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Electromagnetic Wave Absorption Characteristics of Bincho-Charcoal and Bamboo Charcoal

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The electromagnetic wave absorption characteristics of Bincho-charcoals and bamboo charcoals made by carbonizing Ubame-oak and Mousou-bamboo at the temperatures of 550 to 1100 ℃ were measured by a network analyzer accompanied by electrical resistivity measurement, X-ray diffraction analysis and SEM observation. The electrical resistivities of Bincho-charcoal and bamboo charcoal decreased remarkably with increasing carbonization temperature in the same tendency, namely 4 x 10^2 Ωcm at 600 ℃ and 8 Ω cm at 650 ℃, respectively. The permittivities (ε_r' and ε_r") of both charcoals increased with increasing carbonization temperature. Large absorptions (about 50 dB) were observed in both charcoals carbonized at 600 and 650 ℃. The frequencies of peak absorptions of both charcoals shifted to higher frequency side with increasing carbonization temperature, 1-3 GHz at 600 ℃ and 8-13 GHz at 650 ℃.

Key words: charcoal, bamboo charcoal, electromagnetic wave absorption, carbonization temperature, electrical resistivity, X-ray diffraction, density, 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 phone and local area network. As a result, high frequency electromagnetic waves from such new system 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.

In the previous study [1] , we clarified that the Woodceramics (WCS) board carbonized at 650 ℃ showed the remarkable electromagnetic absorption (about 50 dB) at about 7 GHz. Woodceramics are new porous carbon materials which are made by carbonizing wood or woody materials such as MDFs (medium-density fiberboards) impregnated with liquid phenolic resin in a vacuum furnace [2]. The impregnated phenolic resin changes into hard glassy carbon during carbonizing process and reinforces the soft charcoal which originates from wood fibers in the MDF.

Through the previous study [1], we have believed that even the ordinary charcoal or bamboo charcoal without artificial glassy carbon originated from phenolic resin could absorb electromagnetic wave if the suitable carbonization temperature is adopted. Therefore, in this study, the electromagnetic wave absorption characteristics of the Bincho-charcoal* and bamboo charcoal, which were made by carbonizing Ubame-oak and Mousou-bamboo, were measured in order to certify the correctness of our supposition.

*In this paper, we name all the charcoal made by carbonizing Ubame-oak as Bincho-charcoal.

2. EXPERIMENTAL

Disc shape Ubame-oak specimens (50mm diameter x 15 mm thick along growth direction) and rectangular Mousou-bamboo specimens (50 mm long along growth direction x 10 mm wide along circumferential direction x 15 mm thick) were carbonized in an electrical furnace under low vacuum (about 8 MPa) at 550 – 800 ℃ for 4 h. The heating speed was 1 ℃/min. The commercial Bincho-charcoal made at Tanabe city (white charcoal carbonized at about 1100℃) was also examined.

After carbonization, X-ray powder diffraction analyses, SEM observations, electrical resistivity measurements, density measurements and electro magnetic wave absorption characteristics measurements were performed for these specimens.

Test pieces (cylindrical shape of inner diameter 3 mm, outer diameter 7 mm and length 5 mm) for measuring the electromagnetic wave absorption characteristics by the coaxial cable method were formed in parallel with the growth direction of the oak and bamboo by ultrasonic machining.

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. [3].

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 Bincho-charcoal and bamboo charcoal specimens and absorption curves were plotted

[4]. The reflection coefficient (Γ) and return loss (absorption) were calculated by the following equation [3],

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

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

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

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

Here, Z_m and Z_0 are the surface impedance of the absorber and the characteristic impedance of the free space(air), respectively. The d, λ_0 and λ_d are 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 woodceramics and charcoal scarcely show magnetic property [2].

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

2. RESULTS AND DISCUSSION

Figure 1 shows SEM microstructures of Bincho-charcoal specimens carbonized at 550 ℃ (a) and 800 ℃ (b). The sizes of large ducts (arrow mark A) and small ducts (arrow mark B) were reduced with increasing carbonization temperature.

