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# Electromagnetic Wave Absorption Characteristics of Woodceramics

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The electromagnetic wave absorption characteristics of woodceramics boards carbonized at relatively low temperatures (600, 650, 700, 750 and 800℃) were measured mainly by a network analyzer with an attachment for measuring S-parameter (complex reflection coefficient) and discussed in connection with the electrical resistivity, lattice parameter, bulk density and SEM microstructure changes. The electrical resistivity and lattice parameter decreased with increasing carbonization temperature. The bulk density increased with increasing carbonization temperature. The woodceramics boards carbonized at 650-700℃ showed remarkable absorption (about 50 dB) at the frequency of about 7 GHz. The peak frequency and the amount of absorption decreased with increasing carbonization temperature. The boards carbonized at 750-800℃ showed the absorption of about 40 dB at the frequency of about 0.8 GHz. The board carbonized at 600℃ scarcely showed absorption characteristics.

Key words: woodceramics, electromagnetic wave absorption, carbonization temperature, electrical resistivity, X-ray diffraction, density

## 1. INTRODUCTION

Woodceramics are new porous carbon materials which are made by carbonizing wood or woody materials such as MDFs (medium-density fiberboards) impregnated with phenolic resin in a vacuum furnace[1]. The impregnated phenolic resin changes into hard glassy carbon during carbonizing process and reinforces the soft charcoal which originated from wood fibers in the MDF.

As woodceramics have superior mechanical properties[2], wear properties[3], electrical properties[4] and electromagnetic shielding properties[5], they are going to be used in many kinds of industrial fields.

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 has been needed.

It is well known that the woodceramics carbonized at the temperatures above 800 ℃ show metallic properties (relatively high electrical conductivity and electromagnetic wave shielding property) [5]. However, it has not been clarified whether the woodceramics have electromagnetic wave absorbing property. We have supposed that the woodceramics carbonized at relatively low temperatures below 800 ℃ will show the electromagnetic wave absorbing property, because the woodceramics carbonized at such low temperatures have been reported to show semi-conductive properties[1].

In this study, the electromagnetic wave absorbing properties of the woodceramics carbonized at 600, 650, 700, 750 and 800℃ were measured by the coaxial cable method using a network-analyzer with an instrument for measuring S parameter (complex reflection coefficient) [6] and also the free space method [7].

## 2. EXPERIMENTAL

Woodceramics specimen boards were made by carbonizing the moderate density fiber boards impregnated with phenolic resin solution (impregnation percentage of phenolic resin : 50mass%) at 600, 650, 700, 750 and 800℃ for 4 h. The heating rate for carbonizing was 1℃/min. Test pieces (cylindrical shape of inner diameter 3mm, outer diameter 7 mm and length 5 mm) for measuring the electromagnetic wave absorption characteristics by the coaxial cable method were formed from these woodceramics boards by ultrasonic machining. The schematic representation of 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 ($\Gamma$), return loss and absorption curves) were calculated for the metal backed woodceramics specimen and absorption curves were plotted [8]. The reflection coefficient ($\Gamma$) and return loss (absorption) were

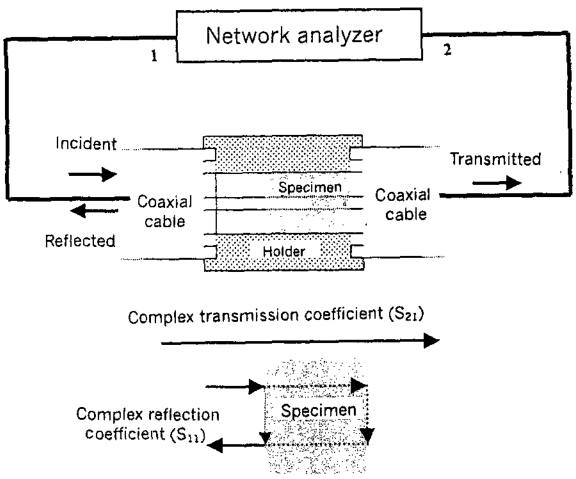


Fig.1 Schematic representation of the coaxial cable method for measuring the absorption of electromagnetic wave by woodceramics specimen.

calculated by the following equation [6],

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

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

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

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

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, $\lambda_0$ and $\lambda_d$ were the thickness of the absorber, the wave lengths in air and the absorber, respectively. In this study, the complex permeability ($\mu_r$) was calculated as 1.0, because the woodceramics scarcely show magnetic property [1].

