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Research on the Application of Porous Ceramic Materials for Environmental Control Part 1. Study of porous ceramic materials with evaporation cooling ability

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Abstract

Outstanding urban environmental problems, which can be referred to as deterioration of heat environments and represented by "heat-island" or "tropical night" effects, are presumably due to the occurrence of phenomena in which structures with great heat capacity occupy most parts of the city, causing substances with high water-retention abilities such as soil and plants to decrease, their evaporative cooling functions to be lost, and consequently heat stored by these structures is not readily dissipated even at night. So, it is crucial for materials used in cities structured by buildings and roads to possess water-retention abilities as well as perform evaporative cooling functions in order to improve the urban heat environment. In this research, we sought to develop porous ceramics with the optimum pore size and amount in order to allow ordinary ceramics as a building material to have evaporative cooling functions in addition to conventional functions as structural material. And using a system that can naturally derive functions from the material in urban space, we studied the possibilities of its application of controlling the heat environment and attempted to further research by the Hoyano team in order to develop materials and systematize the method taking into consideration its application to the actual environment. As a result, we were able to increase the number of pores 0.1 to 1μm in the specimen of roof tile clay by adding calcium carbonate and firing it at 1100°C; it became a suitable material for a PCW with sufficient water absorption as well as retention ability.

Key words: porous ceramic, environmental control, passive cooling wall, evaporative cooling, building material

1. Introduction

Environmental issues have been discussed at various levels: global warming, ozone layer destruction and ecological transformations; urban "heat island" effects and air pollution; contamination of indoor environments. It has become clear that such issues at the urban level have a great impact on indoor as well as global environments. Therefore, improving the urban environment is crucial for solving problems of the entire environment.

Outstanding urban environmental problems, which can be referred to as deterioration of heat environments and represented by "heat-island" or "tropical night" effects, are presumably due to the occurrence of phenomena in which structures with great heat capacity occupy most parts of the city, causing substances with high water-retention abilities such as soil and plants to decrease, their evaporative cooling functions to be lost, and consequently heat stored by these structures is not readily dissipated even at night. Furthermore, higher indoor temperatures influenced by such effects of the outdoor environment brings more dependency on mechanical cooling, and the discharged heat is expelled outside, presumably contributing to the generation of even higher temperatures in the city and the creation of a vicious cycle in which more and more energy is consumed.

Here, an example of control of the heat environment in urban space has been reported by Tanaka[1] and others as an application of latent heat of water vaporization that building materials with water-retention ability used against the heat-island effect in the city can reduce the surface temperature 10°C lower than ordinary paving materials such as asphalt.

Also, Hoyano[2] and others reported that ventilating a water-retentive ventilable brick wall can create a comfortable microclimate on one side of the wall by the cooling effects from latent heat of water vaporization.

As shown by these examples, in our research we sought to develop porous ceramics with the optimum pore size and amount in order to allow ordinary ceramics as a building material to have evaporative cooling functions in addition to conventional functions as structural material. And using a system that can naturally derive functions from the material in urban space, we studied the possibilities of its application of controlling the heat environment and attempted to further research by the Hoyano team in order to develop materials and systematize the method taking into consideration its application to the actual environment. Specifically, after naming the passive cooling wall (hereafter referred to as PCW), consisting of ventilable bricks which the Hoyano team proposed, (1)we studied the porous ceramic material in regards to ventilable bricks that constitute PCW from function and production viewpoints, and simply evaluated the cooling capacity of the material. (2)After preparing water-permeable ventilable bricks by understanding ventilation and cooling capacities, we built a PCW unit integrated with a water supply system by using water-permeable ventilable bricks. Then by using these, we built a small space with PCW to understand the characteristics of temperature and humidity distribution that is generated there, and clarified the scope of microclimate formation in the PCW.

In this report, we summarized the content of (1), and will refer to (2) in the next issue.

2. Outline of the PCW

2.1 Principle of generating cooling capacity

The principle of generating cooling capacity is described below.

When water permeates through the wall built with permeable ventilable bricks punctured for ventilation, water evaporates from the bricks, drawing out the latent heat and bringing the temperature lower than that of the air. So, the temperature of air through the bricks was decreased[2].

2.2 Necessary items concerning materials and shapes

We extracted conditions required as materials for water-permeable ventilable bricks which constitute the PCW, and researched optimum brick materials, thoroughly taking these conditions into consideration.

(1) Functional requirements as PCW

a. Appropriate water-permeability (capillary ability) to swiftly provide water throughout the brick

b. Water-retention ability necessary to keep bricks constantly wet

c. Water-permeability not to allow water to flow over the surface but keep it damp

(2) Functional requirements as building material

a. Esthetically appealing colors and textures as architectural material

b. Sufficient strength as architectural material

c. Economy and workability for proper production

3. Study of water-permeable ventilable brick material

3.1 Selection of main material for bricks

Conventionally, the main material used for bricks has generally been sedimentary clay mostly known as impure clay, often used for roofing tiles.

