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Electromagnetic Wave Absorption Characteristics of Woodceramics/SiC Composites

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The electromagnetic wave absorption characteristics of woodceramics/SiC composites made by sintering the compacted mixtures of phenolic resin powder, wood powder and SiC powder were examined by a network analyzer with an attachment for measuring S-parameter (complex reflection coefficient) and discussed in connection with the bulk density, X-ray analysis, electrical resistivity and SEM microstructure. The woodceramics made by carbonizing the compacted mixture of 30 wt % phenolic resin powder and 70 wt % wood powder showed the large absorption peak (about 50 dB) at the frequency of about 2 GHz and the addition of SiC powder to the starting mixture shifted the absorption peak of the sintered composite to the higher frequency, namely 9 GHz for the specimen containing 47 % SiC. The addition of SiC accelerated the graphitization of the matrix woodceramics, increased the permittivity and bulk density, and decreased the electrical resistivity.

Key words: woodceramics, silicon carbide, composites, electromagnetic wave absorption, electrical resistivity, X-ray diffraction, density, scanning electron microscopy

1. INTRODUCTION

Woodceramics(WCS) 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 [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 WCS 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.

In the previous study [6], we clarified that the WCS board carbonized at 650 ℃ showed the remarkable electromagnetic absorption (about 50 dB) at about 7 GHz. In this study, the electromagnetic wave absorption characteristics of the WCS made by the new powder method, namely by carbonizing the compacted mixtures of 30 wt % phenolic resin powder and 70 wt % wood powder, were measured by the coaxial cable method using a network-analyzer with an instrument for measuring S-parameter (complex reflection coefficient) [7] as same as in the previous study. Moreover, the electromagnetic wave absorption characteristics of WCS/SiC composites made by adding SiC powder into the starting powder mixture were also examined, since it was reported by O.Hashimoto [8] that the plastic sheet reinforced by SiC fibers showed the superior electromagnetic wave absorption characteristics at about 50 GHz.

2. EXPERIMENTAL

Table 1 Compositions of starting mixtures. (wt %)

No.	Ph	W	SiC	W : SiC
C1	30.0	70.0	0	1 : 0
C2	30.0	46.7	23.3	2 : 1
C3	30.0	35.0	35.0	1 : 1
C4	30.0	23.3	46.7	1 : 2
C5*	30.0	0	70.0	0 : 1
A5	10.0	0	90.0	0 : 1

Ph : phenolic resin powder (<75 μm, shonohl)
W : wood powder (<35 mesh)
SiC : SiC powder (α-SiC, 6H, mean 38 μm)
C5* ; swelled out and could not be examined

The WCS and WCS/SiC specimens used in this study were made by the following process. First, the starting mixtures of the compositions shown in Table 1 were compacted into tetragonal and column shapes at the pressure of 100 MPa at room temperature and then carbonized (or sintered) at 650 ℃ for 4 h. The heating speed was 1 ℃/min. The length, volume, weight and

bulk density were measured for the tetragonal shape WCS and WCS/SiC composites. 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 from the columnar WCS and WCS/SiC composites 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..

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 WCS and WCS/SiC specimen and absorption curves were plotted [9]. The reflection coefficient (Γ) and return loss (absorption) were calculated by the following equation [7],

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

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

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

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

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 woodceramics scarcely show magnetic property [1].

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 WCS and sintered WCS/SiC composites. The electrical resistivity was measured by the four probe method (JIS K7194, specimen size : 3 x 2 x 30 mm^3).

3. RESULTS AND DISCUSSION

Figure 1 shows SEM microstructures of the typical specimens carbonized (sintered) at 650 ℃. In the case of the specimen without SiC (a), only porous sponge like structure was observed. However, in the case of the specimen with SiC (b), angular particles (arrow marks) of about 50 μm in length existed in the porous matrix. These dispersed particles seem to be SiC judging from the shape of the starting SiC powder (c).

