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Electrical Response of Woodceramics to Humidity

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Response of electrical resistance for woodceramics (WCMs) to humidity has been studied. The time response of resistance to humidity change from 5%RH to 80%RH showed two kinds of time constants of about 75 s (fast) and 9.2 min (slow) which became faster with increasing measurement temperature. The activation energy for absorption of water at WCMs surface has been derived as about 0.1 eV from the Arrhenius plot of the slow time constant. The decreasing ratio of resistance for humidity depends on the measurement current. It is suggested that the absorption of water may be limited by a electrochemical process.

Key words : woodceramics, humidity sensor, porous carbon, electrical properties, time response

1. INTRODUCTION

Sensing and controlling environmental humidity is receiving a great attention for industrial processes and also human comfort. In recent years the use of humidity control systems has increased in the quality control of production processes and a wide variety of industries. A large number of ceramic, polymeric, and composite sensors have been investigated as sensing elements [1 - 5]. Since each of these have advantages and limitations, no single device can be considered to be universally applicable as a humidity sensor. Ceramic humidity sensors have shown advantages over polymer sensors in terms of their mechanical strength, resistance to chemical attack, and their thermal and physical stability [3, 5]. Polymers are inherently less robust than ceramics, and are limited to lower temperatures in usage with slow response, long-term drift, and hysteresis.

Woodceramics (WCMs hereafter) are new porous ceramic materials and have recently shown a strong promise of constituting the next generation of industrial materials [6 -9]. The WCMs are drawing particularly strong attention as ecomaterials of low cost with the prominent characteristics of lightness, hardness, porosity, corrosion resistance, and heat resistance. The WCMs are fabricated by sintering woody materials impregnated with phenolic resin forming glassy carbon. It is noteworthy that WCMs can be fabricated from wood waste, waste papers, sawdust, telephone books and so on, thereby WCMs are environment conscious materials (ecomaterials) designed for minimizing the environmental impacts. It is reported that the electrical resistance of WCMs decreases with increasing humidity and the change of resistance on humidity is caused by the absorption of water molecules at the porous surface [8, 9].

When WCMs is used as a humidity sensor at commercial base, the response of electrical resistance to humidity change becomes major concern. In this paper, the time response of electrical resistivity to humidity and the humidity dependence of electrical resistance for WCMs have been measured at various measurement temperature and current, and are discussed.

2. EXPERIMENTAL

Medium-density fiber board (MDF hereafter) made *from pinus radiata was used to manufacture* WCMs. The MDF was impregnated with phenolic resin using an ultrasonic impregnation system [7]. After the impregnated MDF was dried at 135°C, it was sintered at 600°C in a vacuum furnace to form WCMs. Aluminum was evaporated in vacuum onto the WCMs surface to make ohmic contact as a electrode. The space between the electrodes was 3 mm. In order to remove physical strain of the specimens during the fabrication and for reproducibility of measurements, the specimens were subjected to a forming by current of 10 mA for 30 min. Electrical resistance were measured in the chamber where humidity was controlled in the range between 5 and 80%RH by introducing steam and dry nitrogen gas. The measurement of time response of electrical resistance for WCMs on humidity was carried out at the measurement temperature of 25 to 45°C. Humidity dependence of electrical resistance were obtained for measurement current of 1 to 100 μA.

3. RESULTS AND DISCUSSIONS

3.1. Time response of electrical resistance

Time response of electrical resistance for WCMs to humidity change from 5%RH to 80%RH is shown in Fig.1, where the response can be classified into two components. In general, the adsorption of water molecules at WCMs surface leads to the dissociation

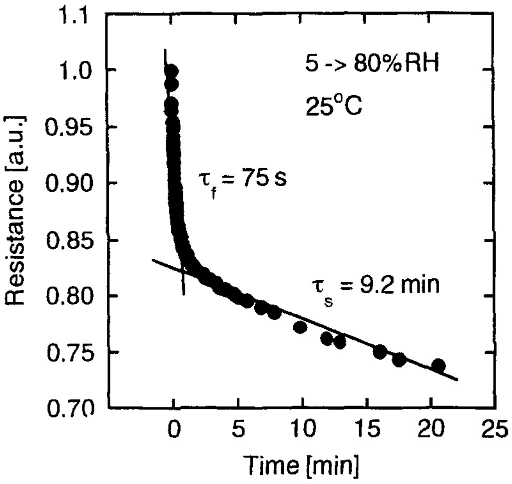

Fig.1 Time response of electrical resistance for WCMs to humidity change from 5 to 80%RH.

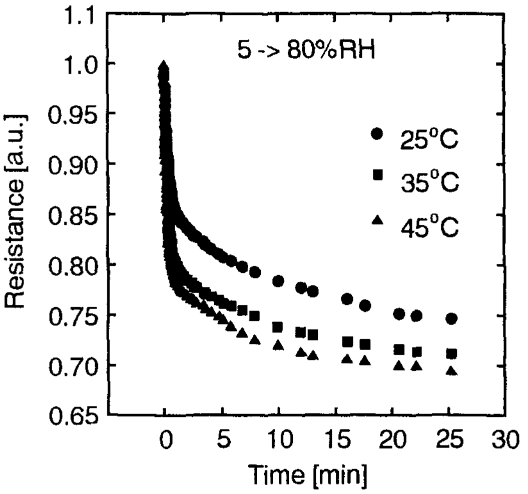

Fig.2 Measurement temperature dependence of time response of electrical resistance for WCMs to humidity change from 5 to 80%RH.

into hydronium (H_3O^+) and hydroxyl (OH^-) ions, which cause the electrical change. The exponential transition response with two components in Fig.1 is expressed by

$$R(t) - R(\infty) = A\exp\left(-\frac{t}{\tau_s}\right) + B\exp\left(-\frac{t}{\tau_f}\right) \quad (1),$$

where R(t) is resistance at time (t) after humidity change, A and B are constants, and τ_s and τ_f are the time constant of slow and fast responses, respectively. The time constants have been determined from Fig. 1 by eq. (1), yielding τ_s = 9.2 min and τ_f = 75 s. The slow time constant (τ_s) is should be improved on the application of WCMs as a humidity sensor.

