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Utilization of Charcoal from Wood Waste I. Properties of charcoal–cement composite boards

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Charcoal obtained from wood–based waste materials is of low quality with amorphous shape and low density. With the aim of utilizing this low–quality charcoal, the properties of charcoal–cement composite board were investigated. Pulverized *Sugi* wood charcoal, Portland cement and water were mixed and then set and hardened in a mold. Thirteen types of mixture ratios of charcoal to cement were used to produce 10 mm–thick composite boards. The flexural strength of the board showed the maximum at the charcoal/cement mix ratio of 0.05 and then decreased as the mix ratio increased. The distinctive features of the composite board are a high water–sorption and a considerably high capacity of moisture sorption and desorption. The increase in the amount of charcoal brought about the increase in the water absorption. Although the boards absorbed great amounts of water, dimensional changes were very small. The capacity of adsorption and desorption of moisture increased with the increase in the amount of charcoal and reached the maximum value around the charcoal/cement mix ratio of 0.3, and then decreased. These characteristics suggest the possibility of applying the board to the interior walls and the roof–cooler of buildings.
Key words: Charcoal, Cement, Board, Density, Water absorption, Dimensional change, Moisture adsorption, Combustibility

INTRODUCTION

In recent years, the recycling of wood–based waste has become a very serious issue because of declining forest resources and the increased awareness of environmental problem. Various companies, researchers, and institutions have conducted research in efforts to promote the utilization of wood–based waste by incorporating it as a raw material into various products. However, to date, most of wood–based waste is, still, finally burnt off. Burning of wood waste is not only the wastage of organic resources, but also is a cause of CO_2 level increment in the atmosphere. Therefore, it is desirable to carbonize the wood–based waste and to utilize the resulting charcoal.

Charcoal has excellent characteristics. Highly fire–enduring and electromagnetic–wave–shielding materials[1–4] were developed from charcoal with novel performance equivalent to those of metallic materials. It also can be used as adsorbents for environmental purification and materials regulating humidity[6–9]. However, the charcoal made from wood–based waste generally is amorphous in shape, low in density and flammable.

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Due to the low quality, it has found only limited uses such as soil modifier. Although an attempt has been made on developing insulation boards from carbonized wood waste[6], it needs further investigation to increase the demand. When powdered charcoal is mixed with cement and allowed to harden, a composite board is formed. Because of the porous nature of charcoal, the composite board will gain some particular properties for the requirements of different specific uses. Thus, the authors investigated the properties of the composite boards with a wide range of charcoal/cement mix ratios.

MATERIAL AND METHODS

Board manufacture

Sugi wood charcoal (particle size:100–mesh pass; bulk density: 0.2; purchased from Kumamoto Tanka Kyodo Kumiai) and commercial ordinary Portland cement were used. The mix ratios of charcoal to cement were 0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, and 0.6. The slurry was prepared by mixing charcoal and cement with the minimum amount of water needed and then poured into the mold and cured for 24 hours at room temperature. After the boards were taken out of the mold, water was sprayed on the surfaces and the boards were wrapped with polyethylene films and cured for 2 weeks at room temperature. Then the boards were air–dried at ambient temperature for one week.

Bending test

The static bending test was conducted in accordance with JIS 2113. Test specimens were 400 mm in length, 50 mm in width and 10 mm in thickness. Modulus of rupture (MOR) was determined with the rate of loading of 5 mm/min on a 150–mm effective span with the use of TENSILON/UTM–1–2500–. Four specimens were tested for each of the board–preparation conditions. The data of MOR are shown as average values.

Water–absorption test

The test specimens (100 mm × 100 mm × 10 mm) were submerged horizontally in water at room temperature (23–25 °C) for 24 hours after the weight and size of specimens were measured. Excess water on the surfaces of specimens was wiped out, and the weights and sizes of the specimens were measured. Then the specimens were dried in an oven with a temperature of 105 °C for 24 hours, and the weights were measured. Also to obtain the relative rates of water absorption, each specimen (100 mm × 100 mm × 10 mm) was placed perpendicularly in a vessel with an area of 76 cm^2 containing 70 g of water for 10 sec, and the increase in the board weight was measured.

Moisture adsorption test

Specimens (100 mm × 100 mm × 10 mm) were placed in a humidity–regulation chamber (Temperature and Humidity Chamber, TABAI ESPEC CORP). The temperature was set at 20 °C. At first, the weighed specimens were placed in the chamber with the relative humidity (RH) of 98% until the equilibrium was attained, the weights being measured, and then the specimens were put under 80% RH, 60% RH, 40% RH, and 20% RH, successively (desorption processes). After the desorption process, all specimens were dried at 105 °C, and the oven–dried weight of each specimen was measured. In a similar fashion, the adsorption process was carried out at the RH levels of 20%, 40%, 60%, and 80% in sequence.