As PCWs are used in a large area to maximize the cooling effect, it is desirable to produce bricks in as a short time as possible and to use existing production facilities if the practicality of PCW is taken into consideration. Therefore, we consider it wise to select the material based on the conventional method by which it can be produced in a relatively economical manner.

Thereby, we selected roofing tile clay from Mikawa, Aichi Prefecture, which is often used as the main material for bricks. Also, in using this roofing tile material, we shall thoroughly study it in order to secure necessary properties taking into consideration the inconsistency due to the variation of the original clay.

3.2 Study of the physical properties of the material

We considered it an appropriate method to supply water by capillary action from the bottom of each brick as it would not supply excess water but keep proper dampness. In the case of such a water supply method, in order for PCW to constantly allow evaporative cooling to occur, it is necessary to quickly supply water to the height of a brick and maintain dampness under continuous evaporation. Therefore, we think it is necessary to sufficently increase water absorption and retention abilities of the bricks.

Important physical properties for investigating these qualities are water absorption rate, changes in the quantity of water evaporation, specific surface areas, pore size distribution and water permeability height. Here, the water absorption rate and changes in the quantity of water evaporation are to be studied as values of physical property to evaluate water retention ability of the material., also, specific surface areas, pore size distribution and water permeability height are to be investigated as physical properties to evaluate water absorption ability of the material. Capillary capacity, which is as important as water absorption ability, is thought to have a high correlation with the pore size of the material. For example, there is a research report in which a cylinder filled with sand particles was used to find the height of water absorption by capillary action[3]. Therefore, we consider it important to understand the pore size of the material especially in developing materials suitable for PCWs.

Height of water permeability was conceived to determine the height of water absorption by capillary action; it was measured from the end assuming that it is in an actual situation.

3.3 Firing temperature of the roof tile clay and evaluation of physical properties

We think that water absorption and retention abilities of the material largely varies by the material composition. In this research, we distinguished the conditions for firing and composition from the viewpoint of material development, produced specimens, evaluated the physical properties, and abstracted the optimum conditions for developing materials.

Here, using roof tile clay material first, we evaluated water absorption and retention abilities of the material by different firing temperatures. Also, as a reference, we added for evaluation specimens that the Hoyano group used in the previous report.

(1).Production of specimen pieces

The roof tile clay that we determined in 3.1 was used to produce specimen pieces. The clay was forced at a pressure of1.0 MPa into approximately 70 x 30 x 15mm pieces by extrusion, and after 24 hours of drying at 80℃, they were heated in an electric kiln from 600℃ to 1300℃ at 100℃ increments for 3 hours to prepare specimen pieces.

(2).Evaluation of physical properties

Physical property values of the specimens are shown in Table 1; water absorption rate, height of water permeability in 90 minutes and median pore size are shown in Figure 1; the correlation between the number of pores over the size of 0.1 μ m and the height of water permeability after 90 minutes is shown in Figure 2; changes in water evaporation are shown in Figure 3. Here, although the height of water permeability was studied for a maximum of 90 minutes, because they were approximately 70mm high, we consider it sufficient for relative comparisons of the height in the order of the firing temperature.

Figure 1 indicates that water absorption increases as firing temperature decreases, and shows no change below 900℃. Also, as shown in the previous report by the Hoyano team, results indicated that the permeability height of the roof tile was the greatest at 1000℃ and the next at 1100℃. Furthermore, Figure 2 indicates that there was a strong correlation between the permeabilty height and the number of pores over 0.1 μ m, and the roof tile of the highest permeability at 1000℃ had the largest number of pores over 0.1 μ m. However, this shows that the specific surface areas were greater with the tiles heated at temperatures lower than 1000℃ and the number of pores were considerably great. From these results, it is clear that the height of permeability was not influenced by the total number of pores open on the surface but had a strong correlation with the number of pores over 0.1 μ m. Consequently, examining the material from the

Table 1. Physical Property of Sample

Name of sample	Water Absorption (%)*1	Specific surface area (m2/g)*2	Median pore size (μ m)	Pore size distribution (μ m)*3			Cumulative pore volume (cc/g)	Bulk density (g/cm3)
				~0.1	0.1 ~ 1.0	1.0~		
Clay 600℃	15.5	15.72	0.10	0.078	0.076	0.008	0.162	1.82
Clay 700℃	15.5	15.19	0.10	0.081	0.075	0.007	0.163	1.82
Clay 800℃	15.7	—	—	—	—	—	—	1.82
Clay 900℃	15.5	6.68	0.14	0.067	0.098	0.012	0.178	1.83
Clay 1000℃	13.4	1.92	0.27	0.025	0.122	0.011	0.156	1.89
Clay 1100℃	7.1	0.38	0.90	0.002	0.057	0.044	0.103	2.08
Clay 1200℃	1.7	0.22	0.95	0.003	0.019	0.021	0.042	2.27
Clay 1300℃	0.7	—	—	—	—	—	—	2.00
Previously reported brick	13.9	2.12	0.36	0.033	0.085	0.046	0.163	1.88