3.2. Measurement temperature dependence of time response

Figure 2 represents the time response of electrical resistance to humidity change from 5%RH to 80%RH at measurement temperature of 25 to 45°C, where resistance is normalized by the resistance at 0 s. The measurement temperature dependence of time responce is summerized in Table 1. The decreasing ratio increases as the measurement temperature increases. The resistance of WCMs indicates the negative temperature dependence, that is, the resistance decreases with increasing measurement temperature. The actual amount of resistance change is of similar order irrespective of the measurement temperature so that the decreasing ratio at high measurement temperature is larger than that at low measurement temperature.

A linear relation is obtained when the electrical

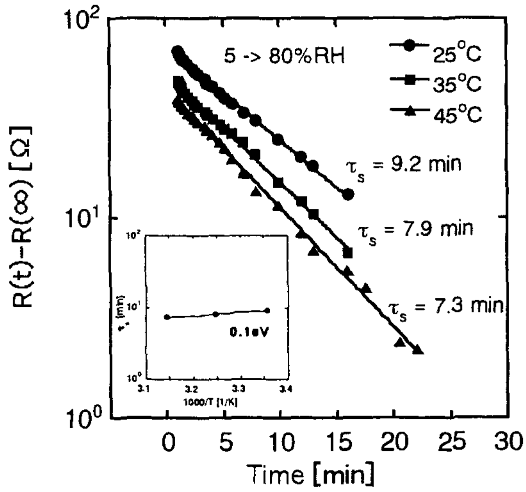

Fig.3 Logarithmic Ordinated plot of electrical response and Arrhenius plot of τ_s (inset).

Table 1 Measurement temperature dependence of time response of WCMs to humidity change from 5%RH to 80%RH.

Measurement Temperature (°C)	Resistance at 5%RH (kΩ)	Actual amount of resistance change (kΩ)	Decreasing raio (%)	Time constant of slow response (min)
25	644	157	25	9.2
35	540	165	29	7.9
45	423	104	30	7.3

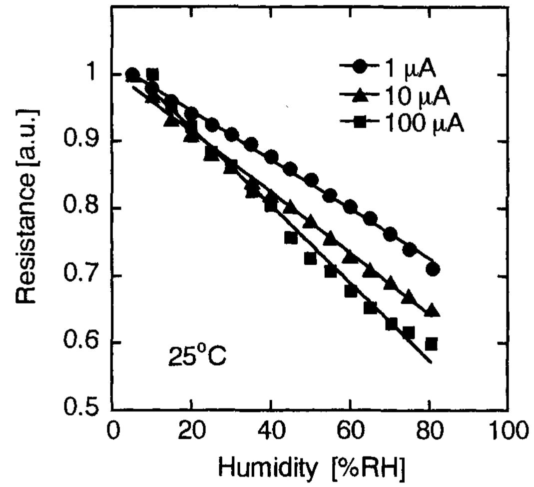

Fig.4 Humidity dependence of electrical resistance measured at various measurement current.

Table 2 Measurement current dependence of electrical characteristics for WCMs.

Measurement Current (mA)	Slope of Humidity Dependence (a. u.)	Resistance at 5%RH (kΩ)
1	-3.7	803
10	-4.5	739
100	-5.7	496

response is plotted on a log scale shown in Fg.3. The time constants of slow responses have been determined using eq.(1) as 9.2, 7.9, and 7.3 min at measurement temperature of 25, 35, and 45°C, respectively. The time response became faster with the increase of measurement temperature. Arrhnius plot of τ_s was shown in the inset of Fig. 3. The activation energy of about 0.1 eV has been derived from the slope of Fig. 3. Consequently, it is certain that the absorption of water at WCMs surface may take place via the small potential barrier of about 0.1 eV like a general absorption process.

3.3. Humidity dependence of electrical resistance

Humidity dependence of electrical resistance for WCMs is shown in Fig. 4. The measurement current was varied from 1 to 100 μA. The resistance is normalized by the value of humidity 5%RH. The resistance at the humidity of 5%RH and the slope of the humidity dependence are summarized in Table 2.

The resistance at humidity of 5%RH decreases with increasing measurement current. It is suggested that aluminum electrode may not form ohmic contact to WCMs and/or temperature may rise locally due to the current flow.

The slope of humidity dependence increases with increasing measurement current. Consequently, the absorption of water at WCMs surface might be limited by electrochemical process: when measurement current is increased , the exchange of electron between water molecules and WCMs may be enhanced so that the change of resistance becomes larger.

4. CONCLUSION

Response of electrical resistance for WCMs to humidity has been studied. The time response of resistance to humidity change from 5%RH to 80%RH showed two kinds of time constants of about 75 s (fast) and 9.2 min (slow), which become faster with increasing the measurement temperature. The activation energy of ts has been derived as about 0.1 eV. The decreasing ratio of resistance on humidity depends on the measurement current. These results suggest that the absorption of water at WCMs surface may take place via the small potential barrier of about 0.1 eV and limited by a electrochemical process.

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