Moreover, another method (the free space method) was performed by using large size woodceramics board (320 x 320 x 26 mm$^3$) carbonized at 650℃ for 4 h. **Figure 2** shows the schematic representation of the free spase method. The wave sent from an antenna at the incidence angle(θ) of 30° is reflected from the front and back surfaces of the woodceramics. The return loss (absorption) was calculated by the following equation[7].

$$\text{Return loss} = -20 \log (E_s / E_r) \quad \text{(dB)}$$

Here, $E_s$ and $E_r$ are the electric fields of the waves reflected from the woodceramics surfaces and from the reference metal (aluminum board) with same size of the woodceramics board specimen, respectively. The distance between the antenna and the specimen was 1 m.

Moreover, the electrical resistivity and bulk density measurements, the X-ray diffraction analysis and the scanning electron microscopic (SEM) observation were also performed for those carbonized woodceramics. The electrical resistivity was measured by the four terminal method (specimen size : 2 x 2 x 70 mm$^3$). As the structural and physical inhomogeneity exists between the near-surface and inner (central) regions of the thick woodceramics board, the mean value of the measurements of the specimens obtained from both regions was adopted. The bulk density was calculated from the weight of the woodceramics board of 150 x 150 x 15 mm$^3$ in volume.

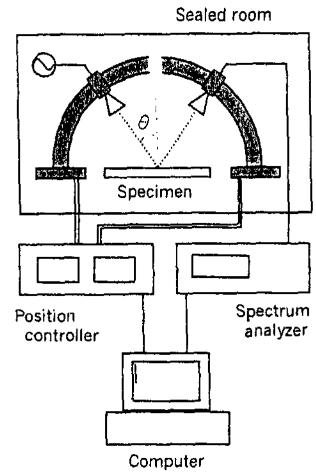


Fig.2 Schematic representation of the free space method for measuring the absorption of the electromagnetic wave by woodceramics board.

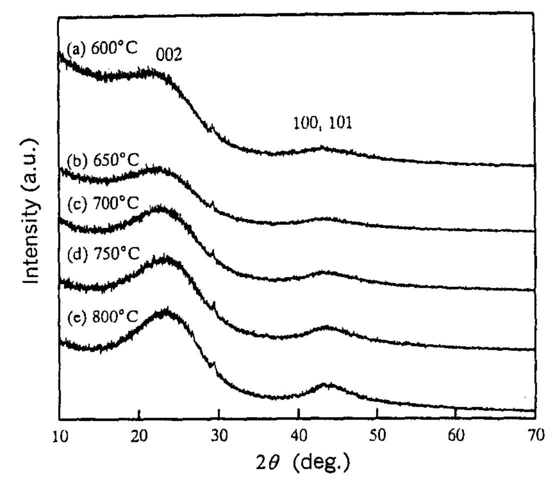


Fig.3 X-ray diffraction patterns of the woodceramics carbonized at various temperatures.

## 3. RESULTS AND DISCUSSION

**Figure 3** shows X-ray diffraction patterns of the woodceramics carbonized at various temperatures. Every peaks are broad and this results show that these woodceramics are amorphous carbon with near graphite structure. As these peaks became sharper with increasing carbonization temperature, the amorphous structure in the woodceramics seems to have progressed more and more to the graphite carbon structure. Moreover, these peaks shifted to higher angle with increasing carbonization temperature, meaning the decrease in the lattice spacing of the woodceramics.

**Figure 4** shows the change in lattice spacing of (002) plane ($d_{002}$) of the woodceramics carbonized at various temperatures. The lattice spacing ($d_{002}$) changed from 0.397 to 0.377 nm with increasing carbonization temperature from 600℃ to 800℃. However, the lattice spacing of the graphite denoted by a dotted line ($d_{002}$ = 0.335 nm) is about 12.5% smaller than that of the woodceramics carbonized at 800℃. The carbon

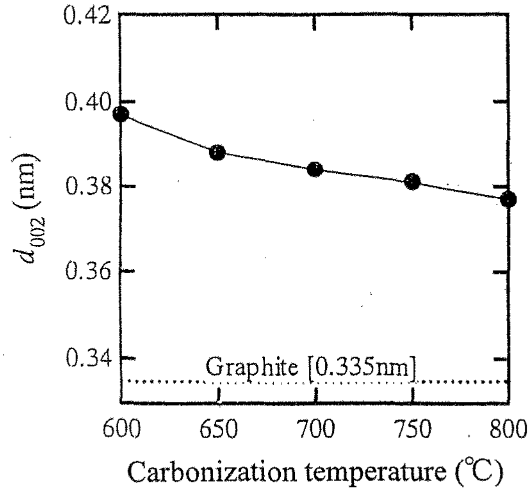


Fig.4 Change in lattice parameter ($d_{002}$) of woodceramics with increasing carbonization temperature.

