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An Experimental Study of Water Vapor Pressure Change by Ambient Temperature at the Interface between Concrete and Fluid-Applied Membrane Layer

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Abstract: Over about 30% of problems in construction is related to water-leaking, and the loss from this problem can incur as much as three times the cost of initial construction. Thus, water vapor pressure is known to be the primary cause of defective waterproofing. Accordingly, the theories on the relationship between water pressure and temperature as well as damp-proofing volume of concrete and the change in vapor pressure volume were reviewed and analyzed in this study by making test samples after spraying a dampness remover and applying waterproofing materials to the prepared test specimens. The result of measuring water vapor pressure with the surface temperature of the waterproofing (fluid-applied membrane) layer at the experimental temperature setting of about 10°C, which is the annual average temperature of Seoul, indicated that (1) the temperature of the fluid-applied membrane elevated to about 40°C, and the water vapor pressure generated from the fluid-applied membrane was about 0.03 N/mm^2 when the surface temperature of the waterproofing layer was raised to about 80°C. (2) when the temperature of the fluid-applied membrane of the waterproofing layer was raised from 30°C to 35°C, water vapor pressure of about 0.01 N/mm^2 was generated, and (3) when a thermal source was applied to the fluid-applied membrane (waterproofing) layer, the temperature increased from 35°C to 40°C, and approximately 0.005 N/mm^2 of water vapor pressure was generated.

Keywords: fluid-applied, membrane, water vapor pressure, air pockets.

1. Introduction

1.1 Research objectives

Waterproofing construction is one of important construction processes from the perspective of livability, comfort, and safety. However, over about 30% of problems in construction is related to water-leaking, and the loss from this problem can incur as much as three times the cost of initial construction.[1] Although most problems of water-proofing work are caused by careless construction so that they can be prevented, air pockets of the water-proof layer at the interface between fluid-applied membrane and concrete occur spontaneously so that they are difficult to deal with.

Various air voids exist in concrete, and most of the air voids are capillary air voids. The size of the capillary air voids is largely 1/500~10 μm, and its shape is long, thin, and flat existing in continuous or discontinuous space. This capillary air void affects water-to-cement ratio of concrete proportion, and there will be more of capillary air voids as the ratio is larger. For example, the air voids in concrete occur depending on the age, water-to-cement ratio and curing methods, and there exist air voids of 0.1~0.2 cm^3/g in typical concrete. Likewise, because air voids inside the concrete hold mixing water and moisture from rain and snow, water vapor pressure is generated at the interface between the concrete substrate and fluid-applied membrane layer due to the humidity difference of the environmental factor during the usage, even if the water-proofing was carried out at a dry surface.

Thus, this study measured water vapor pressure change occurring at the interface between the concrete substrate and fluid-applied membrane layer, and then the trend of the change in water vapor pressure is identified so that it can serve as a useful data for the standard method of applying moisture-proofing for the concrete substrate in the future and for the enhancement of the durability of the fluid-applied membrane layer.

1.2 Research method and scope

This study investigates the change in water vapor pressure occurring at the interface between the concrete substrate and fluid-applied membrane layer experimentally, and the research method is described as follows.

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1) Theoretical review on air void, water-proofing, and water vapor pressure of concrete: reviewed air void, water proofing, and the relationship between water vapor pressure and temperature of concrete per unit area

2) Measurement of water vapor pressure by the change in ambient temperature : installed an aerator in a concrete substrate exposed to the air and applied a fluid-membrane on the concrete to measure the change in water vapor pressure with the change in ambient temperature

3) Measurement of water vapor pressure by the change in the temperature at the surface, inside, and interface with the water-proof layer of the concrete: an aerator was installed on the concrete specimen at a laboratory, and then water-proof fluid was applied on it to form a membrane. A control for the temperature setting of a thermal source was prepared to measure the change in water vapor pressure by the change in the temperature at the surface, inside, and interface with the water-proof layer of the concrete.

