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Effects of Density on Electrical Characteristics of Woodceramics as Far Infrared Heater

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Woodceramics (WCS) are porous carbon materials, where electrical resistance can be widely controlled by changing the baking temperature. This provides a variety of application for WCS, such as humidity sensor and heater. However, the relation between density of WCS and their electrical characteristics has not been elucidated until now. The relation between the density and electrical characteristics for WCS has been studied as far infrared heater. The spectral distribution of WCS energy radiation has been measured at 180℃ for the sample baked at 800℃, that is in good agreement with the blackbody for the emission range between 5 μ m and 25 μ m.

Key words: Woodceramics, Far Infrared Heater, Electrical Characteristics, X-ray

1. INTRODUCTION

Woodceramics (WCS) have recently attracted a great interest for many industrial applications [1,2] as ecomaterials. The WCS indicate excellent characteristics such as lightness, abrasion resistance, and environmentally conscious material with porosity and so on. Since the WCS are hard, it is also suitable as the *grinding material* [3].

The resistance of WCS changes depending on the baking temperatures [4]. Considering this characteristics WCS are attractive materials for electronic materials. The application is expected for temperature sensor, infrared heater, electromagnetic shielding material and the fuel cell.

We have started the development of WCS for the use as the far-infrared heater. The metrology for WCS has not been established yet although the measurement of the density for WCS is important.

We used four-point probe method being not influenced by the contact resistance on the surface as a measuring method of resistance. Measurements of electrical capacitance of WCS were also carried out. The density effect of WCS on the electrical characteristics is discussed. The possibility of WCS as the far-infrared heater is also discussed.

2. EXPERIMENTAL

2.1 Sample preparation

Medium Density Fiberboard (MDF) was used here as a starting material for WCS. Phenolic resin (PX-1600, HONEN Corp.), the thermosetting resin, was used as a binder. MDF was soaked into the phenol liquid, and then, ultrasonic soaking was done in the vacuum for one hour, and, in addition, for 23 hours. The average phenolic resin soaking ratio was 68.9% by weight. After extra resin was wiped off, samples are dried in air for 24 hours. Samples are then dried for four hours at 333K and then for four hours at 408K. The MDF which was thus stiffened were put into the vacuum furnace. Temperature of the furnace was raised to 573K at 1K per minute and was maintained for four hours. Temperature was further raised to 873K at 1K per minute. The size of the WCS used here was 46L*46W*8.6t mm.

2.2 Electrical resistance

Four-point probe method was used to measure electrical resistance of WCS using low resistance resistivity meter MCP-T600, four-point probe MCP-TP08P (Mitsubishi Chemical Corp.). The probe pin head was 2.0 mm in diameter with 5 mm pin distances. Spring pressure used was 240g.

The resistance measurement system is shown in Figure 1 using the voltage and the divided current. However, resistance changes by the shape, the size, and the position, etc. An accurate, electrical resistance can be obtained by the correction using the resistance modification coefficients from the shape and the position where the material is measured.

Relations between resistance and resistivity are described as follows:

$$R=V/I \qquad \rho v=R*RCF*t$$
$$\rho s=R*RCF=\rho v*1/t \qquad \sigma=1/\rho v$$

with resistance R [Ω], voltage V [V], electric current I [A], volume resistivity ρv [Ω・cm], resistivity correction factor RCF, thickness t [cm], surface resistivity ρs [Ω/□], and conductivity σ [S/cm].

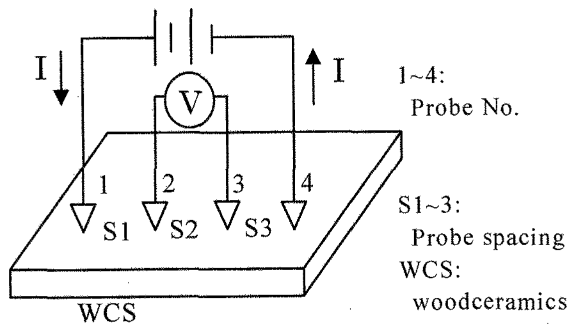

Fig.1 Equivalent circuit of four-point probe method

Figure 2 represents 2 dimensional (D) resistance topography with positions for WCS before annealing. The result indicates two mountain like peaks with 195Ω and 198Ω at 5- S4 and 5- S2, respectively. It has been observed that the resistance is higher at the center part while the resistance is lower at the surrounding edge.

