Transactions of the Materials Research Society of Japan 31[4] 953-955 (2006)

Mechanical Property and Water Absorption Capacity of Okara-ceramics Prepared from Bean Curd Refuse

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We fabricated ceramic materials that are composed of bean curd refuse charcoal and phenolic resin. Effects of the preheating time and the adding amount of phenolic resin on the properties of bean curd refuse ceramics (Okara-ceramics) were studied. The strength of Okara-ceramics could be decreased with increasing preheating time and increased with increasing amount of phenolic resin. However, a large amount of resin addition caused the formation of cracks in the precursor, presumably due to the generation of condensation water from the resin during the curing treatment. The water absorption capacity decreased with increasing the amount of the phenolic resin, due to the reduction of the number of pores and thus the effective surface area.

Keywords: Okara-ceramics, woodceramics, bean curd refuse, carbonization, strength, water absorption

1. INTRODUCTION

In the year 2000, the fundamental law for establishing a recycling-based society was executed in Japan, and thereafter several recycling laws were in effect. However, white paper on the environment shows that the total amount of industrial waste has not decreased in these years. If so, it is hard to say that recycling is promoted in Japan.

The application of biomass such as domestic animal excrement, leftover foods, and thinned woods becomes an action assignment. Carbon dioxide discharged by burning biomass is absorbed by plants through photosynthesis. Hence the burning of biomass will not increase the amount of carbon dioxide in the atmospheric during the life cycle [1].

The promotion of utilization of the biomass was ratified by the cabinet in 2002. Hence the effective utilization of biomass is the key to the creation of a recycling society. Byproducts of soy milk are cited as an example of biomass with difficult use. Bean curd refuse is disposed in the amount of several hundred thousand tons per year in Japan.

Even now a large amount of refuse is trashed with payment. Thus the development of a new way to use bean curd refuse is the key to the realization of a recycling-based society.

In this study, we fabricated Okara-ceramics with carbonized bean curd refuse and phenolic resin as raw materials. The microstructure and mechanical properties of Okara-ceramics were investigated, and compared with those of woodceramics. The application of Okara-ceramics to water absorption was also investigated.

2. EXPERIMENTAL METHOD

2.1 Sample preparation

Carbonized bean curd refuse powders of less than 500 μm in diameter were used as raw material for Okara-ceramics. Crude bean refuse contains oil that disturbs combination between carbonized bean refuse and a binder. The phenolic resin (Bellpearl S890) was used as the binder. Bellpearl is granular phenolic resin with an average grain diameter of 20 μm and has higher strength than conventional phenolic resin. It is commonly used as a binder for rubber commodities, friction materials, and composite materials.

Fig. 1 shows the flowchart for the sample preparation. Carbonized bean refuse powders and phenolic resin were mixed and compacted into the boads with the dimensions of 120×60×10 mm^3 by hot pressing under the pressure of 370 kgf/cm^2 at 180°C for 20 minutes. Then the specimens were cured at 200°C for 3 hours. The precursors were heated in flowing nitrogen from room temperature to 800°C, and kept for 1 hour, and then cooled to room temperature.

The weight ratio of carbonized bean refuse to phenolic resin was varied in the range of 50, 60, 70 and 80wt% to study the effects of the content of the phenolic resin. Preheating time was changed from 3 to 11 minutes to control the density of the final products.

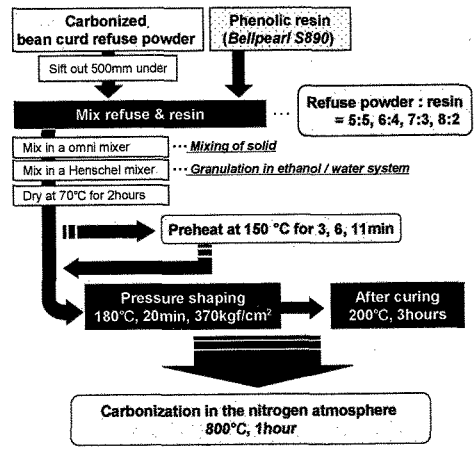

Fig.1 The flowchart for sample preparation

2.2 Characterization

Water absorption abilities of Okara-ceramics were determined as follows. The samples were maintained at 130°C for 1 hour for dehydration. After this treatment, the amount of water absorption was determined from the difference in weight after soaked for 48 hours in ion-exchanged water. The compression strengths of the Okara-ceramics were measured with an Instron-type tensile testing machine with a cross head speed of 1.1 mm/s. The sample dimensions for the compression test specimens were $9 \times 9 \times 18$ mm^3.

3. RESULTS AND DISCUSSION

3.1 Microstructure of the precursors

In some precursors before the final sintering treatment at 800°C, blisters were observed on the surface. Fig. 2 shows the photos of the top surface and the cross section of the precursor with the ratio of bean curd refuse to resin of 6:4 and 5:5. As shown in the photo, the presence of blisters was confirmed on the top surface. The size of the blister ranged from several mm to several tens mm. The samples with higher content of phenolic resin tended to have more blisters.

