Mechanical Properties of Porous Carbon Materials made from Rice Hull

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New utilization of rice hull, which is one of the agricultural waste in Japan, is required from a viewpoint of the recycling. The rice-hull silica carbon material (RHS carbon) is manufactured by mixing the rice hull particles with a phenol resin, pressure forming, drying, and then carbonizing in the nitrogen gas atmosphere at high temperatures. Since the rice hull has a natural porous structure, the RHS carbon is manufactured as a porous carbon material. Since the most of the inorganic component is Si in the rice hull, the produced inorganic compound in the RHS carbon is almost the silica, which is stable under wet and water-ret conditions. Therefore, the RHS carbon has high wet and water-ret stability, and then the high compressive and bending strengths were kept under those conditions.

Key words: Recycle, Rice Hull, Porous Carbon Material, Mechanical Property, Strength

1. INTRODUCTION

Rice hull is a residual product of rice and the amount of it is 2.6 million tons per year in Japan. The rice hull silica carbon material (RHS carbon) is developed in order to utilize the rice hull from a viewpoint of recycling. The RHS carbon is expected as sliding materials such as the linear motion bearing in future, because it has excellent low friction and abrasion resistance under unlubricating conditions. Since the dimensional stability is important for the close tolerance elements such as slid bearing, the hygroscopic expansion of the material is necessary to be low.

The RHS carbon is manufactured by impregnating a phenol resin with the rice hull, and carbonizing it in a nitrogen gas atmosphere. Since the rice hull has a porous structure, the RHS carbon can be a porous carbon material. The inorganic component in the rice hull is almost Si. Therefore, the RHS carbon is expected to be a high water resistant material because most of the inorganic component in it is the silica.

In this study, the effect of carbonizing temperature on the compressive strength and hygroscopic expansion under the wet and water-ret conditions were examined and discussed the mechanical properties of the RHS carbon.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

Fig.1 shows the cross section of the rice hull, which is raw material of the RHS carbon. The diameter of the cell is about 10 μm. The rice hull contains about 20 mass% of inorganic component and 80 mass% of organic component. More than 96 mass% of the inorganic constituent is silica. About 72 mass% of the organic component is carbon and about 8 mass% of it is hydrogen.

Fig.2 shows the manufacturing process of the RHS carbon. A-area shows the manufacturing process of the powder. The rice hull is impregnated with a thermosetting phenol resin (25 wt.%), and carbonizing at 1173K in a nitrogen gas atmosphere.

Two types of forming processes are used in this study. The first process is shown in B-area in Fig.2. The RHS carbon is mixed with a phenol resin (25 wt.%), and the mixture is molded by injection molding. The material is then dried and carbonized at 1173K to 1773K in a nitrogen gas atmosphere (IMRHSC). The final shape of the IMRHSC is a rectangular plate of 60(w)*12(h)*3(t)mm. The test piece for the fracture toughness was same plate. The second process is shown in C-area in Fig.2. The RHS carbon powder is mixed with a phenol resin (25 wt.%). Afterwards, the pressure forming is used to obtain a rectangular plate. The material (CRHSC) is obtained after drying and