Figure 3 shows the 2D resistance topography of the sample after annealing for 20 minutes at 435K. Two mountain like sharp peaks of 68Ω at 4- S4 and 69Ω at 5-S2 were measured. The inside center region is gradient material where the resistance is higher, while the resistance is lower at the surrounding edge. After annealing the resistance became smaller to about 1/3.

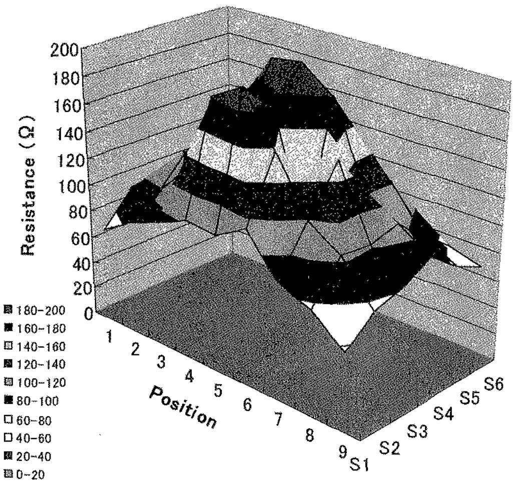

Fig.2 2D electrical resistance of WCS plate (with correction) before annealing

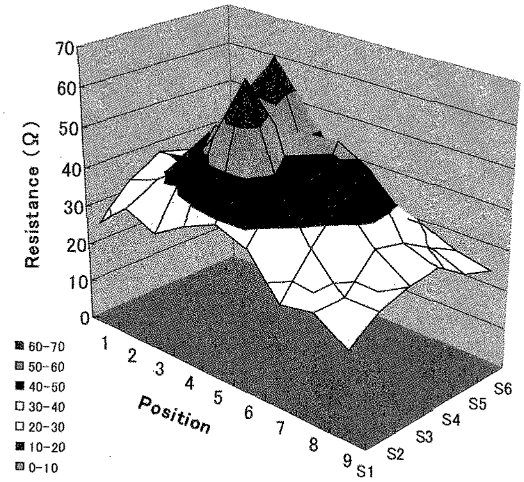

Fig.3 2D electrical resistance at each position after annealing

2.3 Resistance on temperature and humidity

Application to humidity sensor is expected since moisture greatly influences resistance [2]. Figure 4 demonstrates how resistance changes depending on humidity and temperature using the constant temperature and humidity chamber (SH-240, TABAI ESPEC Corp.), meters 34970A and 34901A (Agilent Technologies) . Note that WCS indicate a negative temperature coefficient like the semiconductor, and negative coefficient for humidity. It might be the best to make the humidity sensor thin. It is not possible to make temperature sensor without H_2O shielding because of the influence due to moisture [4]. It is also important that fixed current is driven on the heater because it has negative temperature coefficient and has to be avoided the reckless heat driving.

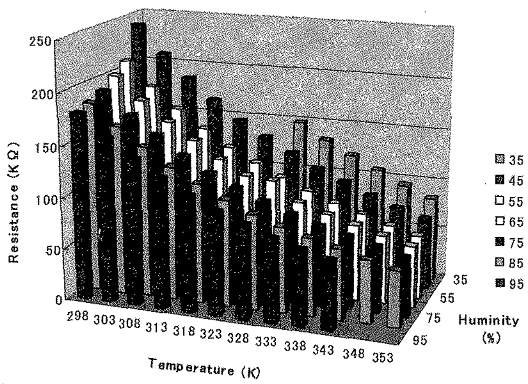

Fig.4 Change in the resistance on temperature and humidity

2.4 Power factor

Meter 2039 (Yokogawa Electric) was used as the power factor meter. A domestic power supply was used for the WCS heater of 30W. The WCS have capacitive power factors slightly. It is possible to contribute to the power factor improvement using WCS as a heater (cos θ =+0.997), with the same behavior as capacitor of 0.1 μF.