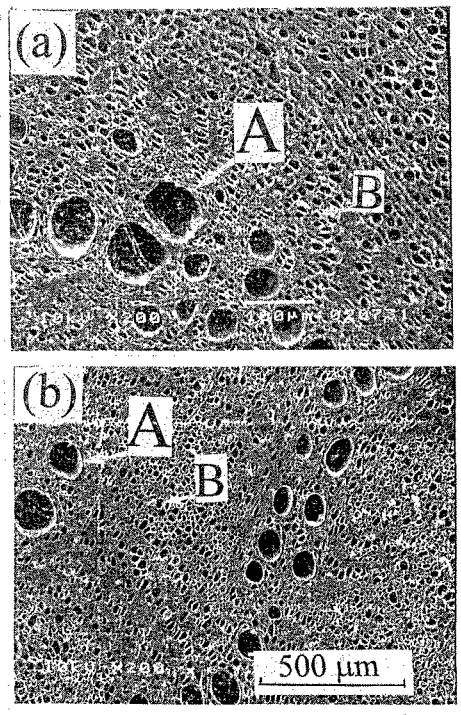

Fig.1 SEM microstructures of Bincho-charcoal specimens carbonized at 550℃ (a) and 800℃ (b).

Figure 2 shows SEM microstructures of bamboo charcoal specimens carbonized at 550℃ (a) and 800℃ (b). The sizes of ducts (arrow mark A) and sieve-like duct (arrow mark B) were slightly decreased with increasing carbonization temperature.

Figure 3 shows the change in bulk density with increasing carbonization temperature. Bulk densities of Bincho-charcoal and bamboo charcoal decreased first by the carbonization under 500℃, then increased by the

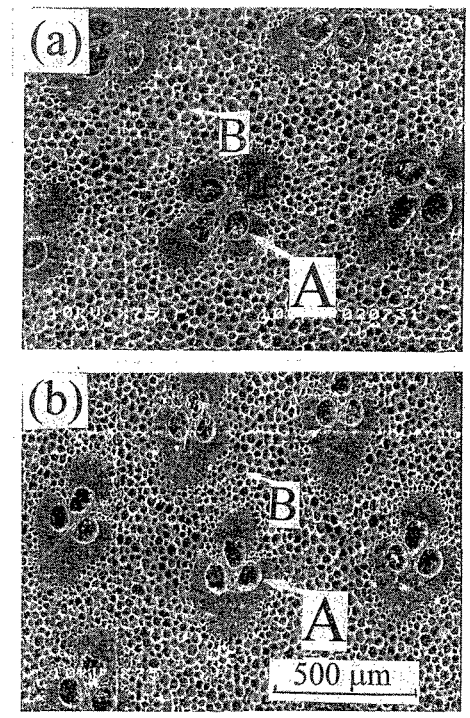

Fig.2 SEM microstructures of bamboo charcoal specimens carbonized at 550℃ (a) and 800℃ (b).

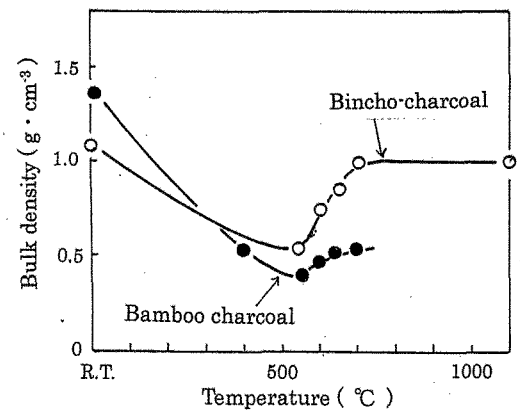

Fig.3 Changes in bulk densities of the Bincho-charcoal and bamboo charcoal with increasing carbonization temperature.

carbonization at 550 – 800℃, and kept the constant values over 800℃, namely about 1.0 g • cm^{-3} for the Bincho-charcoal and 0.5 g • cm^{-3} for bamboo charcoal, respectively.