Figure 2 shows the X-ray diffraction patterns of the specimens carbonized (sintered) at 650 ℃.The specimen without SiC, C1, showed only the broad pattern of amorphous graphite which consists of the soft charcoal originated from wood powder and the hard glassy carbon originated from phenolic resin (a). On the other hand, the specimens with SiC, C3 and C5, showed the mixed patterns of the amorphous graphite and the hexagonal α-SiC ((b)and (c)). Moreover, the diffraction peak from the (002) plane of the amorphous graphite shifted to

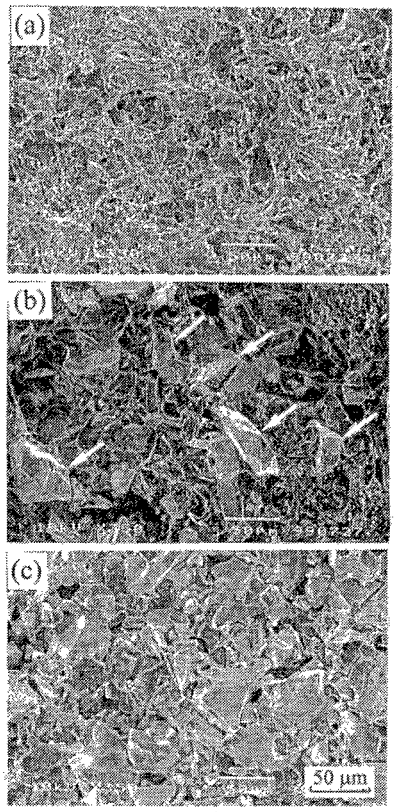

Fig.1 SEM microstructures of the specimens carbonized (sintered) at 650 ℃. (a)C1, (b)C4 and (c)A5.

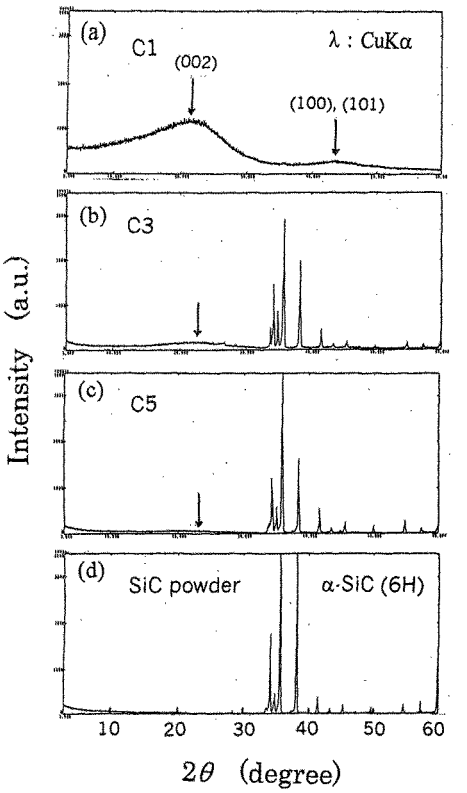

Fig.2 X-ray powder diffraction patterns of the specimens carbonized (sintered) at 650 ℃ and the starting SiC powder.

higher angle, suggesting the decrease in lattice parameter $d_{(002)}$.

The result is shown in **Fig.3**. The lattice parameter $d_{(002)}$ decreased from 0.413 (0 % SiC) to 0.387 nm (70 % SiC) with increasing SiC content. The reason may be due to the catalytic graphitization by SiC particles.

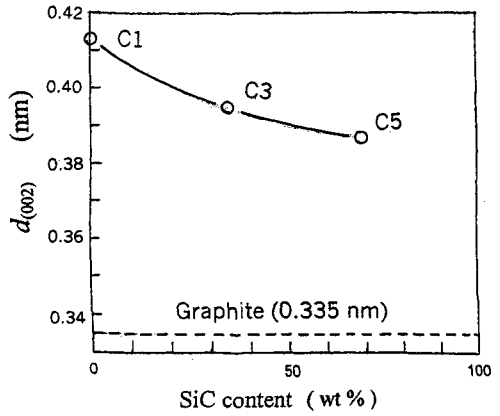

Fig.3 Change in lattice parameter (d_{002}) of woodceramics matrix in the specimens carbonized (sintered) at 650 ℃ with increasing SiC content.

