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Development of Electromagnetic Wave Absorber with White Charcoal

Masamichi Miki, Takeyuki Kikuchi and Mitsunobu Nakamura
Graduate School of Engineering, Himeji Institute of Technology, Himeji 671-2201, Japan
Fax:81-792-67-4925, e-mail:miki@esci.eng.himeji-tech.ac.jp

Electromagnetic wave absorbers consistent of unsaturated polyester resin and 20-60 mass% of white charcoal powder were developed and their electromagnetic wave absorption characteristics, electrical resistivities and bulk densities were measured. The electrical resistivity was decreased with increasing amount of white charcoal powder, namely 1.5 x 10^7 Ωcm and 2 x 10^2 Ωcm in the specimens with 20% and 60% of white charcoal, respectively. The bulk density of the specimen changed from 1.15 (20% white charcoal) to 1.00 (60% white charcoal) with increasing amount of charcoal powder. The specimens with 50% and 60% of white charcoal powder absorbed remarkably the electromagnetic wave of GHz range, namely the absorptions of 45 dB at 1GHz in the specimen with 50% of white charcoal and 40 dB at 5 GHz with 60% white charcoal, respectively.
Key words: electromagnetic wave absorber, white charcoal, unsaturated polyester resin, electrical resistivity, scanning electron microscopy

1. INTRODUCTION

Recently, the utilization of high frequency electromagnetic waves of GHz range has increased with increasing new communication systems such as cellular phones and local area networks. As a result, high frequency electromagnetic waves from such new systems or machines have frequently affected medical and avionics equipments and induced many dangerous incorrect actions and accidents. Therefore, the fast development of such materials that absorb completely (not only shield) above harmful waves is needed.

On the other hand, in the previous study[1], we clarified that white charcoal (Bincho-charcorl in Japanese) and bamboo charcoal carbonized at 600-650℃ showed the superior electromagnetic wave absorption characteristics. However, bulk materials of these charcoals are not suitable for the practical use. Therefore, in this work, we tried to disperse the powders of these charcoals in the base material (heat-hardening unsaturated polyester resin in this work).

2. EXPERIMENTAL

The liquid unsaturated polyester resin and a hardener and the fine charcoal powder (<400 mesh = 35 μm) were mixed and then hardened by keeping at room temperature for 24 h. The white charcoal used in this study was produced by carbonizing Ubame-ork at about 1100℃ and the electrical resistivity of its bulk specimen was 3 x 10^{-2} Ωcm. The contents of white charcoarl powder in the specimens are shown in **Table 1**.

For the hardened specimens, electrical resistivity measurements, SEM observations, bulk density measurements and electro magnetic wave absorption characteristics measurements were performed.

Test pieces (cylindrical shape of inner diameter 3 mm, outer diameter 7 mm and length 5 mm) for measuring the electromagnetic wave absorption

Table 1 Mixing ratio of unsaturated polyester resin and white charcoal powder (mass%)

No.	Polyester resin	Charcoal powder
1	77.7	22.3
2	66.7	33.3
3	57.5	42.5
4	50.0	50.0
5	40.0	60.0

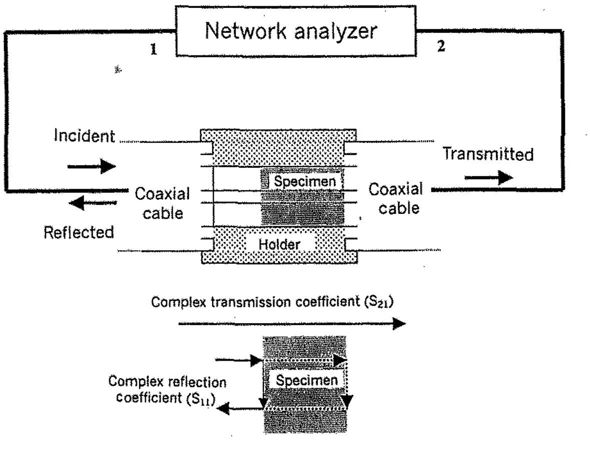

Fig.1 Schematic representation of the coaxial cable method for measuring the electromagnetic wave absorption.

characteristics by the coaxial cable method [2] were made by machining these polyester base specimens.

The equipment for measuring the electromagnetic wave absorption characteristics by the coaxial cable method is shown in **Fig.1.**

A complex reflection coefficient (S_{11}), which denote the total intensity of the waves reflected from the front and back surfaces of the specimen, was measured by a network-analyzer (HP8720ES) made by Agilent Technologies Co. Ltd..

