SOLAR REFLECTANCE OF DRY- AND WET-STATES OF CERAMIC BRICKS WITH HIGH WATER RETENTIVITY

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1. Introduction

Ceramic bricks or other materials with high water retentivity are recently attracting attention for roofing tiles, walls, or paving materials because they are expected to mitigate the urban heat island phenomena (Sugiyama et al., 2006). Development of materials with high water retentivity and its application are being studied. For example, asphalt containing polymers were studied mainly for roadways and ceramic materials were for sidewalks in some research projects in Japan. The materials retain water due to the rain and the water evaporates when the materials are heated in a fine hot weather. The latent heat of the evaporating water decreases the surface temperature and the surrounding temperature.

Ceramic bricks are superior in weather resistance and aesthetic value compared to asphalt with polymers, though they have smaller bending strength. So that ceramic bricks or tiles with high water retention has been proposed for use as roofing tiles, walls, and paving materials for roof gardens. Use of recycled ceramics has been also studied by Nagae et al. (2005).

An important point of this type of ceramic bricks is time scale of drying process, namely, the duration of temperature control due to the water evaporation. Measurement of dehydration rate was carried out by Sugiyama et al. (2006). It was, however, measurement of water content of the sample ceramics placed in drying oven at 43 ^{o}C by weighing the specimen. Effects of other environmental conditions such as humidity, aerial current, solar radiation, and so on were not considered.

The water evaporation might be strongly dependent of humidity, aerial current, and temperature of the surrounding and it would be not easy to predict the dehydration rate or retention durability. Especially in Japan where the humidity is rather high even in summertime, the surface temperature of the bricks would affect the dehydration rate and solar absorption would be an important factor in the surface temperature on fine days.

In this report, we measured spectral reflectance of recycled ceramic bricks with high retentivity in dry-and wet-states and derived solar absorption and also carried out preliminary discussion about the effect of solar radiation on the dehydration rate.

2. Samples and measurement results

2.1. Samples

The six samples shown in fig. 1 are donated by a manufacturer of roof tiles, Kamisei. These bricks were made from inorganic industrial wastes as raw materials, mainly wastes of roof tiles. The size was about 100 mm x 30 mm x 10 mm and water retention is 0.394 g/cm^3, thermal conductivity 0.47 W/(mK) are published by the manufacturer, http://www.kamisei.co.jp/, in japanese.

2.2. Experimental an measurement results

We measured the spectral reflectance of dry- and wet- states of the bricks. The dry process was carried out in a dry oven at 105 ^{o}C for 1.5 hours before the measurement. Water retention was carried out by dipping the samples into distilled water under low pressure atmosphere for 1 hour after the optical measurement of dry-state. Then the samples were lightly wiped off the surface water just before the measurements not to drip in the spectro-photometer.

The optical measurements were carried out to get the hemispherical reflectance in dry- and wet-states with HITACHI U-4100 type spectro-photometer with an integrating sphere. The wavelength range was from 250 to 2500 nm. The weights of dry- and wet-states were also measured to obtain the water retentivity just before the optical measurements.

Fig. 1: Samples #1 to #6, from top to bottom donated by Kamisei.

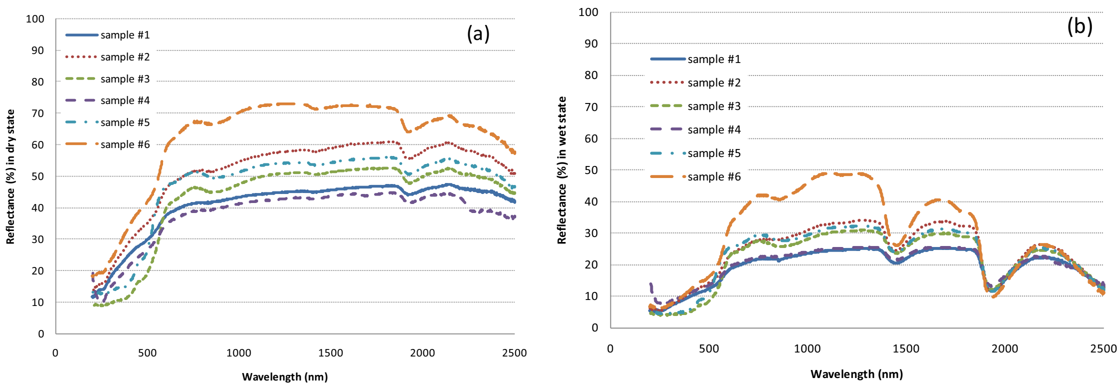

Fig. 2: Measured spectral reflectance of sample #1 to #6 in dry- state (a) and wet- state (b).