Figure 4 shows the frequency dependence of the permittivities (ε_r' and ε_r") and wave absorption characteristics of the specimens carbonized (sintered) at 650℃. From Figs.4(a), (b) and (c), it is evident that the permittivities (ε_r' and ε_r") decrease with increasing wave frequency and increase remarkably with increasing SiC content. Moreover, the changing point (arrow mark) of the slope of the ε_r" curve shifted to higher frequency with increasing SiC content. As a result, the wave absorption peak calculated from the above permittivity value shifted to higher frequency with increasing SiC content (Figs.4(d), (e), (f))

Figure 5 shows the relation between the peak frequency of the wave absorption and the SiC content. The peak frequency of the WCS/SiC composite increased from about 2 GHz (0 % SiC) to 9 GHz (47 % SiC) with increasing SiC content..

Figure 6 shows the relation between electrical resistivity and the SiC content. The resistivity decreased from 1.2 x 10^3 Ω · cm (0 % SiC) to 1.8 x 10^2 Ω · cm (47 % SiC) with increasing SiC content. The reasons may be due to the increase in volume fraction of the SiC particle with lower resistivity than the amorphous matrix graphite (WCS) and the acceleration of the graphitization of the matrix WCS by the existence of the SiC particles.

Figure 7 shows the relation between the volume (length) change and the SiC content. The volume change

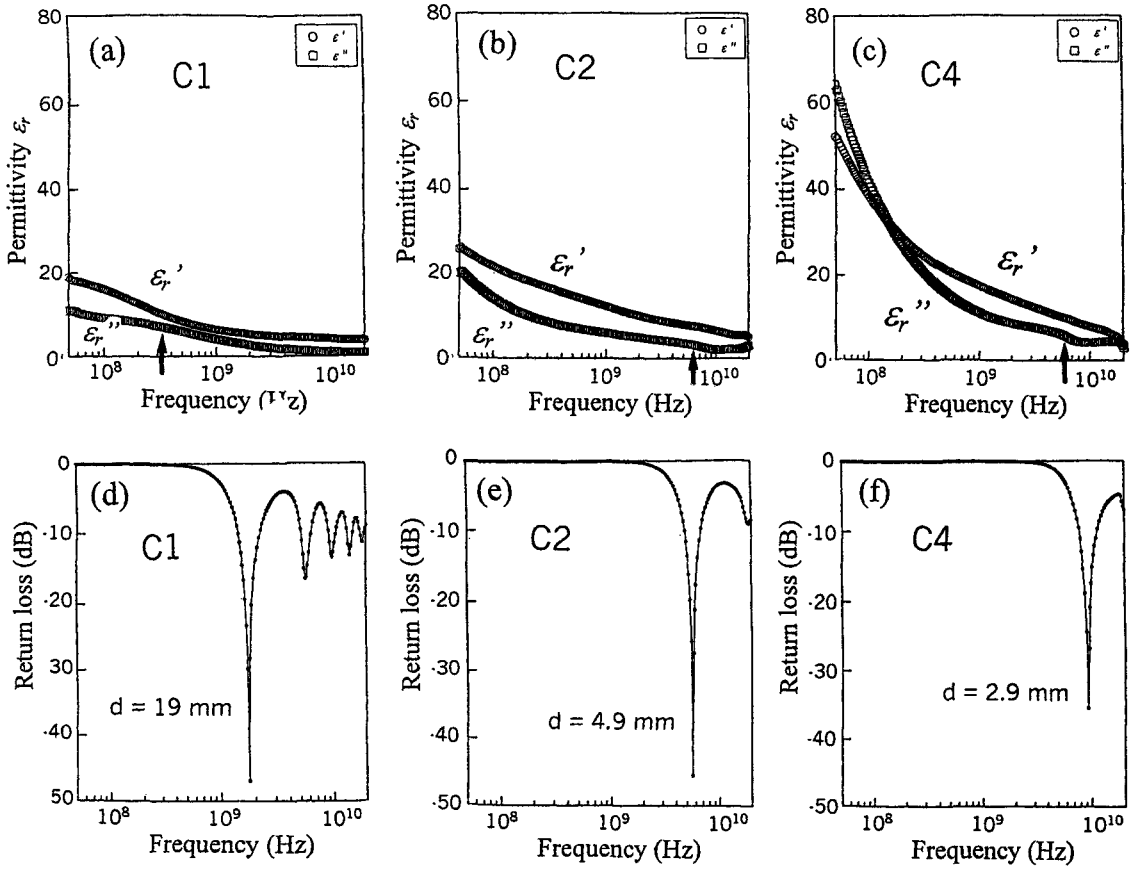

Fig.4 Frequency dependence of permittivities (ε_r' and ε_r") and wave absorption characteristics of the specimens carbonized (sintered) at 650℃. The value of d in the figure denotes the thickness needed for the peak absorption.

