Effect of carbonization temperature on the basic properties of woodceramics impregnated with liquefied wood

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In this paper, a new woodceramics impregnated with liquefied wood is developed and the effect of carbonization temperature on the dimension shrinkage, weight loss, density, compressive strength, and volume electrical resistivity is investigated. The results show that, the higher the carbonization temperature is, the higher the dimension shrinkage is, the higher the compressive strength is, and the lower the electrical resistivity is.

1. Introduction

The population increase and the development of industry are increasing the burden on the environment and natural resources. Concerns for the environment demand that the resources be used with maximum efficiency, while eliminating pollution. Scrap materials such as wood and woody material produced in building industry, waste paper, plant, and fruit waste residues in sugar industry etc., are being considered for reuse, for example, as woodceramics.

Woodceramics are made of wood, or woody material, impregnated with phenol resin and carbonized in vacuum atmosphere at high temperatures, during which the wood or woody material changes into soft amorphous carbon and the impregnated phenol resin changes into hard glassy carbon. Pores, which originally exist in the wood and woody material, still remain in the woodceramics. Accordingly, woodceramics are porous amorphous carbon and glassy carbon composite materials. Useful characteristics of the woodceramics include stiffness, corrosion, friction resistance, and electromagnetic shielding ability [1–5]. At the present time, most of the woodceramics are manufactured with impregnation of phenol resin directly.

On the other hand, in the past several decades, considerable research on conversion into useful materials from the waste lignocellulosic resources mentioned above, which included techniques referred to as "wood liquefaction" due to the conversion of wood chemically or thermochemically into liquid material [6, 7]. Ono *et al*. described a simple wood liquefaction method where they used phenol in the presence of conc. H_2SO_4 to obtain completely liquefied wood [8, 9]. In the manufacturing of woodceramics, the wood liquefaction techniques where the woody material are considered to be liquefied through solvolysis are of interest because the amount of phenol compound used in the production of woodceramics will decrease greatly and the lingnocellulosic waste resources could be used with maximum efficiency.

In the present study, a new woodceramics which is made from wood material impregnated with synthesized liquefied wood is prepared and the effect of carbonization temperature on dimension shrinkage, weight loss, compressive strength and volume electrical resistivity of this material is also investigated.

2. Experimental

2.1. Material preparation

Fig. 1 shows the schematic illustration of the synthesis of liquefied wood. At 150°C, hinoki (*Chamaecyparis obtusa* Endl.) wood powder and phenol compound are mixed while the sulfuric acid is added as catalyst and the beech wood powder is not performed any treatments such as coating and painting *etc*. Fig. 2 shows the physical appearance of synthesized liquefied wood.

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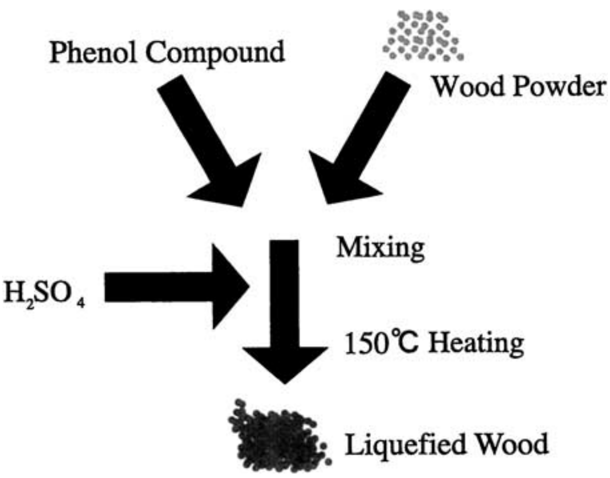


Figure 1 A schematic illustration of the synthesis of liquefied wood.

Fig. 3 shows the woodceramics manufacturing methods. MDF (Medium Density Fiberboard), with the size of 20 × 20 × 15 mm and with the original density of 0.58 Mg/m^3, is impregnated with the liquefied wood diluted with ethanol (ratio 1:1) under the vacuum atmosphere, and then, the MDF is carbonized in vacuum furnace to make woodceramics. The material being processed generates a considerable amount of decomposition products, for example, pyroligneous acid and wood tar etc. In order to make sure the woodceramics quality, the carbonization is carried out under the vacuum furnace where the decomposition product is vented off. In the present study, the carbonization temperature is 400°C, 500°C, 650°C, and 800°C, respectively.

