

Water absorption and retention of porous ceramics fabricated by waste resources

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Several counter measures have been carried out for mitigating heat island effect. One of those is installing on top of the roof with base materials having planted vegetation. The base materials are required good water absorption and retention which is necessary for the plant to survive. Therefore, in this study, we investigate the relationship between water absorption and water retention within the pore structures of porous ceramics. The raw materials of the ceramics were used waste resources. The structures were changed by different state foaming additive. It was found that the water absorption was dependent on open porosity and the pore size. The water retention, was reduced excessively with high porosity. Accordingly, the control of pore structure is described in details in this study.

Key-words : Porous ceramics, Waste resources, Water absorption, Water retention, Pore structure

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1. Introduction

In recent years, heat island effect in urban areas is a big problem. This effect causes elevated temperature and air pollution.¹⁾ Various factors contribute the effect such as exhaust heat from auto emission gas or air conditioner, stagnation of heat between buildings, and the decrease of wooded and water area in urban area. Some counter measures have been carried out. For example, planting on the building roof to increase the green area, and using water retentive material for construction material to cool surroundings according to the evaporation heat.^{2),3)} These materials need permanence, weathering resistance and low density. Because, in many cases, it is difficult to change constructed materials. In addition, water absorption and retention are important factors for the growth of plant and cooling effect by water evaporation.

Ceramic tiles as building materials have the advantages of permanence, weather resistance and decoration. However, dense ceramics such as conventional tiles are heavy and low machinability. Porous ceramics have a lot of advantages as construction materials compare with dense ceramics. It is because of not only lightweight and high machinability but also heat insulation, sound absorption, and others. In addition, water is absorbed and retained into the pore.

Recently, we have reported the technique of fabricating porous ceramics made from industrial wastes such as low-grade silica, glass, and waste alumina.⁴⁾⁻⁷⁾ In this technique, molding does not depend on the plasticity of the raw material. Therefore, the flow process and the solidification process can be separated and the control of the porosity is easy. Furthermore various characteristics based on the pores can be changed. In this study, the relationship between pore structure and water absorption and retention is reported.

2. Experimental procedure

2.1 Fabrication of porous ceramics

Industrial and mining wastes such as low-grade silica, glass and alumina grain were used as raw materials after grinding down to about 15 μm . Four types of organic waste

Table 1. Composition of the Slurry

substance	Amount (mass%)
wastes	73.1
distilled water	25.8
dispersant	0.1
forming additive	1.0

fibers were used as a forming additive. These fillers were fiberized to different condition. Ammonium citrate was used as a dispersant for waste materials. Ammonium lauryl sulfate (LATEMUL AD-25; Kao corporation) was used for the foaming agent. The composition of the waste-loaded slurry is summarized in **Table 1**.

The process for the fabrication of porous ceramics is shown in **Fig. 1**. The initial slurry was prepared by ball-milling. Then, foaming of slurry was conducted by mechanical stirring of the slurry using a double-bladed mixer operating as speed of 900 rpm, with assistance of the foaming agent. The foamed slurry was poured into a metal mold and dried. The drying process was carried out at 323 K for 70 h. The dried sample was then demolded and sintered at 1143 K for 2 h.

2.2 Characterization

Bulk density and open and total porosities of the sintered samples were determined by Archimedes' method. The theoretical density of the fully densified ceramic (2.62 g/cm³) was used as a reference to calculate the relative porosity. The average pore size was measured by mercury penetration method (PASCAL140 and PASCAL240, FISON, measurement range 4 nm-600 μm).

Water absorption was calculated using the following

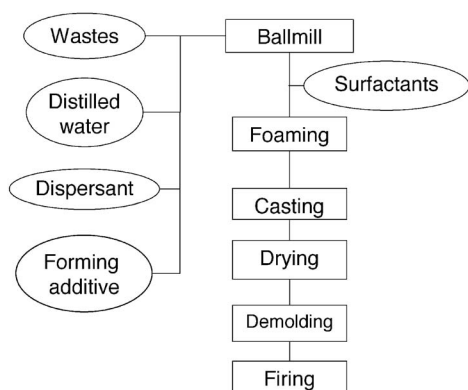


Fig. 1. Flow-chart of the process for the fabrication of porous ceramics.

relationship:

$$a = \frac{m_2 - m_1}{m_1} \times 100 \quad (1)$$

$$b = \frac{m_2 - m_1}{V} \quad (2)$$

where a is the water absorption (JIS A 5209), b is the weight of absorbed water for each unit volume, m_1 is dry sample weight and m_2 is wet sample weight after dipping in water for 24 h.

In humidity and temperature controlled chamber, the moisture absorption was measured by the weight change of samples at 298 K with varying humidity of 70%, 90%, and 99%.

