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Studies on Environmental Load Reduction and Surface Protection Effects of Porous Concrete Used Lapilli by Measuring Temperature in Outdoor Exposure Test

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The outdoor exposure test of the porous concrete plate and beam used lightweight and high absorption lapilli produced in north of Akita Prefecture was carried out. Lapilli is one of the porous and light stone formed by volcanic activity. The temperature in the center of the cross section of the plate and the relative dynamic modulus of elasticity of the beam were measured. As the results of former measurement, the temperature in the center of cross section of the porous concrete plate was 4 degrees lower than atmospheric temperature at the maximum but that of the ordinary concrete plate was higher than the temperature during 2 months in summer. It was clarified that the porous concrete had temperature reduction effect due to vaporization latent heat of water by heat balance calculation. The control of temperature change in summer night and day, the reduction of the freezing and thawing cycle number and the rise of the minimum temperature in winter were observed when the porous concrete plate was covered on the ordinary concrete plate surface. It is considered that these results lead to the deterioration control effects. The relative dynamic modulus of elasticity of the porous concrete beam in the outdoor exposure condition did not decrease for one and half years in spite of its low strength characteristics.

Key Words : Outdoor exposure test, Temperature reduction effect, Deterioration control effect, Ordinary concrete

1. INTRODUCTION

It is necessary to control the heat source effect of the concrete structures such as column and wall member being exposed directly to the sun beam in order to reduce the heat island phenomenon[1]. Moreover, such architectural infrastructures are possible to obtain the long life time by protecting the concrete surface[2].

From these viewpoints, the purpose of this study is to develop the concrete for covering material having both environmental load reduction and surface protecting effects. For the purpose, the exposure test of the porous concrete used the low density and high absorption lapilli produced in north of Akita Prefecture was carried out from 2003 to 2005. The temperature in the center of the cross section of the porous concrete plate used lapilli and ordinary concrete one was measured in the exposure test, and the temperature in the ordinary concrete covered by the porous concrete was also measured. From these results, the environmental load reduction and concrete surface protecting effects were examined by assuming the cover on the surface of concrete member. In addition, the durability of the porous concrete itself in outdoor exposure condition was examined by measuring the weight loss and relative dynamic modulus of elasticity because of its low strength materials characteristics. Thus, this paper shows an original idea referring to the surface covering material having the effects of both the reduction of the heat island phenomenon and the improvement of the durability of the concrete structures by effectively using natural lightweight aggregate, lapilli which has lightweight, high absorption and evaporation characteristics.

2. EXPERIMENTAL OUTLINE

2.1 Materials and mixture proportions

Ordinary portland cement C (density : 3.16g/cm^3) and some chemical admixtures such as a superplasticizer SP, supplementary air entraining agent SAE and air entraining agent AE were used for the concrete mixtures. Natural mixed sand S (density in saturated surface-dry condition : 2.58g/cm^3, absorption : 3.03%, fineness modulus : 2.72) was used as fine aggregate. Lapilli L (maximum size : 15 mm) and crushed stone G (maximum size : 20 mm, density in saturated surface-dry condition : 2.68g/cm^3, absorption : 1.34%) were used as coarse aggregate. Table 1 and 2 show physical properties of lapilli and mix proportions of concrete.

Table 1 Physical properties of lapilli

Density in saturated surface-dry condition (g/cm³)	Water absorption (%)	Weight of unit volume (kg/l)	Percentage of absolute volume (%)
1.18	68.97	0.42	60.4

Table 2 Mix proportions of porous and ordinary concrete

Porous concrete used lapilli

Target void ratio (%)	p/g	W/C (%)	Unit content (kg/m³)					
			W	C	$L_{5\sim10}$	$L_{10\sim15}$	SP	SAE
30	0.07	25.0	19	81	309	463	0.81	0.02

Ordinary concrete

W/C (%)	s/a (%)	Slump (cm)	Air content (%)	Unit content (kg/m³)				
				W	C	S	G	AE
60.0	46.3	8.0±1	0.6±0.5	172	287	804	878	0.17