Combustibility test

Combustibility test was conducted according to JISA1322. The specimens (250 mm × 170 mm × 10 mm) were dried at 50 °C for 48 hours and then placed at room temperature for 24 hours prior to testing.

RESULTS AND DISCUSSION

Minimum amount of water required for preparing boards

It is well known that the mixture of charcoal and cement has to be changed into slurry for forming boards first. The minimum amount of water required for forming slurry increased with the increase in the charcoal/cement mix ratio as shown in Fig. 1. The amount of water was expressed as weight in unit volume of board in this figure. The board prepared from cement only needed 450 kg of water in 1 m^3 of volume, however, the board with the charcoal/cement mix ratio of 0.6 required 630 kg of water.

The relations between minimum amount of water needed (y) and the charcoal/cement mix ratios (x) were expressed as $y = 450 + 300\ x$.

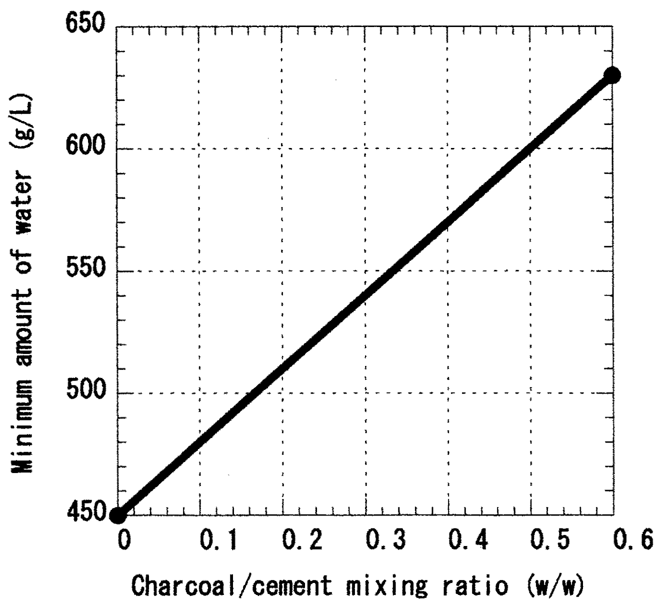

Fig. 1. Relationships between the charcoal/cement mix ratio and minimum amount of water needed for forming slurry.

Board density

The changes in the board density with the charcoal/cement mix ratio are shown in Fig. 2. As was expected, board densities decreased with the increase in the charcoal/cement mix ratio. However, the tendency of the decrease in density changes at the charcoal/cement mix ratio of around 0.3. This indicates that there exists a structural change in board at the charcoal/cement mix ratio of around 0.3

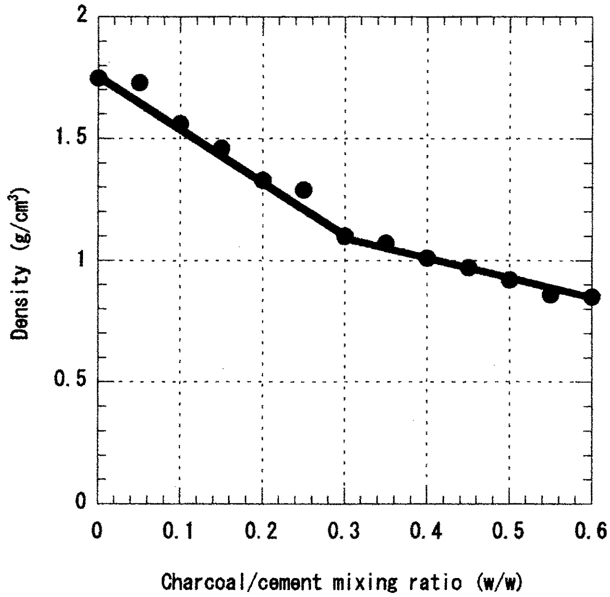

Fig. 2. Change in the board density with the charcoal/cement mix ratio.

