Transactions of the Materials Research Society of Japan 33[4] 1205-1208 (2008)

Effects of Pretreatment and Kneading on Mechanical Properties of RHS Carbon

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Rice hull, which is one of the agricultural by-products in Japan, is required to utilize for the industrial resources from a viewpoint of recycling. The rice hull silica carbon (RHS carbon) is manufactured by impregnating a phenol resin into the rice hull, and then carbonizing in nitrogen gas atmosphere at high temperatures. The RHS carbon has the natural porous structure that is originated from the natural structure of the rice hull. In this study, pretreatment and kneading processes were added in the making process of the RHS carbon to improve the mechanical properties. The inserted processes achieved the uniform impregnation of the phenol resin into the porous structure, and improved the mechanical strengths and the distribution of them.

Key words: Rice Hull, Carbon, Mechanical Strength, Making Process, Porous Structure

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 elements for a linear motion bearing and so on, since it has an excellent low friction, high mechanical strength and high water resisting property [4].

The distribution of the fracture strength is one of the important mechanical factors, and it is necessary to be narrow for the industrial applications. The extent of the distribution is usually expressed using the Weibull modulus [5]. The modulus is required to be higher than 15-20 for the brittle materials. The modulus of the original RHS carbon was about 5-8 for the compressive strength [6]. Therefore, it is indispensable to improve the distribution, investigating the cause of the low Weibull modulus.

The RHS carbon is manufactured by impregnating a phenol resin into the porous structure of the rice hull, and carbonizing in nitrogen gas atmosphere. Therefore, the basic constitution of the RHS carbon is the cellular structure [7]. The uniform impregnation is the most important factor for the distribution of the mechanical properties in the making procedure.

The outer skin of the rice hull consists of a hard silicic acid cortex, and has high water repellency. Since the impregnation of the phenol resin is difficult through the outer skin, the wide distribution of the mechanical properties may be induced by the water repellency of the outer skin.

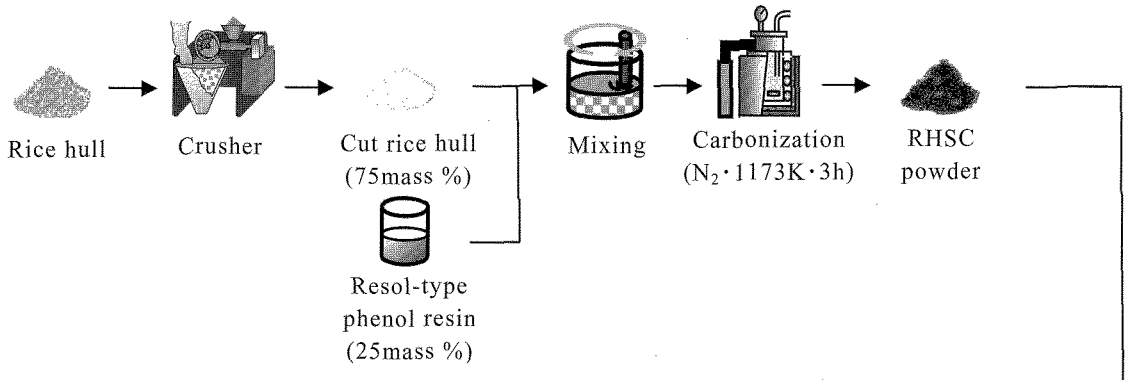
In this study, a new making process was proposed to improve the distribution of the mechanical properties. Especially, two types of pretreatments were added to obtain a uniform porous macro-structure for the RHS carbon.

2. EXPERIMENTAL PROCEDURE

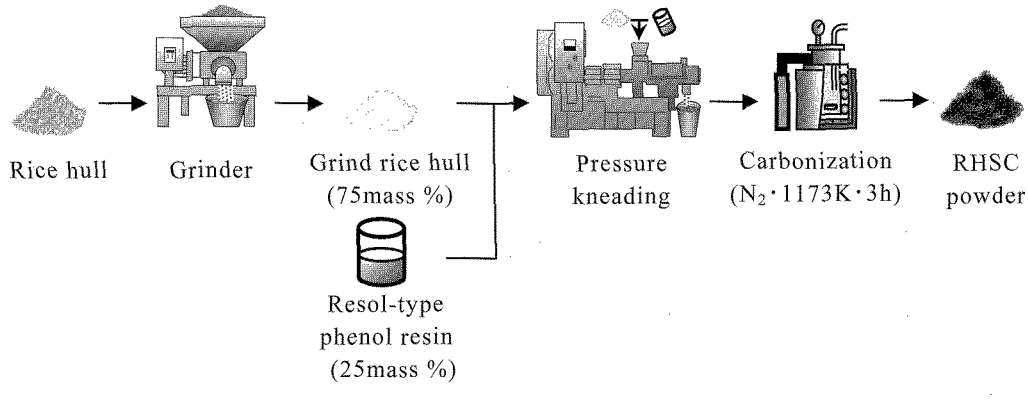
2.1 Materials

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, SiO_2. The mass ratio of the carbon is about 72 mass% of the organic constituent, and that of the hydrogen is about 8 mass%.