Complex permittivity ($\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$) and complex permeability ($\mu_r = \mu_r' - j\mu_r''$) were calculated from the complex reflection coefficient (S_{11}). By using the calculated complex permittivity and permeability values, the electromagnetic wave absorption characteristics (reflection coefficient (Γ), return loss and absorption curves) were calculated for the metal backed specimens and absorption curves were plotted [3]. The reflection coefficient (Γ) and return loss (absorption) were calculated by the following equation [2],

$$Z_m = Z_0 \sqrt{\mu_r / \varepsilon_r} \cdot \tanh\left(j(2\pi d/\lambda_0)\sqrt{\varepsilon_r \cdot \mu_r}\right)$$

$$\Gamma = (Z_m - Z_0)/(Z_m + Z_0)$$

$$\text{Return loss} = -20\log|\Gamma| \quad \text{(dB)}$$

$$\lambda_d = \lambda_0 / \sqrt{\varepsilon_r'} .$$

Here, Z_m and Z_0 were the surface impedance of the absorber and the characteristic impedance of the free space(air), respectively. The d, λ_0 and λ_d were the thickness of the absorber, the wave lengths in air and the absorber, respectively. In this study, the complex permeability (μ_r) was calculated as 1.0, because the unsaturated polyester resin and charcoal scarcely show magnetic property [4].

The electrical resistivity was measured by the four probe method (JIS K7194).

3. RESULTS AND DISCUSSION

Figure 2 shows the SEM microstructure of the starting white charcoal powder. The sizes of powder particles are 1 – 10 μm.

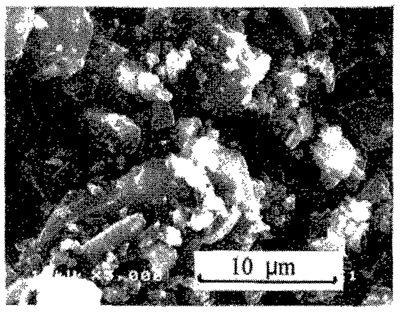

Fig.2 SEM micrograph of the starting white charcoal powder particles.

Figure 3 shows the SEM microstructures of the polyester resin specimens containing 60% and 42.5% of white charcoal powder. Many large pores of 100 – 200 μm diameter (A), which seem to be caused by the aggregation of the air included in the starting porous charcoal powders and the chemical reaction gases during hardening reaction, were observed on the fractured surfaces. The amount of these large pores decreased with decreasing powder content. On the enlarged photographs of the areas B in the 60% white charcoal specimen (b), many charcoal powder particles (arrow marks) were observed. However, on the enlarged micrograph of the area B in the 42.5% white charcoal specimen (d), the amount of charcoal powder particles decreased.

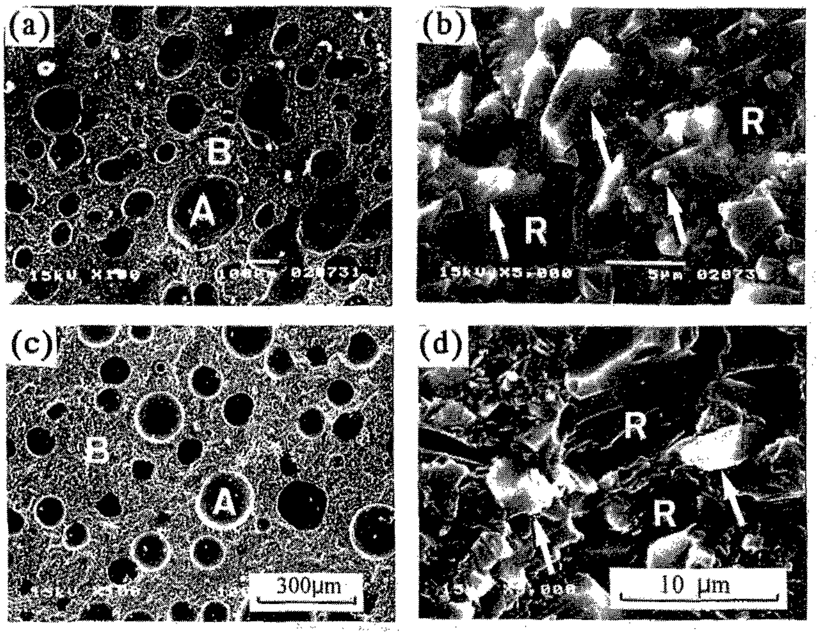

Fig.3 SEM micrographs of fractured surfaces of the polyester resin/white charcoal powder composite specimens. (a)(b)60% white charcoal powder specimen, (c)(d)42.5% white charcoal powder specimen. (b) and (d) denote the enlarged structures of area B in the photographs (a) and (c).

