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Humidity Dependence of Impedance for Woodceramics Made from Waste Paper

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Waste paper of postcards was used for the fabrication of woodceramics (WCMs). The electrical impedance and humidity sensitivity were measured. The impedance for WCMs fabricated from the waste paper (WP-WCMs) decreased with the increase of annealing time at 620°C and the impedance of WCMs mixed with 40% phenolic resin was smaller than that of WCMs mixed with 30% phenolic resin. The WP-WCMs had higher quality than WCMs fabricated from medium density fiberboard (MDF-WCMs). In addition, the humidity sensitivity was twice as large as that of MDF-WCMs, because the density of WP-WCMs was smaller than that of MDF-WCMs and the specific surface area of WP-WCMs was larger than that of MDF-WCMs. Consequently, waste paper of postcards is suitable raw material for WCMs humidity sensor.
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 [1-10]. 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, so that WCMs has been developed as a humidity sensor [3-9] and an ammonia sensor [10]. Although a large number of polymer sensors are widely used, they are limited

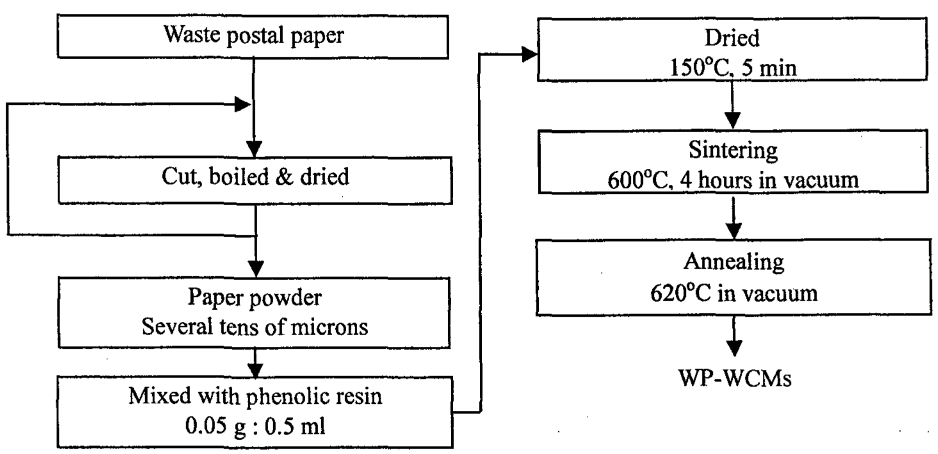


Fig. 1 Fabrication process for WP-WCMs

in usage at low temperature and tend to have mold grown on the sensor surface by prolonged use. Using WCMs has an advantage of being able to avoid the mold at higher operating temperature.

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. In order to use WCMs as humidity sensor commercially, the problem of reproducibility on individual material composition has to be solved.

In this paper, WCMs have been fabricated from waste paper of postcards (WP-WCMs hereafter) and the humidity dependence of impedance for WP-WCMs has been measured. The humidity sensitivity for WCMs fabricated from waste paper of postcards and medium density fiberboard (MDF) has been compared.

2. EXPERIMENTAL

Fabrication process for WP-WCMs is shown in Fig.1. The waste paper was cut, boiled and dried and these processes were repeated several times and 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 were mixed by the ratio of 0.05 g and 0.5 ml, respectively, and were pressed with hand at room temperature to form specimens with the size of 19.5 ϕ x 5 mm thick. The solution of phenolic resin was produced by dissolving powder phenolic resin (Bellpearl, Air Water Belllpearl Inc.) with methanol and concentration of phenolic resin was varied at 30% and 40% (WP-WCMs$^{30\%}$ and WP-WCMs$^{40\%}$ hereafter). After drying specimens at 150°C for 5 min, the specimens were sintered at 600°C for 4 hours to form WP-WCMs. After sintering, they were subjected to annealing at 620°C for various times to control the electrical impedance. WCMs were also fabricated from MDF (MDF-WCMs hereafter) for comparison. Fabrication process of MDF-WCMs is as follows: commercially produced medium density fiberboards were impregnated with phenolic resin (Honen Co.) using an ultrasonic impregnation system. The impregnated fiber boards were dried at 130°C and then they were sintered at 600°C for 4 hours in a vacuum furnace and annealed at 600°C for 10 min. The specimen size for WP-WCMs and MDF-WCMs was 19.5 ϕ x 0.3 mm and 4 x 5.6 mm^2 with 10 mm thick, respectively.

