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Density Dependence of Electrical Characteristic for Woodceramics Made of Waste Paper

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Woodceramics have been fabricated from the waste paper of postcard with various thicknesses and densities. Impedance of woodceramics decreased with increasing the sample thickness and did not depend on the sample density at a range of 1.5 – 4.5 g/cm^3. The humidity sensitivity for the thick samples improved in spite of low impedance. The samples with high humidity sensitivity have larger density of macro-pore. It is suggested that not macro- and meso-pore but the macro-pore plays a prominent role in the improvement of humidity sensitivity.
Key words: Woodceramics, Humidity sensor, Waste paper, Postcards

1. INTRODUCTION

Woodceramics (WCMs hereafter) are the new functional carbon materials and have recently shown a strong promise of constituting the next generation of industrial materials [1-11]. In general, WCMs are fabricated by sintering woody materials impregnated with phenolic resin to form glassy carbon which reinforces the fibrous structure of wood. It is well known that WCMs can be fabricated from waste wood, waste paper, saw dust and so on; hence WCMs are environmentally conscious materials (ecomaterials) designed for minimizing the environmental impacts. The WCMs have the prominent characteristics of lightweight, hardness, corrosion resistance and heat resistance.

WCMs particularly have the porous structure caused by woody fiber and the electrical impedance of WCMs decreases with humidity resulting from the supply of electrons and/or ions by adsorption of water molecules on WCMs porous surface, so that WCMs has been studied as a humidity sensor [3-10] and an ammonia sensor [11]. In order to use WCMs as a sensor commercially, waste paper of postcards was used for the fabrication of WCMs (WP-WCMs hereafter) and reproducible results of the impedance and the humidity sensitivity were obtained [10]. It was also reported that the humidity sensitivity of WP-WCMs was twice as large as that of WCMs fabricated from medium density fiber board (MDF-WCMs hearafter). This result is probably due to the difference of density and specific surface between WP-WCMs and MDF-WCMs.

In this paper, WCMs have been fabricated from waste paper of postcard with various thicknesses and densities. The humidity sensitivity for WCMs has been measured and the improvement of sensitivity is discussed.

2. EXPERIMENTAL

The waste paper was cut, boiled and dried and these processes were repeated several times. Then the paper was passed through a sieve with 53 μm apertures to make the paper powder with the size of several tens of microns in diameter. The diameter of paper powder was confirmed by scanning electron microscope. The paper powder and the solution of powder phenolic resin (Bellpearl, Air Water Belllpearl Inc.) were mixed by various ratios; 45 mg – 150 mg for the paper powder and 0.5 ml for the solution. The solution of phenolic resin was produced by dissolving powder phenolic resin into methanol with the concentration of phenolic resin 40%. Mixtures were pressed into various thicknesses; 0.9 mm – 5.0 mm thick x 19.5 mmϕ. After drying specimens at 150°C for 5 min, the specimens were sintered at 600°C for 3 hours to form WP-WCMs. After sintering, they were subjected to annealing at 620°C for 3 hours to control the electrical impedance.

Electrode was formed on WCMs surface by conductive adhesive. The space between the electrodes was 8 mm. Measurement of the humidity dependence of WCMs impedance was performed in the environmental testing equipment (PL-2KP, Espec Inc.). Measurement temperature was fixed at 30°C as the humidity was changed from 30 to 80%RH. The electrical impedance was measured by applying a constant AC voltage of 5 V at a frequency of 100 Hz between the two electrodes at equilibrium condition after changing the humidity. The specific surface area of WCMs was measured using the adsorption system, where nitrogen gas was used as adsorbate at 77.4K.