2.2. Characterization

In order to investigate the effect of the process on dimension shrinkage and weight loss for woodceramics impregnated with liquefied wood, the dimensions of 10 samples are measured using a pair of digital slide calipers (Mitutoyo, CD-15CP Co., Ltd.) before and after carbonization, respectively. Similarly, the weight changes are also measured using an electrical balance (Kensei, ER120-A Co., Ltd.). Because MDF consists of fiber layers, the dimension changes in length and width

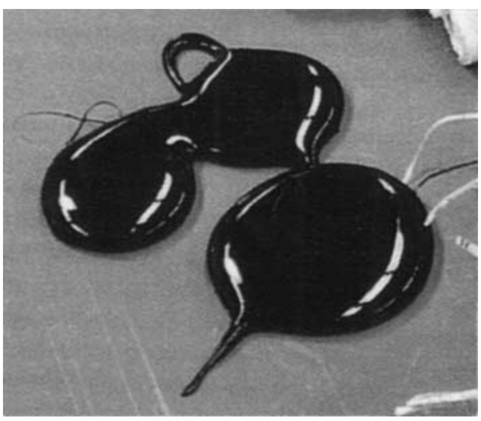


Figure 2 Physical appearance of liqufied wood.

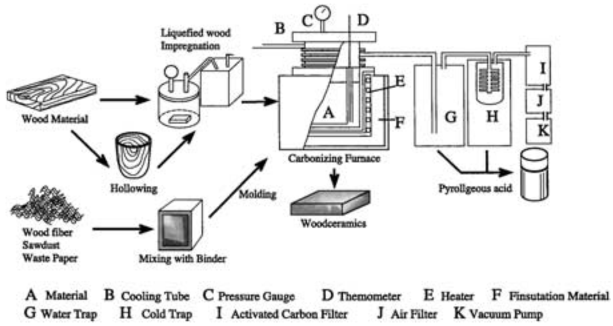


Figure 3 Woodceramics manufacturing method.

(the fiber directions) and the change in thickness (the layer direction) are different.

The compressive tests of woodceramics are carried out in Shimadzu material testing system, where the crosshead speed is 1 mm/minute, and the deflection is measured with a dial gauge. The volume electrical resistivity of woodceramics is measured with Mitsubishi MCP-PR02 resistivity system. In order to avoid the effect of the water content on the electrical resistivity of woodceramics, the specimens are dried at 60°C for 1 hour and at 105°C for 1 hour before measurement.

Microstructures of the resultant woodceramics are observed in Scanning Electron Microscope (S-2250N) operated at 20 kV and 20 mA.

3. Results and discussion

Fig. 4 shows the relationship between the carbonization temperature and the decrease in dimensions and weight. In the length and width direction, the dimension shrinkage of woodceramics carbonized at 400°C, 500°C, 650°C and 800°C are 14%, 18%, 22% and 25%, respectively, while in the thickness direction, shrinkage of woodceramics are 25%, 28%, 34% and 36%, respectively. The results show that the higher the carbonization temperature is, the higher the dimension

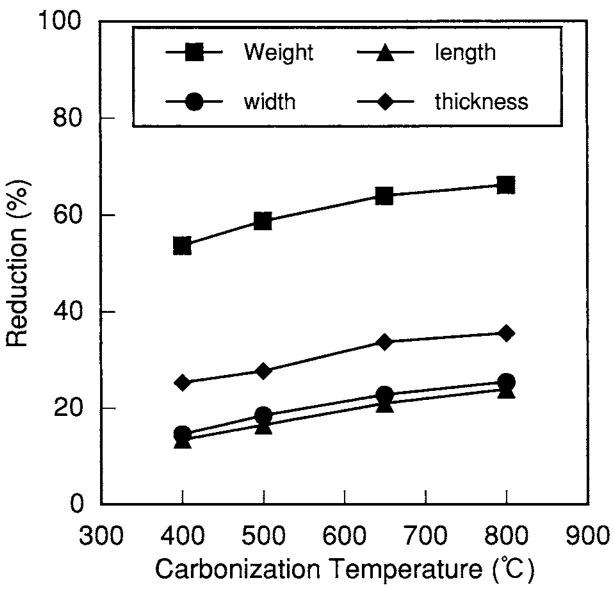


Figure 4 Dimensional and weight changes of woodceramics made from MDF impregnated with liquefied wood.

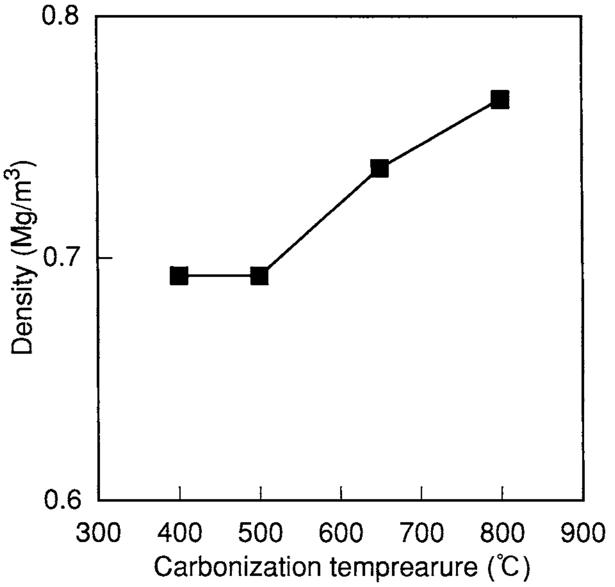


Figure 5 The relationship between carbonization temperature and density of woodceramics made from MDF impregnated with liquefacient wood.

