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# Control of Porosity in Porous Carbon Materials made from Rice Hull

K.Yoshida[1)], S.Endo[2)], T.Takahashi[2)] and H.Iizuka[2)]

[1)] Doctor's Program of Systems and Information Engineering,
Graduate School of Science and Engineering, Yamagata University,
4-3-16 Jonan, Yonezawa 992-8510, Japan
Fax: +81-238-26-3212, e-mail: een64078@dipfr.dip.yz.yamagata-u.ac.jp
[2)] Graduate School of Science and Engineering, Yamagata University,
4-3-16 Jonan, Yonezawa 992-8510, Japan

Rice Hull is one of the agricultural by-products, and is required to utilize as the industrial resources from a viewpoint of recycling. Previously, authors have proposed a manufacturing process of a carbon material made from the rice hull. The rice hull is impregnated with a phenol resin and is carbonized in a nitrogen gas atmosphere at 900℃. The carbon material is called rice-hull silica carbon (RHS carbon). The RHS carbon has the porous structure that is originated from the natural structure of the rice hull. In this study, the authors proposed an artificial procedure to control the porosity of the RHS carbon. Then, the effect of the porosity on the mechanical and frictional properties was discussed. The friction coefficient is excellent in the porosity-controlled RHS carbon. It is expected to use the material for the application of the linear motion bearing and so on.

*Key words*: Porous Carbon Materials, Rice Hull, Frictional Properties, Porosity, 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 [1]. The rice-hull silica carbon (RHS carbon) is developed in order to utilize the rice hull from a viewpoint of recycling [2,3]. The RHS carbon is expected to use as the sliding materials such as a linear motion bearing in future, because it has an excellent low friction and abrasion resistance under unlubricating conditions [4].

The RHS carbon is manufactured by impregnating a phenol resin with the rice hull, and carbonizing it in a nitrogen gas atmosphere. The RHS carbon retains many unique properties of the carbon such as excellent friction property, lightness, high electric conductivity, and so on. Moreover, since the porous structure has possibility to improve the friction properties [5], it is expected to control the friction property of the RHS carbon by adding the porosity.

On the other hands, the RHS carbon is a brittle material. Therefore, it is necessary to pay a lot of attentions to the fracture during the cutting and grinding operations. One of the corrective strategy is the porosity control because the porous structure can induce low Young' modulus and therefore can absorb a large elastic deformation [6].

In this study, the authors proposed a new manufacturing process of the porosity control for the RHS carbon. Then, the compressive strength and the friction coefficient of the porosity controlled RHS carbon were measured.

## 2. EXPERIMENTAL PROCEDURE

### 2.1 Materials

The rice hull contains about 20 mass% of the inorganic constituent and 80 mass% of the organic constituent. More than 96 mass% of the inorganic constituent is silica. The mass ratio of the carbon is about 72 mass% of the organic constituent, and that of the hydrogen is about 8 mass%.

Fig. 1 shows the making process of the porosity -controlled RHS carbon. The amount of pore was controlled by adding the rice-hull powder in carbon powder. After adding the rice-hull powder, the material was pressure formed or injection molded, and then carbonized again. The rice-hull without phenol resin was expected to be burned away and make the pore in the RHS carbon during the second carbonizing process at 1173 K. The median diameter of the rice-hull powder was 13 μm, and the blend ratio was 10, 15, 20 and 25 mass%.

The geometry of the injection-molded material was 60x12x3 mm$^3$. The geometry of the pressure-formed material was 150x75x5 mm$^3$. The test pieces for measurements of the compressive strength, the coefficient of dynamic friction and the amount of wear were made from these materials. The geometry of the test piece for the compressive strength measurement was 10x5x5 mm$^3$ and 6x3x3 mm$^3$ made from the pressure-formed material and the injection -molded materials, respectively. The test piece for the measurements of the coefficient of dynamic friction and for the amount of wear was 3.5x3.5x2 mm$^3$.

Fig. 2 shows the macrostructure of the pressure-formed RHS carbon without porosity control. There are two types of pores in the structure. One is the large pores with the size of 100 μm, which are formed among the rice-hull particles. The pores are considered to be formed during the carbonization at high temperature, as the volatile dust was flowed. Another one is the small pores with the size less than 10 μm, which origin is the porous structure of the rice hull.

