Experimental studies on effect of atmospheric temperature reduction due to water evaporation of porous concrete used lapilli

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ABSTRACT: It was supposed that the porous concrete plate used lightweight and high absorption lapilli produced in north of Akita-prefecture in Japan (lapilli POC) was covered on the surface of concrete structure member. In this study, the absorption of the lapilli and its POC after 24 hours water immersion was tested, and the results were 62.3 and 45.4 % respectively. Then, the environmental burden reduction effects such as temperature reduction effects based on the outdoor exposure test was clarified. From the result of measuring the temperature in the center of cross section of ordinary concrete plate covering by the porous concrete used lapilli, heat balance calculation was carried out. Finally, it was shown that this new type concrete could reduce the atmospheric temperature due to water evaporation. Moreover, it was shown that the curing effect by the surface covering contributed to the improvement of durability of concrete structure and this construction material had a characteristics for sustainable development of the mankind.

1 INTRODUCTION

Recently, heat island phenomenon occurs in the advanced countries, and there exists an apprehension about the deterioration of the life environment. A cause of this phenomenon is pointed out as follows. The high temperature condition continues a whole day by the radiant heat from the surface of concrete structure which absorbs the insolation. The reduction of the temperature by using the construction materials with high absorption and water evaporation is proposed as a countermeasure to mitigate the heat island phenomenon (Tokyo Metropolis Propulsion Committee on Countermeasures to Heat Island Phenomenon 2003).

On the other hand, the preservation materials for concrete structures is needed to extend the lifetime to save the resources. One of the construction materials with such properties is lapilli (Kagaya et al. 2003). Lapilli is found in abundance in Japan, and it is often used as water retention material for tree planting in the landscape gardening or drainage supplement for burying directly.

Observing at the lightweight and high absorption properties of the lapilli, it was supposed that the porous concrete used lapilli was covered on the surface of the concrete structures. Then, the temperature in the center of cross section of the ordinary concrete plate covered by the lapilli POC plate was measured in the outdoor exposure test, and the temperature was compared with the case of non-covered ordinary concrete plate. It was clarified that the POC had mitigation properties of heat island phenomenon from the result of measuring the temperature. Moreover, it was shown that the curing effect by the surface covering contributed to the improvement of durability of concrete structure and this construction material had a characteristics for sustainable development of the mankind.

2 EXPERIMENTAL OUTLINE

2.1 *Materials and mixture proportions*

Normal portland cement C (density : 3.16 g/cm^3) and some chemical admixtures such as an air entraining agent AE_1, superplasticizer SP and supplementary air entraining agent AE_2 were used for the concrete mixtures. Natural mixed sand S (density in saturated surface-dry condition 2.57 g/cm^3, absorption : 3.45 %, fineness modulus : 2.74) was used as fine aggregate. Lapilli L (maximum size : 15mm) and crushed stone G (maximum size : 20 mm, density in saturated surface-dry condition : 2.68 g/cm^3, absorption : 1.34 %) were used as coarse aggregate. Table 1 and 2 shows physical properties of lapilli and chemical compositions of lapilli produced in north of Akita-prefecture. Table 3 and 4 shows mixture proportions of ordinary concrete and porous concrete used lapilli.

Table 1. Physical properties of lapilli.

Density in saturated surface dry condition (g/cm^3)	24 hours Water absorption (%)	Weight of unit volume (kg/l)	Percentage of absolute volume (%)
1.18	68.97	0.42	60.4

Table 2. Chemical compositions of lapilli produced in Akita Prefecture.

SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)
61.6	15.2	4.13	4.22	1.30	0.84	3.85

Table 3. Mixture proportions of ordinary concrete.

Water-cement ratio (%)	Sand percentage (%)	Slump (cm)	Air content (%)	Unit content (kg/m^3)				
				Water	Cement	Sand	Coase aggregate	Air entraining agent
60.0	46.3	7.0 to 9.0	5.5 to 6.5	172	287	804	878	0.17

Table 4. Mixture proportions of porous concrete used lapilli.

