Transactions of the Materials Research Society of Japan 31[4] 949-952 (2006)

Development of Bean-Curd Refuse Origin Ceramics Materials

Seiji Kakuta[1], Hiroyuki Ono[1], Masanori Kushibiki[1], Toshihiro Okabe[1],
Hideyuki Degawa[2], Hideto Hatanaka[2], Yasushi Iwamoto[2],
Makoto Ogawa[3], Akito Takasaki[3] and Masato Murakami[3]
[1]Aomori Industrial Research Center, 4-11-6, Daini-Tonyamachi, Aomori, Japan 030-0113
Fax: 81-17-739-9613, e-mail: kakuta@aomori-tech.go.jp
[2]Taishi Foods Inc., 25-1, Maekawara, Aisaka, Towada, Aomori, Japan 034-0041
Fax: 81-176-25-1546, h-degawa@taishi-food.co.jp
[3] Department of Engineering, Shibaura Institute of Technology 3-9-14, Shibaura, Minatoku, Tokyo, Japan 108-8548
Fax: 81-3-5859-8001, ogawa@sic.shibaura-it.ac.jp

We have studied the applicability of ceramics materials made of bean-curd refuse (called Okara) and thermosetting resin to water absorbers and infrared radiators. The Okara origin ceramics were prepared with varying the adding amount of the resin. The volume density of the Okara ceramics varied from 1.33 to 1.50 g cm^{-3} depending on the amount of the resin addition. The specific surface area of low-density Okara ceramics was 30 m^2 g^{-1}, and its water absorption reached 19wt%. Meanwhile, the infrared emissivity of the Okara ceramics was 0.945 at 423 K, which was equivalent to that of the Oya stone commonly used for an infrared radiator. These results suggest that Okara ceramics can be used for water absorbers and infrared radiators.

Key words: Okara, Ceramics, Water absorption, Infrared emissivity

1. INTRODUCTION

The bean-curd refuse (called Okara) is a by-product in the manufacturing process of Tofu, and the total amount produced per year is estimated to be 800,000 tons in Japan. A small amount of Okara is reused as foods, but most of them are used as forage or discarded as industrial waste. Thus, the efficient recycling method or new applications of Okara are desired in the view of environmental conservation and for the cost reduction of the disposing. The dried Okara mainly consists of bean origin proteins and has a powder form. It therefore has an excellent formability into useful shapes and can easily be mixed with other powder materials.

In the present work, Okara ceramics have been prepared from Okara powder mixed with thermosetting resin powder in the various weight ratios referring to the fabrication process of woodceramics that are prepared by sintering wood materials impregnated with thermosetting resin [1]. They were subjected to water absorption and infrared emissivity measurements. Based on the measurement results, we will discuss the usability of Okara ceramics as water absorbents and infrared radiators.

2. EXPERIMENTAL

2.1 Preparation of Okara ceramics board

The Okara which was produced in the Tofu manufacturing process in the bean-curd factory (Taishi Foods) was dried and carbonized at 923 K for 1 hour in N_2. The obtained carbonized Okara powder and thermosetting resin powder (Air Water Inc., Bellpearl S) were mixed with the ratio 60 ~ 90 wt.% of carbonized Okara powder. The 40g of mixed powder was pressed (453 K, 34 MPa, 8min) to form 6×12cm^2 board with the thickness of 0.3 ~ 0.4 cm using a stainless mold. The

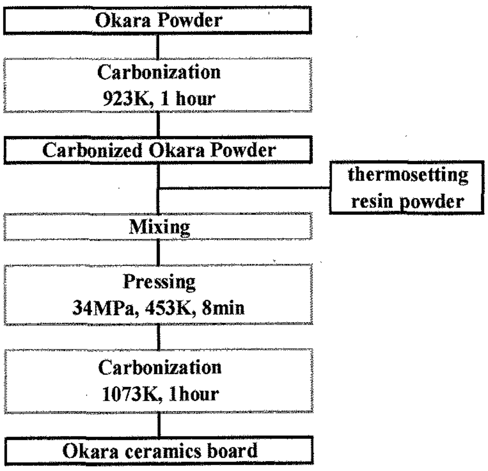

Fig. 1 Flowchart of the fabrication process for Okara ceramics boards.

