Greening Material Consisting of a Porous Ceramic Made from Waste Glass Fiber Reinforced Plastic Coated with Moss

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Abstract- In this study, to recycle glass fiber reinforced plastic (GFRP) discarded as industrial waste and moderate the heat island phenomenon by greening architectural structures, a greening material consisting of moss and a porous ceramic base material made from clay and waste GFRP was developed. The properties of the greening material were examined. First, it was confirmed that moss could be grown on the porous ceramic base material by performing pH measurements of an immersion of the porous ceramic base material made from clay and GFRP and germination tests of moss on the porous ceramic base materials. Second, the ability of the greening material to decrease solar radiation heat and CO_2 concentration were investigated. The results show the usefulness of a greening material consisting of moss and a porous ceramic base material made from clay and waste GFRP in these roles.

Keywords – GFRP, Waste, Moss,Greening Plant, Recycling, Base Material

I. Introduction

The disposal of waste glass fiber reinforced plastic (GFRP) has recently become a social problem [1]. Mechanical, thermal and chemical recycling technologies [2-3] are used to recycle waste plastics depending on their type. However, recycling waste GFRP is very difficult. As a result, much of this waste is buried underground as industrial waste. Fine glass fiber dust and leachates from landfills containing GFRP may cause serious health and environmental damage, and the area available for landfill sites will be insufficient in the future. Therefore, to use waste GFRP effectively so that it is disposed of without pollution, we previously developed a process to produce porous glass fiber reinforced ceramics by mixing clay and crushed waste GFRP before the mixture is fired [4-5].

In this study, to recycle waste GFRP and moderate the heat island phenomenon, we develop a greening material for architectural structures that consists of moss and a porous ceramic base material made from clay and waste GFRP. This material uses the characteristics of the porous ceramic, including itslight weight and ability to absorb water.

First, we measure the pH of an immersion of the porous ceramic base materials made from clay and GFRP. We then investigate the germination of moss on the porous ceramic base materials. A greening material is produced by distributing moss with a size of approximately 2 mm over the porous ceramic base material covered with adhesive solution. The effects of the moss-covered ceramic on solar radiation heat and concentration of CO_2 are also examined.

II.EXPERIMENTAL

A. Production of greening material consisting of moss and ceramic base material –

Clay produced in Miyazaki Prefecture, Japan and polyamide (PA) plastic containing 40% glass fiber were used to fabricate the ceramic base material. The GFRP was crushed to a size of 1 mm or less using a rotary mill. The crushed GFRP (20% of the total mass) was mixed with the clay. The mixture was solidified by pressing into a mold under a pressure of 5 MPa. The molded samples were squares with sides of 100 mm and had a thickness of approximately 15 mm, or with sides of 250 mm and a thickness of approximately 10 mm. The molded samples were heated in an oxidizing atmosphere at a rate of 100 °C h^{-1} to 1000 °C using an electric furnace (Kyoei Electric Kilns Co., Ltd., Japan, KY-4N). The samples were held at 1000 °C for one hour. The samples were then cooled to room temperature in the furnace. Table 1 and 2 give the chemical composition and physical properties of the porous ceramic base material, respectively. The porous ceramic exhibited high water absorption compared with that of a typical brick of less than 15% (Japanese Industrial Standards R 1250).

Moss was grown on the ceramic by distributing moss (Racomitriumcanescens) with a size of approximately 2 mm over the porous ceramic base material covered with adhesive solution. A solution of Mowinyl (3 g, Nippon Synthetic Chemical Industry Co., Ltd., Japan) dissolved in water (1 L) was used as the adhesive. Figure 1 shows a photograph of a moss sample produced in this manner.

B. pH measurement of immersions of ceramic base material –

In general, moss can grow on soil or inorganic substances from slightly acid to alkaline (pH of approximately 6–8). Therefore, we investigated the pH of immersions of the porous ceramic base material made from clay and GFRP. To measure the pH of the immersions containing the porous ceramic base material, the ceramic was crushed to approximately 1 mm or less. The powder was then immersed in distilled water with a mass five times that of the powder for at least 30 minutes before the pH of the solution was measured [6].