Target void ratio (%)	Paste coase aggregate volume ratio	Water-cement ratio (%)	Unit content (kg/m^3)				
			Water	Cement	Coase aggregate	Superplasticizer	Supplementary air entraining agent
30	0.07	25.0	19	81	772	0.81	0.02

2.2 *Production of test specimens and the plates*

A paddle mixer with 50 liter capacity was used and a mixing time was 90 seconds after putting lapilli, cement and water and admixture into the mixer in the order of putting the materials for the lapilli concrete. Porous concrete plates with 300 mm length, 300 mm width and 60 mm thickness were produced. The test specimen of ordinary concrete was manufactured by using steel form of 400 mm length, 100 mm width and 100 mm depth after measuring the slump and air content. The form was removed at 24 hours after manufacturing concrete, and some curings such as water curing at 20 ℃, atmospheric curing at 18 to 22 ℃ and covering by the lapilli POC plate in the same environmental condition of atmospheric curing were carried out respectively until the age of 14 and 28 days.

2.3 *Strength test and measurement of water absorption and evaporation*

The compressive and bending strength test were carried out by using the test specimen at the age of 28 days after each curing according to JISA1108 and 1106. The test specimen was weighed before the strength test, and weight of unit volume was calculated.

24 hours water absorption of the lapilli POC and lapilli itself was measured by using the cylindrical specimen (100 mm diameter, 200 mm height) which was dried for 24 hours at 110℃. In the case of lapilli itself, the amount of the lapilli which was contained in a cylindrical specimen was weighed based on the mixture proportions. The lapilli was put into the wire-netting cage which had the same size as a cylindrical specimen. Each three layers of the lapilli in the cage were rodded so as to be 200 mm height. Amount of water absorption for lapilli itself and the lapilli POC were measured according to JISA1135. The amount of water evaporation was measured at 20℃ and 60% relative humidity by using the specimen which was absorbed water for 24 hours in the water bath.

2.4 *The measurement of the temperature in the center of the cross section of the concrete plate in the summer outdoor exposure test*

The outdoor exposure test was carried out on the roof of laboratory building with three floors from July 30 th to September 23 rd, 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 the cross section of ordinary concrete plate covered by the lapilli POC plate 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. Heat capacity for the plate was calculated from these measured values (Shirokado et al. 2005). Figure 1 shows the size of concrete plate and position of fixed thermocouple and Figure 2 shows the outdoor exposure situation.

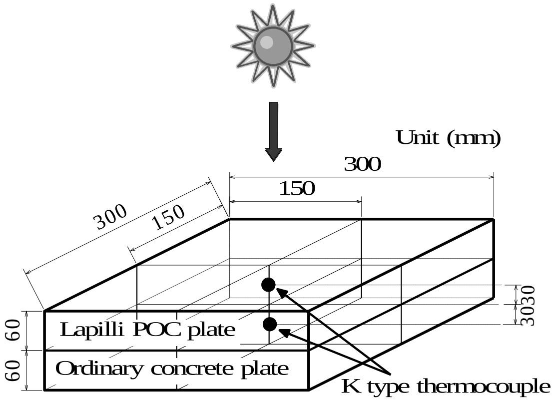

Figure 1. Size of concrete plate and position of fixed thermocouple.

Figure 2. The outdoor exposure situation.

Effect of atmospheric temperature reduction was examined in the case of sprinkling water on the lapilli POC plate after drying in summer. The amount of water for sprinkling was 800cc and the water was sprinkled at 9 and 17 o'clock.

Relative dynamic young's modulus of elasticity and weight loss percentage were measured by using exposed beam test specimen (400 mm length, 100 mm width and 100 mm depth) during a year in order to carry out the outdoor exposure durability test of the lapilli POC itself.

2.5 *Freezing and thawing test of the ordinary concrete covered by the lapilli POC plate*

The form was removed at 24 hours after manufacturing concrete specimens and water curing at 20 ℃, atmospheric curing at 18 to 22 ℃ and covering by the lapilli POC plate in the same environmental condition of atmospheric curing were carried out until the age of 14 days respectively. In the case of covering, the surfaces of test specimens of ordinary concrete were covered by the lapilli POC plates which were saturated surface dry condition after 24 hours absorption. The lapilli POC plates were removed before starting the test. The freezing and thawing test was carried out according to JISA1148.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 *The examination of physical properties and durability of porous concrete used lapilli and lapilli itself*

Figure 3 shows the change of water absorption of lapilli with elapsed time. The lapilli absorbed about 85% of 24 hours water absorption in an initial 10 minutes after that it gradually increased. A characteristics of the lapilli was high rate of water absorption in the initial stage. From these results, some properties, such as mechanical properties, water absorption and evaporation of porous concrete used lapilli were examined.