Okara ceramics boards were manufactured by carbonizing the board at 1073 K for 1 hour under N_2 gas (Fig. 1).

2.2 Structural characterization

The specific surface area of Okara ceramics was determined by the B.E.T. method (Shimadzu-Micromeritics, FlowSorb II 2300). The observation of the surface morphology and chemical analyses were carried out with a scanning electron microscope (Hitachi, S-800) equipped with energy dispersive X-ray spectroscopy (Kevex, Quantum Dry). The crystal structure of carbonized Okara powder was determined with an X-ray diffractometer (Shimadzu, XD-610).

2.3 Water absorption properties

For water absorption measurements, the Okara ceramics board was first dried at 403 K for 1 hour and then immersed in de-ionized water for 24 hours. The amount of water absorption was determined by measuring the weight gained after the immersion.

2.4 Infrared emissivity of Okara ceramics board

The carbonized Okara powder was mixed with the thermosetting resin powder (10wt.%) and pressed into a disk (ϕ =40mm, thickness 5mm), and was carbonized at 1073 K for 1 hour (*vide supra*). The infrared emissivity was measured with a Fourier transform infrared spectrophotometer (JASCO, FT-IR 660 Plus) equipped with an electric furnace for sample incubation [2,3]. For comparison, apple woodceramics [4], bentonite (Nihon Koken, Tsugaru 2), zeolite (Nihon Zeolite, Zeoclean 8) and oya stone were also formed into disks in a similar size and subjected to the measurements. The daub (Tempil Inc., Pyromark) having an infrared emissivity of 0.91 was used as a standard.

3. RESULTS AND DISCUSSIONS

X-ray diffraction patterns of Okara powder carbonized at various temperatures are shown in Fig. 2. The (002) and (100) / (101) peaks were broad, showing that the carbonized Okara powder is amorphous graphite [5]. Meanwhile, the carbonized Okara powder contained calcium and potassium according to chemical analysis, although the data is not shown here. Therefore, the weak peak near 30° may be ascribed to the carbonate or oxide.

Figs. 3 and 4 show the SEM photographs of the surface

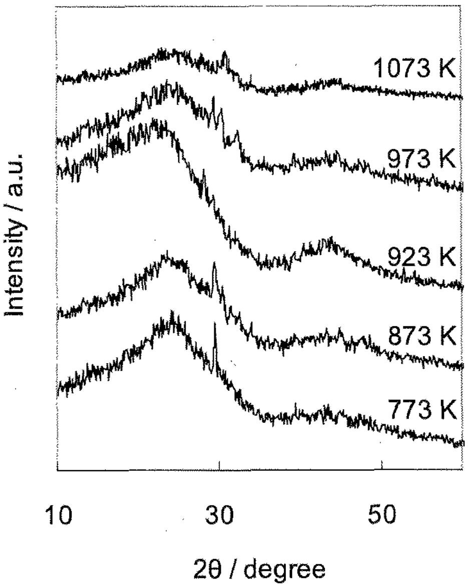

Fig. 2 X-ray diffraction patterns of carbonized Okara powder carbonized at various temperatures.