Table 3 Physical and mechanical properties of concrete

	Porous concrete used lapilli	Ordinary concrete
Water absorption for 24 hr (%)	45.4	6.2
Weight of unit volume (kg/l)	1.01	2.31
Compressive strength (N/mm²)	0.7	28.8
Bending strength (N/mm²)	0.3	4.2

Porous concrete plates with 300 mm length, 300 mm width and 60 mm thickness for the thermometry were produced. Table 3 shows weight of unit volume and strength of the porous concrete used lapilli and the ordinary concrete at the age of 28 days after water bath curing. The compressive strength of porous concrete used lapilli is the same as that of the stabilized soil by lime for subbase which is required at the age of 10 days in the pavement specification. So, this porous concrete cannot use for structural members but it can use for surface covering material because of its lightweight. Figure 1 shows a porous concrete plate used lapilli.

2.2 The measurement of the temperature in the center of cross section of the plate in summer and winter outdoor exposure test

The outdoor exposure test was carried out on the roof of laboratory building with three floors from August 30 th to October 19 th, 2003, and from July 30 th to September 23 th, 2004. The thermocouple was buried at 30 mm depth from the center of the plate surface which was set horizontally and the temperature in the center of cross section was measured for every 5 minutes. The temperature in the center of cross section of ordinary concrete plate covered by the porous concrete which was fixed by the stainless steel wire was automatically recorded. Short-wave reflection percentage of the insolation was measured at the 3 points on the plate surface by a colorimeter for 2 hours during 9 to 17 o'clock, and the mean value was obtained.

The outdoor exposure test in the winter was carried out from February 14 th to March 20 th, 2005. The temperature in the center of cross section of the ordinary concrete plate with and without covering by the porous concrete was measured as well as in the summer test. The plate was set with 60 degrees of inclination facing south. Figure 2 shows set angle of concrete plate and set positions of thermocouple.

2.3 Exposure durability test

Relative dynamic modulus of elasticity and weight loss percentage were measured by using exposed column test piece (100×100×400 mm) during a year in order to test the outdoor exposure durability of the porous concrete itself.

3. RESULTS AND DISCUSSION

3.1 The control effect of the atmospheric temperature rise by using the porous concrete plate used lapilli in summer

Figure 3 shows the change of the average temperature for a week in the center of the cross section of the porous concrete plate used lapilli and the ordinary concrete one. In this figure, the temperature in the porous concrete plate is 4 degrees lower than the atmospheric temperature at the maximum. This shows the heat absorption from the atmosphere, and it is clarified that the porous concrete plate has temperature reduction effect. On the other hand, the temperature in the ordinary concrete plate is 4 degrees higher than the atmospheric temperature at the maximum