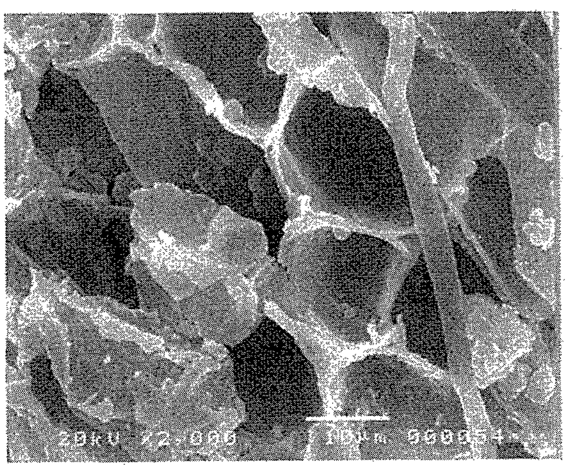

Fig.1 Cross section of rice hull

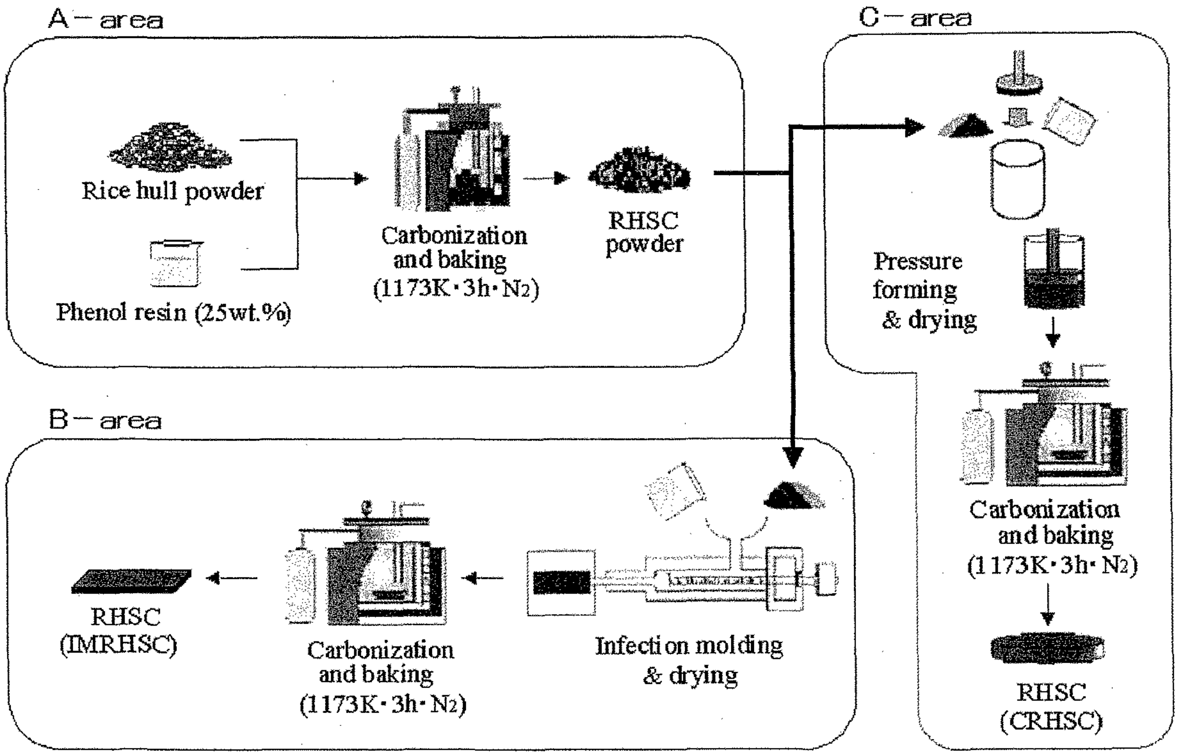

Fig.2 Manufacturing process of RHS carbon
(RHSC: Rice Hull Silica carbon)

carbonizing at 1173K to 1773K in a nitrogen gas atmosphere. The dimensions of the plate are 150(w)* 75(d)*5(t)mm. The test pieces for the hygroscopic expansion and the compression tests were prepared from this plate.

The dimensions of the test piece are 50(w)* 5(h)*5(t)mm for the hygroscopic expansion test, and 10(w)*5(h)*5(t)mm for compression test.

2.2 Mechanical Tests

Schematic figure of the measuring system for bending strength and fracture toughness is shown in Fig.3. The bending test was carried out referring to the Japanese Industrial Standards of JIS-R1601. The fracture toughness test was performed using the SENB method [4], referring to JIS-R1607. The pre-crack is introduced using a thin diamond wheel. The radius of the wheel-tip curvature was 0.03 mm.