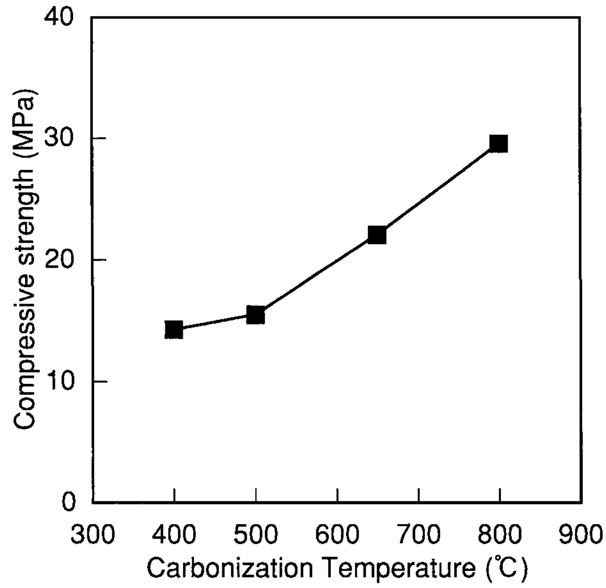


Figure 6 The relationship between carbonization temperature and compressive strength of woodceramics made from MDF impregnated with liquefied wood.

shrinkage is. The shrinkage rate is consistent enough that the raw material can be manufactured to suit the dimensions of the final product. Overall, the shrinkage ratio in thickness direction is 11% greater than that in length and width direction because the shrinkage in horizontal direction depends on the decrease in the space of the board, while the shrinkage in a parallel direction depends on the shrinkage of the fiber. The weight loss follows a curve similar to those of the dimensional changes, which are 53%, 59%, 64% and 66% at the carbonization temperature 400°C, 500°C, 650°C and 800°C, respectively.

Fig. 5 shows the relationship between carbonization temperature and the apparent density of the woodceramics. The apparent density of the woodceramics carbonized at 400°C, 500°C, 650°C and 800°C were 0.69×10^3 Kg/m^3, 0.69×10^3 Kg/m^3, 0.75×10^3 Kg/m^3 and 0.78×10^3 Kg/m^3, respectively. The result show that the apparent density increase with increasing the carbonization temperature, which lies in that the weight loss rate is lower than dimension shrinkage rate with increasing carbonization temperature.

Fig. 6 shows the relationship between carbonization temperature and the compressive strength of the woodceramics impregnated with liquefied wood. The compressive strength is about same at the temperatures between 400 and 500°C, but increase remarkably with increasing carbonization temperature above 500°C. It is known that, in the thermal decomposition of wood, the hydrocarbon structure forms through the dehydration and depolymerization of cellulose between 250°C and 310°C, and the condensation aromatic polynuclear structures starts to form above 400°C and develops gradually above 500°C [2]. For phenol compound, it was known that depolymerization occurs between 300 and 400°C, and that the aromatic polynuclear structure starts to form above 400°C and develops above 500°C [10–12]. As a result, uniting phenol compound