*1; JIS A 5209, *2; BET, *3; Porosimeter Method

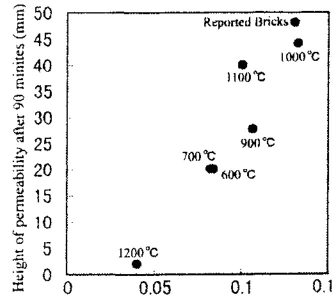

Figure2. Correlation Between Number of Pores & Height of Permeability

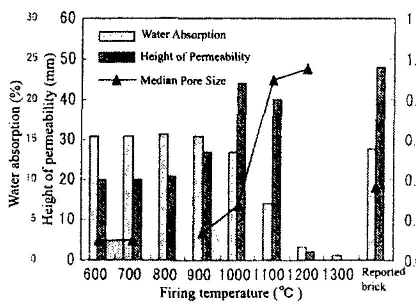

Figure1. Absorption/Permeability Difference Due To Clay Firing Temperature

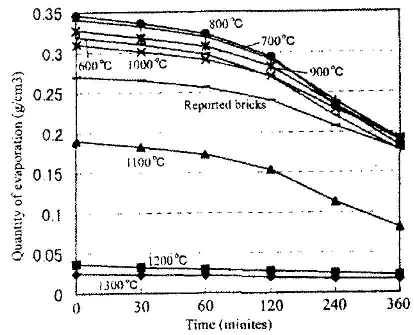

Figure3. Change in the Quantity of Water Evaporation

viewpoint of water absorption ability, we think that material of great permeability height and heated at 1000℃ is suitable for PCW bricks.

As regards water evaporation, it was clear that although the quantity of water evaporation differed at 1100℃, there was little change in the quantity of evaporation with that of specimen pieces from 600 to 1000℃.

Consequently, as a result of investigating conditions for firing temperature from the viewpoint of water absorption and retention, we think that the material heated at 1000℃ is suitable for PCW bricks. However, compared to the bricks already reported, it is not easy to say that it excels in water absorption and retention. Thereby, we added filler to the roof tile clay to study improvements in these aspects.

3.4. Material composition with consideration for production and evaluation of physical properties

(1) Firing conditions

In the case of using roof tile clay as the main material, it became clear that the height of water permeability, an important property in materials for PCW bricks, increased by setting the firing temperature at 1000℃. However, firing temperature generally applied in the ceramic industry is between 1100 and 1300℃; temperatures as low as 1000℃ are rare. Taking actual production into consideration, as it may be deemed necessary to investigate firing conditions at about 1100℃, we decided to proceed with three standards of 1000 , 1050, 1100 and 1150℃ for firing to investigate material composition.

(2) Material composition

In selecting additive material, we extracted porous materials, which may excel in water absorption and retention, from the existing ceramic materials, and evaluated the physical properties shown in 3.2. As a result, it became clear that wollastonite and calcareous materials were excellent. However, materials such as wollastonite which have many pores over 10μm lack proper dampness and plasticity, and although they excel in the height of water permeability, they are difficult to form by extrusion which is the conventional method of producing bricks. Calcareous materials with good dampness lack plasticity as with wollastonite materials; thus are not suitable for extrusion. Taking these points into consideration, if we use roof tile clay with high plasticity and add wollastonite (CS) or calcium carbonate (CaO) as a filler, it may be possible to obtain extrudable material while taking advantage of these characteristics. Thereby, we investigated the improvement of the height of permeability and dampness by using specimens with various fillers added to them.

Specimens were composed of six kinds as shown in Table 2. they were extruded into an approximately 15 x 33 x 150mm form (extrusion pressure at 2.0MPa). To make the specimen pieces, the formed units were fired in an electric kiln under the conditions of the temperature at 1000, 1050, 1100, 1050℃.

(3) Evaluation of physical properties

Water absorption, bulk density and contraction of each composition specimen are shown in Table 3; differences in the height of water permeability due to composition and firing temperature are shown in Figure 4.

Considerable contractions were seen in all compositions at the firing temperature of 1150℃, a decrease in air gaps may have occurred due to material dissolution. Since added calcium carbonate and slag, etc., react at approximately 1100℃, specimens fired at that temperature became the most water-permeable.