Figures 4 and 5 show the X-ray powder diffraction patterns of Bincho-charcoals and bamboo charcoals carbonized at 550 – 700℃. The broad peaks from the (002) planes of the amorphous graphite in the Bincho-charcoal and bamboo charcoal shifted to higher angles with increasing temperature. Several sharp peaks (arrow marks) besides main broad peaks from (002) and (100)/(101) planes of amorphous graphite appeared in

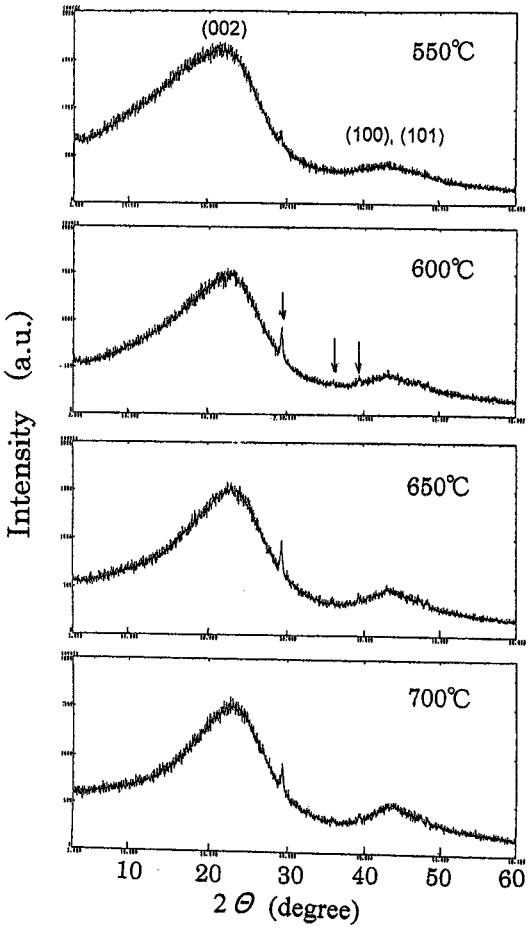

Fig.4 X-ray powder diffraction patterns of the Bincho-charcoal specimens carbonized at 550 – 700℃.

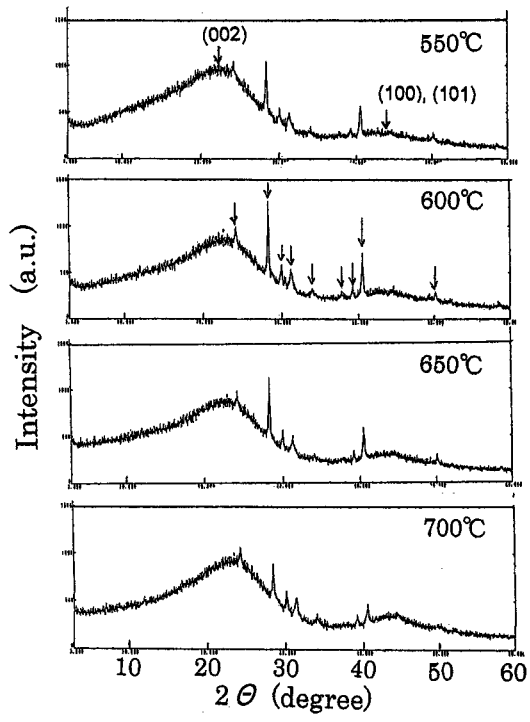

Fig.5 X-ray powder diffraction patterns of the bamboo charcoal specimens carbonized at 550 – 700℃.

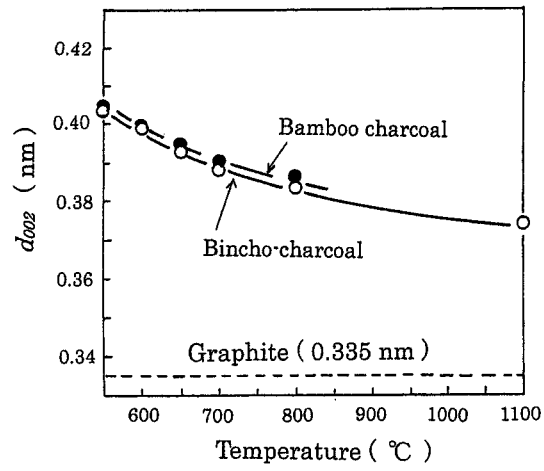

Fig.6 Changes in lattice spacing d_{200} of the Bincho-charcoal and bamboo charcoal with increasing temperature.

