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Non-contact measurement of CNT compounding ratio in composite material by eddy current method

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Abstract

Carbon nano-tubes (CNT) are new materials which have an excellent mechanical and electric characteristics. Electric conductivity and high rigidity (high strength) can be given to a resin by mixing CNT with a usual resin. The compounding ratio of CNT was estimated by optical observation and resistance measurement by 4 probes method so far. But, both methods are time-consuming. Therefore, the resistivity of the composite material was measured with non-contact using the eddy current method that used the differential probe coil, and the method of estimating the compounding ratio was applied in this study.

Keywords: Carbon nano-tube; Composite material; Eddy current method; Non-contact measurement; Compouding ratio

1. Introduction

Carbon nano-tube (CNT) is a material of high aspect ratio, with excellent electrical and mechanical characteristics [1,2]. CNT is noted as a new material with a high potential in various fields such as the electronic material [3–5]. The CNT compounding material (CC material) with a resin is molded by injection molding. As for this CC material, electrical conductivity and high rigidity (high strength) are given. Such a CC material has been used for tennis rackets, the golf shafts, and the aircraft machine parts recently.

In this study, we made samples of the compound material that mixed CNT with nylon, and examined the non-contact methods of identifying the compounding ratio. Until now, methods for estimating the compounding ratio by optical observation or resistance measurment by 4 probes have been performed. We have enhanced the general eddy current method in the field of the non-destructive testing [6]. We decided to identify the compounding ratio of the measuring object by expanding on the non-contact eddy current method.

In this study, the compounding ratio of CNT of the CC material made as a measuring object is a range from 0.1 to 20%. For the 4 probes method, when the compounding ratio is 5% or less, the measurement becomes very difficult, because of its extremely high electric resistivity. On the other hand, this expanded method can plainly measure the compounding ratio even if it is 5% or less. Moreover, this method can distinguish the difference of 0.1% by emphasizing the difference of the result. Because it is simple, and is possible to measure it in short time, the measurement system is applicable during production process.

In addition, the distribution of the CNT compounding ratio in the CC material is measured by using a small carbon electrode, and the results are compared with the result by the eddy current method.

This paper describes the following:

(1) Non-contact measurement principle using expanded eddy current method.
(2) Non-contact measurement result using the eddy current method.
(3) Measurement of distribution of the compounding ratio.

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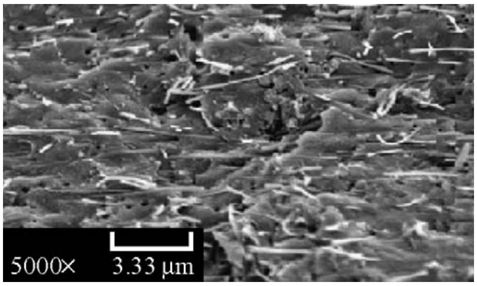

Fig. 1. Photomicrograph of surface of the CC material.

2. Non-contact measurement principle using eddy current method

2.1. Structure of CC material

The sample of CC material for the measuring object is a compound material that mixed CNT with polypropylene. The compound material was made by injection molding. Fig. 1 shows a photomicrograph of a surface of the CC material. The thickness of the sample is 2 mm, and a square size of 60 mm × 60 mm. The injection entrance of the injection molding is chopped off.

2.2. Measurement principle

Fig. 2 shows principle of non-contact measurement using the eddy current method. ac magnetic flux is generated if the ac current is thrown into the probe coil of Fig. 2, then eddy current is generated in the CC material. Therefore, we can measure the impedance change of the probe coil. Then we are able to measure the compounding ratio.

Impedance graph of *XY* coordinate system which shows the vector quantity is used the change of the coil impedance [6]. Expression (1) and (2) show definition for illustrating the impedance graph.

$$\frac{\Delta R}{\omega L_0} = \frac{R_0 - R_0}{\omega L_0} \quad (1)$$

$$\frac{\Delta \omega L}{\omega L_0} = \frac{\omega L_0 - \omega L_1}{\omega L_0} \quad (2)$$

where ω (rad/s) is the angular frequency, R_0 (Ω) the coil resistance, R_1 (Ω) the coil resistance after the change by the CC material, L_0 (H) the coil inductance, L_1 (H) the coil inductance after the change by the CC material.

3. Non-contact measurement result using eddy current method

3.1. Measurement result

Fig. 3 shows impedance–frequency characteristics. The number of coil turns for the measurement is 50, and its outer diameter is 37 mm, inner diameter 28 mm, coil thickness 1 mm, diameter of coil wire 0.2 mm. The measurement is carried out on the center of the CC material placed next to the coil. As the compounding rises of the CC material rises, the resonance frequency is lowered. Expression (3) shows the resonance frequency.

$$\omega_0(\text{rad/s}) = \frac{1}{\sqrt{LC}} \quad (3)$$

$$f_0(\text{Hz}) = \frac{1}{2\pi\sqrt{LC}} \quad (4)$$

where ω_0 (rad/s) is the resonance angular frequency, L (H) the inductance, C (F) the capacitance, f_0 (Hz) the resonance frequency.

The change of the inductance increased as the compounding ratio rises, and the resonance frequency seemed to lower.

3.2. Comparison by the impedance graph

Fig. 4 shows impedance graph in 4.5 MHz, and Fig. 5 shows impedance graph in 5.5 MHz. And the distances from the origin of Figs. 4 and 5 are shown in Fig. 6.

As the compounding ratio of the carbon rises, the tendency in which the distance from the origin is lengthened is shown from the result of the impedance graph.

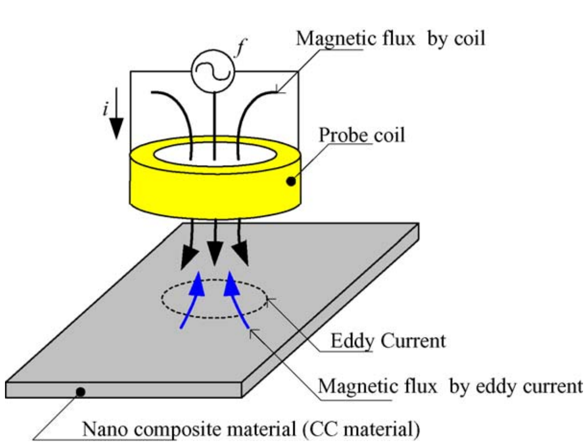

Fig. 2. Principle of non-contact measurement.

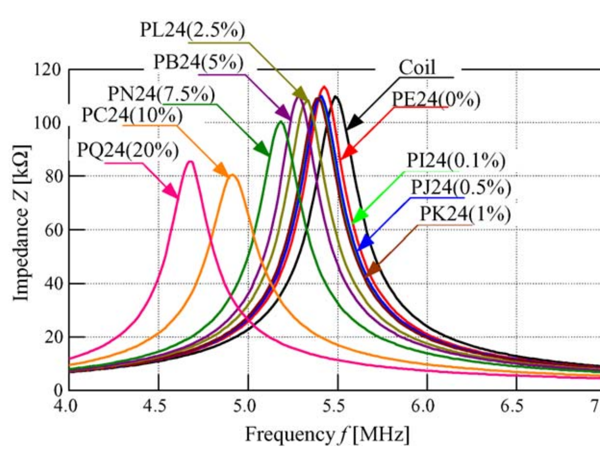

Fig. 3. Impedance–frequency characteristics.