The compression test was carried out using a universal testing machine with 5kN maximum load. The crosshead speed of the testing machine is 0.5mm/min. The displacement of the test piece was measured using a laser displacement measurement system. The effects of the water immersing on the compressive strength was also measured. The test pieces were maintained in a deionized water for 1 to 1000 hours and then dried.

Fig.4 shows the test instrument for hygroscopic expansion. The test piece was maintained in a deionized water at room temperature, and obtained the relationship between the immersing time and the strain which was measured by using

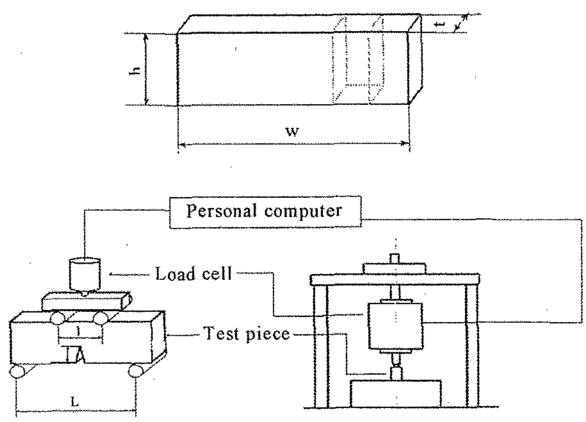

Fig.3 Outline of mechanical tests

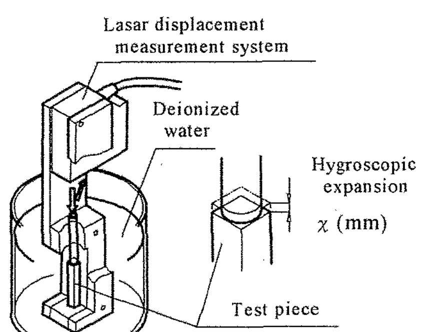

Fig.4 Test instrument for hygroscopic expansion

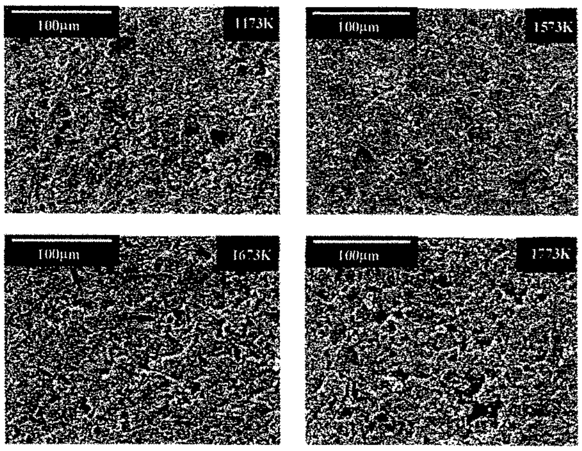

Fig.5 Macrostructure of IMRHSC

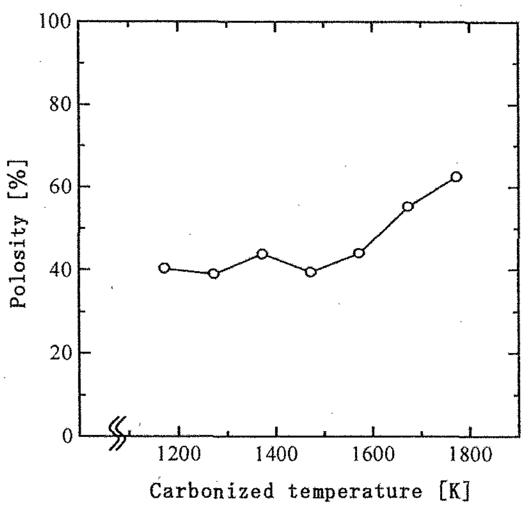

Fig.6 Relationship between porosity and carbonized temperature

a laser displacement measurement (resolution was $1*10^{-6}$m).