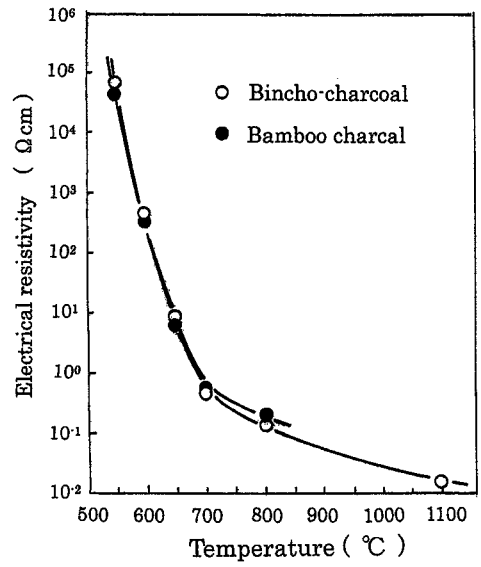

Fig.7 Changes in electrical resistivities of the Bincho-charcoal and bamboo charcoal with increasing carbonization temperature.

the X-ray diffraction patterns of the Bincho-charcoal and bamboo charcoal. The intensities of these sharp peaks were strongest in the specimens carbonized at 600℃. These sharp peaks seem to be originated from intermediate products at the formation process of the Bincho-charcoal and bamboo charcoal. However, in this study we could not identified the names of the intermediate products.

Figure 6 shows the change in lattice spacing $d_{(002)}$ of amorphous graphite in the Bincho-charcoal and bamboo charcoal. The lattice spacings of both charcoals decreased with increasing temperature in the nearly same manner.

Figure 7 shows the electrical resistivity changes of the Bincho-charcoal and bamboo charcoal with increasing carbonization temperature. The electrical

resistivities of both charcoals decreased with increasing temperature in the nearly same manner.

Figure 8 shows the electromagnetic wave absorption characteristics (permittivity and return loss) of the Bincho-charcoal specimens carbonized at 600 and 650℃. Both the real part (ε ') and imaginary part(ε ") of the complex permittivity were increased with increasing carbonization temperature ((a) and (b)). The maximum absorption (return loss) calculated from these permittivities were 50 dB at about 1GHz for the specimen carbonized at 600℃ (c) and 45 dB at 13 GHz for that at 650℃ (d). No absorption were appeared for the specimens carbonized at another temperatures.

Figure 9 shows the electromagnetic wave absorption characteristics (permittivity and return loss) of the Bamboo charcoal specimens carbonized at 600 and 650℃. Both the real part (ε ') and imaginary part(ε ") of the complex permittivity were increased with increasing carbonization temperature ((a) and(b)). The maximum absorption (return loss) calculated from these permittivities were 50 dB at about 3 GHz for the specimen carbonized at 600℃ (c) and 60 dB at 8 GHz for that at 650℃ (d). No absorption were appeared for the specimens carbonized at another temperatures.

It is suggested that the total wave energy loss of electrical resistance loss and dielectric loss was maximum in the both charcoal specimens carbonized at 600℃ and 650℃