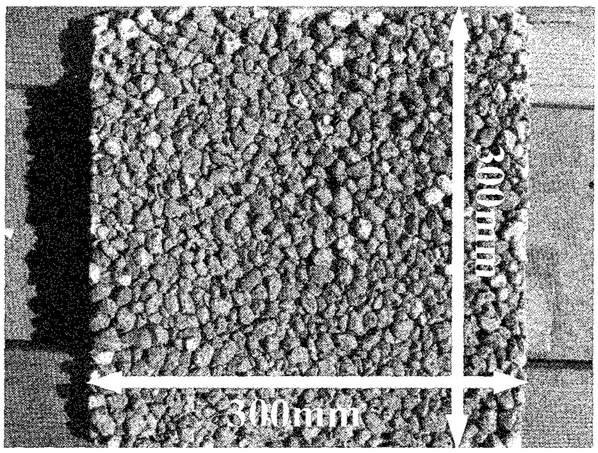

Figure 1 The porous concrete plate used lapilli

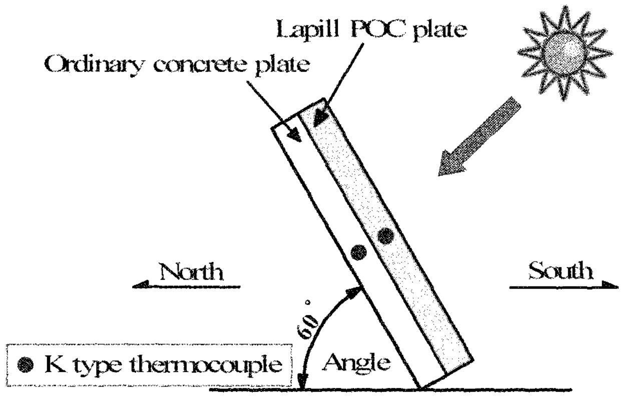

Figure 2 Set angle of concrete plate and set positions of thermocouple

and this shows the heat radiation to the atmospheric.

In order to make clear the mechanism of control of the temperature rise, the shortwave reflection of the insolation was measured by a heliograph and colorimeter.

Figure 4 shows the change of the average shortwave reflection of the insolation during a week from the porous concrete plate surface and ordinary concrete one. This figure shows that the average shortwave reflection during exposure period from the porous concrete plate surface is 15.3% less than that from the ordinary concrete one, and that the amount of radiant heat which increases in the atmospheric temperature is less. This fact indicates the absorption of the heat of the sun beam.

Figure 5 shows the comparison of the heat balance in the porous concrete plate and ordinary concrete one on September 9th and 15th, 2003. The data shown in this figure are the average heat capacity per 1 hour during 9 to 17 o'clock by heat balance calculation[3]. This figure shows the inflow heat capacity (the total intensity of solar radiation and atmospheric radiation quantity) to these concrete plates was 2.95 and 3.38 MJ/m^2 on September 9th and 15th respectively. The radiant heat capacity (the total intensity of long-wave radiation, shortwave radiation and the sensible heat quantity) from the ordinary concrete plate to the atmosphere was almost the same as the inflow heat capacity on both days, while in case of the porous concrete plate, it was 2.27 and 3.11 MJ/m^2 on September 9th and 15th, respectively. From these results, it is clarified that 0.68 and 0.27 MJ/m^2 of the inflow heat capacity to the porous concrete plate has been cancelled as a latent heat on September 9th and 15th, respectively. Since the difference of heat capacity between inflow and radiation is regarded as the reduction degree of the heat source effect, the porous concrete plate had 5 and 9 times of the reduction degree of the ordinary concrete one on September 9th and 15th, respectively.

From these results, it was clarified that the porous concrete plate used lapilli covered on the ordinary concrete could fall the heat source effect of the concrete and control the effect of the atmospheric temperature rise by the reduction of the shortwave reflection of the insolation due to vaporization latent heat of water.

3.2 The surface protection effect of the porous concrete plate used lapilli by covering on the ordinary concrete plate

The temperature was measured in the ordinary concrete plate covered by the porous concrete plate which has the above mentioned low heat source effect in order to verify the covering effect. The covering thickness is 60 mm. When the thickness decreases, the temperature reduction effect lowers because of the decrease in the amount of water evaporation from the porous concrete plate.

Figure 6 shows the change of the daily maximum and minimum temperature in the center of the cross section of the ordinary concrete plate with and without covering by the porous concrete plate in summer and winter.

The average of the atmospheric temperature for a day was also shown in the figure. In this figure, the temperature difference between the maximum and minimum temperature of the ordinary concrete plate with covering is small compared with the temperature difference of the ordinary concrete without covering during the test period. This means that the porous concrete plate can control the temperature variation. The reason of having the