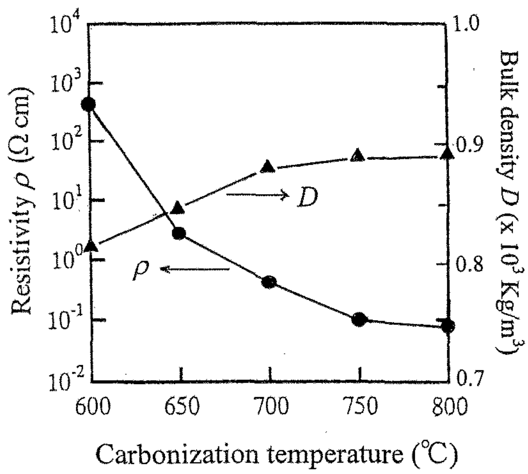


Fig.5 Changes in bulk density ($D$) and electrical resistivity ($\rho$) of woodceramics with increasing carbonization temperature.

originated from the phenolic resin seems to suppress the graphitization.

**Figure 5** shows changes in bulk density and electrical resistivity of the woodceramics specimen with increasing carbonization temperature. The bulk density increased gradually from 0.81 to 0.89 x $10^3$ Kg/m$^3$ with increasing carbonization temperature from 600 to 800 ℃. Inversely, the electrical resistivity decreased gradually with increasing carbonization temperature from 600 to 800℃.

**Figure 6** shows the changes in permittivities ( $\varepsilon_r$' and $\varepsilon_r$") of woodceramics carbonized at various temperatures with increasing frequency. The $\varepsilon_r$' and $\varepsilon_r$" show the real part and imaginary part of the complex permittivity, respectively. The permittivity of the woodceramics carbonized at 600℃ showed the lowest value at the low frequency range (near $10^8$ Hz) and decreased gradually with increasing frequency. In the frequency range below 3 x $10^8$ Hz, the specimens carbonized at higher temperatures showed the higher permittivity values, however, in the higher frequency range ($10^9$ – $10^{10}$ Hz), the permittivities of the specimens

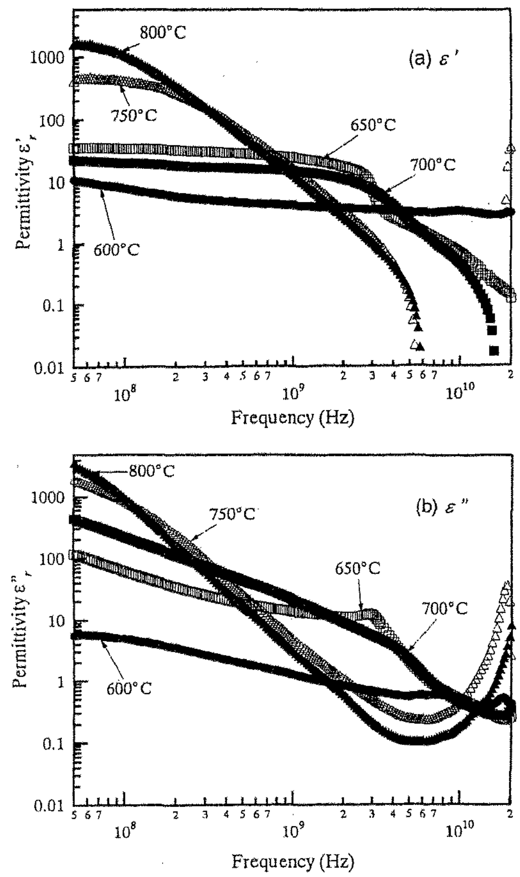


Fig.6 Changes in permittivity ( $\varepsilon_r$', $\varepsilon_r$") of woodceramics carbonized at various temperatures with increasing frequency.

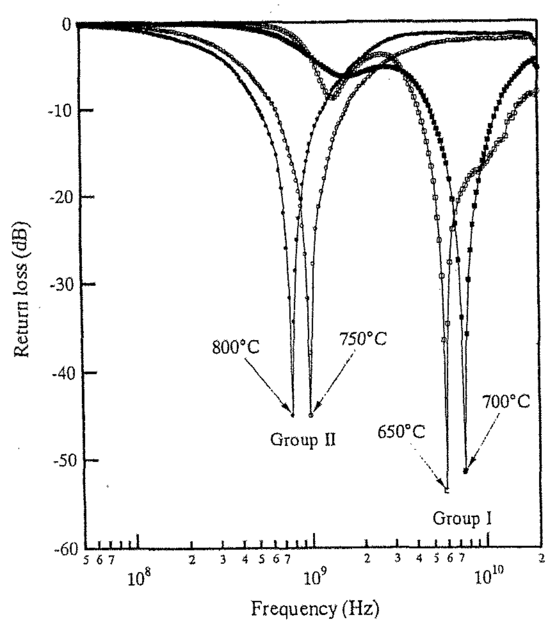


Fig.7 Absorption characteristics of woodceramics carbonized at various temperatures measured by coaxial cable method.

carbonized at higher temperature decreased remarkably with increasing frequency. As a result, the specimen carbonized at 650 and 700 ℃ showed the highest permittivity at the frequency range of $10^9 - 10^{10}$ Hz.