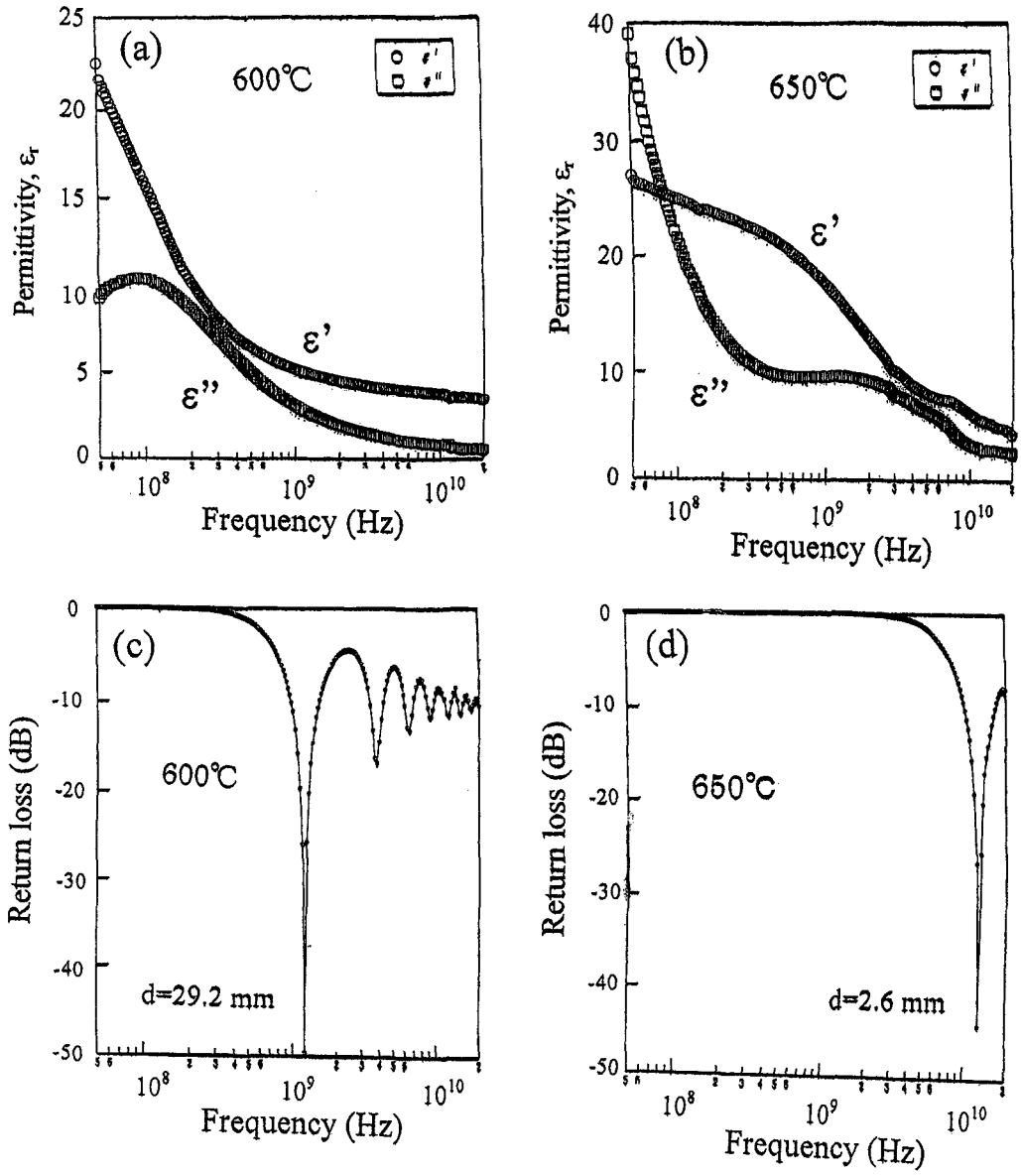

Fig.8 Electromagnetic wave absorption characteristics (permittivity and return loss) of the Bincho-charcoal specimens carbonized at 600℃ ((a) and (c)) and 650℃ ((b) and (d)). The value of d in the figure denotes the thickness needed for the peak absorption.