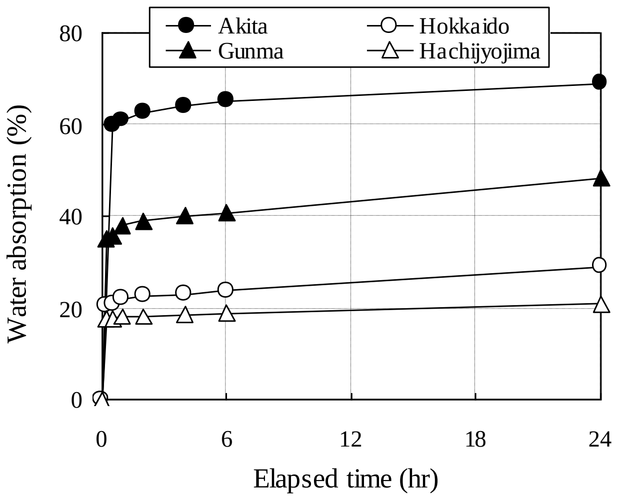

Figure 3. Change of water absorption of lapilli with elapsed time.

Table 5 shows the weight of unit volume at 24 hours water absorption and compressive and bending strength at the age of 28 days after water curing for the porous concrete used lapilli and ordinary concrete. The 24 hours water absorption of lapilli POC was very high and the value was 45.4%. The lapilli POC was light weight and the value was about half of ordinary concrete. The compressive and bending strength were low and their values were 0.7 and 0.3 N/mm^2.

Table 5. Physical and mechanical properties of concrete.

	Lapilli porous concrete	Ordinary concrete
24 hours water absorption (%)	45.4	6.2
Weight of unit volume (kg/l)	1.01	2.31
Compressive strength (N/mm^2)	0.7	28.8
Bending strength (N/mm^2)	0.3	4.2

Figure 4 shows the comparison of lapilli itself and lapilli POC with regard to amount of water absorption and evaporation. The differences between lapilli itself and lapilli POC with regard to amount of water absorption and evaporation were 37 g and 26g at the passage of 24 hours, and their increasing tendency with progress of the time was similar to each other. The amount of water absorption and evaporation of lapilli POC were 427g, and 406g, at the passage of 48 hours and 95% of absorbed water was evaporated. These amounts were about 2 and 4 times as much as amount of water absorption and evaporation of ordinary concrete. Therefore, the effect of the cement paste coating was not significant, and it was clarified that amount of water absorption and evaporation of lapilli itself and lapilli POC were almost the same.

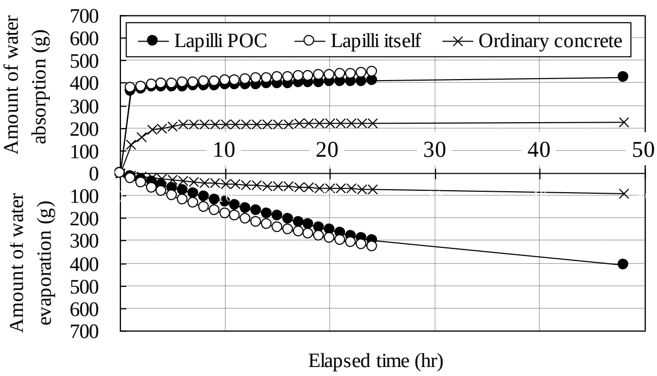

Figure 4. The comparison of lapilli itself and lapilli POC with regard to amount of water absorption and evaporation.

It was supposed that the lapilli POC with light weight and high absorption was covered on the surface of the concrete structures in this study. Then, durability of the lapilli POC itself was examined by outdoor exposure test.

Figure 5 shows the relative dynamic Young's modulus of elasticity and weight loss percentage of the lapilli POC beam in the outdoor exposure test at 180 and 530 days. They did not change clearly at both ages. The weight loss percentage was calculated based on the weight of the saturated surface-dry specimen after 7 days water curing. It was judged that about 40% weight loss percentage was depend on water evaporation and that the lapilli POC was durable because the degradation of the specimen could not be observed visually. The lapilli POC itself could keep the durability under the actual freezing and thawing cyclic condition but further long outdoor exposure durability test should be carried out continually. Moreover, it was durable in the drying-wetting cycle laboratory test.