Modulus of rupture

The changes in the modulus of rupture (MOR) with the charcoal/cement mix ratio are shown in Fig. 3. Maximum MOR value was observed at the charcoal/cement mix ratio of 0.05, and then the MOR decreased with the increase in the mix ratio. The same results were obtained when boards were made once again under the same conditions. Thus, smaller amount of wood charcoal (around 5% based on the weight of the cement) is considered to work as a reinforcing material. The changes in the specific modulus of rupture (MOR divided by board density) with the charcoal/cement mix ratio are shown in Fig. 4. The specific MOR increased with the addition of charcoal in the region of the charcoal/cement mix ratios below 0.3, while it decreased in the region of the mix ratios above 0.3. It is supposed that the boards with the charcoal/cement mix ratios below 0.3 have a structure in which the charcoal powder is scattered in the cement matrix, while the boards with the larger mix ratios have a structure in which the cement plays a role as a binder of charcoal. It is considered that the decrease in specific MOR in the region of

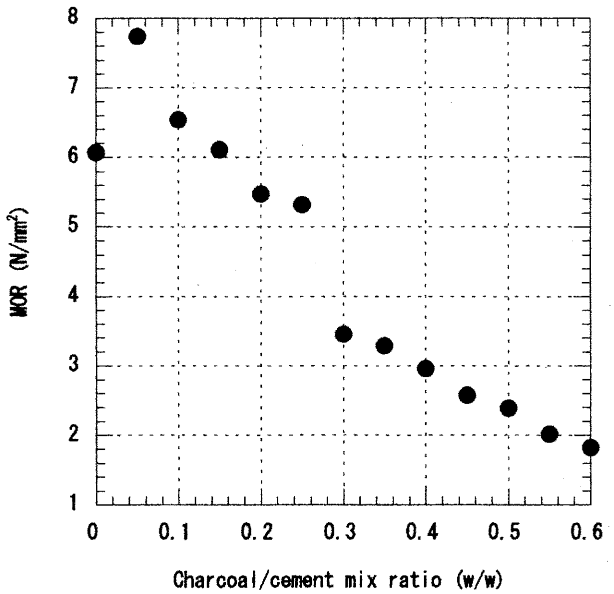

Fig. 3. Change in the flexural strength with the charcoal/cement mix ratio.

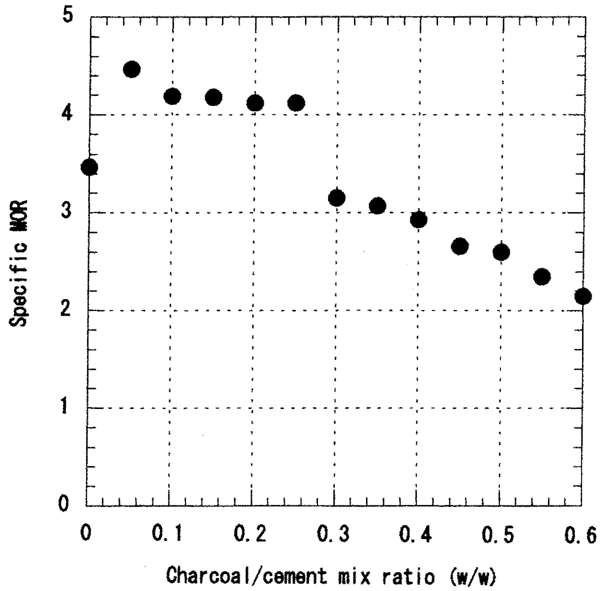

Fig. 4. Change in the specific MOR with the charcoal/cement mix ratio.

high charcoal/cement mix ratios is due to the decrease in the amount of binder in board.

Water absorption

The amounts of water absorbed by the immersion of the boards for 24 hours are shown in Fig. 5. The amount of water absorbed increased with the increase in the charcoal/cement mix ratio as expected. Figure 6 shows the amounts of water absorbed by the boards placed perpendicularly in water with the depth of 1 cm for 10 sec. The obtained values can be considered to be the relative rates of water absorption in the initial stage. The relative rate of water absorption increase with the increase in the charcoal/cement mix ratio, fairly slowly in the region of the mix ratio below 0.1 and steeply in the region of the mix ratio above 0.1.

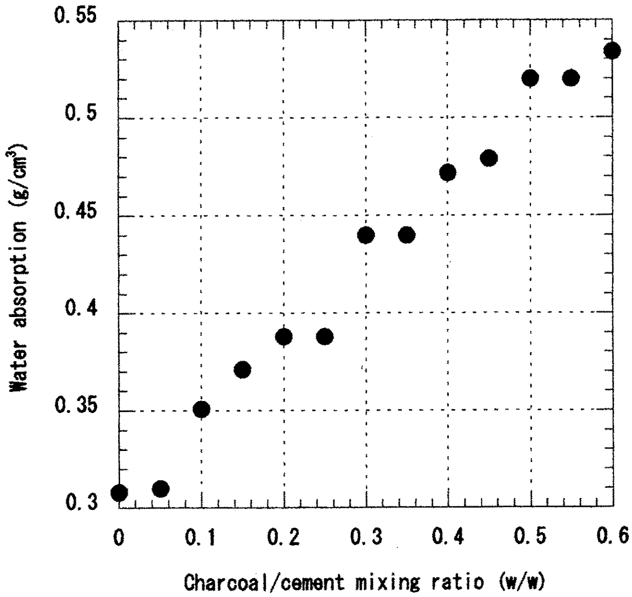

Fig. 5. Change of water–absorption capacity with the charcoal/cement mix ratio.