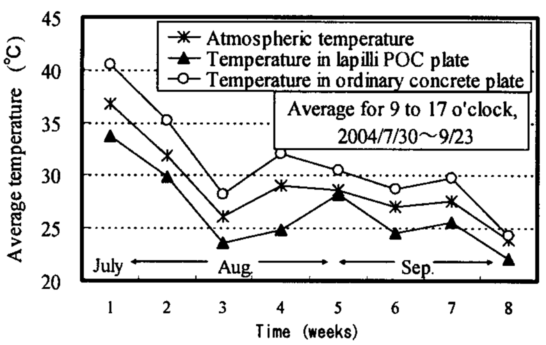

Figure 3 Change of average temperature for a week

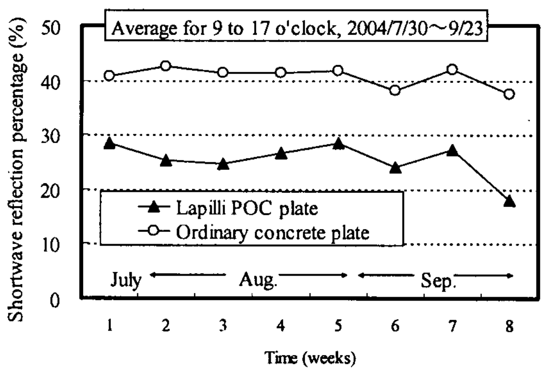

Figure 4 Change of shortwave reflection percentage on the concrete plate surface

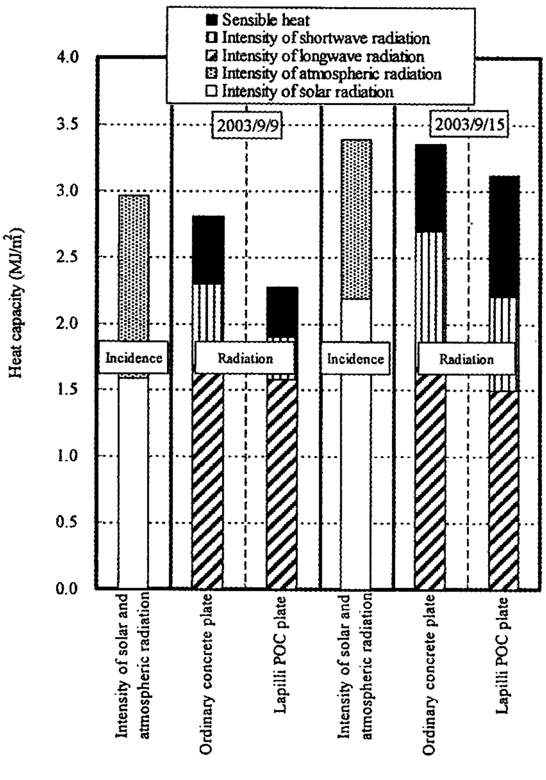

Figure 5 Results of calculated heat balance for concrete type

control effect of temperature variation is due to the existence of micro voids in the lapilli particle and its low thermal conductivity. The thermal conductivity of the porous concrete plate could not measure but the value of the concrete using lapilli was about 40% lower than the ordinary concrete[4)]. Moreover, it controls heat source effect of the ordinary concrete plate in summer, and it contributes to the rise of the minimum temperature in the ordinary concrete plate in winter.

Figure 7 and 8 shows the time depending change of the average temperature for 2 hours in the center of the cross section of the ordinary concrete plate with and without covering in summer and winter. The average of the atmospheric temperature was also shown. The temperature in the ordinary concrete with covering is 8.3 degrees lower than that without covering at the maximum in the daytime, and both of them are almost equal in the night in summer. The temperature in winter night is 4 degrees higher than that without covering at the maximum. The rate of temperature variation between the daily minimum and maximum temperature in the ordinary concrete plate with covering is slower than that without covering in summer and winter. Thus, the covering by the porous concrete plate which is lightweight and high absorption leads to the reduction of heat source effect and the expansion and shrinkage due to the temperature variation of the ordinary concrete in summer. In winter, it leads to the rise of the minimum temperature in the center of the cross section, the reduction of the freezing and thawing rate, and the thermal protection effect of the ordinary concrete.