4) Analysis of the relationship of research interest : various relationships of research interest such as temperature change by the depth of the concrete substrate, the relationship between ambient temperature and surface temperature of the concrete, the relationship between the surface and interface temperature of the concrete, the relationship between ambient temperature and water vapor pressure, the relationship between surface temperature and water vapor pressure, the relationship between interface temperature of the concrete and water vapor pressure inside the concrete, etc. were analyzed.

2. Theoretical review

This section pertains to the theoretical review on air void ratio, water-proofing, and water vapor pressure per unit area of the concrete under the research interest of this study, and the total air void ratio, free air void ratio, water-proof quantity of the concrete, and the relationship between ambient temperature and water vapor pressure were analyzed.

2.1 Air void ratio of concrete

Although concrete is a structure of relatively high density and air void, the shape, size, distribution, etc. of the air voids inside the concrete vary greatly due to the variety of mixing ratios of the concrete substrate. The types of air voids inside the concrete are cement gel air void, capillary air void, air void under the aggregate, entrained air void, and irregular air void such as entrapped air void. Because these air voids are closely connected to provide the water passage, the permeability mechanism of the concrete is very complex.[2]

When the concrete material with air voids are immersed in water and is subjected to vacuum, the air inside the test specimen is vacuumed out and water fills in its place. Then, its air void can be computed, and it is called "total air void ratio." On the other hand, the air void ratio concerning the movement of water through a capillary action is called "free air void ratio."[3]

Figure 1 below shows coefficient of water absorption, which is used as the index for the evaluation of free air void ratio of the concrete and water-sealing of construction materials, and it indicates that free air voids of about 5~8% exist typically inside the concrete although there are some differences depending on the water-to-cement ratio. Moreover, the free air void ratio and coefficient of water absorption increase gradually with the increase in water-to-cement ratio of the concrete. In other words, water-to-cement ratio and water absorptivity are correlated proportionally.[4]

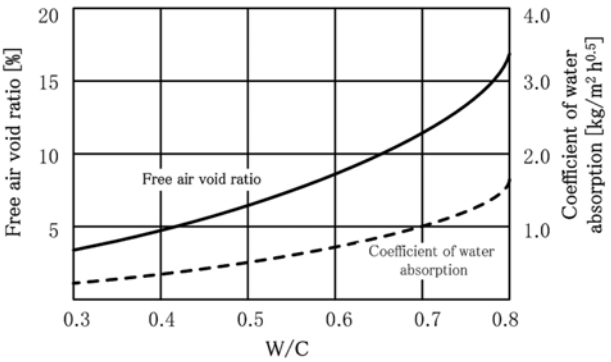

Fig. 1 Free air void ratio by the water-to-cement ratio of the concrete coefficient of water absorption.

2.2 Moisture-proofing of concrete

Figure 2 illustrates the result of computing water-proof quantity of the concrete by unit area in relation to the aging time. Water-proof quantity of 10~20 g/m^2·day and 6~10 g/m^2·day was measured six months and 12~24 months, respectively, after the concrete placement. Although there was a definite difference in water-proof quantity of the concrete with respect to the presence or absence of a heat insulator at the initial stage of the measurement, the difference with respect to the presence or absence of a heat insulator was almost unnoticeable after two months. Additionally, there has been a research report of measuring very high water absorptivity of about 6~8% at relative humidity of 40% for a concrete substrate at the depth of 150 mm six months after the concrete placement.[5]

Therefore, it is deemed that there can be a problem in water-proofing work due to the moisture from the concrete, if water-proofing is applied on inadequately dried concrete.