3. RESULTS AND DISCUSSION

Figure 1 shows the relationship between sample thickness and impedance for WP-WCMs. The sample with various thicknesses at fixed paper powder content as 50 mg and the samples with various paper powder contents were fabricated in this work. Circles and triangles in Fig.1 are represented for the samples with various thicknesses and with various paper powder contents, respectively. Impedance of WP-WCMs decreases with the increase of sample thickness and it did not depend on sample density. Density for the samples with various thicknesses increased with increasing the sample thickness; on the contrary, it decreased as the sample thickness increased for the samples with various powder contents. Density of WCMs was controlled by not paper powder content but liquefied phenol contents in WP-WCMs. Thus, the large pressure due to the fabrication of thin samples or the samples with large paper powder content led to outflow of liquefied phenol from the samples and the sample density becomes small.

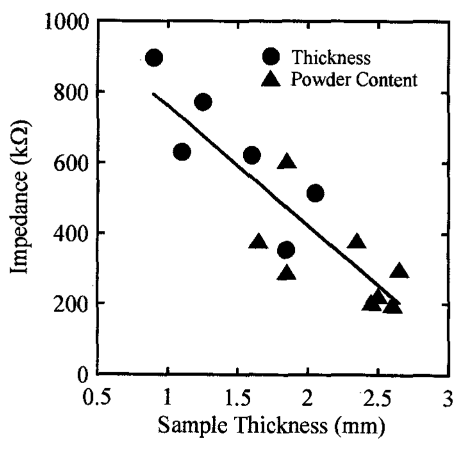


Fig.1 Sample thickness dependence of impedance. Circles and triangles are represented the results for the samples with various thicknesses and with various paper powder contents, respectively.

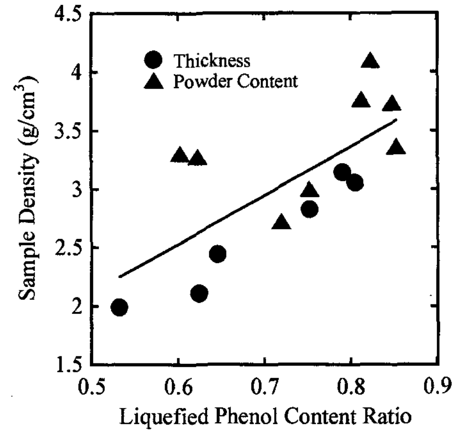


Fig.2 Relationship between liquefied phenol content ratio and sample density.

Figure 2 shows the relationship between liquefied phenol content ratio and sample density. The sample density increased as liquefied phenol content ratio increased. In this experiment, the density varied from 1.5 to 4.8 g/cm^3. These results suggest that density above 1.5 g/cm^3 does not affect the impedance of WP-WCMs.

Impedance dependence of humidity sensitivity (HS) is shown in Fig.3. HS was defined by

$$HS = \frac{(Z_{30\%} - Z_{80\%})}{Z_{30\%}} \quad (1),$$

where $Z_{30\%}$ and $Z_{80\%}$ was impedance at humidity of 30%RH and 80%RH, respectively. The impedance dependence was different between samples with various

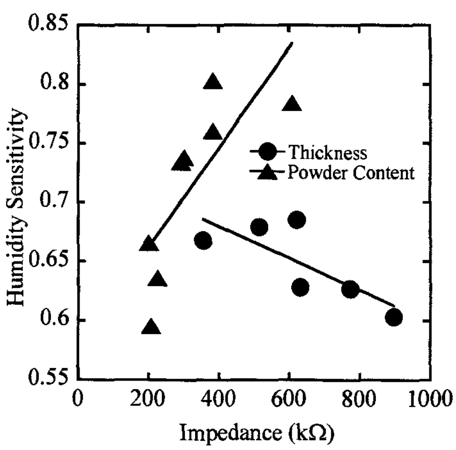


Fig.3 Impedance dependence of humidity sensitivity.

thicknesses and that with various powder contents; humidity sensitivity increased as increase of impedance for the samples with various powder contents. On the contrary, it decreased with the increase of impedance for the samples with various thicknesses. Assuming that the amount of water molecule adsorption does not differ a lot between the samples, the humidity sensitivity should increase with impedance. Thus, this result suggests that the humidity sensitivity for the thick samples with low impedance improved because the amount of water molecule adsorption was larger than that for the thin samples with high impedance.