Figure 4 shows the electrical resistivity change of the composite specimen with increasing white charcoal powder content. The electrical resistivity remarkably decreased with the white charcoal powder content. The resistivities of the specimens containing 50% and 60% of white charcoal powder were 5×10^2 Ωcm and 2×10^2 Ωcm, respectively.

Figure 5 shows the electromagnetic wave absorption characteristics of the composite specimens. The permittivity (ε 'and ε ") increased with increasing white charcoal content and the remarkable return loss (absorption) of about 40 dB was observed only in the specimens containing 50% and 60% of white charcoal powder (b)(d). The peak frequency of absorption shifted to higher frequency side with increasing amount of white charcoal powder, namely 1.3 GHz for the 50% charcoal powder specimen and 5 GHz for the 60% charcoal specimen. The specimen thicknesses needed for the above peak absorptions were 15.0 mm for the 50% white charcoal powder specimen and 4.1 mm for the 60% white charcoal powder specimen, respectively.

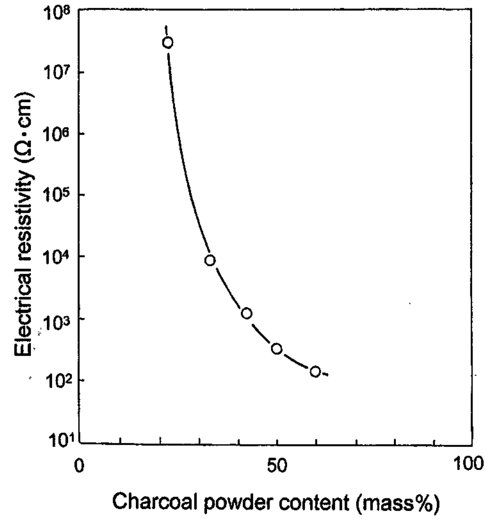

Fig.4 Electrical resistivity change of the polyester resin/white charcoal powder composite specimen with increasing white charcoal powder content.

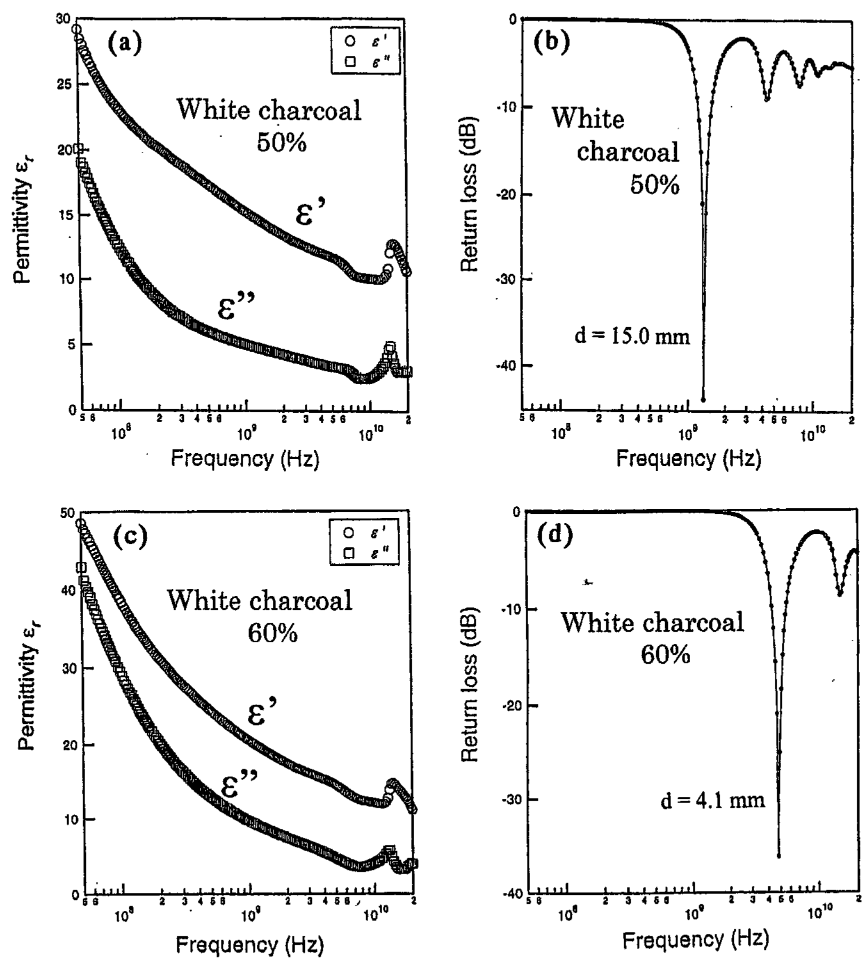

Fig.5 Electromagnetic wave absorption characteristics of polyester resin/white charcoal powder composite specimens. (a)(b)50% white charcoal powder specimen, (c)(d)60% white charcoal powder specimen.