Table 2. Additive and Composition Ratio

	Clay	Calcium carbonate	CS	Slag-fine	Slag-coarse
Composition 1	88	12			
Composition 2	70		30		
Composition 3	50		50		
Composition 4	80			20	
Composition 5	70			30	
Composition 6	80			10	10

Table 3. Water Absorption per Composition, Bulk Density, Contraction

	1000℃ firing			1050℃ firing			1100℃ firing			1150℃ firing		
	Water absorption (%)	Bulk density (g/cm3)	Contraction (%)	Water absorption (%)	Bulk density (g/cm3)	Contraction (%)	Water absorption (%)	Bulk density (g/cm3)	Contraction (%)	Water absorption (%)	Bulk density (g/cm3)	Contraction (%)
Composition 1	13.34	1.760	0.32	13.13	1.766	0.18	12.37	1.775	0.53	6.94	1.916	5.80
Composition 2	16.76	1.725	0.31	15.67	1.743	0.90	14.01	1.771	1.27	8.55	1.894	5.26
Composition 3	18.48	1.641	-0.24	17.95	1.646	-0.16	17.16	1.657	0.04	12.01	1.718	0.74
Composition 4	14.16	1.859	0.35	13.96	1.860	0.41	13.13	1.873	0.30	0.42	2.313	2.28
Composition 5	15.48	1.844	0.20	15.26	1.845	0.36	13.30	1.891	0.68	0.22	2.388	2.66
Composition 6	12.82	1.920	0.80	12.37	1.923	0.74	11.00	1.936	1.11	3.11	2.187	3.55

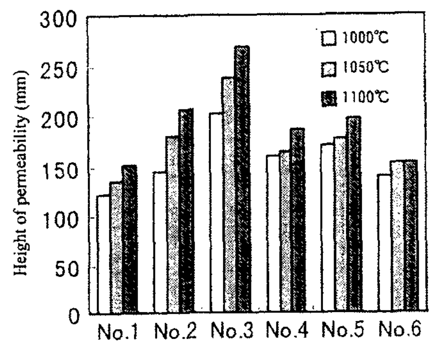

Figure4. Difference in Height of Permeability Due to Composition (after 8 hours)

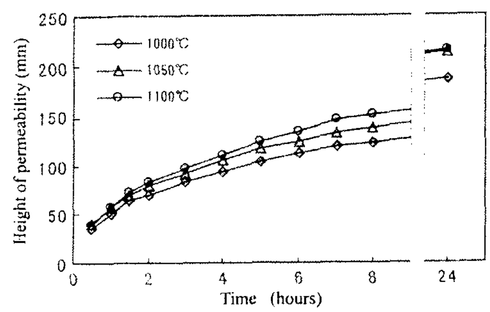

Figure5. Difference in Height of Permeability Due To Firing Temperature (No.1, after adding calcium carbonate)

Table 4. Brick Material Specification

Item	Specification								
Material composition	Pot soil (red): calcium carbonate = 88 : 12								
24-hour water absorption %	14.8								
Bulk density g/cm3	1.75								
Specific heat J/gK	1.035								
Pore size distribution cc/g	~ 0.1 μm			0.1 ~ 1.0 μm			1.0 ~ μm		
	0.000			0.054			0.184		
Composition analysis %	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O_3	TiO_2	igloss
	60.2	14.4	2.8	8.3	0.4	1.7	0.1	0.6	11.6

Observing the change in the height of water permeability No. 1 (Figure 5), which shows the lowest permeability, the specimens at 1100℃ reached nearly 100mm, nearly equal to the height of one brick, in approximately 3 hours, which may be considered a sufficient property. Comparing these to specimens without additives and fired at 1100℃, all the compositions showed improvement in the height of water permeability compared to Figure 1, and sufficient properties for PCWs were obtained. In the meantime, as stated in 2.2, the outside appearance and texture are important elements for brick material; lines and cracks generated on surfaces of the sliced test pieces No. 2, No. 3 and No. 6 due to large particles; smooth sections were obtained with No. 1, No. 4 and No. 5. Also, taking production cost into consideration, since composition No. 1 is the lowest and may likely possess sufficient property for water permeable ventilable bricks fired at 1100℃, we selected composition No. 1 (Table 4).

4. Conclusion

In this report, we investigated materials based on roof tile clay from the functional and manufacturing point of view for the purpose of developing materials suitable for passive cooling walls, and conducted basic evaluations on porous ceramic materials which excel in water absorption and retention. Information.

As a result, we were able to increase the number of pores 0.1 to 1 μm in the specimen of roof tile clay by adding calcium carbonate and firing it at 1100℃; it became a suitable material for a PCW with sufficient water absorption as well as retention ability.

In the next report, taking into consideration the application of actual space, we will clarify the characteristics of microclimate created in a small outdoor space surrounded by PCW units integrated with a water supply system by ventilating bricks and using water permeable ventilable bricks.

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