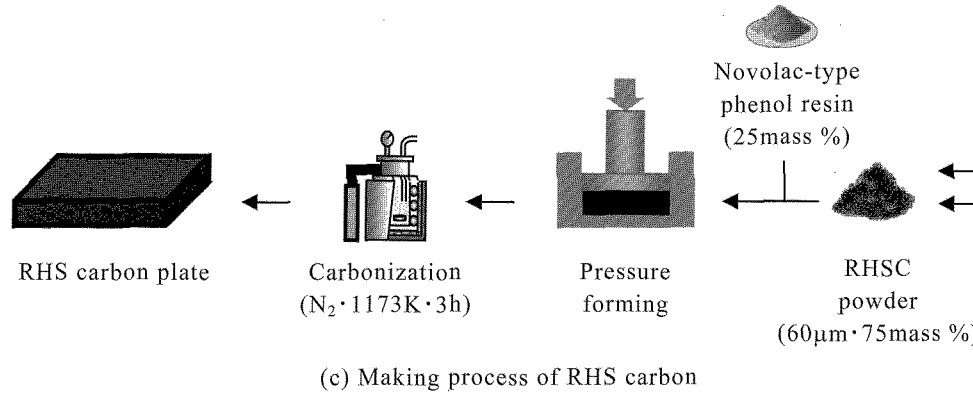
Figure 1 shows the making process of the RHS carbon. Two types of pretreatments are added to improve the distribution of the impregnated phenol resin into the natural porous structure of the rice hull. The first addition is the cutting



(a) Cutting pretreatment



(b) Grinding pretreatment and pressure kneading



(c) Making process of RHS carbon

Fig.1 Making process of RHS carbon with pretreatments.

pretreatment (Fig.1(a)) using a crusher (Hosokawa Micron Ltd. AP-B). The rice hull was cut into less than 3mm. Then, the cut rice hull was mixed with a resol-type phenol resin using a cooking mixer.

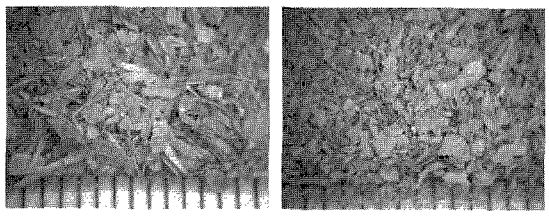
The second addition is grinding pretreatment and pressure kneading (Fig.1(b)). The grinding pretreatment was performed with a grinder (Kitagawa, Ltd. Millkuru). Then, the mixing was carried out using a pressurization kneader machine (Kurimoto, Ltd. KRC kneader).

Figure 1(c) shows the making process of the RHS carbon plate for the mechanical tests. A novolac- type phenol resin was further mixed with the RHS carbon powder for the pressure forming, and then carbonized in nitrogen atmosphere at 1173K.

The RHS carbon with cutting pretreatment is expressed as RHSC-A. The RHS carbon with grinding pretreatment and pressure kneading is named as RHSC-B. The original RHS carbon without pretreatment was also prepared.

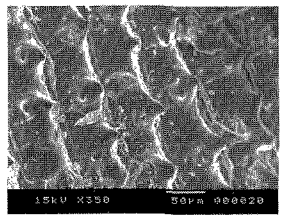
The geometry of the pressure formed RHS carbon plates was 150x75x5 mm^3. The test piece

(a) Original rice hull

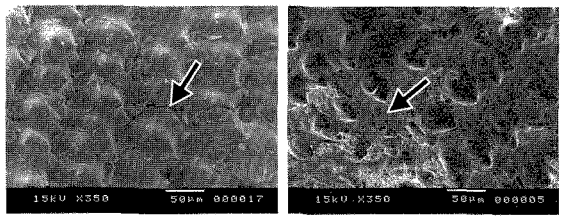


(b) After cutting (c) After grinding

Fig.2 Macroscopic view of pretreated rice hull.



(a) Original rice hull



(b) After cutting (c) After grinding

Fig.3 Macro-structures of silicic acid cortex of rice hull.

for the compressive strength was prepared by cutting out from the plates. The geometry of the test piece was 10x5x5 mm^3.

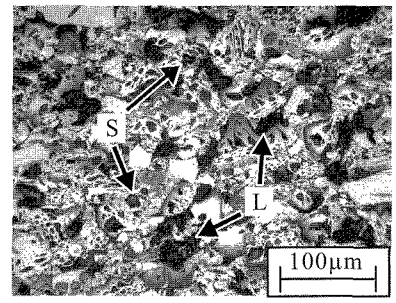
2.2 Compression test

The compression test was carried out using a universal testing machine. The crosshead speed was set to be 0.5 mm/min. The strength was measured in the parallel to the direction of the forming pressure. The displacement of test piece was measured using a laser displacement measuring system.