Dimensional stability

The volumetric swelling (VS) on water absorption increased as the charcoal/cement mix ratio increased from 0.05 to around 0.3, and then leveled off as shown in Fig. 7. Though the VS increased with the addition of charcoal, the maximum VS was less than 0.9%.

Moisture absorption

The changes in the equilibrium moisture contents (EMC) of the boards with the charcoal/cement mix ratios of 0, 0.3 and 0.6 in the desorption and the adsorption

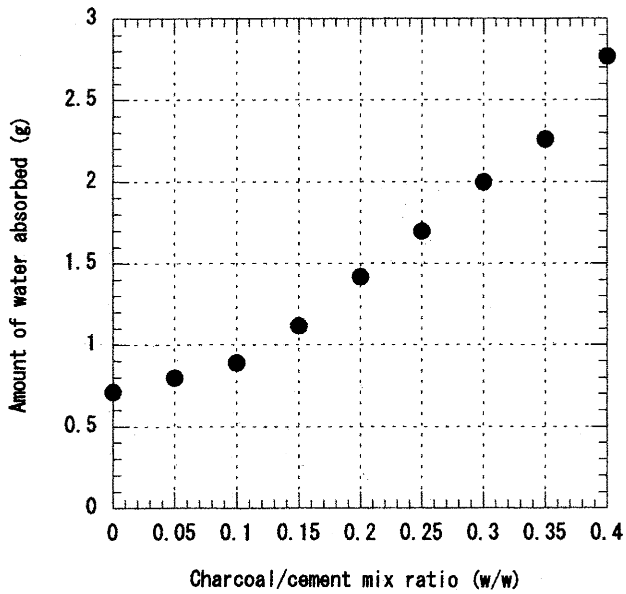

Fig. 6. Change of amount of water absorbed in 10 seconds with the charcoal/cement mix ratio.

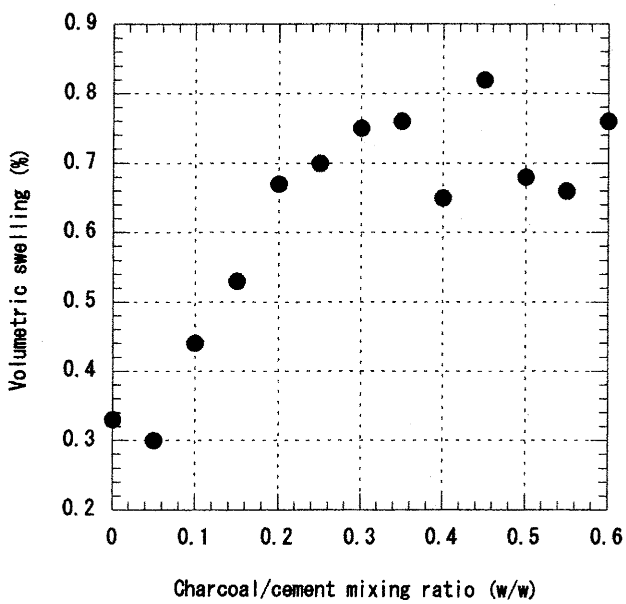

Fig. 7. Change of the volumetric swelling with the charcoal/cement mix ratio.

processes at 20 °C are shown in Fig. 8. This figure shows that the board prepared from cement only adsorbs a considerable amount of moisture in the adsorption process, but desorbs very small amount of moisture in the desorption process. In contrast to this, the boards prepared from charcoal and cement adsorb and desorb much more moisture.