2.3 Relationship between water vapor pressure and ambient temperature

The average of daily temperature fluctuation in Seoul[6] is

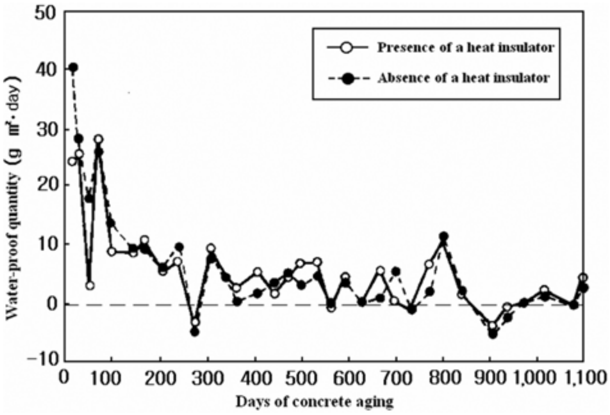

Fig. 2 Water-proof quantity of the concrete by unit area.

Table 1 Monthly average of daily temperature fluctuation in Seoul, Korea (2007).

Month	1	2	3	4	5	6	7	8	9	10	11	12	Range
Daily temperature fluctuation (°C)	6.9	8.6	8.0	8.6	9.8	8.5	6.5	6.1	6.5	8.3	8.6	6.8	6~10

about 6~10°C, and the highest daily temperature fluctuation throughout the year was measured at about 14°C. Especially, when the water-proof layer of a roof top is exposed to direct sunlight, the surface temperature of the water-proof layer rises up to about 60~80°C, creating a high pressure at the interface of the concrete and the water-proof layer. The following Fig. 3 illustrates the relationship between water vapor pressure and ambient temperature. It can be seen that when the temperature difference of about 60°C is assumed for the graph, about 0.02 N/mm^2 of water vapor pressure takes place through the concrete substrate.

3. Overview of experiment

3.1 Method of test specimen preparation

The basis test specimen used in this experiment was prepared in accordance with the mix proportion of Table 2, was cured for 28 days under water, and left alone for 7 days indoor at the temperature of 20 ± 5°C and humidity of 60 ± 5%.

Next, after installing an aerator on the basis test specimen, the polyurethane composite of 90 ± 5 KU/25°C viscosity from A company and polyurethane composite of 500 ± 100 CPS/25°C viscosity from B company are applied at the thickness of 2 mm on the specimen. Then, the specimen is cured in air. Table 3 shows the physical properties of the materials used.

3.2 Method of temperature measurement

T-type thermocouple temperature sensors were installed at the depth of 10~60 mm from the surface prior to the concrete placement in order to measure the temperature change inside the concrete substrate, and then a thermometer from Y. company was employed for the temperature measurement. Additionally, T-type thermocouple temperature sensors were installed at two places on the basis test specimen around the aerator in order to measure the change in temperature at the interface between the concrete substrate and fluid-applied membrane layer. Next, polyurethane composite and polyurea composite were applied on the

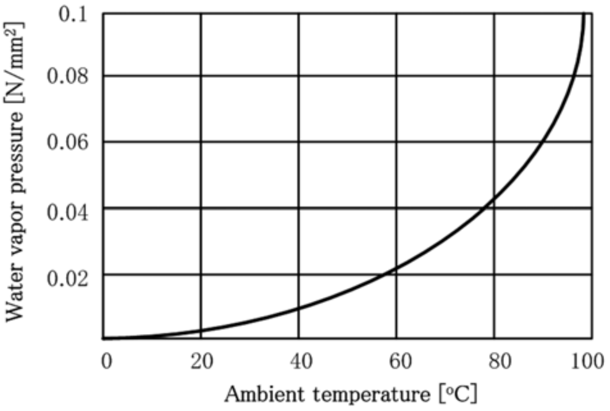

Fig. 3 Relationship between water vapor pressure and ambient temperature.