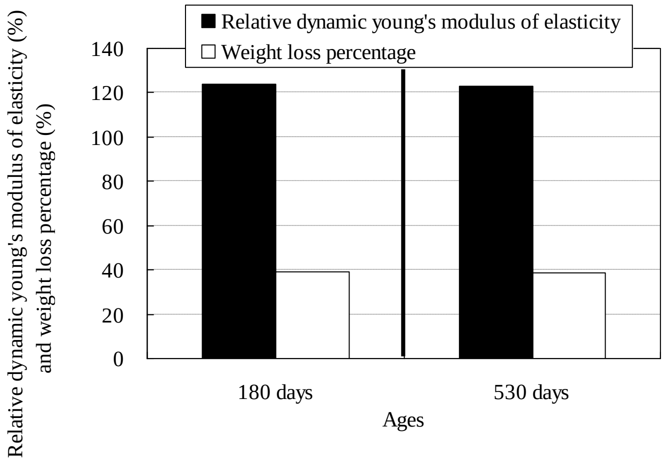

Figure 5. Relative young's modulus of elasticity and weight loss percentage of the lapilli POC beam in the outdoor exposure test.

3.2 *Effect of atmospheric temperature reduction of the porous concrete used the lapilli*

3.2.1 *Effect of atmospheric temperature reduction of the lapilli POC plate itself compared with ordinary concrete plate*

Observing at the lightweight and high absorption properties of the lapilli POC, it was examined on the effect of atmospheric temperature reduction utilized the properties. Figure 6 shows the change of the average temperature during a week in the center of cross section of the lapilli POC and the ordinary concrete. The temperature in the lapilli POC plate was 4 degrees lower than the atmospheric temperature at the maximum. This shows the heat absorption from the atmosphere, and it is clarified that the lapilli POC plate has temperature reduction effect. On the other hand, the temperature in the ordinary concrete plate was 4 degrees higher than the atmospheric temperature at the maximum and this shows the heat radiation to the atmosphere.

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 7 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 lapilli POC 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 lowers. This fact indicates that the lapilli POC plate can cut the reflection of the heat of the sun beam.

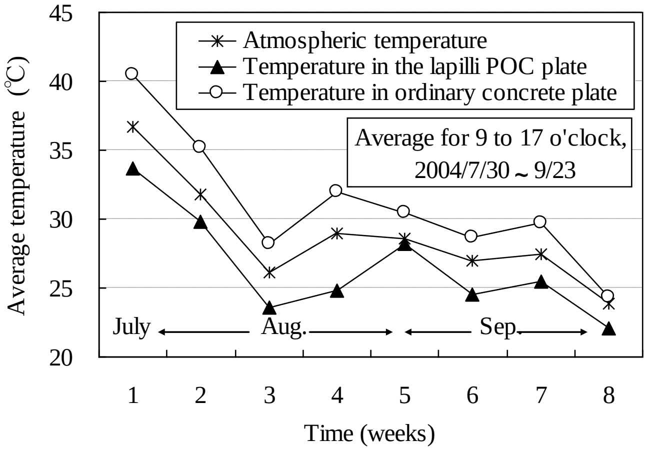

Figure 6. Change of the average temperature during a week.

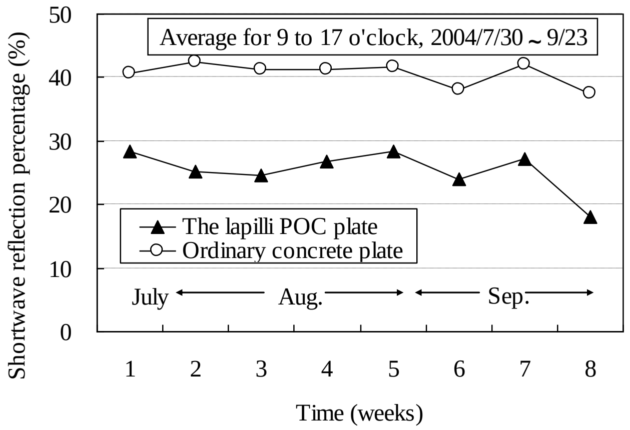

Figure 7. Change of shortwave reflection percentage on the concrete plate surface.

Figure 8 shows the amount of water evaporation from the lapilli POC and ordinary concrete for 2 weeks during 9 to 17 o'clock. In this figure, the amount of water evaporation from the lapilli POC plate was more than that from the ordinary concrete plate, and it was shown the recovery of water evaporation phenomenon from the lapilli POC by precipitation after drying. From these results, it is considered that a large amount of water evaporation from the lapilli POC plate can produce the vaporization latent heat of water and this fact leads to lowering the heat source effect of the plate due to the reduction of the temperature in the center of cross section.