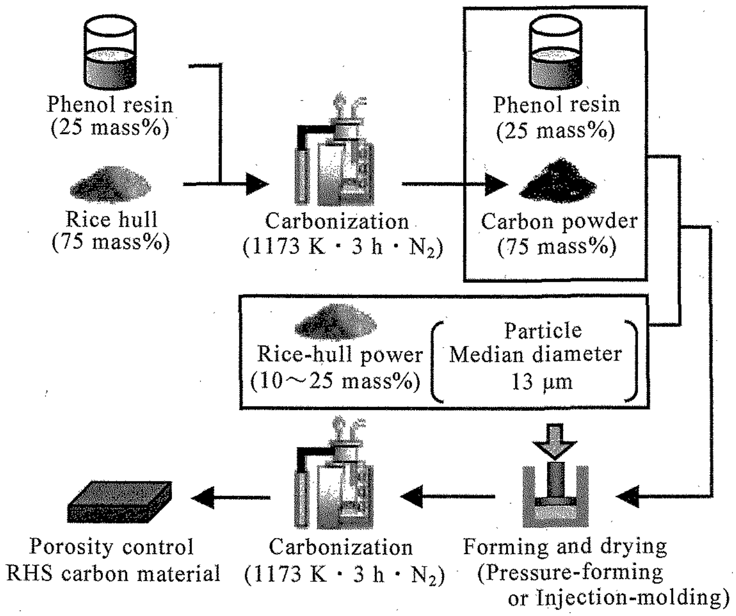



Fig.1 Making process of RHS carbon with porosity control

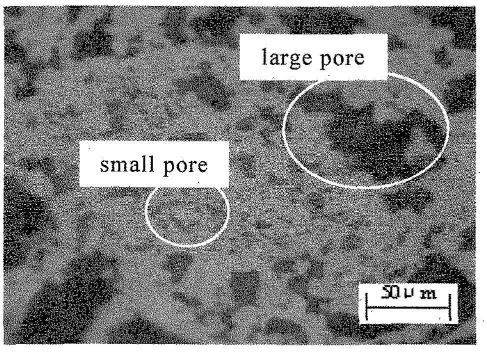



Fig. 2 Macrostructure of RHS carbon

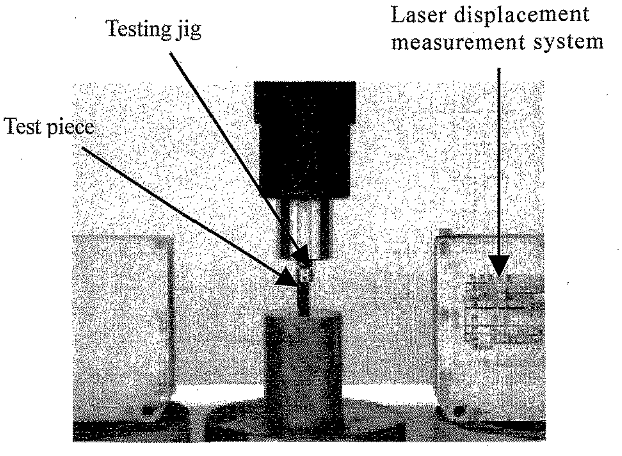



Fig. 3 Test instrument for compressive strength

2.2 **Mechanical test**

***2.2.1 Compression test***: Fig. 3 shows the test instrument for the compressive strength. The compression test was carried out using a universal testing machine (maximum load was 50 k N) . The crosshead speed was set to be 0.5 mm/min. The strength was measured in the parallel direction to the forming pressure. The displacement of test piece was measured by a laser displacement measuring system (resolution was $1x10^{-6}$m) .

***2.2.2 Friction properties***: Fig. 4 shows the test instrument for the coefficient of dynamic friction and the amount of wear. The test type was the pin-on-ring type. The partner material was SUS304. The coefficient of dynamic friction was estimated by measuring the resistance in the torque meter. The frictional speed was set to be 1.5 m/s. The running distance was about 130 km. The applied stress was 1 MPa. The amount of wear was estimated by measuring the reduction of the test piece length using a dial gauge.

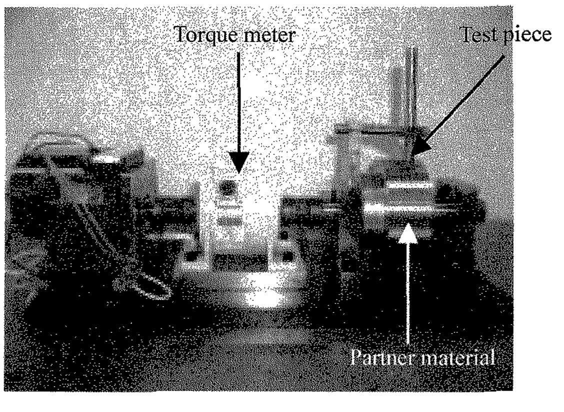
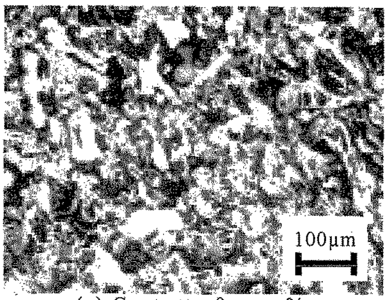
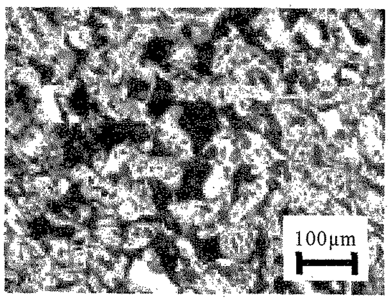