We cut the portion where the blister was observed perpendicularly to the surface and observed cross sectional microstructure. As shown in the figure, the presence of the crack whose size is almost the same as that of the blister was observed at the location about 1-2 mm deep from the top surface.

It is probable that blisters and cracks were formed with the stress caused by the generation of condensation water associated with thermal hardening reaction of phenolic resin. The thickness of Okara-ceramics was 10mm, and thus there was a temperature difference between the surface which is in contact with a metal mold and the interior region of the sample. As a result, hardening did not take place simultaneously within the entire sample. The surface started to harden while condensation water was generated in the interior region. The condensation water generated internally will vaporize at 200°C and will be entrapped in the neighborhood of the surface, which caused the formation of the blisters and cracks.

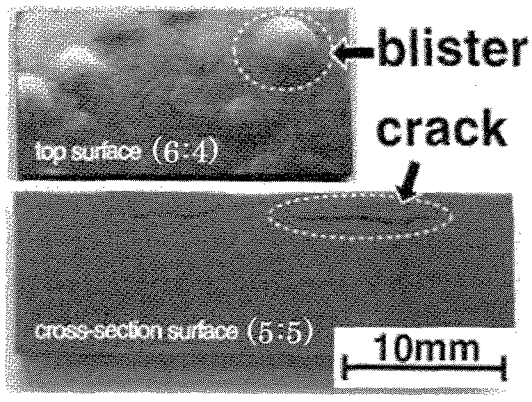

Fig. 2 Top surface and cross section of the precursor with the ratio of bean curd refuse to resin of 6:4 and 5:5.

3.2 Effect of preheating time

Fig. 3 shows the relationship between preheating time, specific compressive strength and density of Okara-ceramics. Preheating is performed prior to pressing for the purpose of removing wick moisture from the sample. One can see that the specific compressive strength and the density of the sample decreased with increasing preheating time. The specific compressive strengths were 36.5 MPa/Mg·m^3 for the sample with preheating time of 3 minutes, and 18.4 MPa/Mg·m^3 for 11 minutes. The densities were 1.35g /cm^3 for 3 minute sample and 1.21 g/cm^3 for 11 minute sample.

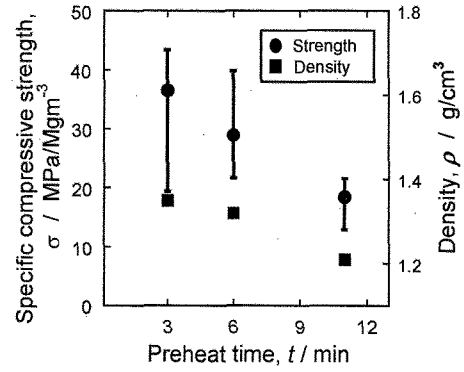

Fig. 3 Relationship between preheating time, the specific compressive strength, and the density of Okara-ceramics.

Fig. 4 shows SEM micrographs of Okara-ceramics with different preheating times. Dark contrasted sports distributed in the figure are carbonized phenolic resin particles. The distribution of phenolic resin for the sample with short preheating time was rather uniform. In contrast, the resin distribution was inhomogeneous for the samples with longer preheating time, for which some cracks were also observed.

3.3 Effect of the chemical ratio

Fig. 5 shows photos and SEM micrographs of Okara-ceramics with different content of carbonized bean curd refuse. The crack formation and the sample deformation occurred when phenolic resin content exceeded 40%. It is attributed to the fact that in contrast to carbonized bean curd refuse powder, phenolic resin contracts more acutely, leading to the stress concentration at the interfaces.

Fig. 6 shows the relationship between the content of bean curd refuse, the strength, and the density of Okara-ceramics. The data for the sample that contained more than 40% were not presented because of the presence of the cracks and severe sample deformation. In the figure we also plotted the data for the precursor before the final treatment at 800°C and the woodceramics carbonized at 650°C for reference. Okara-ceramics exhibited 3-7 times higher specific strength than woodceramics, in that the strength increased with increasing the content of phenolic resin.

Fig. 7 shows the relationship between the content of bean curd refuse, and the amount of water absorption for Okara-ceramics, the precursor, and Woodceramics. The amount of water absorption of Okara-ceramics was about half that of woodceramics even in the best sample. The amount of water absorption of the precursor also exceeded that of Okara-ceramics. The large water absorption capacity

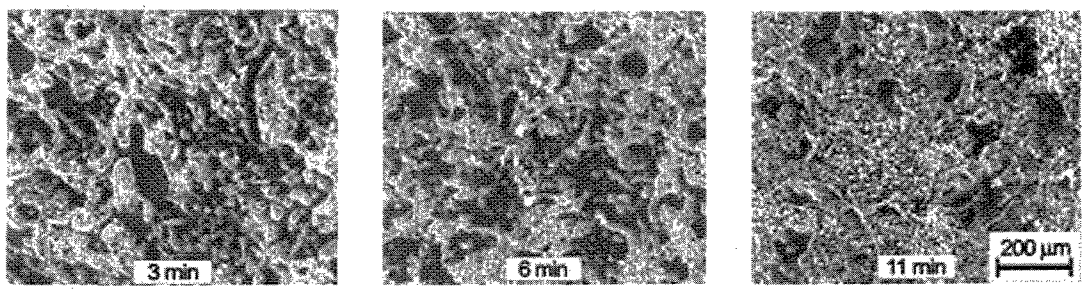

Fig. 4 SEM micrographs of Okara-ceramics with different preheating periods.