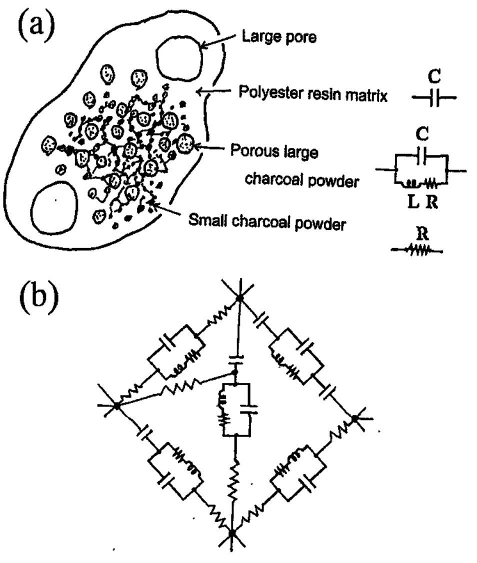

Fig.6 Explanation of the electromagnetic wave absorption mechanism in the polyester resin/ white charcoal powder composite. (a)schematic representation of the microstructure, (b)equivalent electrical circuit.

Figure 6(a) shows the schematic representation of the microstructure in the composite specimen. A porous large charcoal powder particle acts electrically as an impedance circuit consistent of condenser, resistance and inductance [5] and a small charcoal powder particle acts as a resistance. Moreover, unsaturated polyester resin matrix areas exist among charcoal powders act as condensers. Therefore, the equivalent electrical circuit is considered as shown in Fig.6(b). In this study, the resistivities of the specimens which showed the remarkable electromagnetic wave absorption were 5 x 10^2 Ωcm (50% white charcoal) and 2 x 10^2 Ωcm (60% white charcoal) as shown in Fig.4. Therefore, it is thought that that the suitable electrical resistivity (of the order of 10^2 Ωcm) and high permittivity are needed for the remarkable absorption.

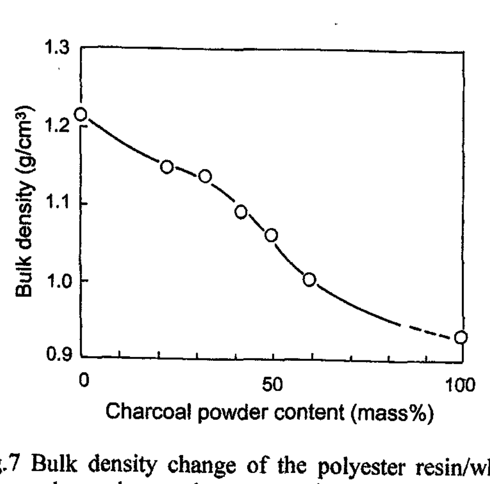

Fig.7 Bulk density change of the polyester resin/white charcoal powder composite with increasing charcoal powder content.

Figure 7 shows the bulk density change of the composite specimen with increasing white charcoal powder. The bulk density decreased with increasing amount of charcoal powder, namely 1.2 g/cm^3 for 0% charcoal powder and 1.0 g/cm^3 for 60% charcoal powder.

4. SUMMARY

In order to develop the superior material to absorb the high frequency electromagnetic waves of GHz range, we tried to make the composite material consistent of unsaturated polyester resin and white charcoal powder. The remarkable absorption of 40 – 50 dB was observed in the composite specimens containing 50% and 60% of white charcoal powders. The frequencies at the peak absorptions were 1 GHz (50% white charcoal specimen) and 5 GHz (60% white charcoal specimen). The electrical resistivities of both composite specimens are 5 x 10^2 Ωcm (50% white charcoal powder) and 2 x 10^2 Ωcm (60% white charcoal powder). A porous large white charcoal powder particle in the composite specimen acts as an impedance consistent of condenser, resistance and inductance in the electrical circuit and a small one acts as a resistance. Moreover, the unsaturated polyester resin areas exist among white charcoal powders act as condensers. It is clarified from this study that the suitable electrical resistivity (2 - 5 x 10^2 Ωcm) and high permittivity are needed for producing the remarkable absorption.

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