Fig.4 Measuring equipment for friction coefficient and amount of wear

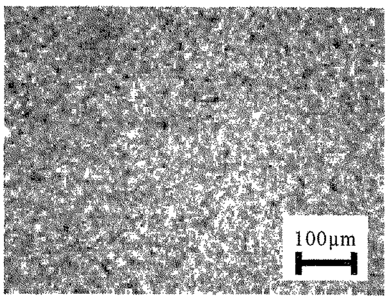



(a) Content ; 0 mass%

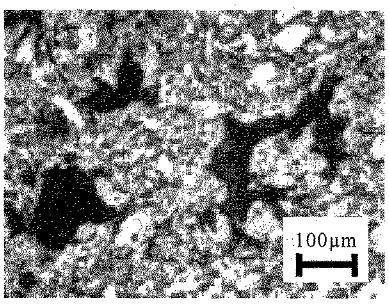



(b) Content ; 25 mass%

Fig.5 Macrostructures of pressure-formed RHS carbon




(a) Content ; 0 mass%




(b) Content ; 25 mass%

Fig.6 Macrostructures of injection-molded RHS carbon

## 3. EXPERIMENTAL RESULTS

### 3.1 Porous structure

Fig. 5 (a) and (b) show the macrostructures of the pressure-formed RHS carbon. The mixing ratio of the rice-hull powder is 0 mass% and 25 mass%, respectively. The amount of the large pore is increased by adding the rice-hull powder. The added large pores are almost uniformly dispersed in the structure.

Fig. 6 (a) and (b) show the macrostructures of the injection-molded RHS carbon. The mixing ratio is 0 mass% and 25 mass%, respectively. The RHS carbon particles are finely crashed in the material with 0 mass% content. In contrast, the particles are not finely crached in the material with 25 mass% content. The added rice-hull powder may worked as a cushioning material during the injection molding.

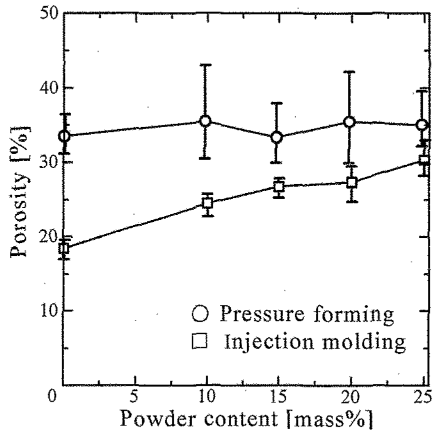



Fig.7 Relation between rice-hull powder content and porosity of RHS carbon

Fig. 7 shows the effect of the rice-hull powder content on the production of the porosity in the RHS carbon. The porosity increases with increasing the amount of the rice-hull powder content, and the range of the data variation among samples is narrow in the injection molding. The rice-hull powder effectively works as the pore-making agent in the injection-molded RHS carbon.

The porosity control is more important for the injection-molded materials than for the pressure-formed materials, because the former is more brittle and have a lower friction coefficient. From these points of view, the porosity controlling method with the rice hull powder is considered to be effective for the RHS carbon.

### 3.2 Compressive strength

Fig. 8 shows the relationship between the rice-hull powder content and the compressive strength. The compressive strength of the injection-molded material is adequately high value of about 250 MPa for the material with 0 mass% content. The compressive strength decreases with increasing the amount of the rice-hull powder content in the injection-molded materials. However, the strength of 100 MPa in 25 mass% added material is still enough for the linear motion slider.

The strength of the pressure-formed materials is lower than that of the injection-molded material, and slightly decreases with increasing the amount of the rice-hull powder.

Fig. 9 shows the relationship between the rice-hull powder content and the Young's modulus of the RHS carbon. The Young's modulus decreases with increasing the amount of the rice-hull powder content. The low Young's modulus is not demerit for the brittle materials, and rather tend to be convenient for the linear motion slider.