Figure 9 shows the comparison of the heat balance in the lapilli POC plate and ordinary concrete one on August 8th and 9th, 2004. The data shown in this figure are the average heat capacity per 1 hour during 9 to 17 o'clock by heat balance calculation. This figure shows the inflow heat capacity (the total intensity of solar radiation and atmospheric radiation quantity) to these concrete plates was 3.97 and 3.14 MJ/m^2 on August 8th and 9th 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 lapilli POC plate, it was 3.73 and 3.02 MJ/m^2 on August 8th and 9th, respectively. From these results, it is clarified that 0.12 to 0.24 MJ/m^2 of the inflow heat capacity to the lapilli POC plate has been cancelled as a latent heat on August 8th and 9th respectively, but a latent heat decreased after drying of the lapilli POC plate.

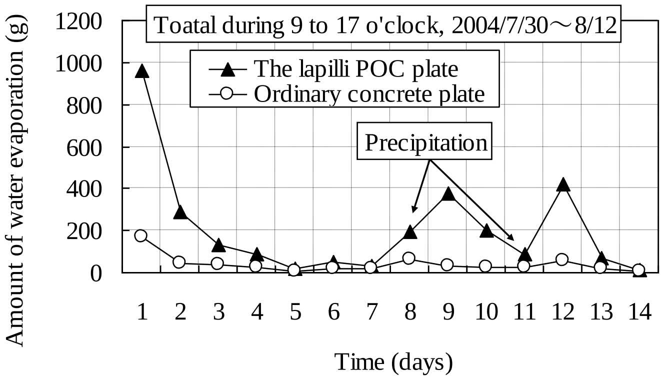

Figure 8. Change of amount of water evaporation during 2 weeks.

3.2.2 *Effect of atmospheric temperature reduction of the lapilli POC plate covered on the ordinary concrete plate*

Then, the effect of atmospheric temperature reduction of the lapilli POC plate covered on the ordinary concrete plate was examined.

Table 6 shows the average of daily maximum temperature in the atmosphere and the center of cross section of ordinary concrete plate with and without covering by the lapilli POC for 30 days in summer, 2004. In this table, the average of daily maximum temperature in the center of cross section of ordinary concrete plate with covering was 6.2 degrees lower than that without covering, and it was 2.3 degrees lower than the average of daily maximum atmospheric temperature but the temperature without covering was 3.9 degrees higher than the average of the daily maximum atmospheric temperature. It therefore, is considered that the covering by the lapilli POC plate on the amount of sprinkling water was 800cc, and the water was sprinkled at 9 and 17 o'clock. By sprinkling water, the temperature in the center of the cross section of covered ordinary concrete plate was 5 degrees lower at the maximum than the atmospheric temperature in the daytime, and it was almost the same or 1 degree lower than that in the nighttime and the effect of the temperature reduction was revived by the water sprinkling twice a day.

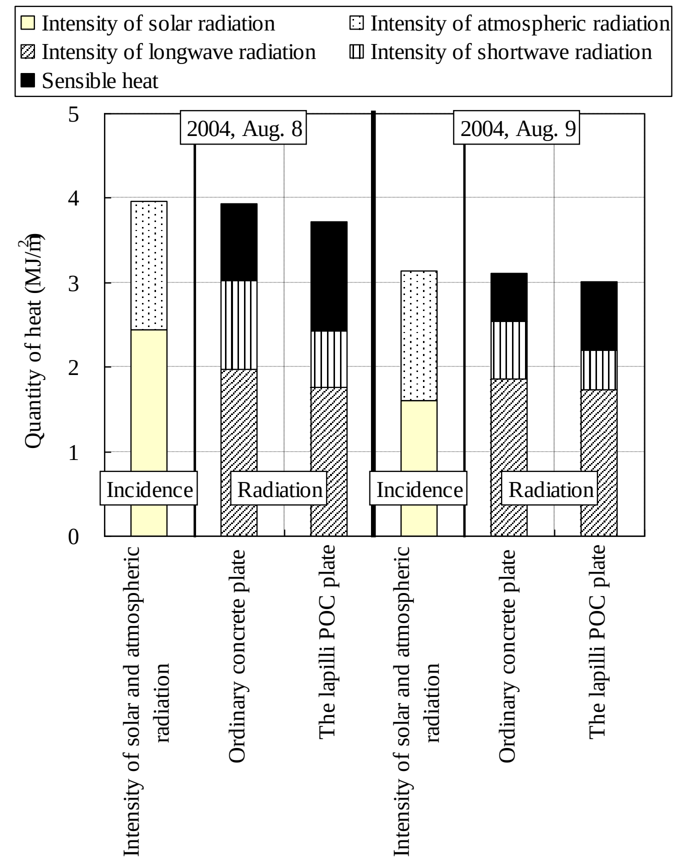

Figure 9. The comparison of heat balance in the lapilli POC plate and ordinary concrete plate.