2.5 Electrostatic capacitance

20 pieces of Al electrodes with 7 mm diameter were vacuum deposited on WCS (4 pieces in length and 5 pieces in width.) at intervals of 9 mm. The electro conductive paste of silver was used for the leads connection. Meter 4263B (Agilent Technologies) was used for the LCR meter. VPC-260 (ULVAC SINKU KIKO) was used for the vacuum evaporation.

The capacitance at each position of WCS plate is shown in Figure 5. The capacitance changes depending on the frequency and the position. However, there is a tendency of smaller capacitance value at the center part. The permittivity is also lower at the center part. The cause of the change seems to be attributed to the measurement leads defect and or humidity influence.

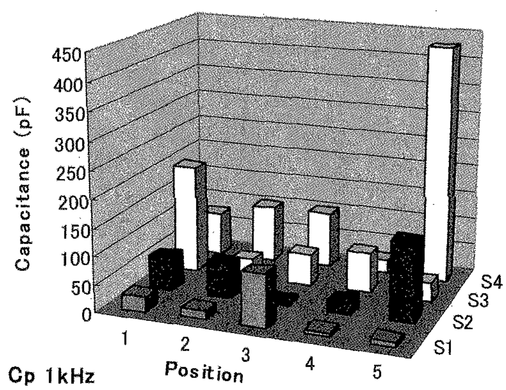

Fig.5 Electrostatic capacitance at each position (Measurement frequency of 1 kHz)

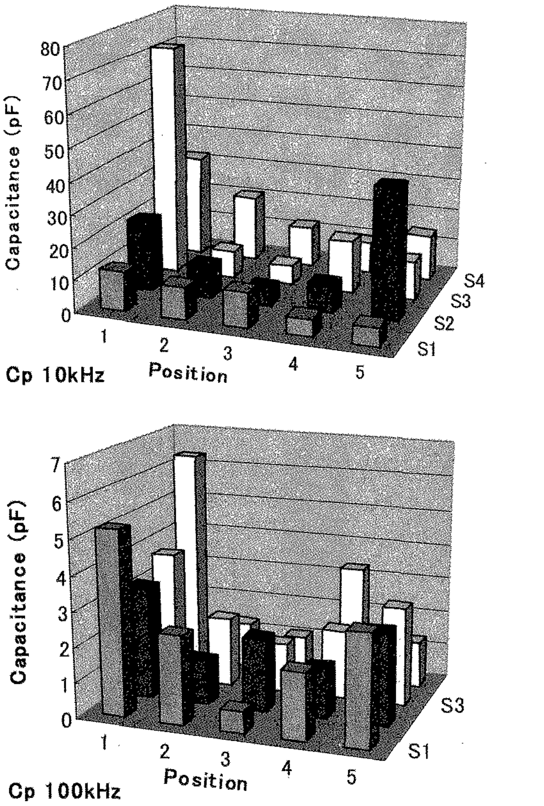

Fig.5 Electrostatic capacitance at each position (Measurement frequency of 10 k/100kHz)

2.6 Density measurement by transmission X-rays

Radiofex 130GB (RIGAKU) was used for transmission X-rays measurement[The output : 130kV、5mA]. # 100 film (Fuji Film) was used as an X-ray film. The schematics of the measurement is shown in Figure 6 and the measurement result is represented in Figure 7 .

The center part is blunt and less dense, while dense at the surrounding edge part. Note that the density is distributed like the disk denser from the center toward the edge part. Thus, an electrical characteristics of Figures 2・3・5 have the influence due to the density effect of WCS plate.