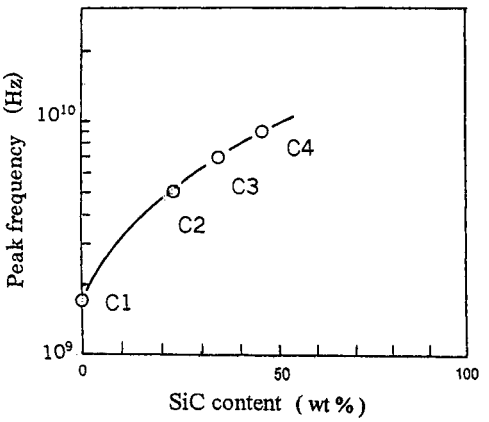

Fig.5 Relation between peak frequency of wave absorption and SiC content.

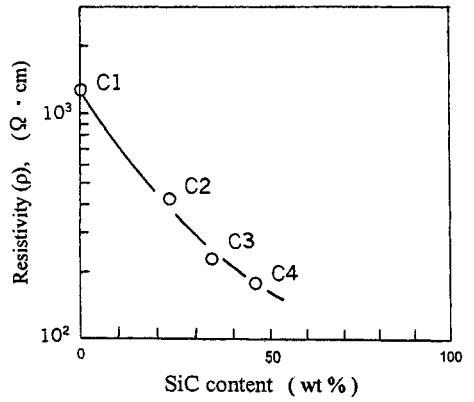

Fig.6 Relation between electrical resistivity of the specimens carbonized (sintered) at 650 ℃ and SiC content.

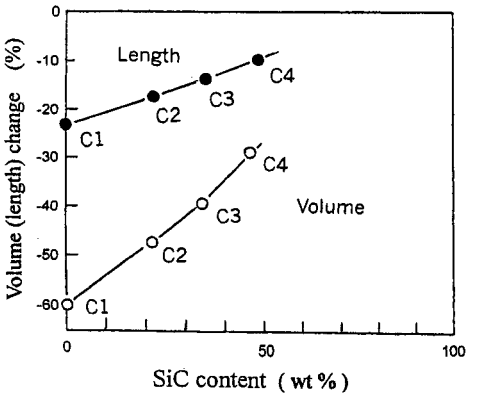

Fig.7 Relation between volume (length) change of the specimens carbonized (sintered) at 650 ℃ and SiC content.

and length change decreased with increasing SiC content. The reason will be due to the little structural change of the SiC powders in contrast to the large structural change of the wood and phenolic resin powders during sintering process.

Figure 8 shows the relation between the bulk density of the specimens carbonized (sintered) at 650 ℃ and the SiC content. The bulk density increased from 0.80 g • cm^{-3} (0 % SiC) to 1.4 g • cm^{-3} (47 % SiC) with increasing SiC content.

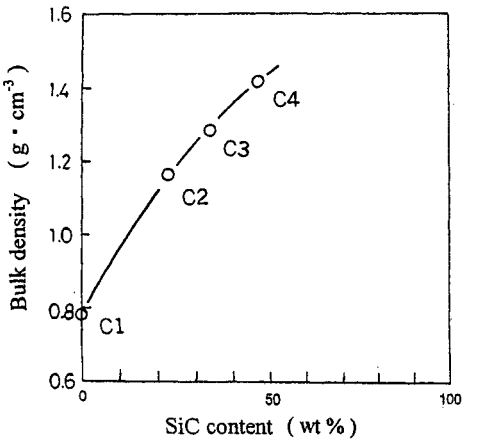

Fig.8 Relation between bulk density of the specimens carbonized (sintered) at 650 ℃ and SiC content.

4. SUMMARY

The woodceramics obtained by the powder method, namely carbonizing at 650℃ the compacted mixture of 30 % phenolic resin powder and 70 % wood powder showed the superior absorption (about 50dB) to the electromagnetic wave of about 2 GHz. The addition of SiC powder in the starting mixture increased the permittivity of the sintered specimen and shifted the absorption peak to higher frequency with increasing SiC content. The specimen with 47 % SiC showed the large absorption peak (about 35 dB) at about 9 GHz.

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