3. EXPERIMENTAL RESULTS

3.1 Macrostructure

The macrostructure of the IMRHSC is shown in Fig.5. When the carbonized temperature exceeds 1673K, a lot of porosity is generated in the macrostructure. The distribution of the pore is almost even. The relationship between the porosity and the carbonized temperature is shown in Fig.6. The porosity increases with increasing the temperature, and it became almost 53% at 1773k.

3.2 Mechanical Strength

The comparison of the compressive strength is shown in Fig.7. The compressive strength of IMRHSC is higher than that of CRHSC. The maximum compressive strength was 227MPa in the IMRHSC that is carbonized at 1473K.

The bending strength of the IMRHSC is shown in Fig.8. The strength is about 50MPa, which is almost constant from 1173 to 1673K carbonized temperature. The strength then decreased at 1773K.

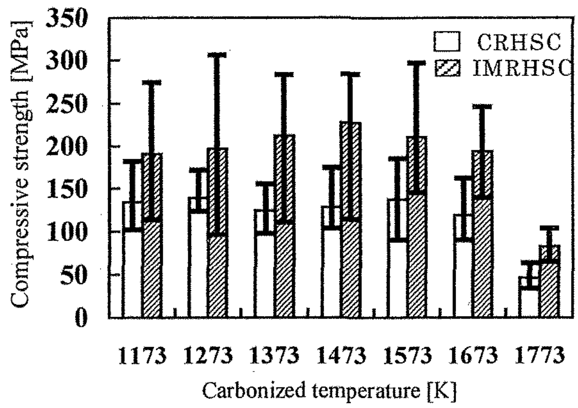

Fig.7 Effect of carbonized temperature on compressive strength

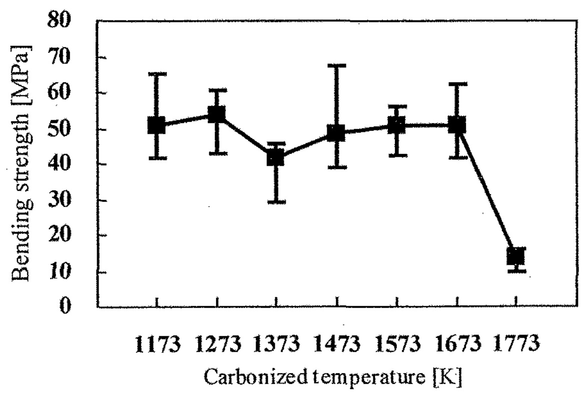

Fig.8 Effect of carbonized temperature on bending strength of IMRHSC

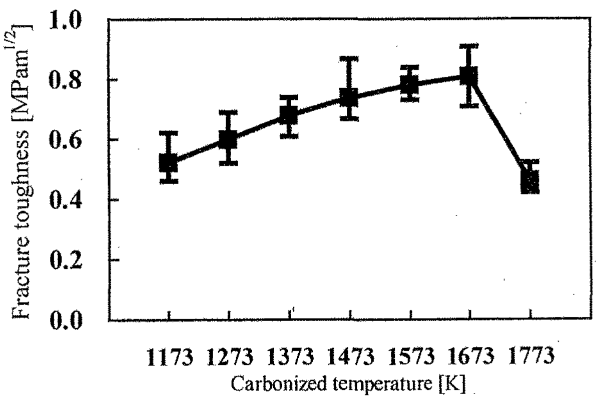

Fig.9 Effect of carbonized temperature on fracture toughness of IMRHSC

The fracture toughness is shown in Fig.9. The fracture toughness was increased with increasing the carbonized temperature and the maximum value was reached to $0.8MPam^{1/2}$ at 1673K.