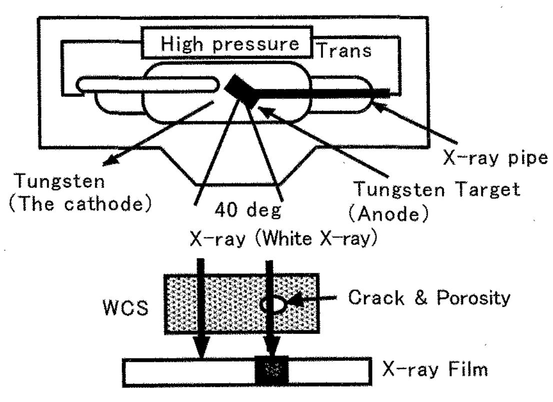

Fig.6 Schematics of transmission X-rays

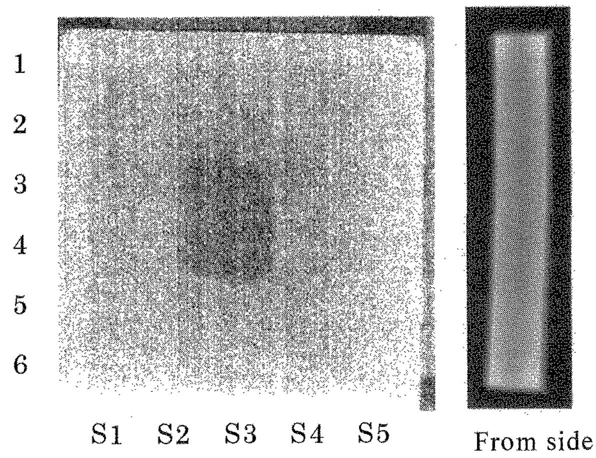

Fig.7 Radiograph image

2.7 Density by electron microscope

JSM-6700F (JEOL) was used for the scanning electron microscope. The sample is cut to 10×10 mm. The SEM photograph of center part is shown in Figure 8 . SEM photograph of surrounding edge part is shown in Figure 9. Figure 10 represents pattern diagrams of the density distribution in the direction of accumulating. The hollows of the center part indicate less dense, while the surrounding edge shows denser than center. The measurement of transmission X-rays confirms the density distribution of the WCS with positions effectively.

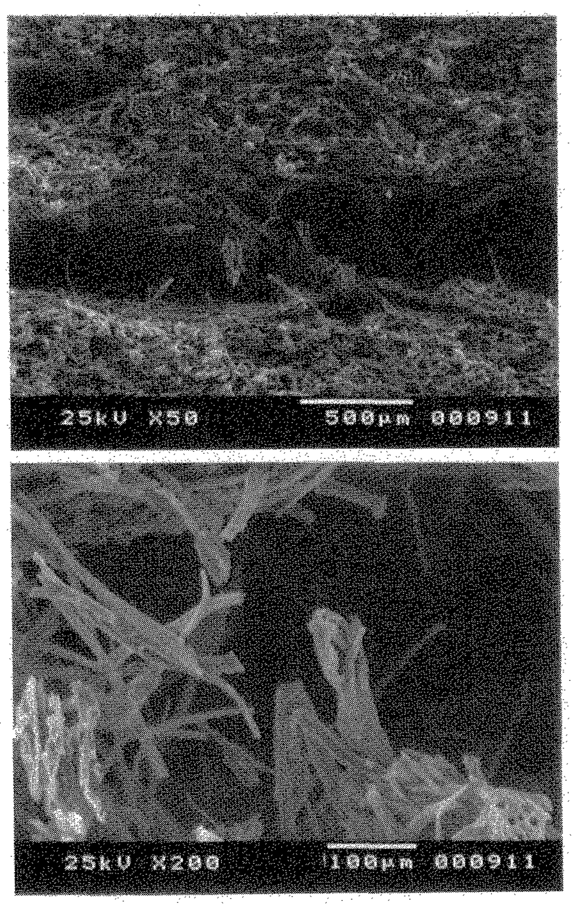

Fig.8 SEM photograph at center part (×50 and ×200)

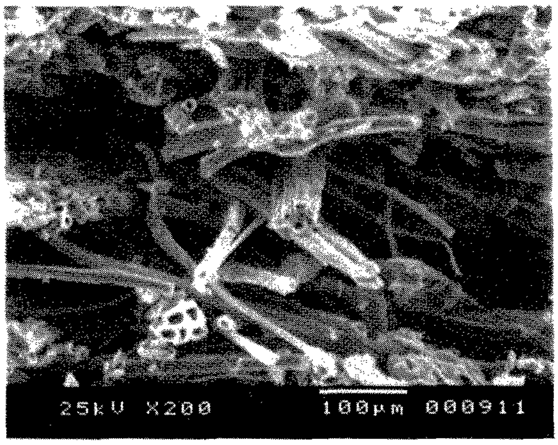

Fig.9 SEM photograph at edge (×200)