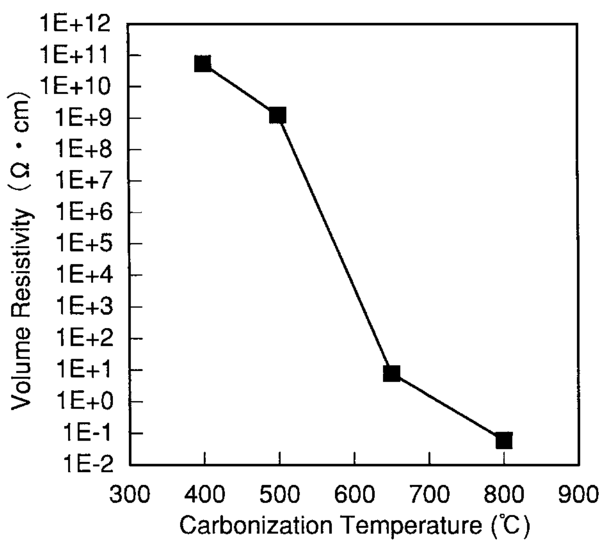


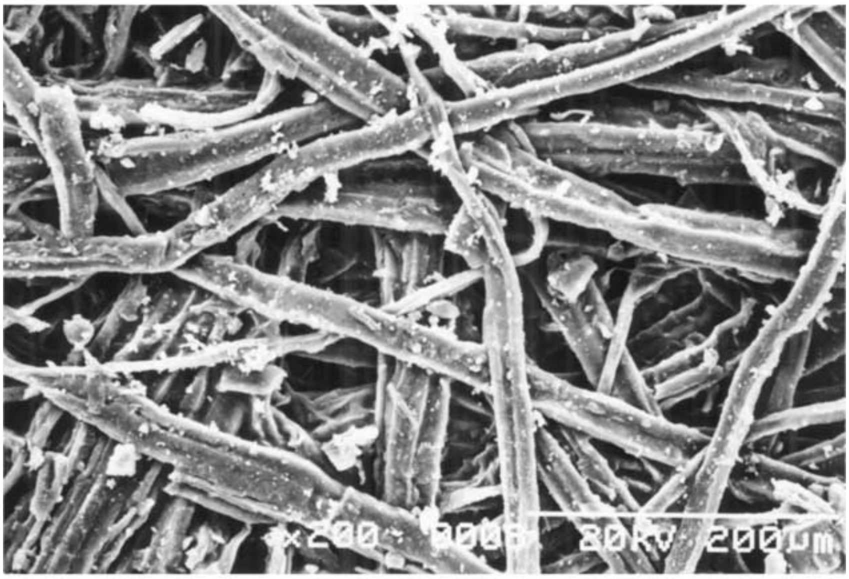
Figure 7 The relationship between carbonization temperature and volume resistivity of woodceramics made from MDF impregnated with liquefied wood.

advances as the carbonization temperature rises, which result in the increase in the strength.

Fig. 7 shows the relationship between the carbonization temperature and the ambient volume electrical resistivity of the woodceramics impregnated with liquefied wood. It is shown that the electrical resistivity of this material depends on the carbonization temperature. There is a rather large difference in the volume resistivities of woodceramics carbonized between 650°C and 800°C. As mentioned above, during this temperature period, both the wood fiber and the phenol compound cause a big structural change, which result in rapid decrease in electric resistance. It has the same tendency as the woodceramics impregnated with phenol resin directly.

Fig. 8 shows SEM photographs of woodceramics impregnated with liquefied wood. As shown in the figures, the dimensions of the MDF fiber decrease and

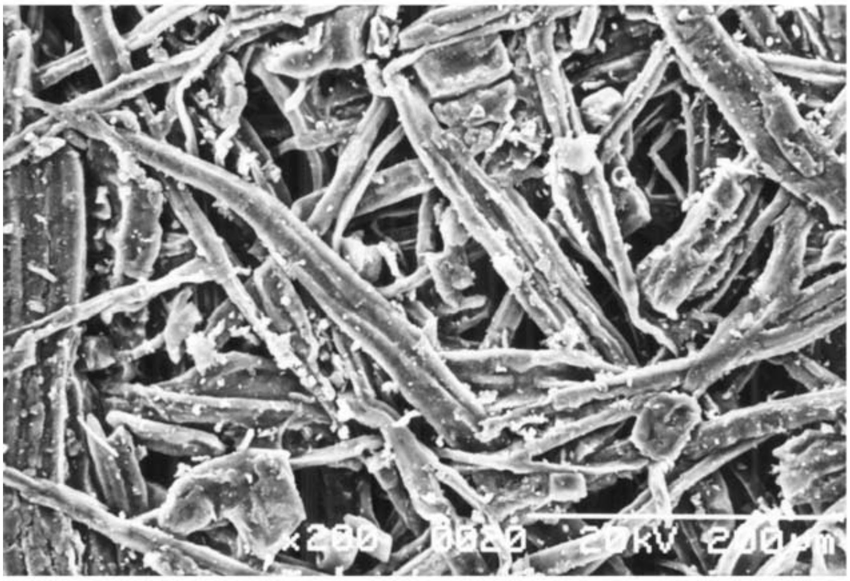
(a)



(b)

(c)

Figure 8 SEM photograph of woodceramics. (a) 400°C, (b) 500°C, (c) 650°C, (d) 800°C. (*Continued*)



(d)

Figure 8 (*Continued.*)

the spaces among the MDF fibers increase with increasing carbonization temperature.

4. Conclusions

In the present study, a new woodceramics impregnated with liquefied wood is developed, and the effect of carbonization temperature on the dimensional shrinkage, weight loss, density, strength, and electrical resistivity are investigated. The results show that the higher carbonization temperature is, the higher the dimension shrinkage of the woodceramics is, the higher the compressive strength is, and the lower the electrical resistivity is.

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