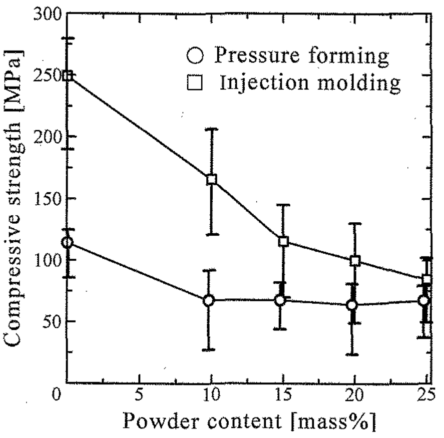



Fig.8 Relationship between rice-hull powder content and compressive strength of RHS carbon

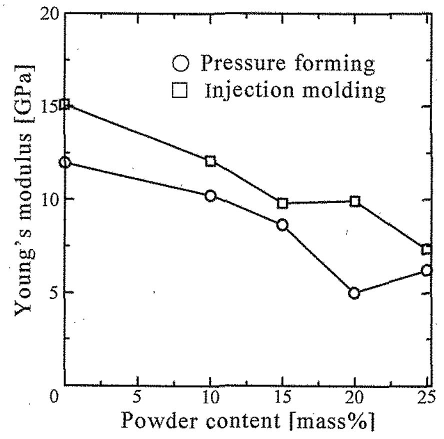



Fig.9 Relationship between rice-hull powder content and Young's modulus of RHS

### 3.3 Coefficient of dynamic friction

Fig. 10 shows the relation between the rice-hull powder content and the coefficient of dynamic friction of the RHS carbon. The coefficient of dynamic friction is lower than 0.17, which value is considerably low comparing with any other ceramics materials, for example about 0.4 for SiC [7]. Moreover, the coefficient of dynamic friction was slightly improved for the 10-15 mass% content materials.

These results show that the porosity-controlled RHS carbon have low friction coefficient, low Young' modulus, and enough strength. Moreover, as shown in Fig.7, the porosity could be increased up to about 30% in the injection-molded materials, which is almost similar to that in the pressure-formed materials. Therefore, it is expected that the brittleness for the machining performance can be reduced as well as the pressure-formed materials.

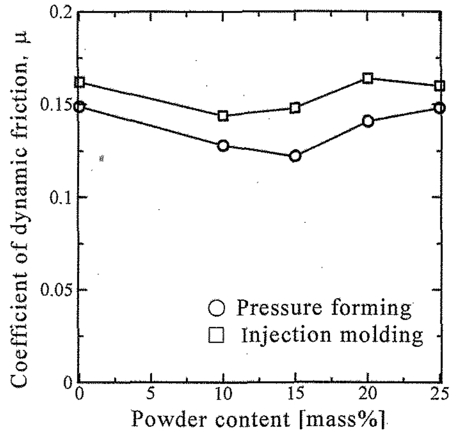



Fig.10 Relation between rice-hull powder content and coefficient dynamic friction of RHS carbon

## 4. CONCLUSION

The rice-hull powder was mixed in the RHS carbon as a pore formation agent. The summary of the results is shown as follow.

(1) The porosity can be controlled using rice-hull powder for RHS carbon.
(2) The high Young's modulus can be reduced by the porosity control, especially for the injection-molded RHS carbon.
(3) Coefficient of dynamic friction of the RHS carbon can be improved by the porosity control using the rice-hull powder.

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## REFERENCES

[1] T.Ishitani, K.Ohtsubo, "The Science of Rice", Asakura Shoten, Tokyo, p.172 (1995).
[2] H.Iizuka, G.Kato, K.Igarashi, S.Shikano and T.Takahashi, "Mechanical Properties of Porous Carbon Materials made from Rice Bran", J. Soc. Mat. Sci., Japan, Vol.49, No.6, pp.625-630 (2000).
[3] M.Shishido, S.Kubo, T.Takahashi and H.Iizuka, "Mechanical Properties of Porous Carbon Materials made from Rice Hull", Trans. Mat. Res. Soc. Japan, Vol.31, pp.993-996 (2006).
[4] K.Yoshida, H.Iizuka, Y,Shibata, H.Unuma, T.Nakamura and S.Shikano, "Water Resistance of Porous Carbon Materials made from Rice Hull", Int. J. Mater. Eng. Resour. Vol.13, No.2, pp.49-53 (2006).
[5] K.Kato, "Mechanism of Friction and Wear of Ceramics", J. Jpn. Soc. Tribo. Vol.34, No.2, pp.88-90 (1989)
[6] L. J. Gibson and M. F. Ashby, "Cellular Solids", Cambridge university press. United Kingdom. pp.93-173 (1997)
[7] Japanese Society of Tribologists, "Tribology of Ceramics (in Japanese)", Yokendo,Tokyo, Japan, p.40 (2003)

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