Fig. 2(a) and (b) show the measured spectral reflectance in dry-state and wet-state, respectively. One can see big difference between these two figures, for example, reflectance in wet-state was much smaller than that in dry-state, especially around 1450 nm and 1950 nm in wavelength due to the electromagnetic absorption of water.

Visible and solar hemispherical reflectance calculated from fig. 2 and weights are shown in table 1. The amount of water retention estimated from weights of dry- and wet-states were between 23.8 % and 29.3 %. Both the visible and solar reflectance decreased by water retention and the differences were dependent on the samples. Roughly, the decrease of solar reflectance is rather high in case of pale colored samples.

Tab. 1: Measurement results

Sample Number	Sample Color	Dry-state			Wet-state			Decrease of Vis. Ref., %	Decrease of Sol. Ref., %	Increase of Weight, %
		Visible Reflectance, %	Solar Reflectance, %	Weight, g	Visible Reflectance, %	Solar Reflectance, %	Weight, g			
#1	**gray**	33.8	39.1	52.1	15.3	19.6	65.9	18.5	19.5	26.5
#2	**light gray**	40.5	48.5	55.4	18.3	24.8	68.6	22.2	23.7	23.8
#3	**light red**	29.5	39.8	56.7	15.2	22.2	70.8	14.3	17.6	24.9
#4	**dark gray**	30.8	36.4	53.5	16.4	20.3	67.4	14.4	16.1	26.0
#5	**light yellow**	39.4	45.2	53.5	19.7	24.2	66.5	19.7	21	24.3
#6	**light pink**	50	60.8	86.1	23.4	34	111.3	26.6	26.8	29.3

3. Discussion on dehydration rate

3.1. Dehydration rate in previous works

Measurements of dehydration rate were published by Sugiyama et al. (2006), for example. They carried out the measurements by weighing the samples in drying oven controlled at 43 °C. The samples were sintered high water retentive ceramics and commercial red bricks. The important difference between the former and the latter was porosity or retentivity; the former showed higher porosity or higher water retentivity.

In the results, they showed that the dehydration rate of the high water retentive ceramics was almost constants throughout and the dependence on the composition was very small. As for the commercial red bricks, one can see that the dehydration rate has three phases, namely, rapid dehydration phase, constant dehydration phase, and no dehydration phase retaining water in case of thick bricks. They discussed that, in the publication, during the first 10 hours, the dehydration rate was considered to be determined by the vaporization on the top surface or water transfer in the brick. In the later stage, a possible factor to influence the dehydration rate is a condition of diffusion of water vapor in the brick. After 50 hours, the rather tall sample contained 20 to 30 % of water.

Based on the above discussion, we drew fig. 3 showing images of changes of water retention vs. time in drying oven controlled at 43 °C.

While these results are obtained from experimental data in drying oven and solar absorption is not considered, the above discussion would be useful as base models. We discuss about the dehydration rate affected by solar absorption as an important factor in the actual environment as changes of water retention and dehydration rate of fig. 3(a) in consideration of fig. 3(b).

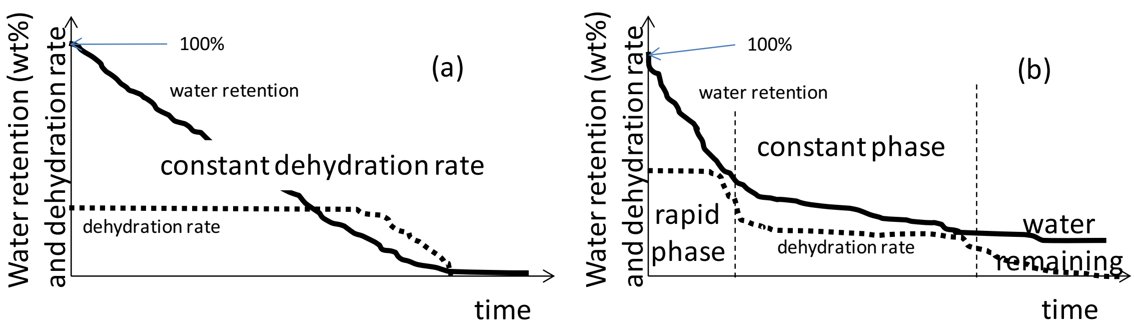

Fig. 3: Images of dehydration rate in drying oven controlled at 43 °C based on discussion by Sugiyama et al. (2006).