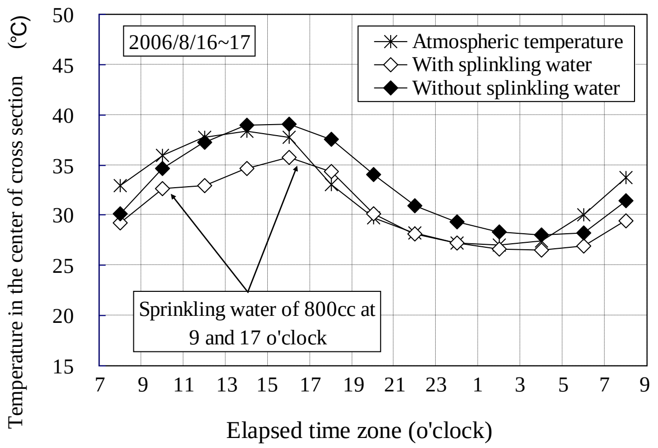

Figure 10. Change of temperature in the center of the cross section of ordinary concrete plate with covering for a day in summer.

Table 6. Average of daily maximum temperature in the atmospheric and the center of cross section of ordinary concrete plate with and without covering by the lapilli POC plate for 30 days in summer.

	Without covering	With covering
Average of daily maximum atmospheric temperature (℃)	32.7	
Average of daily maximum temperature in the center of cross section of ordinary concrete plate (℃)	36.6	30.4

ordinary concrete one has the effect of atmospheric temperature reduction.

The examination on the effect of the water sprinkling on the lapilli POC plate after drying was tried, since the water in the lapilli POC plate is lost and the temperature in the center of cross section of the lapilli POC plate increases with progress of the time when the fine weather continues.

Figure 10 shows the change of average temperature for every 2 hours in the center of the cross section of the covered ordinary concrete plate with or without sprinkling water in summer. The

3.3 *Preservation effects by the covering of the lapilli POC plate*

The temperature in the center of the cross section of ordinary concrete plate covered by the lapilli POC plate was measured in order to verify the preservation effects by the covering of the lapilli POC plate. Figure 11 and 12 show the time depending change of the average temperature for every 2 hours in the center of the cross section of the ordinary concrete plate with and without covering by the lapilli POC plate in summer and winter. The average of the atmospheric temperature was also shown. The rate of temperature change between the daily minimum and maximum temperature in the ordinary concrete plate with covering is lower than that without covering in summer and winter.

Table 7 shows the average of daily temperature range in summer and winter, and the average of daily minimum temperature in the winter and freezing and thawing cycle number in the center of the cross section of ordinary concrete plate with and without covering by the lapilli POC plate. The temperature variation in the cross section causes the expansion and shrinkage but the variation with covering was about half of it without covering in

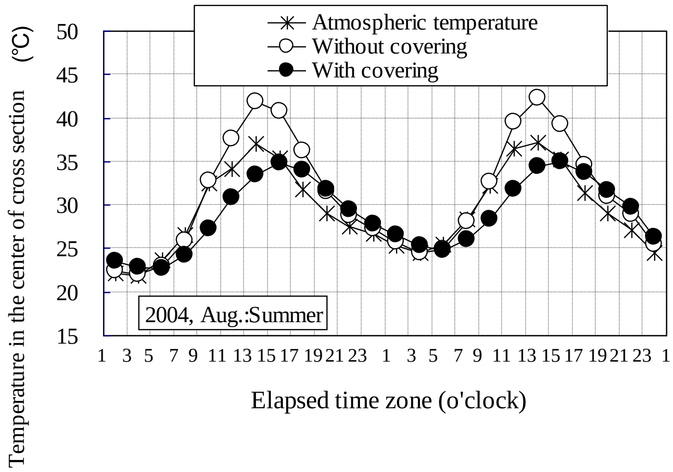

Figure 11. The time depending change of the average temperature for every 2 hours in the center of the cross section of the ordinary concrete in summer.

