled in composite sheets and verified the heat behaviors.

2. Experimental

We prepared the magnetic composites filled with FeCo hollow fibers using an electroless plating method on island-in-the-sea polyester polymer fiber as a substrate (diameter of 2 μm and length of ~180 μm). Before the metal plating step, the polyester fibers were functionalized by polydopamine. The polydopamine functionalized polyester fibers were sensitized and activated in a tin chloride ($SnCl_2$) and hydrochloric acid (HCl) for 15 min. Similarly, to activation process, polymer fibers were mixed in solution which palladium chloride ($PdCl_2$) and HCl for 15 min.

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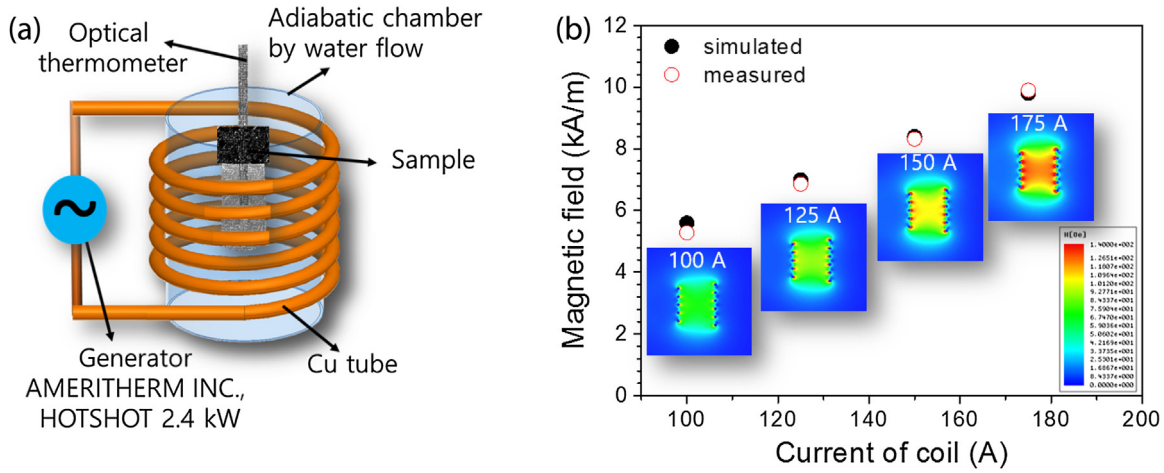

Fig. 1. (a) Schematic of AC magnetic field applicator and (b) the measured magnetic fields in comparison with that of the simulated values with the increment of current of coil.

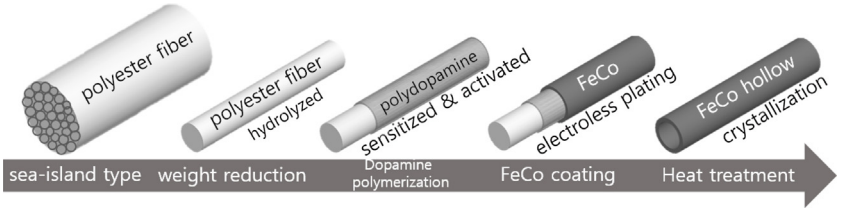

Fig. 2. Schematic of FeCo hollow fiber fabrication process.

For FeCo plating, the polydopamine functionalized polymer fibers mixed with ferrous sulfate ($FeSO_4{\cdot}7H_2O$, 20 g), cobalt sulfate heptahydrate ($CoSO_4{\cdot}7H_2O$, 20 g), potassium sodium tartrate ($C_4H_4KNaO_6$, 230 g), sodium hydroxide (NaOH, 40 g), potassium tetrahydroborate (KBH_4, 20 g) in D.I. water 1800 ml. The weight ratio of Fe to Co was 5:5 which was controlled with the weight ferrous sulfate and cobalt sulfate heptahydrate reagent. And this solution were stirred for 90 min at 45 °C. In order to make the hollow structure without fiber deformation, the polyester fiber substrates were removed by heat treatment at 700 °C for 1 h under the argon atmosphere. Then the mixtures of TPU resin and FeCo hollow fibers with 50 wt.% were homogenized for well dispersion. Those mixtures were casted on thin PET films. After dried these films, the FeCo hollow composite sheets with the thickness of about 100 μm were cast from the PET films, and cured at 120 °C for 3 h.

The structural phase were examined by X-ray diffraction (XRD; X'Pert PRO, PANalytical) using Cu Kα radiation (1.54 Å). Scanning electron microscope (SEM, S-4800, HITACHI) and Energy dispersive spectroscopy (EDS) was used to confirm the morphology of the composites. The magnetic properties were measured by using vibrating sample magnetometer (VSM, Lakeshore 7410). To evaluate the heat behaviors, FeCo hollow fiber composite sheet was prepared in silicon oil of 4.7 mg/ml, which the disk shaped composite sheet has the thickness of about 110 μm and diameter of 7 mm, respectively. The induction heat temperature were measured by AC heating system which is composed of RF power supply (AMERITHERM INC., HOTSHOT 2.4 kW, 150–400 kHz) ad 5.5 turns-helical shaped Cu coil with the 80 mm-height and 70 mm-inner diameter as an AC magnetic field applicator. For heat elevation of FeCo hollow fiber composite, a specimen in dual structured vial put in the chamber that can be maintained constant temperature by water flowing on the wall of chamber as shown in Fig. 1(a). The strength of AMF was measured by a magnetic field transducer (SENIS AG.), which was in comparison with that of the simulated results (EM3D ANSYS) as shown in Fig. 1(b). The temperature was measured by using 4 channel thermometer (FISO, EasyGrid) and fiber optic probes (FISO, TPT-62) with the resolution and accuracy of 0.1 °C and ±1 °C, respectively.

3. Results and discussion

The FeCo hollow fibers were fabricated through the following process: hydrolyzed fiber, dopamine polymerization, sensitized and activated process, FeCo coating by electroless plating and finally heat treatment for removal polyester fiber and crystallization of FeCo, as shown in Fig. 2. The SEM images in Fig. 3(a) and (c) show the microstructure of before and after heat treatment FeCo hollow fibers, respectively. The FeCo hollow fibers have an inner diameter of about 2 μm and 500 nm thick- FeCo coated layer. The Fe to Co atomic ratio of before and after heat treated FeCo hollow fibers exhibited 60.3:39.7 and 49.5:50.5, respectively, as shown in Fig. 3(b) and (d). As observed from SEM-EDS analysis, the hollow fibers mainly consist of Fe and Co. XRD pattern of the heat-treated FeCo hollow fibers at 700 °C revealed that the three main peaks at 2 theta values of 44.6°, 65.1° and 82.4° correspond to the (110), (200), and (211) reflection planes of body centered cubic (BCC) FeCo phase, although the as-deposited FeCo hollow fibers was not clearly shown crystalline peak, as shown in Fig. 4. The saturation magnetization and coercivity of FeCo hollow fibers before and after heat treatment were 115.6 Am^2/kg, 176.5 Am^2/kg and 11.5 kA/m, 6.2 kA/m, respectively, as shown in Fig. 5. The magnetic properties of heat treated FeCo hollow fibers enhanced due to the grain growth and crystallization process.

To verify the heat elevation of FeCo hollow fiber composite sheet, the specimen was placed in an isolated air environment with ambient temperature of 26 °C. The specimen in silicon was measured with the reference of silicon oil without specimen. Time-temperature curves of FeCo hollow fiber composite sheet were obtained with the change of AC magnetic field strength and various frequency as shown in Fig. 6 (a) and (b). The temperature

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