Figure 9 shows the freezing and thawing cycle number of ordinary concrete plate with and without covering. The freezing and thawing cycle number was counted as a cycle when the

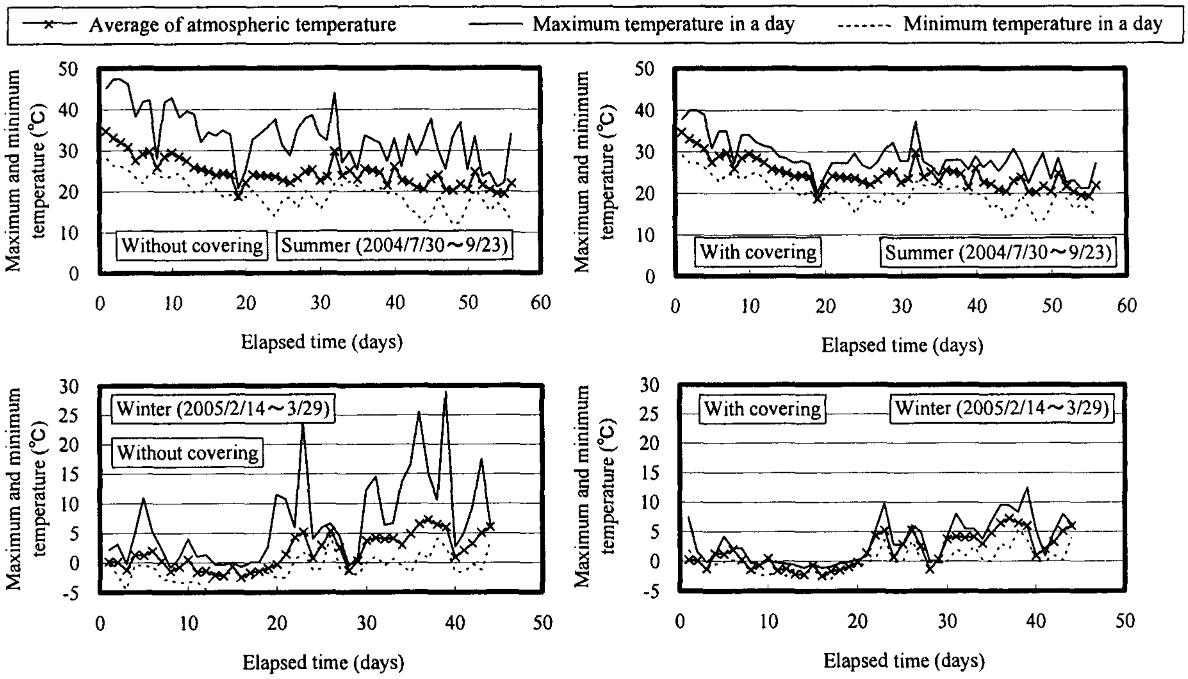

Figure 6 Change of maximum and minimum temperature in ordinary concrete plate with and without covering by porous concrete compared with atmospheric temperature in summer and winter

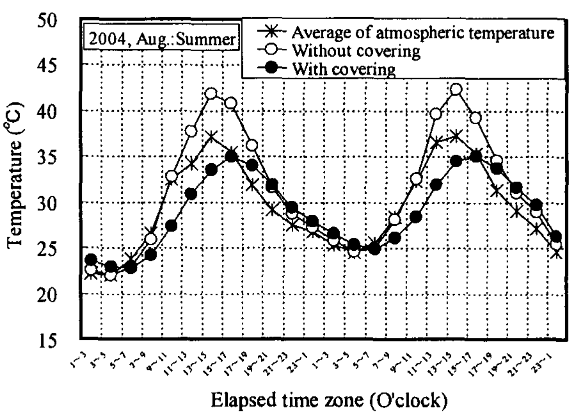

Figure 7 Change of temperature in the center of the cross section of ordinary concrete plate for 2 days in summer

