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Fundamental Properties of Woodceramics Sheet for Electrode of Polymer Electrolyte Fuel Cell

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We have proposed an application of woodceramics sheet to electrode for Polymer Electrolyte Fuel Cell (PEFC). In order to apply the woodceramics sheet to the electrode, it is important to understand the fundamental properties such as electric resistivity. We made woodceramics sheet from a paper filter. The electric resistivity, bulk density and microstructure of the woodceramics sheet were investigated. The bulk density was measured to estimate the gas permeability, i.e., the permeability may go up with a decrease in the bulk density. In the investigation, we considered the influence of the degree K of impregnation of phenolic resin on these properties. It was confirmed that the bulk density increased with K although the resistivity decreased. We also analyzed the chemical compositions contained in the woodceramics sheet. As a result, the main component was carbon whose weight percentage was more than 90 wt%. There was a very small amount of impurities such as silicon and aluminum in the woodceramics sheet. This might mean that the woodceramics has desirable properties as the electrode of PEFC.

Key words: woodceramics, Polymer Electrolyte Fuel Cell (PEFC), electrode, resistivity, density

1. INTRODUCTION

In recent years, woodceramics has got into the spotlight as an ecological and low-cost material because woodceramics is made from ligneous waste such as waste paper[1].

On the other hand, fuel cell is attracting an attention as an ecological power generation method[2]. Especially, the research and development task on the application of polymer electrolyte fuel cell (PEFC) is now energetically pushed forward. That is because the PEFC may be made lighter and smaller and work at lower temperature than the other types of fuel cells such as phosphoric acid fuel cell, molten carbonate fuel cell and solid oxide fuel cell. However, there are some problems to be solved for further spread at present. One of the biggest problems is how to reduce the price.

We have proposed the application of woodceramics to the PEFC to solve the problem of fuel cell system mentioned above[3]-[5]. First, the manufacturing procedure of the woodceramics sheet for electrode of PEFC was demonstrated in this paper. Secondly, the fundamental properties such as electric resistivity, bulk density, microstructure and chemical compositions were estimated. In this investigation, the influence of the degree of the impregnation of the phenolic resin was considered.

2. MANUFACTURING PROCEDURE OF WOODCERAMICS SHEET

The electrode for the PEFC is needed to be thin and porous so that both the electrolyte from one side and the gas (hydrogen or oxygen) from the other side can penetrate. The product water is expelled through the pores. We have found that it is especially important that the electrode is sufficiently porous to generate the electric power[4]. Thus we adopted a qualitative paper filter (No. 1) as the raw material for the woodceramics sheet. The specifications of the paper filter used are summarized in Table 1. The filter paper was made from

Table 1. Specification of filter paper (No. 1) adopted as raw material.

Surface density	9 mg/cm^2
Thickness	0.02 cm
Retained particle diameter	6 μm
Ash content	0.1 wt%

Raw material (Filter paper)

↓

Cutting (35 mm × 35 mm)

↓

Immersion into methanol solution of phenolic resin (48 h)

↓

Vacuum-drying (150 ℃, 15 min)

↓

Carbonization (see Fig. 2 (a))

↓

Annealing (see Fig. 2 (b))

↓

Woodceramics sheet

Fig. 1. Outline of manufacturing procedure for woodceramics sheet.

cotton fiber and contained more than 90 wt% alpha cellulose. The amount of ash content is about 0.1 wt%.

The manufacturing procedure for the woodceramics sheet is illustrated in Fig. 1. The filter paper was cut into a size of 12.3 cm^2 (3.5 cm×3.5 cm) and immersed into a methanol solution of phenolic resin (Bellpearl, Air Water Bellpearl Inc.) for about 48 hours. We prepared some solutions with different concentrations to investigate the influence of the degree of the impregnation of phenolic resin on fundamental properties of the woodceramics sheet. Then, we vacuum-dried it at a temperature of 160 ℃ for 15 min. The carbonization temperature was increased at a rate of 1 ℃/min and was maintained at 300 ℃ for 3 hours. After that, we raised the temperature at the same rate again and maintained 600 ℃ for 3 hours[4]. In the annealing, the temperature was raised at a rate of 10 ℃ /min. The annealing temperature and time were 900 ℃ and 3 hours, respectively.

Figure 2 demonstrates the photographs of the raw material (filter paper) and the woodceramics sheet made from that. In this paper, D and K are defined by following expressions.