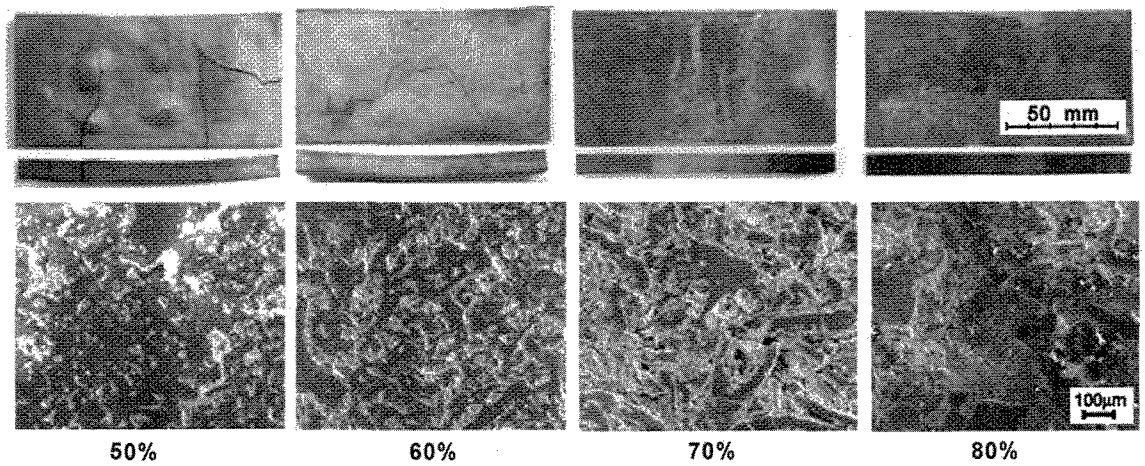

Fig. 5 Top surfaces and SEM micrographs of Okara-ceramics with different carbonized bean curd refuse content.

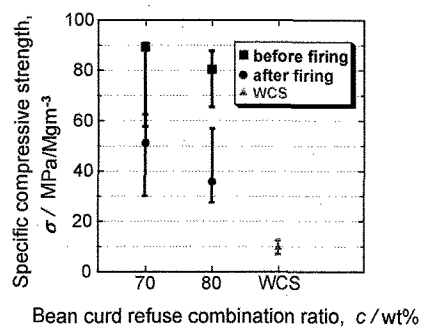

Fig. 6 Relationship between the content of bean curd refuse, the strength, and the density of the precursor and Okara-ceramics.

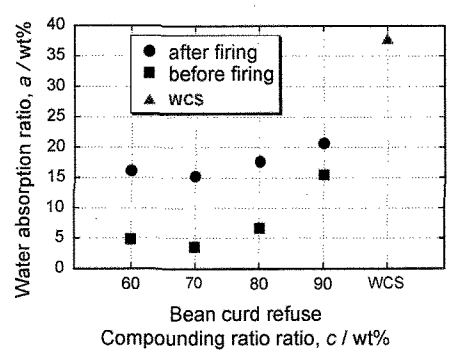

Fig. 7 Relationship between the content of bean curd refuse and the amount of water absorption for the precursor and Okara-ceramics.

is ascribed to the presence of pores and thereby a large effective specific surface area. The amount of water absorption for both the precursor and Okara-ceramics tended to decrease when the content of phenolic resin increased. The sample with 90% bean curd refuse (10% resin) showed the highest water absorption of 20.6%. It is thus apparent that water absorption of Okara-ceramics can be controlled by adjusting the blending quantity of phenolic resin.

4. SUMMARY

We fabricated Okara-ceramics by mixing and sintering the carbonized bean curd refuse powder and granular phenolic resin. We measured compressive strength and water absorption abilities of Okara-ceramics with various mixing ratios. The bending strength and anti-cracking properties could be improved drastically when the amount of phenolic resin exceeded 40wt%. The compressive strength of Okara-ceramics increases with increasing phenolic resin content and decreases with increasing preheating time. Water absorption of Okara-ceramics can be controlled by controlling the blending quantity of phenolic resin.

5. REFERENCES

[1] O. Kitani, Biomass-Bioresources and Environment, CORONA PUBLISHING CO., LTD., Tokyo (2004) p145.

(Received July 12, 2006;Accepted September 15, 2006)