(a) in case of sintered high water retentive ceramics. (b) in case of commercial red bricks.

Solid lines: water retention, Doted lines: dehydration rate.

3.2. Dehydration rate in consideration of solar absorption

When we discuss the effect of solar absorption on the water retention, we can start with three issues, those are, solar absorption occurring only on the surface of the bricks, water transfer being expected higher due to the higher evaporation rate of water near the surface, and diffusion of water vapor diffusion being not affected by the solar absorption. The first and second ones may form a rapid phase in fig. 3(a) such as fig. 3(b). As an effect of the third one, the constant phase remains. Water remaining after 50 hours in fig. 3(b) should not be considered because this was not observed in fig. 3(a).

While the drying oven experiment was carried out at 43°C, the surface temperature under solar radiation on fine day would be mainly determined by heat balance of absorbed solar energy and evaporation, and it may be beyond the temperature of the drying oven depending on color of bricks. When the surface temperature becomes higher, the evaporation rate at the surface increases and the retention durability would be small. The high evaporation rate may not continue longtime because of the lack of water near the surface.

Fig. 4 shows the measured changes of solar absorption in dry- and wet-states derived from fig. 2 or table 1. When the change of solar absorption between dry- and wet-states is assumed gradual, the thermal insulation may also increase gradually. That would be another reason why the dehydration rate would be affected by solar radiation only in early phases.

Fig. 5 shows the resultant behavior of water retention from above discussion. In the figure the solar absorption increases the dehydration rate in early phase and decreases the water retention durability comparing to the experimental results in drying oven.

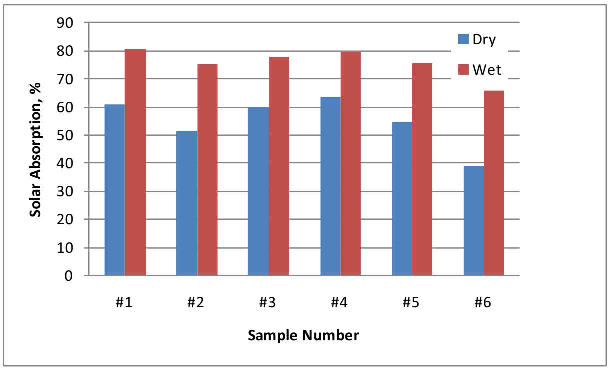

Fig. 4: Solar absorption of dry- and wet-states of samples.

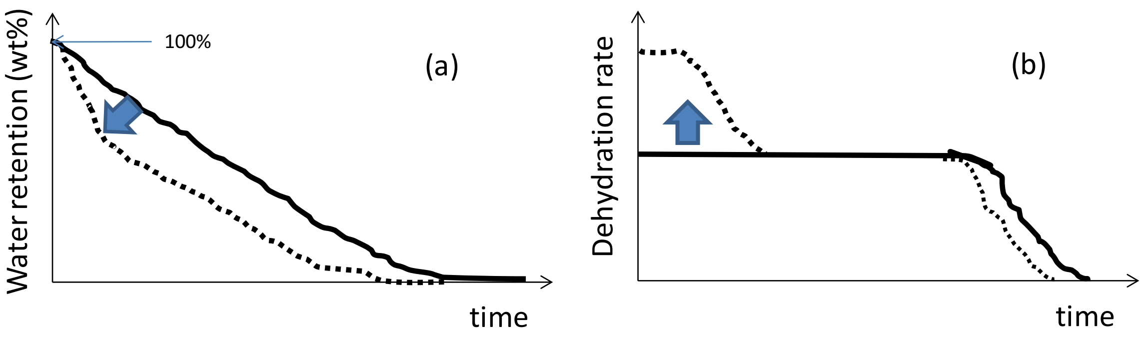

Fig. 5: Images effect of solar absorption on water retention (a) and dehydration rate (b) vs. time.

Solid lines: water retention (a) and dehydration rate (b) derived from previous work. Thick arrows: effect of solar radiation. Dotted lines: expected water retention (a) and dehydration rate (b) affected by solar absorption.

4. Conclusion

The solar absorption is one of the most important factor in dehydration rate of ceramic bricks with high water retentivity in use as outdoor materials such as roofing tiles, walls, paving materials and so on. We measured the solar absorption of some samples of the ceramic bricks and carried out preliminary discussion about the effect on the dehydration rate referring to a previous work. In the results, the solar absorption may affect the dehydration rate in early phase and decrease the water retention durability comparing to the experimental results in drying oven.

References

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