Water retention was calculated using the following relationship:

$$c = \frac{m_3 - m_1}{m_2 - m_1} \times 100 \quad (3)$$

where b is the water retention, m_1 and m_2 is similar to Eq. (1), m_3 is the weight of sample which hanged from a balance in humidity and temperature controlled chamber at 60% and 298 K. Samples were dipped in water for 24 h before conducting the measurements. In addition, the filling of water in porous sample was observed by X-ray Computerized Tomography (SMX-90CT, Snimadzu Corp.). Water volume was calculated from X-ray CT image by image analysis using Image-Pro4.5 (Planetron Inc.).

3. Results and discussion

3.1 The pore structure

Table 2 shows density, open and total porosities and average pore size of porous ceramics fabricated using different types of forming additive. Correspondingly, the open porosities of these samples are 72.2, 73.8, 78.7 and 83.6%, which are similar to the total porosity. This result indicates that almost all pores are interconnected with each other causing open pores. The average pore sizes (Sample 1 to 4) are 11.92, 7.08, 20.85 and 4.80 μm . Sample 4 has the smallest average pore size. But the open porosity of Sample 4 measured by mercury penetration method is 44%. This difference in values indicates that the large pores over 600 μm cannot be detected. It is thought that an actual pore size of Sample 4 is

Table 2. Microstructure Parameters of the Porous Ceramics

Sample number	Bulk density (g/cm ³)	Total porosity (%)	Open porosity (%)	Average pore size (μm)
1	0.68	73.9	72.2	11.92
2	0.64	75.6	73.8	7.08
3	0.53	79.7	78.7	20.85
4	0.39	85.3	83.6	4.80

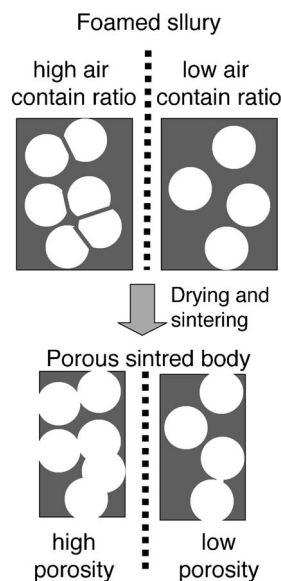


Fig. 2. Schematic image of changing to pore of the sintered body from bubble of the foamed slurry.

larger. The tendency that pore size increases along with porosity was seen, considering large pore.

In foaming process, contact area and contact probability of each bubble became bigger along with air contain ratio (Fig. 2). That contact area change to connecting window at drying and sintering process. The size of the connecting window is measured as the pore size in mercury penetrating method. Therefore, the pore size has relationship with porosity.

3.2 Humidity absorption

Figure 3 shows the humidity absorption of each sample. It could be observed that the humidity absorption of the samples increases according to humidity, but the change was very small. This was supported with water retention measurement, in which the influence of humidity absorption was negligible. And, it was impossible to supply water by the humidity absorption. The supply of water from the outside is needed to use these samples as a water retentive material.

3.3 Water absorption and retention

Figure 4 shows the relationship between open porosity with water absorption. The water absorption increases according to open porosity. The water absorption is calculated from sample weight. Because the density of the high porosity

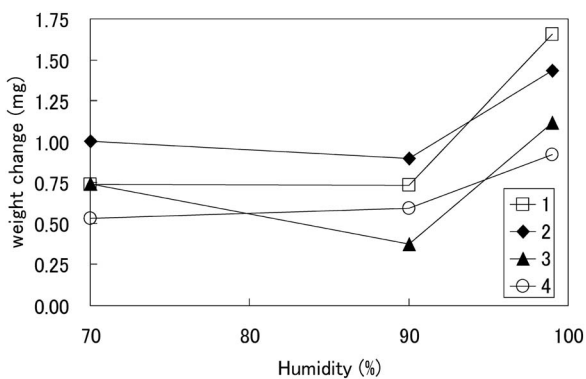


Fig. 3. Moisture absorption of porous ceramics in each humidity.

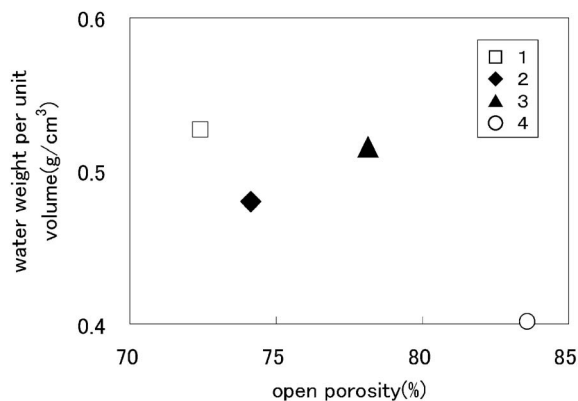


Fig. 5. Relation of open porosity with amount of water each unit volume.

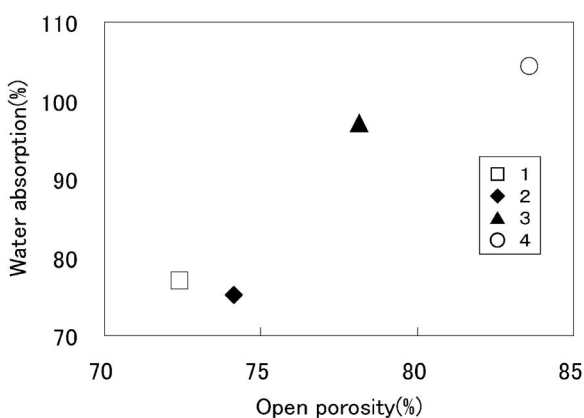


Fig. 4. Relation of open porosity with water absorption.