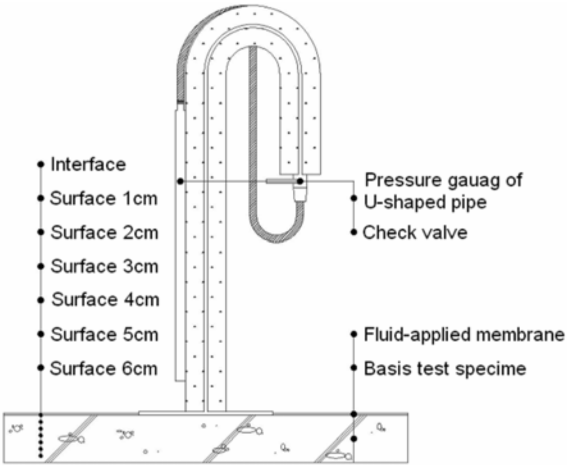

Fig. 4 Overview of the aerator.

Table 2 Mix proportion of the basis test specimen.

Classification	Mix proportion by the volume (l/m^3)				Mix proportion by the mass (kg/m^3)			
	c	w	s	a	c	w	s	a
Mix ratio	99	156	323	372	312	156	775	934

(note) c: cement (specific gravity 3.15), w: water, s: sand (specific gravity 2.4), a: crushed rock (specific gravity 2.51).

Table 3 Physical properties of the materials used.

Classification	Polyurethane composite from A company	Polyurethane composite from B company
Appearance	Color / 2-nuclei	Color / 2-nuclei
Composition	Polyurethane composite	Polyurethane composite
Specific gravity	1.5 ± 0.1	1.05 ± 0.05
Viscosity	90 ± 5 KU/25°C	500 ± 100 CPS/25°C
Solid ratio	98%	99%
Open time	50 ± 10 (minutes)	within 3 seconds
Hardening time	24~48 (hours)	within 1 minute

(note) U : stomer viscosity meter, CPS : brook field viscosity meter.

Table 4 Experimental plan.

Specimen type	Evaluated variable	Measurement method
Polyurethane composite (specimen A)	Water vapor pressure	U-shaped pressure-measuring device
	Surface temperature	Infrared thermometer
Polyurea composite (specimen B)	Interface temperature	T-type thermocouple
	Temperature inside the concrete	

test specimen. Then, the change in temperature at the interface between the concrete substrate and fluid-applied membrane layer was measured by the method just described.

The four locations of temperature measurement are marked on the surface of fluid-applied membrane of Fig. 5. These measurements are taken to investigate the temperature change in the water-proof layer by the aging (hardening) time of the concrete. Next, infrared thermometer produced by F. company was used to measure the surface temperature at four locations indicated in Fig. 5. Then, the average of these four measurements is shown. Additionally, because the measured values differed by the time of the measurement of the surface temperature of the fluid-applied membrane and the angle and the height of the infrared thermometer, the temperature measurements were taken by setting the height and angle of the measurement constant at 100 mm and 0^o, respectively.

3.3 Method of water vapor pressure measurement

An aerator and a U-shaped pipe were installed on the basis test specimen in order to measure the change in water vapor pressure, which occurs at the interface between the concrete substrate and fluid-applied membrane, by the temperature of the fluid-applied membrane and the passage of hardening (aging) time of the concrete. Water was injected into the U-shaped pipe, and the measurement of water vapor pressure was taken by the change in height of water in the pipe. Based on the result of the measurement, water vapor pressure was computed by the following equation.

$$P_1 - P_2 = (r - r_1)\,h \tag{1}$$

where r : specific gravity of the measured solution (N/mm^2)
P_1, P_2 : pressure on the both ends of the pipe (N/mm^2)
r_1 : specific gravity of the fluid taking the pressure measurement (N/mm^2)
h : height difference of the fluid in the pipe (mm)

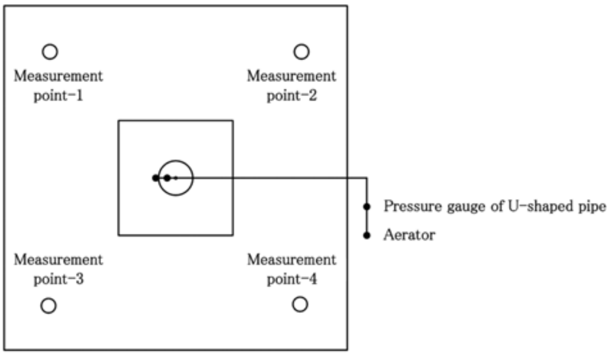

Fig. 5 Locations of surface temperature measurement.