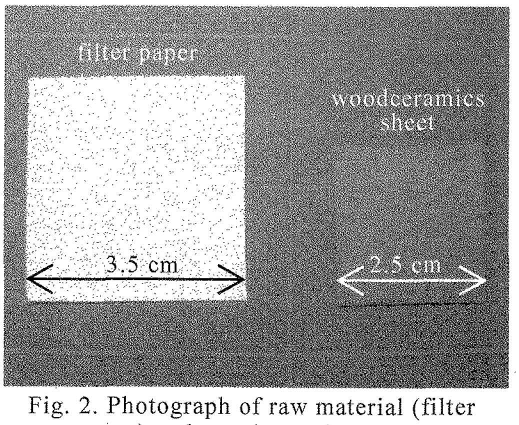


Fig. 2. Photograph of raw material (filter paper) and woodceramics sheet.

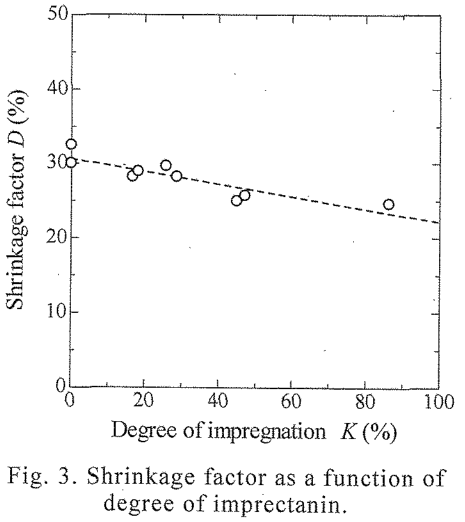


Fig. 3. Shrinkage factor as a function of degree of imprectanin.

$$D = \frac{l_0 - l}{l_0} \times 100\ (\%). \qquad (1)$$

$$K = \frac{W_i - W_n}{W_n} \times 100\ (\%). \qquad (2)$$

where, l_0 and l are the length of one side of the material (3.5 cm) and that of the woodceramics sheet, and W_i and W_n are the mass of the filter paper with phenolic resin (after vacuum-drying) and that of the material. The degree K of impregnation of phenolic resin and D of the woodceramics sheet were 28.2 % and 28.6 %. As shown in this photograph, the woodceramics sheet shrunk. Figure 3 indicates the shrinkage factor D as a function of the degree K of the impregnation of phenolic resin. The shrinkage factor D slightly decreased with an increase in K. The shrinkage factor D for K=0 % was about 31 %. On the other hand, D was less than 25 % in the case of K of more than 85 %.

It is important that the material used for the electrode of PEFC contains unnecessary chemical compositions having bad influence upon the performance of the PEFC. We estimated the chemical compositions contained in the woodceramics sheet by fluorescent X-ray analysis. Figure 4 shows the chemical compositions of woodceramics sheet. The degree K of impregnation of phenolic resin of the sample woodceramics was 28.2 %. Carbon was proved to be the main component of the woodceramics sheet and the weight percentage was 94.5 wt%. It was also confirmed that oxide was contained. Furthermore, trace of silicon (0.02 wt%) and aluminum (0.02 wt%) were detected. As a result, it was found that the amount of impurities in the woodceramics was very small.

3. INFLUENCE OF DEGREE OF IMPREGNATION ON PROPERTIES OF WOODCERAMICS SHEET

3.1 Observation of Surface by Electron Microscope

Figure 5 indicates the electron micrographs of the surface of woodceramics sheet. Figure 5 (a), (b), (c) and (d) correspond to the woodceramics sheets whose K's are 0 %, 16.9 %, 44.9 % and 86.3 %, respectively. As

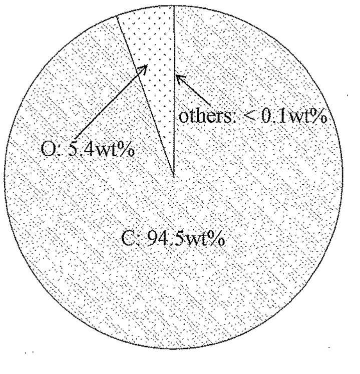
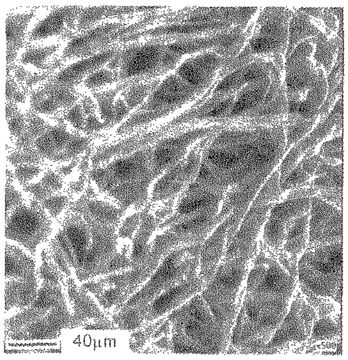
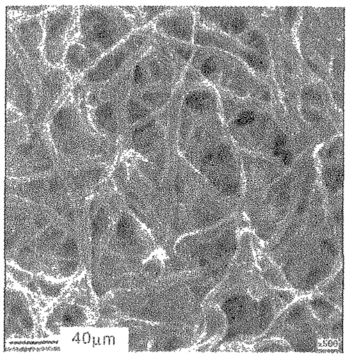


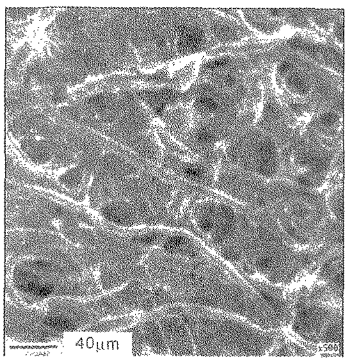
Fig. 4. Chemical compositions of woodceramics sheet (Degree of impregnation: 28.2 %).