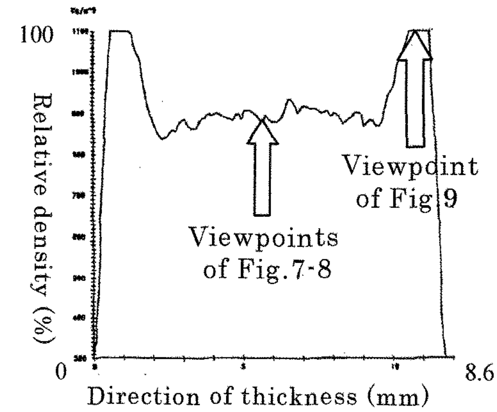

Fig.10 Pattern diagrams of density

2.8 Emissivity of far-infrared radiation

TF-10SP (JASCO Corp.) was used for energy spectrum measurement. Figures 11-13 show the far-infrared radiation spectra for the apple charcoal WCS. Ideal black body characteristics are also shown in Figs.11-13. Moreover, it can be confirmed that both Ra and Em rise as the content of the apple charcoal increases where Ra denotes radiation energy and Em denotes emissivity.

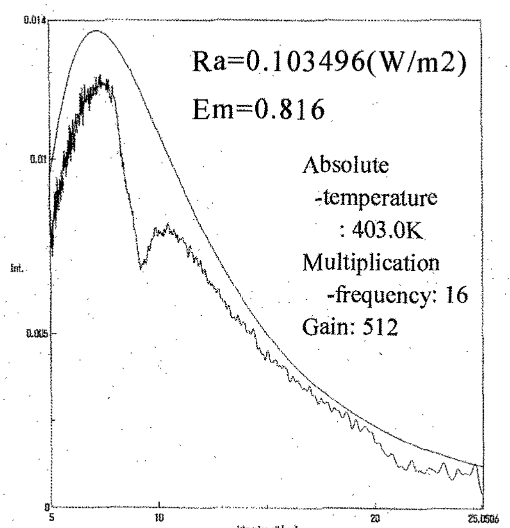

Fig.11 Infrared radiation characteristics of WCS with apple charcoal 20%

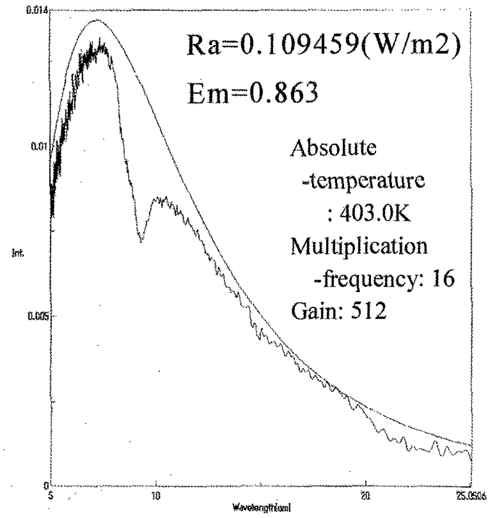

Fig.12 Infrared radiation characteristics of WCS with apple charcoal 30%

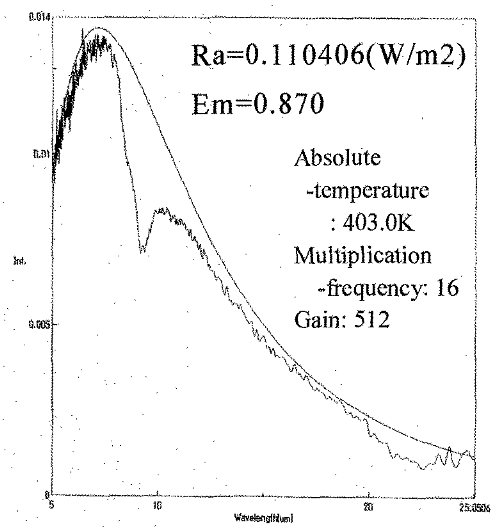

Fig.13 Infrared radiation characteristics of WCS with apple charcoal 50%

3. CONCLUSION

Electrical characteristics of WCS depended on the distribution of the density, because of the different content of the carbon at each position.

The infrared radiation spectra of WCS as heater are in good agreement with the black body.

4. REFERENCES

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