4. Experimental method

4.1 Water vapor pressure experiment by ambient temperature change

An aerator was installed on the concrete basis exposed to air, and fluid-applied membrane material of polyurethane composite was applied at the thickness of 2 mm on the specimen. Then, the change in water vapor pressure by the change in ambient temperature was measured. Because the temperature and water vapor pressure taken in the outdoor air are influenced by the altitude and atmospheric pressure, these measurements should be calibrated under the same condition. However, this study used the actual measurement, which was not calibrated. Additionally, the experiment was conducted at one hour interval between 9 am and 5 pm during the month of September to measure the ambient temperature and water vapor pressure. The weather conditions were classified into clear day, overcast day, cloudy day, and rainy day. The temperature was taken in celsius, and the water vapor pressure was computed by taking the measurement of the height of water in the U-shaped pipe, which was pushed down, and then by converting it into N/mm^2 unit dimension.

4.2 Water vapor pressure experiment by the temperature change at the inside, interface, and surface of concrete

The experiment of measuring water vapor pressure by the change in temperature of the concrete inside, concrete interface, and fluid-applied membrane surface involved the installation of an aerator on the basis test specimen in a laboratory and the fluid-applied membrane materials made of polyurethane com-

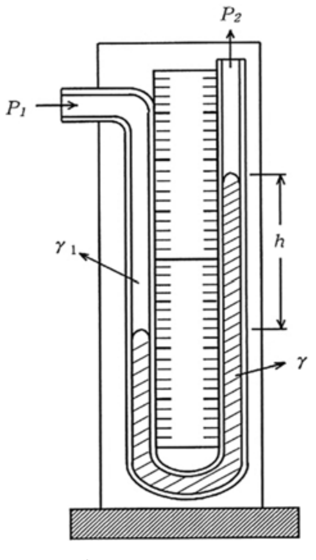

Fig. 6 U-shaped pipe for the measurement of water vapor pressure.

posite (specimen A) and polyurea composite (specimen B) were applied at the thickness of 2 mm each to prepare the basis test specimens for the experiment. Next, heat supply time was set at two settings of 20 minutes and 30 minutes. Then, the height of the heat supplier was lowered by 150 mm intervals to measure the change in water vapor pressure in response to the change in temperature of the concrete inside, concrete interface, and the surface of the water-proof layer.

5. Experimental result and analysis

5.1 Result of water vapor pressure measurement in response to ambient temperature change

After an aerator is installed on the concrete basis exposed to outdoor air, the change in water vapor pressure from the inside of the concrete substrate in response to the ambient temperature change is measured and depicted in Figs. 7, 8, 9, and 10.

First of all, the result of measurement during sunny days exhibited a very conspicuous change in water vapor pressure in response to ambient temperature change as the hardening (aging) time of the concrete goes on. The water vapor pressure was about 0.1 N/mm^2 at the highest ambient temperature of 26.7^{o}C within the scope of the measurement time of this study, and the difference between the highest and lowest water vapor pressure was about 0.17 N/mm^2.

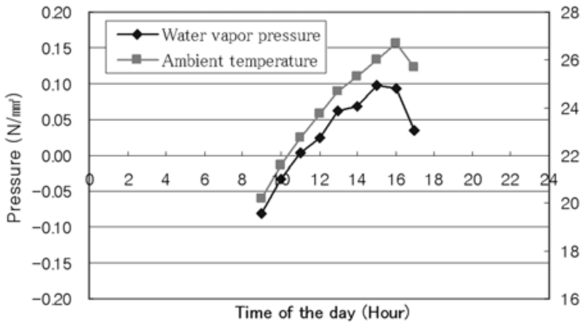

Fig. 7 Water vapor pressure measurement during sunny days.