Table 1 Chemical compositions of inorganic substances contained in clay, GFRP and ceramic base material

Component	Clay (Mass %)	Inorganic matter included in GFRP (Mass %)	Ceramic base material made from clay and 20% GFRP (Mass %)
SiO_2	66.0	47.3	64.7
Al_2O_3	22.2	22.6	21.9
Fe_2O_3	4.72	1.14	4.36
K_2O	3.60	4.97	3.29
MgO	1.51	0.90	1.50
CaO	0.97	15.0	3.20
TiO_2	0.90	-	0.82

Table 2 Physical properties of a ceramic base material made from clay and GFRP

Bending strength (MPa)	7.1
Density (kg/m^3)	1.5×10^3
Water absorption (%)	18

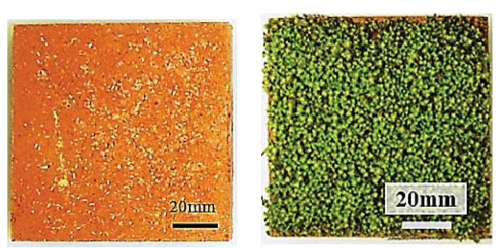

Figure 1. Photographs of ceramic base material and moss samples

C. Germination of moss on the ceramic base material –

To examine whether moss could grow on the porous ceramic base material, germination tests were carried out by distributing moss with a size of approximately 2 mm and mass of 0.5 g on the samples of the porous ceramic base materials. The distributed moss was supplied with water, and its germination was observed using a microscope for more than 3 months.

D. Measurement of temperature change caused by radiant heat for moss and mortar plate samples –

To examine the effect of the moss sample on radiant heat, the temperature changes of a moss-covered surface,porous ceramic base material and mortar plate without moss were measured when their surfaces were irradiated with infrared light.

Figure 2(a) shows a schematic illustration of the setup for temperature measurement. A halogen heater (Mini Halogen Heater, DX-4616, Japan) was used to irradiate the sample with infrared light. The porous ceramic base material and mortar plate both had sides of 100 mm, and thickness of approximately 15 mm. The irradiation with infrared light was carried out in a darkroom. The power of the halogen heater was set at 400 W. The light intensity near the samplesurfaces was 15 cd, and the illuminance was 162 lx; they were measured using a multienvironmental measuring instrument (LM-8102, Japan).

The temperatures of the front and back surfaces of the samples were measured using thermocouples. The samples containing maximum amounts of absorbed water were used in the experiments. The apparent water absorption of a moss-covered sample was 25%. The water absorption of the porous ceramic base material without moss was approximately 18%, as shown in Table 2. The water absorption of the mortar plate was approximately 1%.

To examine the temperature difference between the front and back surfaces of the porous ceramic base material and mortar plate, their apparent thermal conductivities were also measured, as shown in Figure 2(b). The surface temperature of the porous ceramic base material or mortar plate placed on a metal plate held at a constant temperature of 90 °C was measured. From the temperature difference between front and back surfaces, each apparent thermal conductivity was calculated using the following equation (1),

$$\lambda = \frac{\alpha\, t(\theta_2 - \theta_3)}{(\theta_1 - \theta_2)} \qquad (1)$$

whereθ_1 is the temperature of the heated metal plate, θ_2 is the surface temperature of the sample, θ_3 is the atmospheric temperature, α is the heat transfer coefficient of air, and t is the thickness of the sample.$\alpha$was 10W/(m^2K^{-1}) [7].

E. Measurement of atmospheric temperature and CO_2 concentration around a moss sample –

Figure 3 shows the box used to measure the atmospheric temperature and CO_2 concentration around moss and mortar plate samples outdoors. Different boxes were used for the moss sample and mortar plate without moss. The roof of each box was open and the side walls at positions A1 and A2 were enclosed by transparent acrylic plates. The side walls and floor at position A3 were surrounded by heat-insulating materials. Each sample was located at position A2 in the box. We intended that position A2 corresponded to the roof of a building, and position A3 to a room within a building. The atmospheric temperature at positions A2 and A3 and CO_2 concentration at position A1 were measured in both boxes. The atmospheric temperature was measured every 5 s using a temperature tracer (Sumitomo 3M, TL-30, Japan). CO_2 concentration was measured every 1 min using a CO_2 sensor (MCH-383SD, Japan). In this experiment, the moss and mortar plate samples had sides of 250 mm, and a thickness of approximately 10 mm. The weather was fine on the day that the experiment was carried out.