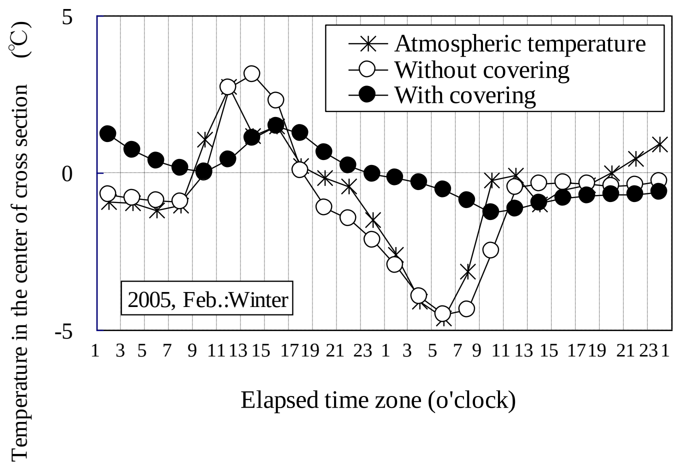

Figure 12. The time depending change of the average temperature for every 2 hours in the center of the cross section of the ordinary concrete in winter.

Table 7. Average of daily temperature range in summer and winter, and the average of daily minimum temperature in the winter and freezing and thawing cycle number in the center of the cross section of ordinary concrete plate with and without covering by the lapilli POC plate.

	Without covering	With covering
Average of temperature range in ordinary concrete plate in a day (In summer) (℃)	15.7	8.7
Average of temperature range in ordinary concrete plate in a day (In winter) (℃)	5.6	2.2
Average of minimum temperature in ordinary concrete plate in a day (In winter) (℃)	-1.5	-0.6
Average of minimum atmospheric temperature in a day (In winter) (℃)	-1.8	
Freezing and thawing cycle number	20	6

both summer and winter. The daily minimum temperature with covering was 0.9 degrees higher than the temperature without covering and was 1.2 degrees higher than the average of daily minimum atmospheric temperature in winter. The freezing and thawing cycle number of ordinary concrete with covering was one third of it without covering.

From these results, the covering by the lapilli POC could reduce the expansion and shrinkage of the ordinary concrete due to the atmospheric temperature change in summer and winter, and reduce the freezing and thawing cycle number of the concrete in winter. It was judged that the lapilli POC plate had preservation effect to the deterioration of the ordinary concrete induced by temperature change.

Then, the freezing and thawing test of ordinary concrete with covering by the lapilli POC plate was carried out. Figure 13 and 14 show the relationship between relative dynamic young's modulus of elasticity and weight loss percentage, and the freezing and thawing cycle number for the curing method. The relative dynamic young's modulus of elasticity of the concrete with covering by the lapilli POC plate was intermediate value between the case of water curing and atmospheric curing until 270 cycles, and these values were almost the same ranged from 66 to 69% at 300 cycles. The weight loss percentage of the concrete with covering was the same as the case of water curing and they were less than the case of atmospheric curing. It therefore, is considered that the covering by the lapilli POC plate has the curing effect for frost resistance.

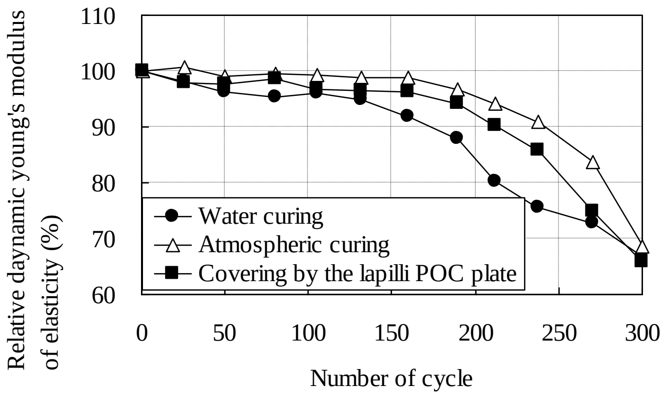

Figure 13. Relashionship between freezing and thawing cycle number and relative dynamic young's modulus of elasticity.