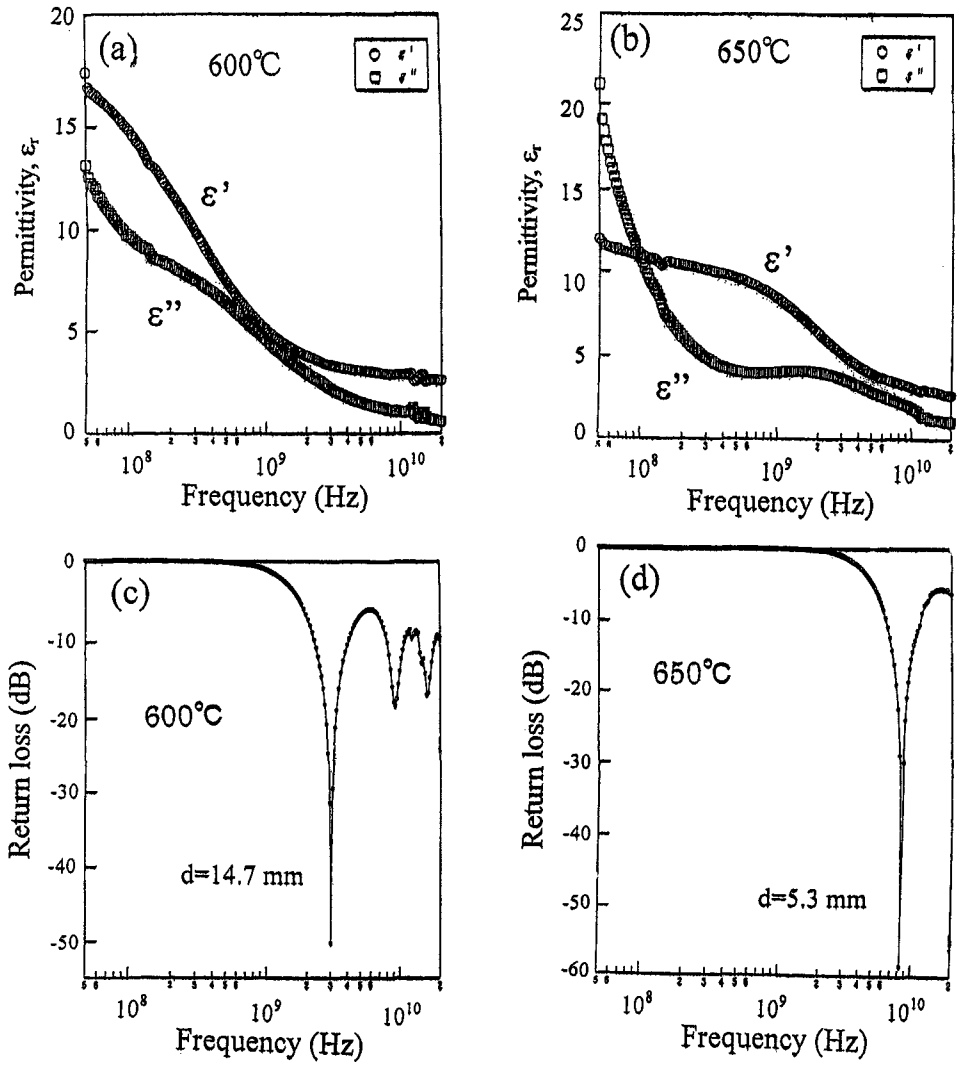

Fig.9 Electromagnetic wave absorption characteristics (permittivity and return loss) of the bamboo charcoal specimens carbonized at 600℃ ((a) and (c)) and 650℃ ((b) and (d)). The value of d in the figure denotes the thickness needed for the peak absorption.

4. SUMMARY

The Bincho-charcoal and bamboo charcoal carbonized at 600℃ and 650℃ absorbed remarkably the electromagnetic wave, about 50 dB. The frequencies of the peak absorption of both charcoals shifted to higher side with increasing carbonization temperature, namely 1-3 GHz at 600℃ and 8-13 GHz at 650℃. However, those carbonized at the other temperatures scarcely absorbed the electromagnetic wave. The reason why the maximum absorption was obtained in the charcoals carbonized at 600 – 650℃ is probably ascribed to the suitable electrical resistivity (about 10^2 Ω cm) and permittivity of these charcoals.

Thus, both charcoals were nearly the same absorption characteristics. However, the densities of bamboo charcoal and Bincho-charcoal are about 0.5 g/cm^3 and 1.0 g/cm^3, respectively. Therefore, in the case of developing the new type of absorber using these charcoal powders, the bamboo charcoal seems to be superior to the Bincho-charcoal in the respect of its lightness.

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