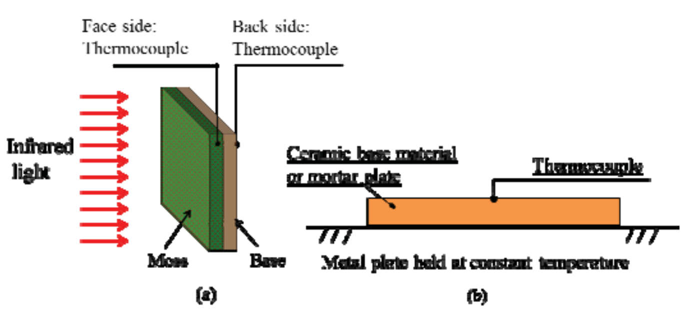

Figure 2. (a) Measurement of temperature change by radiant heat for moss and mortar plate samples, and (b) measurement of apparent thermal conductivity

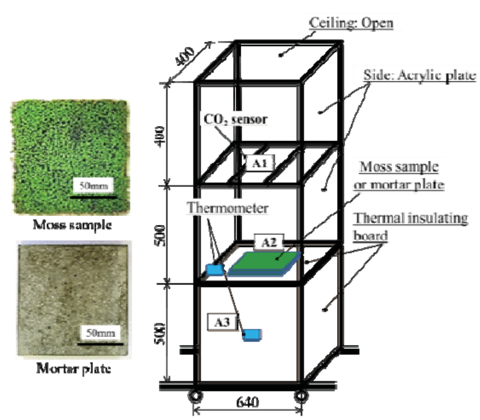

Figure 3. Measurement of atmospheric temperature and CO_2 concentration around moss and mortar plate samples

III. RESULTS AND DISCUSSION

A. Examination of moss growth on the ceramic base material –

pH of immersion of ceramic base material

Table 3 shows the pH of immersions containing the ceramic base material. The pH of the immersions containing porous ceramics made by mixing clay with 20% or 40% crushed GFRP were slightly alkaline. In contrast, the immersion containing clay alone was neutral. From the chemical compositions of the samples shown in Table 1, the ceramic contains more CaO than the clay. It is considered that CaO reacted with water to generate hydroxide ions of the form $Ca(OH)_2$, which increased the pH of the immersions containing GFRP.

Table 3 Hydrogen ion concentration of immersions of ceramic base material in water

Mixing ratio of GFRP	0%	20%	40%
pH	7.0	7.5	8.0

Germination of moss on the ceramic base material

Figure 4 shows photographs of the moss distributed over porous ceramic base material, confirming its germination. The germination rates of moss on the porous ceramic base materials containing different proportions of GFRP are presented in Figure 5. The germination rate of moss was defined as the ratio of the area occupied by germinated moss to the total area of moss. The area occupied by the germinated moss was computed by image analysis. Moss germinated on all porous ceramic base materials in which the mixing ratio of GFRP to the total mass ranged from 20 to 60% after approximately one month. The germination of moss increased daily, although some variation was observed. These results show that moss can grow on the porous ceramic materials without chemical fertilizer.

B. Ability of a greening material to decrease radiant heat –

Figure 6 (a) shows the temperature change of the front and back surfaces of moss-covered ceramic and mortar plate samples when each front surface was irradiated with infrared light [8]. For the ceramic base material, the mixing ratio of GFRP was 20%. The temperature of the front surface of the moss-covered ceramic sample is relatively low compared with that of the mortar plate without moss. The change in temperature of the front and back surfaces of moss-covered ceramic and porous ceramic base material without moss are presented in Figure 6 (b). The temperature of the front surface covered with moss is relatively low compared with that of the porous ceramic base material without moss. These results show that the moss has the ability to decrease radiant heat.

The temperature of the front surface of the moss sample was lower than those of the mortar plate and porous ceramic base material without moss. Therefore, its heat of evaporation was larger than those of the mortar plate and porous ceramic base material without moss because the emissivity of the ceramic base material is almost equal to that of the mortar plate (approximately 0.9), and the water absorption of the moss-covered sample was much larger than those of the mortar plate and porous ceramic base material without moss.

The apparent conductivities of the porous ceramic base material and mortar plate were approximately 0.2 and 0.92 W/(m·K), respectively. The thermal conductivity of the porous ceramic base material was slightly lower than that of the mortar plate. Therefore, the back surface temperature of moss sample was lower than that of the mortar plate. The above results confirm that the greening material consisting of moss and a porous ceramic base material readily absorbed water and decreased radiant heat.

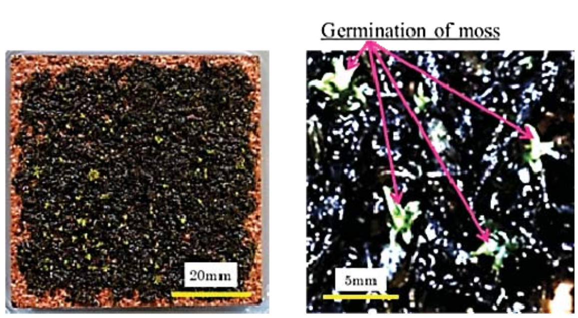

Figure 4. (a) Moss distributed over ceramic base material, (b) enlarged view of germinated moss