It is considered that the high mechanical properties are obtained at lower than 1673K carbonized temperature. The strength reduction at 1773K is considered to associative with the amount of the inorganic components. The amount of inorganic components in the RHS carbon is shown in Fig.10. The amount of inorganic component decreases at 1773K the carbonized temperature.

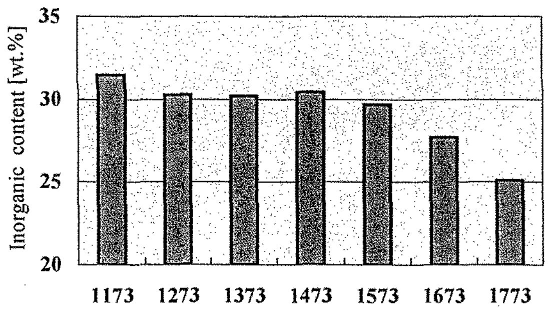

Fig.10 Amount of inorganic component in RHS carbon

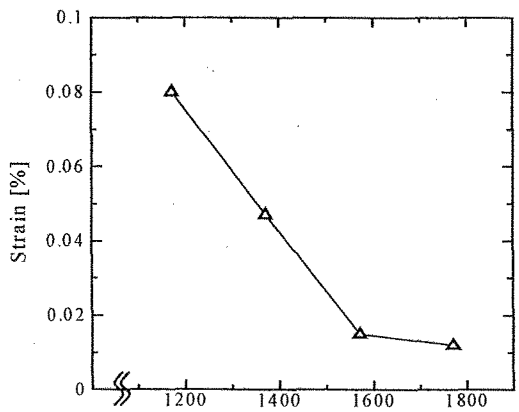

Fig.11 Relationship between carbonized temperature and hygroscopic expansion

3.3 Water Resistance

Fig.11 shows the relationship between carbonized temperature and hygroscopic expansion. The carbonized temperature is from 1173K to 1773K. The hygroscopic expansion is improved with increasing the carbonized temperature. The measured expansion is considerably small compareing with that for rice bran carbon material[6].

The relationship between relative compressive strength and water immersing time is shown in Fig.12. The compressive strength does not decrease under 1000 hours water immersing. The same property was obtained at all the carbonized temperature from 1173K to 1773K. Namely, the RHS carbon achieves high water resistance.

In linear motion bearing, the amount of clearance between the friction element and shaft is important for the transmission accuracy and the limiting speed for safety. The RHS carbon has stable under humidity and water-ret conditions. Namely, the RHS carbon achieves high water resistance and nonlubrication, which become the core competence as the friction elements.

4. CONCLUSION

Some strength tests and hygroscopic expansion test were carried out for the porous carbon materials made from rice hull (RHS carbon). The summary of the obtained results was shown as follows.

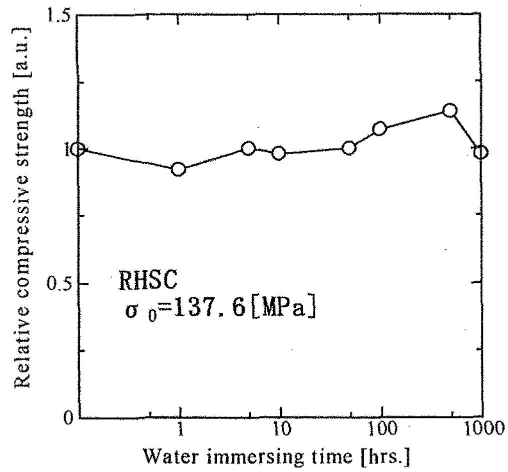

Fig.12 Relationship between water immersing time and relative compressive strength

(1)Almost even porous structure is produced from rice hull, the porosity is about 20-60%.

(2)High mechanical strength is obtained at 1173-1673K carbonized temperature. The maximum compressive strength was 227MPa.

(3)Mechanical strength is kept high under wet and water-ret condition. Moreover, hygroscopic expansion was lower than 0.08%.

(4)Namely, high water resistance is established as a core competence of the RHS carbon.

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