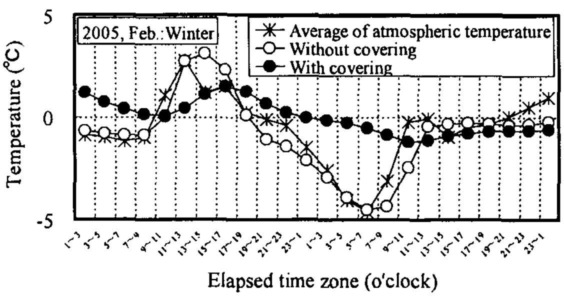

Figure 8 Change of temperature in the center of the cross section of ordinary concrete plate for 2 days in winter

temperature in the center of the cross section of the ordinary concrete plate changed from the positive to negative and the negative to positive on the boundary for 0 degrees. The freezing and thawing cycle number in the ordinary concrete plate with covering is reduced to about 1/3 of that without covering. This means that the plate contributes to the improvement of freezing and thawing resistance of the ordinary concrete member facing the south. From these results, it was clarified that the covering by the porous concrete plate used lapilli contributes to the surface protection effect to improve the durability and the environmental load reduction effect.

Figure 10 shows the relative dynamic modulus of elasticity and weight loss of the porous concrete beam used lapilli in the outdoor exposure test at 180 and 360 days. They did not change clearly at both days. It, therefore, was clarified that the porous concrete used lapilli itself was durable under the freezing and thawing cycle condition in spite of low strength and high absorption. The outdoor exposure durability test for further long term will be carried out continually on the assumption of the application to existing structure.

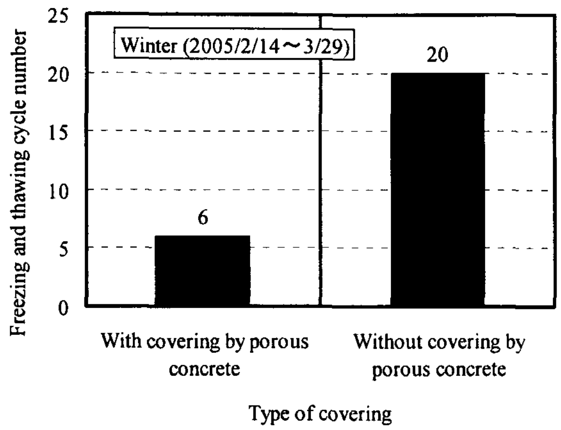

Figure 9 *Freezing and thawing cycle number in ordinary concrete plate with and without covering by porous concrete*

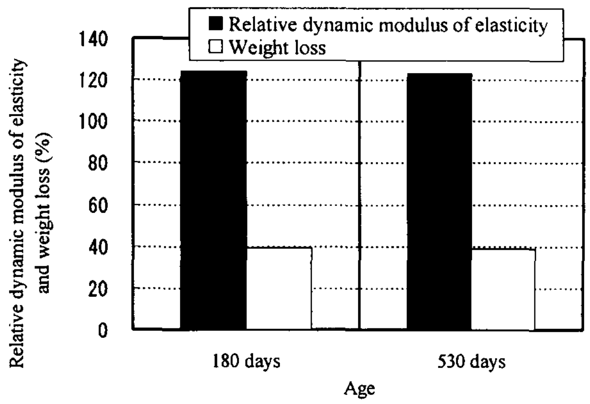

Figure 10 Relative dynamic modulus of elasticity and weight loss of porous concrete at each days during exposure test

4. CONCLUSIONS

The temperature in the center of the cross section of the ordinary concrete plate with and without covering by the porous concrete plate used lapilli and that of the porous concrete plate itself were measured in summer and winter outdoor exposure test. The environmental load reduction and concrete surface protection effects of the porous concrete plate were examined and following results were obtained.

1) The porous concrete plate had the effect which lowered the temperature due to absorbing a heat from the atmosphere. This fact was made clear by measurement of the shortwave reflection percentage and heat balance calculation of the porous concrete compared with that of the ordinary concrete.

2) The covering on the ordinary concrete plate surface by the porous concrete plate produced the reduction of heat source effect and the expansion and shrinkage of the ordinary concrete due to the temperature change in summer and it did the reduction of the freezing and thawing cycle number in winter. It was clarified that the porous concrete plate used lapilli had both surface protection and environmental load reduction effects.

3) The porous concrete used lapilli itself was durable during outdoor exposure test, but the further long term test has to be continued.

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