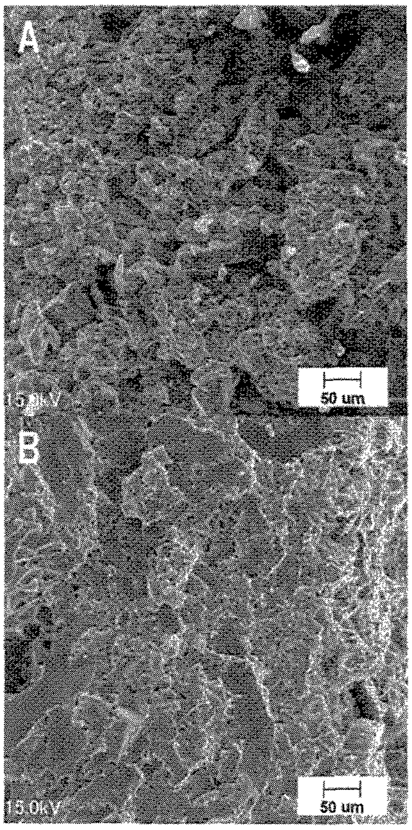

Fig. 3 SEM images of Okara ceramics (Okara 90wt.%, resin 10wt.%). A: surface of the board, B: cross section.

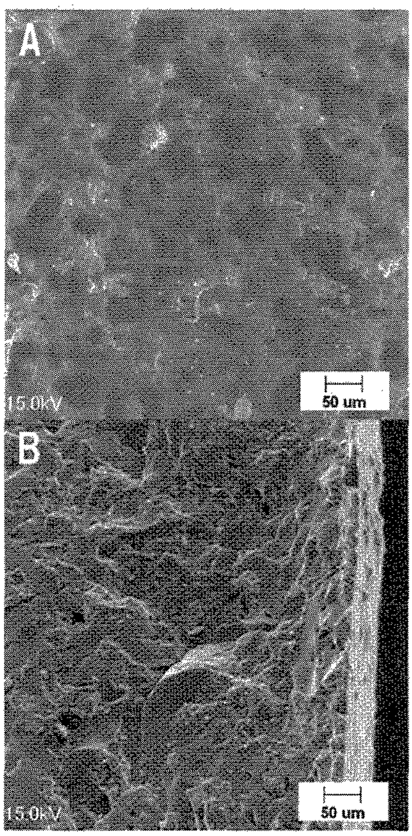

Fig. 4 SEM images of Okara ceramics board (Okara 60wt%, resin 40wt%). A: surface of the board, B: cross section.

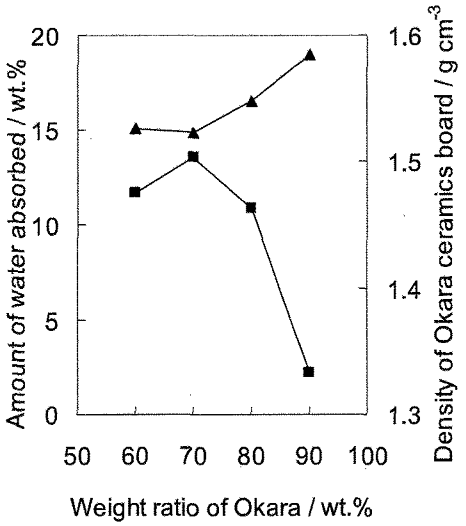

Fig. 5 The amount of water absorbed (▲) and the density (■) of Okara ceramics board fabricated with various weight ratio of Okara.

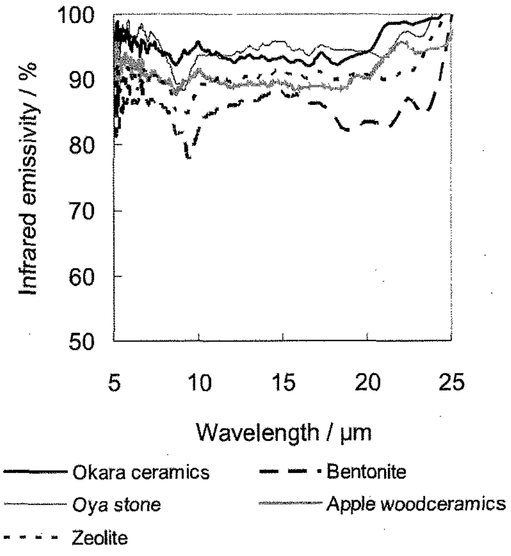

Fig. 6 Infrared emissivity of Okara ceramics, bentonite, Oya stone, and apple woodceramics incubated at 423 K.