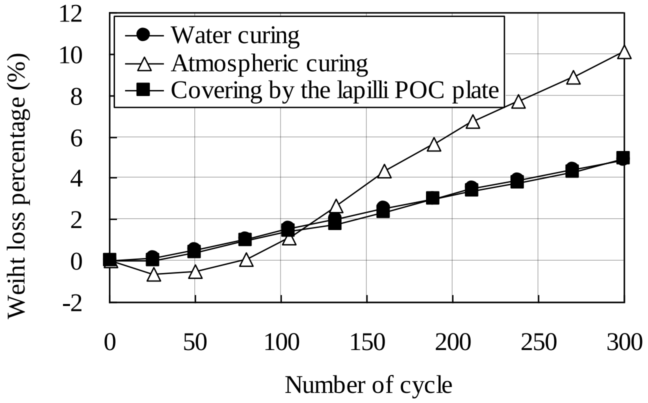

Figure 14. Relashionship between freezing and thawing cycle number and weight loss percentage.

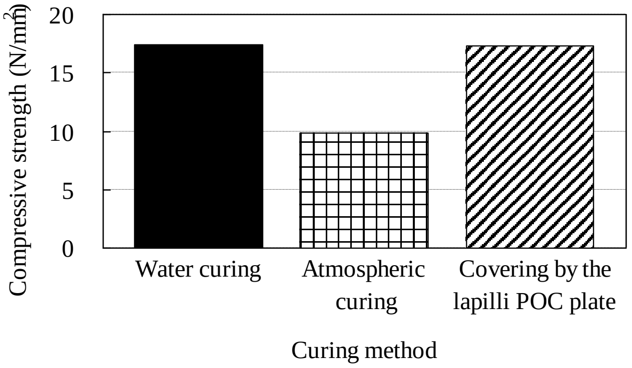

Figure 15. The comparison of compressive strength of the test pieces sampled from the bending strength test after the freezing and thawing 300 cycles test.

Figure 15 shows the comparison of compressive strength of the test pieces sampled from the bending strength test after the freezing and thawing 300 cycles test. The compressive strength in the case of covering by the lapilli POC plate was 1.7 times higher than that in the case of the atmospheric curing, and it was almost the same as the case of the water curing. Since the covering by the lapilli POC plate improved as the frost resistance of the ordinary concrete even in the same environmental condition as the atmospheric curing, it was verified that the lapilli POC plate had surface preservation effect for the frost resistance in the case of covering on the surface of the concrete structure members such as column and beam which was difficult to cure in the wet condition.

From these results, it was clarified that the lapilli POC was the construction materials having environmental burden reduction and surface protection effects.

4 CONCLUSIONS

Effect of atmospheric temperature reduction and surface protection of lapilli POC plate covered on the ordinary concrete surface were examined by measuring the temperature in the center of cross section of the concrete and by carrying out freezing and thawing test of the ordinary concrete. Following results were obtained.

(1) The initial water absorption rate and 24 hours absorption of the lapilli produced in north of Akita-prefecture were very high and the value of absorption was 68.97%.
(2) The tendency of the increase in the amount of water absorption and evaporation of the lapilli itself and lapilli POC were almost the same, and the water absorption and evaporation of the lapilli POC was not affected by the cement paste coating.
(3) The relative dynamic Young's modulus and weight loss percentage of the porous concrete used lapilli didn't clearly change and the porous concrete was durable in spite of low strength and high absorption at the passage of one and half years of the outdoor exposure test.
(4) The temperature in the center of the cross section of the lapilli POC plate was 4 degrees lower than the atmospheric temperature at the maximum during two months in the summer. The inflow heat capacity from the atmosphere was cancelled as 0.13 to 0.51 MJ/m^2 of latent heat in the lapilli POC plate but it was not done in the ordinary concrete plate from the result of heat balance calculation. It is considered that the lapilli POC plate has an effect of atmospheric temperature reduction.
(5) The average of the daily maximum temperature in the center of cross section of the ordinary concrete plate covered by the lapilli POC plate was 6.2 degrees lower than the temperature of non-covered ordinary concrete plate, and it was 2.3 degrees lower than the average of daily maximum atmospheric temperature during 30 days in summer.
(6) A whole day temperature in the center of cross section of the ordinary concrete plate covered by the lapilli POC one could be lowered by the water sprinkling twice a day, when the lapilli POC plate was dried. This fact shows the reduction effect of heat island phenomenon by using the lapilli POC plate.
(7) The reduction of the expansion and shrinkage of the ordinary concrete covered by the lapilli POC due to the temperature change in summer and the reduction of the freezing and thawing cycle number of the concrete in winter could be obtained. It was clarified that the lapilli POC plate had preservation effect and the surface covering contributed to the improvement of frost resistance of ordinary concrete by the curing effect from the results of freezing and

thawing test.

(8) From these results, it was considered that the lapilli POC was the construction materials with a characteristics of sustainable development for the mankind.

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