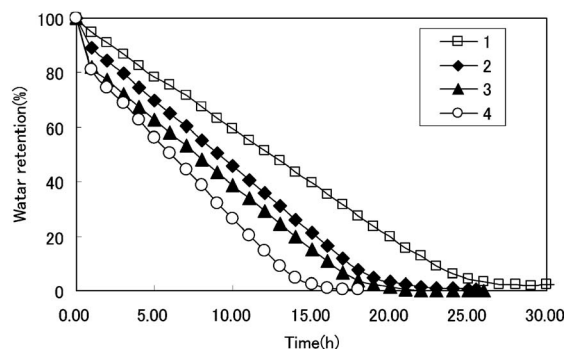


Fig. 6. Water retention of four samples as a function of time.

sample is low, the water absorption is estimated high. In fact, it turned out that the amount of the water contained in the sample decreased (Fig. 5).

Figure 6 shows the result of water retention measurements. The water retention time decreased according to increase of porosity. The longest time of water retention was shown by Sample 1. And the rate of decrease was constant. On Samples 3 and 4, significant decrease was observed at first 1 h.

It is thought that the above result depends on pore structure. The following equation is the liquid surface height of capillary phenomenon.

$$h = \frac{2\gamma \cos \theta}{\rho g r}$$

where h is the liquid surface height, γ is the surface tension, θ is contact angle, ρ is density of liquid, and r is radius of capillary. The h is retentivity of water by the capillary. The retentivity became weak by the increase of pore size. At large pore size sample such as samples 3 and 4, the pore could not keep water. This is considered to be due to the reduction of the amount of water weight in unit volume and decrease of retention at first 1 h.

The connecting state of pores is considered to be another cause. At high porosity, connecting window and contact probability of each pore became bigger along with porosity (Fig. 2 shows). The shape of connected pore is similar to

straight pipe. And many channels are formed. For this reason, it becomes easy to move the water to the outside from the inside of a sample. The water evaporates easily on the sample surface. Therefore the water retention time was shortened.

Figure 7 shows the X-ray CT picture of Sample 1. Picture (A) is an initial state after dipping in water for 24 h. (B) and (C) are the states after 1 h and 10 h after. In those photographs, the white area is the ceramic matrix, black area is the unfilled pores, and gray area is water-filled pores. The domain which contains water on the picture (A) was 64% of a sample. And then, after 1 h, the domain decrease to 57%. After 10 h, the water in a sample disappeared. From this result, the water in a sample decreased with fixed speed about 7% per hour. Total retention time of water was differing between water retention examination and X-ray CT analysis. This reason is different of sample size. The sample of X-ray CT was smaller than the sample of water retention examination. However the tendency of the water decrease in each analysis was similar. The good water retention property of the Sample 1 was confirmed.

4. Conclusion

Porous ceramics fabricated from waste material shows better water absorption and retention. The water absorption and retention were depending on the pore structures. These properties were deteriorated with the large pore size, or the too high porosity. In this study, Sample 1 shows good

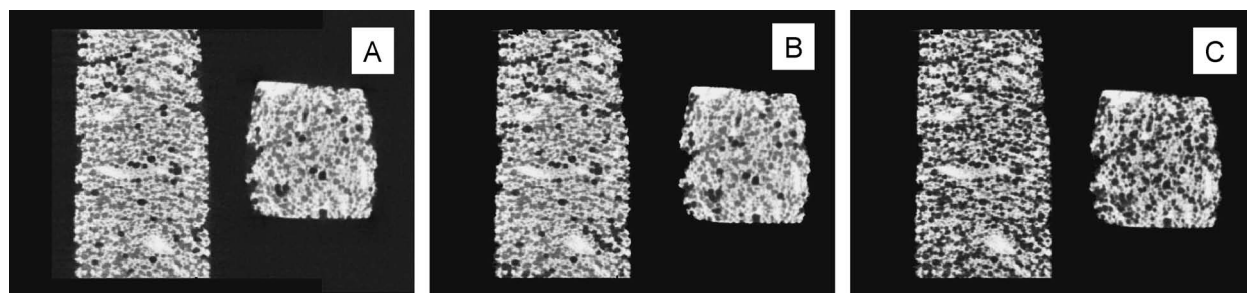


Fig. 7. X-ray CT picture of water containing sample 1 with (A) initial state after dipped in water 24 h, (B) 1 h after, and (C) 10 h after. Left side: vertical cross section. Right side: horizontal cross section.

properties. As a result, in the design of water retentive building materials, the control of pore structure is important to control of water absorption and retention. Ideally, the small contact area of each pore is effective to improve in a water retention property at high porosity.

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