and the cross sections of Okara ceramics boards with the Okara/resin weight ratios of 90/10 and 60/40 %, respectively. The sample with the Okara ratio of 90wt% has more porous surface and cross section than those with the Okara ratio of 40 wt%. The respective densities, which were calculated from the size of board and the weight, were 1.33 to 1.50 g cm^{-3} for the Okara ceramics boards with the Okara amounts of 90 and 60wt%.

Fig. 5 shows the density and the amount of water absorbed for the Okara ceramics as a function of the Okara weight ratio. The amount of water absorbed varied from 15 to 19wt% with changing the weight ratio of carbonized Okara powder; the water absorption increased with decreasing the volume density. As is already shown in SEM photos in Fig. 3, in the sample with a small amount of thermosetting resin, the spaces between carbonized Okara powders were not filled with resin. Hence, it seems that the pores observed in Fig. 3 mainly contribute to water absorption. Consequently, the Okara ceramics board with the smallest amount of resin (10wt%) had the lowest density and thereby the highest water absorptive ability. However, it should be noted that the specific surface area of this sample was below 30 m^2 g^{-1}. This value is not high compared to those of the conventional water absorbers. Thus if one can find the fabrication method to increase the specific surface area, the water absorption ability of the Okara ceramics will further be improved.

Fig. 6 shows the infrared emissivity spectra for Okara ceramics (90wt% Okara, 10wt% resin) and reference materials incubated at 423 K in air. The infrared emissivities were 0.945 for the Okara ceramics, 0.946 for the Oya stone, 0.904 for the apple woodceramics, 0.897 for the zeolite and 0.854 for the bentonite.

It is to be noted that the Okara ceramics exhibited a high infrared emissivity comparable to that of the Oya stone. It is also interesting to note that the emissivity of the Okara ceramics is higher than that of the apple woodceramics, despite the fact their compositions are similar and mainly consist of charcoal. The effective emissivity depends on the surface roughness of the radiator. Hence, such a difference in the emissivity can be explained in terms of the difference in the surface roughness, since the surface of Okara ceramics board is rough as already presented in Fig. 3.

These results indicate that Okara ceramics board can be utilized for infrared radiators with high emissivity rate as well as other charcoal materials such as woodceramics and minerals.

4. CONCLUSIONS

The effective volume density of the Okara ceramics depends on the weight ratio of the carbonized Okara ceramics powder and thermosetting resin, in that the density increased with increasing the ratio of the resin. The Okara ceramics board with low density exhibited high water absorptive ability. However, the specific surface area was below 30 m^2 g^{-1}. Thus, the enhancement of the specific surface area is important for practical applications of the Okara ceramics such as the adsorbent for chloride in tap water.

The infrared emissivity of Okara ceramics was 0.945 at 423 K, which was comparable to that of the Oya stone commonly used as an infrared radiator. Therefore, the Okara ceramics boards can also be used for infrared radiators.

ACKNOWLEDGMENTS

The authors would like to thank Naoto Yoshinaga at Air Water Inc. for providing Bellpearl.

REFERENCES

[1] T. Okabe, "Woodceramics", Uchida Roukakuho Co. Ltd., (1996).

[2] JIS R 1801, Method of measuring spectral emissivity of ceramic radiating materials for infrared heaters by using FTIR (2002).

[3] JIS R 1803, Method for the spectral radiant energy measurement of far infrared heaters specified in the far infrared region (2005).

[4] R. Ozao, T. Okabe and T. Arii, *Trans. Mat. Res. Soc. Japan*, **28**, 1075 (2003).

[5] M. Miki, T. Kikuchi, S. Inada, M. Suzuki and J. Takada, *Trans. Mat. Res. Soc. Japan*, **30**, 1167 (2005).

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