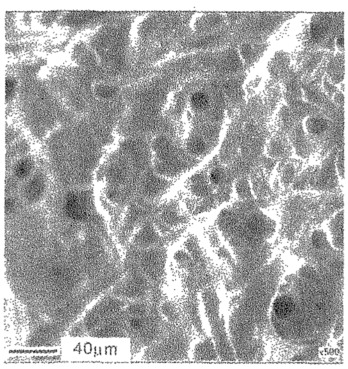
(a) Degree of impregnation: 0 %



(b) Degree of impregnation: 16.9 %



(c) Degree of impregnation: 44.9 %



(d) Degree of impregnation: 86.3 %

Fig. 5. Scanning electron microscope photograph of woodceramics sheet.

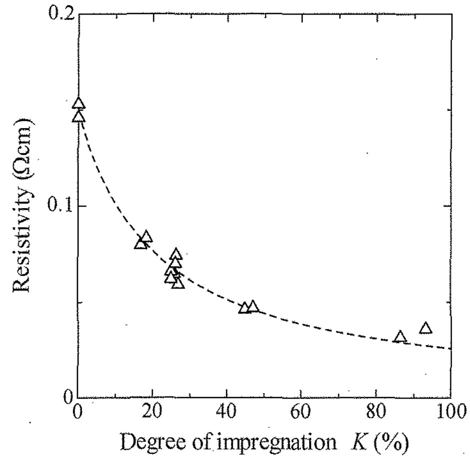


Fig. 6. Resistivity as a function of degree of impregnation.

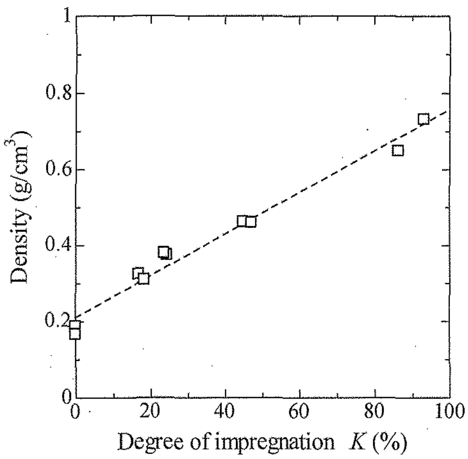


Fig. 7. Density as a function of degree of impregnation.

seen from these figures, the number and size of pores reduced with a decrease in *K*.

3.2 Electric Resistivity

The material having significantly small electric resistivity must be used for the electrode of PEFC. We measured the resistivity of the woodceramics sheet by van der Pauw's method. Figure 5 shows the relation between resistivity and *K*. The resistivity of woodceramics without the impregnation of phnolic resin (K=0 %) was about 0.15 Ω cm. The resistivity decreased as *K* rose. The resistivity was less than 0.05 Ω cm for K > 50 %. It is desirable that the resistivity is as small as possible. Hence, it is effective to increase *K* from the point of view of the resistivity.

3.3 Bulk Density

The electrode of PEFC must have good gas permeability. We measured the bulk density to estimate the gas permeability of the woodceramics sheet[4]. Figure 6 shows the bulk density as a function of *K*. The bulk density increased in proportion to *K*. The bulk density for *K*=0 % was about 0.18 g/cm^3. When *K* was more than 80 %, the bulk density exceeded 0.6 g/cm^3. From this result, it might be said that the porosity of woodceramics sheet is lower for smaller *K*. This means that the smaller *K* becomes, the lower the gas permeability of the woodceramics might become. Hence it is desirable to use the woodceramics sheet with as small *K* as possible.

5. CONCLUSIONS

We investigated the fundamental properties of woodceramics sheet made for the electrode of PEFC. The filter paper was adopted as the raw material. The main element of the woodceramics sheet was carbon and the amount of impurities was very small. It might be said that the woodceramics is desirable as the material for electrode. The resistance and bulk density were measured. The bulk density was measured to estimate the gas permeability because the material with small bulk density might have higher gas permeability. The resistivity was from 0.03 to 0.15 Ωcm and depended on the degree of impregnation *K*. The bulk density also changed with the magnitude of *K* and the value of the bulk density was from 0.2 to 0.8 g/cm^3. It is desirable to choose larger *K* from the viewpoint of the resistivity. However, the woodceramics sheet with lower *K* is preferred for higher gas permeability. We should decide the value of *K* estimating the performance as PEFC.

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