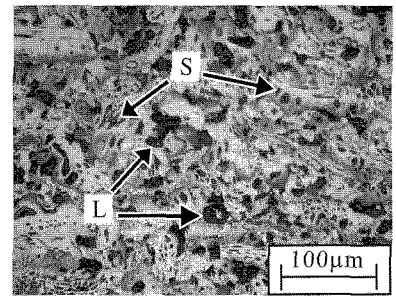
3. EXPERIMENTAL RESULTS

3.1 Observation of macro-structure

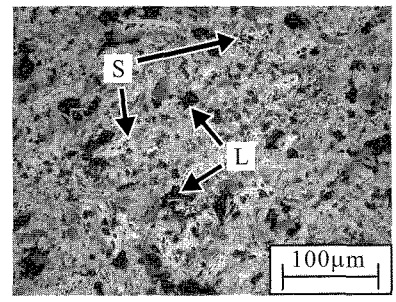
Figure 2 shows the macroscopic view of the



(a) Original RHS carbon



(b) RHSC-A



(c) RHSC-B

Fig.4 Macro-structures of RHS carbon.

pretreated rice hull. The grinding pretreated rice hull damaged significantly. Figure 3 shows the damaged surfaces of the pretreated rice hulls. Although the cutting pretreatment induces the cracks in the outer skin layer (arrow in Fig.3(b)), the layer is not damaged heavily. In contrast, the grinding pretreatment breaks heavily the outer skin layer (arrow in Fig.3(c)). The grinding is more effective than the cutting to crack the skin.

Figure 4 shows the macro-structure of the original RHS carbons and the pretreated RHS carbons. A bright part is corresponds to the RHS carbon, and a dark part is the area of the pores. There are two types of pores in the structure. One is the small pore of about 10μm diameter that was made from the natural porous structure of the rice hull (arrow "S" in Fig.4). Another is the relatively large pore that was produced by the contraction during the carbonization between the RHS carbon particles (arrow "L" in Fig.4).

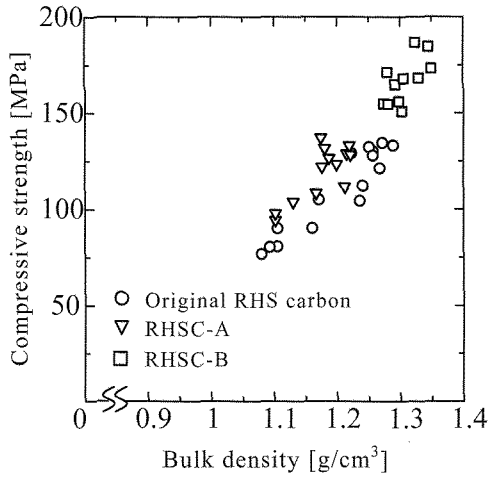


Fig.5 Relationship between bulk density and compressive strength of RHS carbon.

The macro-structure of the original RHS carbon has many large pores as shown in Fig.4(a). In contrast, the size of the large pores is smaller in the RHSC-B. Moreover, since the size of the small pores of RHSC-B is smaller than that of the original RHS carbon, the phenol resin is considered to be uniformly impregnated into the porous rice hull structure in the RHSC-B. Therefore, it is considered that the grinding and pressure kneading pretreatment is more effective for the production of the uniform structure than the cutting pretreatment.

3.2 Compressive strength

Figure 5 shows the relationship between the bulk density and the compressive strength. The grinding and pressure kneading pretreatment make high bulk density and high compressive strength for the RHS carbon.

The mechanical properties of the RHS carbon are listed in Table 1. The pretreatments improved the mechanical properties and the Weibull module which shows the extent of the distribution of the fracture strength. The cutting pretreatment, and the grinding and pressure kneading pretreatment are effective for the improvement of the mechanical strengths. The Weibull modulus is also increased and is achieved the value of about 15.

4. CONCLUSION

A new making process was proposed for the development of high quality RHS carbon. The summary of the results is shown as follow.

Table 1 Mechanical properties of RHS carbon

Materials	$\rho^{1)}$ [g/cm^3]	$\sigma_c^{2)}$ [MPa]	$E^{3)}$ [GPa]	$m^{4)}$
Original RHS carbon	1.20	119	14.4	5.3
RHSC-A	1.17	126	19.5	9.0
RHSC-B	1.31	172	25.2	14.8

1) Bulk density, 2) Compressive strength, 3) Young's modulus, 4) Weibull modulus

(1) The pretreatment of the grinding is effective for destruction of the outer skin of the rice hull.
(2) The phenol resin was evenly impregnated into the pretreated rice hull structures.
(3) The mechanical properties were improved by the new production method with the pretreatments of the grinding and pressure kneading.

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(Recieved June 6, 2008 ; Accepted September 5, 2008)