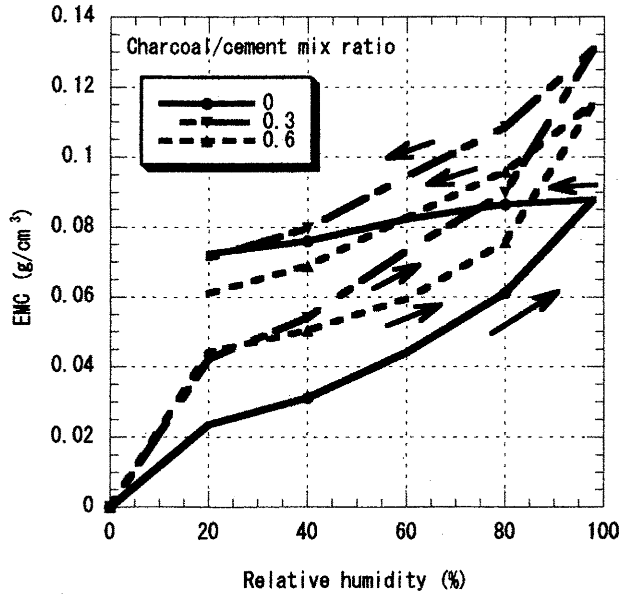

Fig. 8. Change of moisture-absorption capacity with the relative humidity at 20 °C.

Figure 9 shows the changes in the EMC with the charcoal/cement mix ratio at 80% RH and 20 °C in the adsorption process. The EMC increased with the increase in the charcoal/cement mix ratio and reached the maximum at the mix ratio of around 0.3 and then decreased. This behavior is different from that in the case of water absorption where the total volume of pores in the board plays an important role. In the case of moisture adsorption, the EMC decreased in spite of the increase in the pore volume as the charcoal/cement mix ratio exceeded 0.3. It may be attributed to the balance of the hydrophobic nature of charcoal and the hydrophilic nature of cement. The EMC of charcoal itself was measured to be only 9.86% (w/w) at 80% RH and 20 °C. This value indicates that if we made a charcoal board with the bulk density of 0.2 the EMC would be 0.02 g/cm^3, which is almost 1/3 of that of the board prepared from cement only. When the charcoal is added to cement, internal voids in board increases. Thus, the increase in voids in board will result in the increase of EMC until the charcoal/cement mix ratio reaches around 0.3, but as the mix ratio becomes higher, the decrease in the amount of cement with hydrophilic nature and the increase in the amount of charcoal with hydrophobic nature will cause the decrease of EMC.

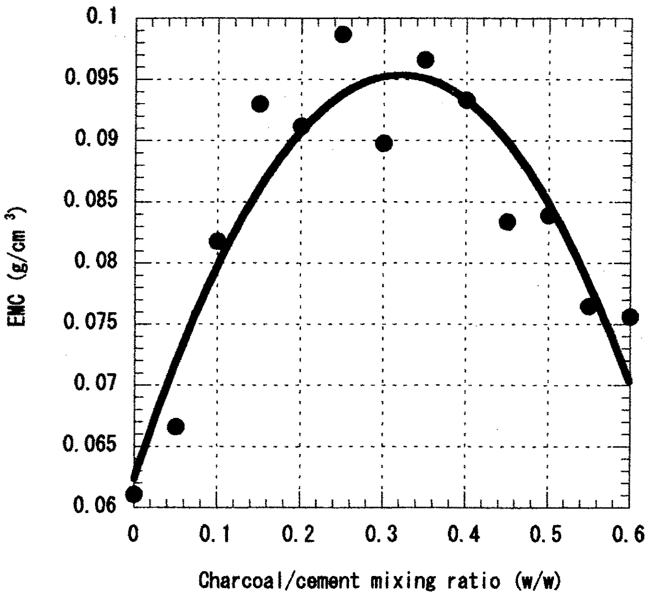

Fig. 9. Change of moisture–absorption capacity with the charcoal/cement mix ratio under 80% RH at 20 °C.

Combustibility

The results of combustion test showed that all the boards prepared from charcoal and cement reached the first–level non– combustion quality according to JISA1322 (Testing method for incombustibility of thin materials for buildings). This test method is based on char length, flaming time and post–flaming time. Not only flame and post flame but also smoking combustion and smoldering combustion were not observed.

CONCLUSIONS

When charcoal was added to cement, porosity of board increased and board density decreased as the mix ratio of charcoal increased. Although the modulus of rupture increased at the charcoal/cement mix ratio of 0.05, it decreased with the increase in the amount of charcoal. As a result, boards of higher charcoal/cement mix ratios are not suitable for the use that requires strength. The distinctive features of the composite boards of high charcoal/cement mix ratios are a high water absorption capacity and a high moisture adsorption–desorption capacity. These characteristics suggest that the composite board can be used as interior wall materials in the places where dewing occurs. Moreover, the boards are considered to be useful as a cooling panel installed on the roof connected with watering device.

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