Chemical composition of WCMs was investigated by fluorescence X-ray spectroscopy method. The specific surface area of WCMs was measured using the adsorption system, where nitrogen gas was used as adsorbate at 77.4K. Aluminum was evaporated on WCMs surface in vacuum as electrodes. The space between the electrodes was 8 mm for WP-WCMs and 7 mm for MDF-WCMs. Measurement of the humidity dependence of WCMs on impedance was performed in the environmental testing equipment (PL-2KP, Espec Inc.). Measurement temperature was fixed at 30°C and 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.

3. RESULTS AND DISCUSSION

Figure 2 shows the annealing time dependence of impedance for WP-WCMs. Irrespective of the phenolic resin concentration, the impedance for WP-WCMs decreased with the increase of

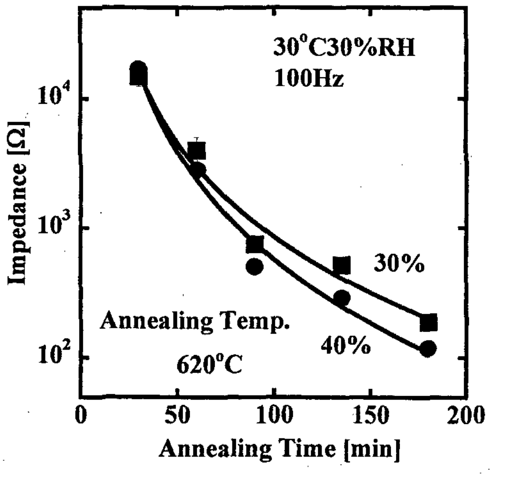


Fig. 2 Annealing time dependence of impedance for WP-WCMs.

Table 1 Chemical composition of WP-WCMs and MDF-WCMs

Composition	C	Al	Si	Ca	O	Na	K	Mg	Cl
WP-WCMs (wt%)	100	0.063	0.405	0.013	-	-	-	-	-
MDF-WCMs (wt%)	95	0.012	0.024	0.11	5.4	0.3	0.075	0.051	0.023

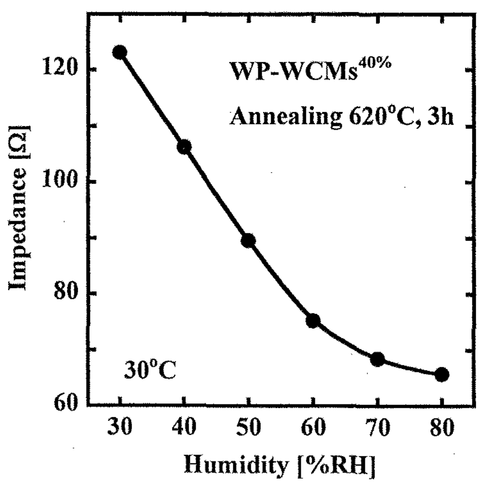


Fig. 3 Humidity dependence of impedance for WP-WCMs.

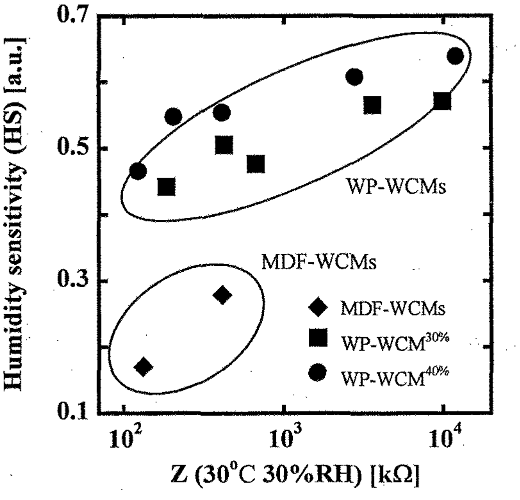


Fig. 4 Relationship between humidity sensitivity and impedance for WP-WCMs and MDF-WCMs at humidity of 30%RH.