**Figure 7** shows the wave absorption curves of the woodceramics carbonized at 650 – 800℃. These curves were simulated by adopting the permittivity data shown in Fig.6 to the metal-backed absorber model[8]. The specimens carbonized at 650 – 700 ℃ showed the large absorption peaks (about 50 dB) at the frequency range of 6 – 8 GHz (the matching thickness for the peak frequency (wave length) [8] : 11 – 14 mm). The specimens carbonized at 750 – 800 ℃ showed the large absorption peaks (about 45 dB) at the frequency range of 0.7 – 0.9 GHz (the matching thickness for the peak frequency: 19 – 21 mm). These large absorption by the specimens carbonized at 650-700℃ seems to be caused mainly by their high permittivity values (dielectrical loss) at the frequency range of 2-8 GHz as shown in Fig.6 and their suitable electrical resistivity values for the wave absorption (ohm's loss) as shown in Fig.5.

**Figure 8** shows the SEM microstructures of the surfaces of the woodceramics specimens carbonized at 650℃ (a) and 800℃ (b). Many pores originated from wood fibers in MDF boards were observed in both photographes. However, the distribution and amount of the pore are not so different in both photographes. Therefore, it seems that the more microscopic pores, which are not able to be observe by a SEM, affect the dielectric properties of these woodceramics..

As shown in Fig.7, the woodceramics carbonized at 650℃ showed the most remarkable absorption (about 50dB) at the frequency of about 7 GHz in the case of the coaxial cable method. So, a further experiment was done in order to confirm the above result by another method (the free space method) for a large woodceramics board specimen (320 x 320 x 26 $mm^3$) carbonized at 650℃. The result is shown in **Fig.9**. The absorption was occurred at about 9 GHz, which was nearly the same frequency as that in the case of the coaxial cable method as shown in Fig.7. However, the amount of the absorption (about 7 dB) was not so large. The main reason is as follow: The most suitable specimen size for this method was 900 x 900 $mm^2$, but the specimen used in this study was too small for this method, 320 x 320 $mm^2$. Therefore, extra reflection from the specimen edges or corners might be included besides the normal surface reflection and the absorption was apparently decreased.

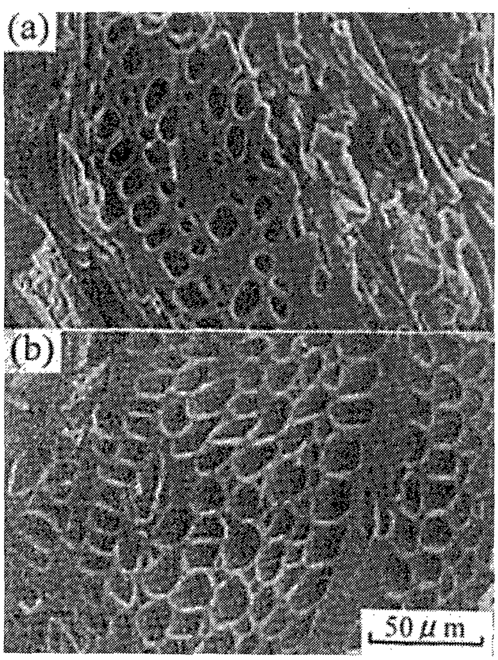


Fig.8 SEM microstructures of woodceramics carbonized at 650℃ (a) and 800℃ (b).

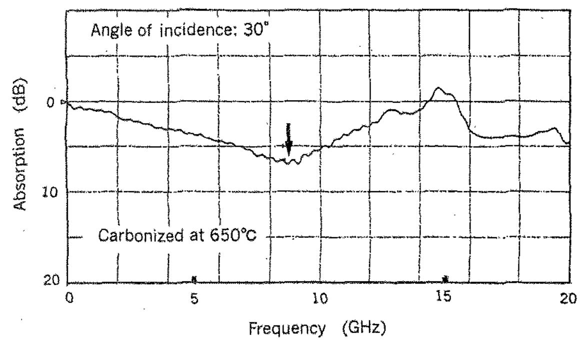


Fig.9 Absorption characteristics of the woodceramics carbonized at 650℃ measured by free space method.

## 4. SUMMARY

It was clarified, from this study, that the woodceramics boards manufactured by carbonizing the phenolic resin impregnated MDFs at the temperatures of 650 – 800℃ absorbed the electromagnetic waves of about 9 - 1 GHz.

## ACKNOELEDGEMENT

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