The sample which has high humidity sensitivity with low impedance was thickest sample with high density and high liquefied phenol content ratio. Figure 4 shows the relationship between humidity sensitivity and liquefied phenol content ratio. The humidity sensitivity improved with the increase of liquefied phenol content ratio. That is, the samples without the large pressure and high density at fabrication process have high humidity sensitivity.

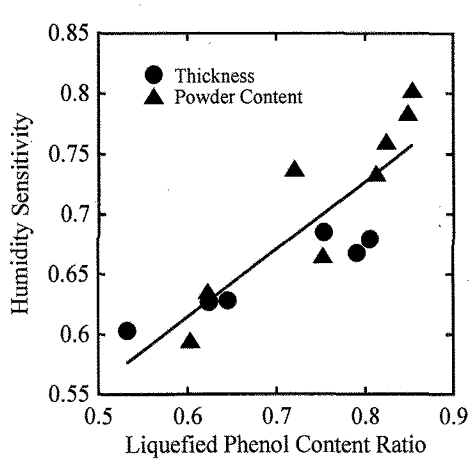
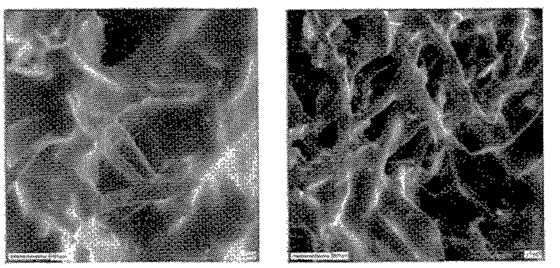


Fig.4 Relationship between humidity sensitivity and liquefied phenol content. ratio

The sensitivity improvement may be attributed to the specific surface area of the samples. Table 1 shows the specific surface area and density for the samples with various thicknesses. The specific surface area is constant, about 416 – 456 m^2/g, among the samples. The specific surface area was measured by the gas adsorption method where the comminute WP-WCMs was used as measured samples, so that only the effect of macro-pore (0.1 nm – 1 nmϕ) and meso-pore (1 nm – 100 nmϕ) is available and the effect of macro-pore (more than 100 nmϕ) is ignored. Thus, the result suggests that the densities of macro- and meso-pore are constant among the samples because the concentration of phenolic resin and sintering temperature for fabrication process of WP-WCMs are constant.

Figure 5 shows the surface morphology of the samples. The sample indicated by Fig.5 (a) has higher density and higher humidity sensitivity than the sample indicated by Fig.5 (b). It is obviously observed that the sample indicated in Fig.5 (a) has sizable gap and the density of macro-pore is larger than that for the sample indicated in Fig.5 (b). Consequently, these results suggest that the macro-pore plays a prominent role in the improvement of humidity sensitivity.



(a) density (3.145 g/cm^3) (b) density (2.109 g/cm^3)

Fig.5 Surface morphology of the samples.

The increase of liquefied phenol content ratio may also plays a role in the improvement. Considering water molecules adsorbed to OH basis resulted from phenolic resin, the increase of phenol content ratio causes the increase of the adsorption sites for water molecules; as a result, the sensitivity becomes larger with liquefied phenol content ratio.

4. CONCLUSIONS

WP-WCMs have been fabricated from waste paper of

Table 1 Specific surface area and density of the samples with various thicknesses.

Sample Density (g/cm^3)	3.145	3.057	2.829	2.442	2.109	1.989
Specific Surface (m^2/g)	453	445	443	456	452	416

postcard with various thicknesses and densities. Impedance of WP-WCMs decreased with the increase of sample thickness and did not depend on the sample density at a range of 1.5 – 4.5 g/cm^3. The humidity sensitivity for the thick samples improved in spite of low impedance because the amount of water molecule adsorption was larger than that for the thin samples with high impedance. The samples, where the densities of macro- and meso-pore are constant and with high humidity sensitivity, has larger density of macro-pore. It is suggested that not macro- and meso-pore but the macro-pore plays a prominent role in the improvement of humidity sensitivity.

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