annealing time. The impedance for WP-WCMs$^{40\%}$ became smaller than that for WP-WCMs$^{30\%}$ after the long annealing time above 100 min. Phenolic resin contained in WP-WCMs is carbonized by sintering and changes into glassy carbon which has low impedance, so that it is suggested that the decrease of impedance of WP-WCMs is caused by the increase of impregnated amount of phenolic resin.

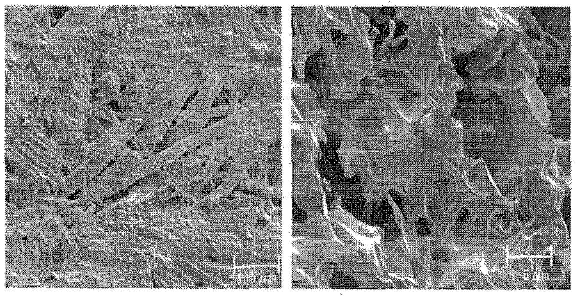
Chemical composition of WP-WCMs and MDF-WCMs investigated by the fluorescence X-ray spectroscopy method is shown in Table 1. The result indicates that the major element of WCMs is carbon with very small amount of impurities such as aluminum, silicon and calcium in both samples. However, the impurities such as sodium, potassium and magnesium were not observed in WP-WCMs because these impurities were probably removed during fabrication process of postcards. Thus, it is noted that WP-WCMs has higher quality than MDF-WCMs.

Humidity dependence of electrical impedance for WP-WCMs is shown in Fig. 3. The impedance is normalized by the impedance at humidity of 30%RH. It is obvious that the impedance decreases with the increase of humidity. Relationship between the humidity sensitivity and the impedance for WP-WCMs and MDF-WCMs at humidity of 30%RH is shown in Fig. 4. The Humidity sensitivity (HS) was defined as the rate of impedance reduction subjected to the humidity change from 30 to 80%RH. HS was expressed by

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

Assuming that the micro pore structure does not depend on annealing temperature and the amount of water molecule adsorption in the micro pore of WDMs surface does not depend on the electrical impedance of the specimen, the humidity sensitivity should increase with impedance. From

Fig.4, it is found that the sensitivity for WP-WCMs is twice as large as that of MDF-WCMs.



(a) MDF-WCMs (b) WP-WCMs

Fig.5 Surface morphology of (a) MDF-WCMs and (b) WP-WCMs.

Figure 5 shows surface morphology of WP-WCMs and MDF-WCMs. The surface of WP-WCMs was rougher than that of MDF-WCMs. Density and specific surface area of both WCMs were summarized in Table 2. The density for WP-WCMs was smaller than that for MDF-WCMs and the specific surface area for WP-WCMs was larger than that of MDF-WCMs. Since the water molecules mainly adsorb on the WCMs surface, the humidity sensitivity becomes larger as the surface area increases.

Table 2 Density and specific surface area of WP-WCMs and MDF-WCMs

	WP-WCMs	MDF-WCMs
Density [g / cm^3]	0.35	0.8
Specific surface area [m^2 / g]	410	200 - 400

4. CONCLUSIONS

Waste paper of postcards was used for the fabrication of WCMs. The electrical impedance and humidity sensitivity were discussed. The impedance for WP-WCMs decreased with the increase of annealing time. The impedance for WP-WCMs$^{40\%}$ was smaller than that for WP-WCMs$^{30\%}$. The WP-WCMs had higher quality than MDF-WCMs and the humidity sensitivity for WP-WCMs was twice as large as that of MDF-WCMs, because the density of WP-WCMs was smaller than that of MDF-WCMs and the specific surface area for WP-WCMs was larger than that of MDF-WCMs. Consequently, these results suggest that the electrical impedance and the humidity sensitivity can be improved by using the waste paper of postcards as the raw material for WCMs humidity sensor.

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