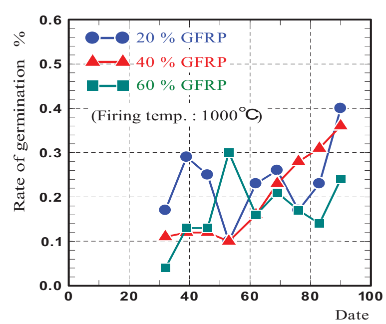

Figure 5. Germination rates of moss on different ceramic samples

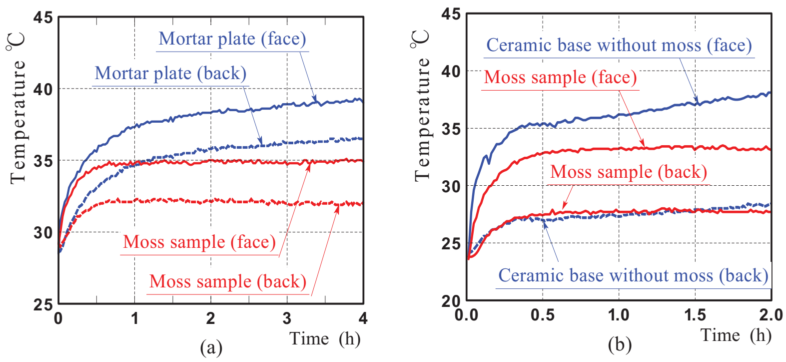

Figure 6. (a) Temperature variation of the front and back surfaces of moss and mortar plate samples. (b) Temperature variation of the front and back surfaces of moss-covered ceramic and ceramic base material without moss

C. Ability of a greening material to decrease atmospheric temperature

The atmospheric temperature measured at positions A2 and A3 in the boxes are depicted in Figure 7. The atmospheric temperature at positions A2 and A3 in the box containing a moss sample was low compared with that of the box with a mortar plate. These results show that a greening material consisting of moss and a porous ceramic base material made from clay and waste GFRP can reduce a rise in atmospheric temperature from solar radiation heat and lower the room temperature in a building.

D. Change of CO_2 concentration

Figure 8 shows the CO_2 concentrations measured in the boxes containing moss and mortar plate samples. The CO_2 concentrationin the box containing a mortar plate increased gradually until approximately midday. In contrast, the CO_2 concentration in the box with a moss sample decreased. The maximum difference of CO_2 concentration between the two boxes was over 100 ppm. This shows that the moss had the ability to decrease CO_2 concentration. Figure 7 shows that the CO_2 concentration in the box containing a moss sample was the lowest near midday, when atmospheric temperature was the highest. Therefore, it is considered that photosynthesis of moss occurred at the time. In contrast, the increase of the CO_2 concentration in the box with a mortar plate was probably caused by a surrounding environmental change; e.g., an increase in traffic volume.

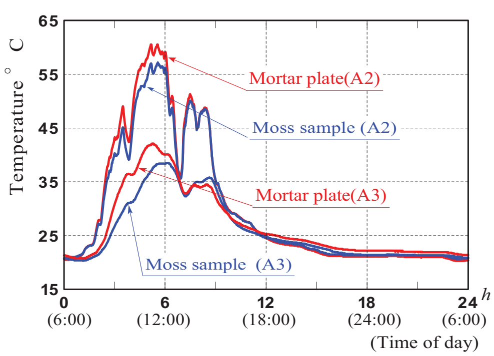

Figure 7. Atmospheric temperature around moss and mortar plate samples

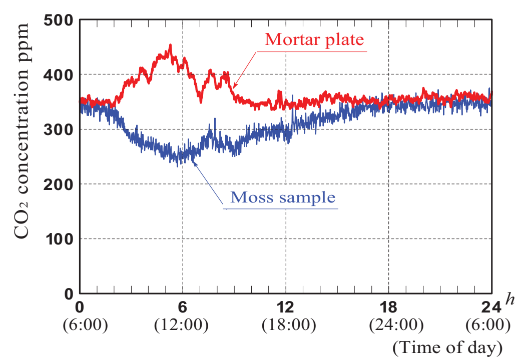

Figure 8. Variation of CO_2 concentration near moss and mortar plate samples

IV. CONCLUSIONS

To recycle waste GFRP and reduce the heat island phenomenon, a greening material consisting of moss grown on a porous ceramic base material made from clay and waste GFRP was produced. The ability of the greening material to decrease solar radiation heat and CO_2 concentration was demonstrated. This greening material can be simply fixed on the roof of buildings using adhesive without the need for expensive mounting components. It is also expected that the greening material can be used as an interlocking block for pavement because the ceramic base material has high strength.

ACKNOWLEDGMENT

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