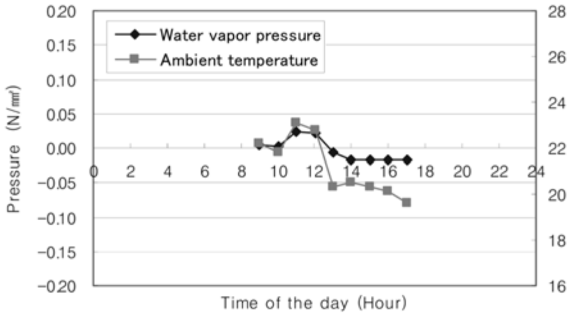

Fig. 8 Water vapor pressure measurement during overcast days.

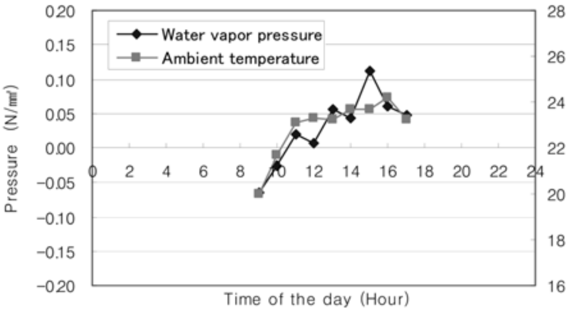

Fig. 9 Water vapor pressure measurement during cloudy days.

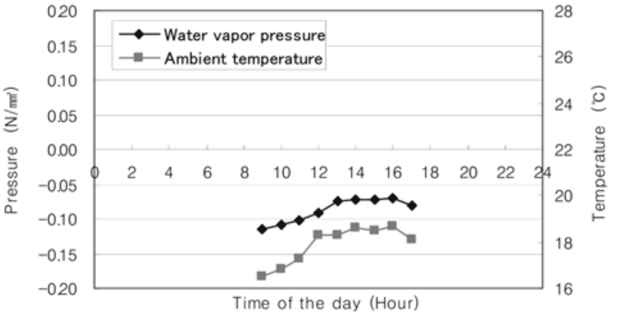

Fig. 10 Water vapor pressure measurement during rainy days.

Although there was a large temperature fluctuation between morning and afternoon of overcast days, the difference in water vapor pressure between morning and afternoon was relatively smaller than the temperature fluctuation. The highest water vapor pressure of 0.024 N/mm^2 was measured during the hours of measurement, and it stayed almost constant throughout all afternoon.

The trend of water vapor pressure change for cloudy days exhibited almost the same as sunny days, and the highest temperature and water vapor pressure were measured at 24.2^{o}C and about 0.11 N/mm^2, respectively, during the hours of measurement.

Lastly, the result of the experiment during the day, when it was rainy in the morning and sunny in the afternoon, indicated that the trend of ambient temperature change and water vapor pressure change was very similar, and the highest temperature and water vapor pressure were measured at 18.7^{o}C and about −0.071 N/mm^2, respectively, during the hours of measurement.

From the above experimental results of measuring ambient temperature change and water vapor pressure change during days of different weather characteristics indicate that the ambient temperature and water vapor pressure are correlated proportionally. Thus, it is construed that the ambient temperature is closely related to the water vapor pressure occurring inside the concrete substrate.

5.2 Result of water vapor pressure measurement by the temperature change in concrete inside

Figures 11, 12 display the result of water vapor pressure change in response to the change in the temperature inside the concrete while the heat supply time is controlled at 20 minutes. They show that the surface temperature increased rapidly as the height of the thermal source approached closer to the surface of the fluid-applied membrane. However, the interface temperature and the temperature inside the concrete changed to about one half of the surface temperature and then increased gradually. It is reasoned that the thermal source greatly affects the surface of the fluid-applied membrane only. Additionally, the reason that the water vapor pressure was measured high at the initial stage of

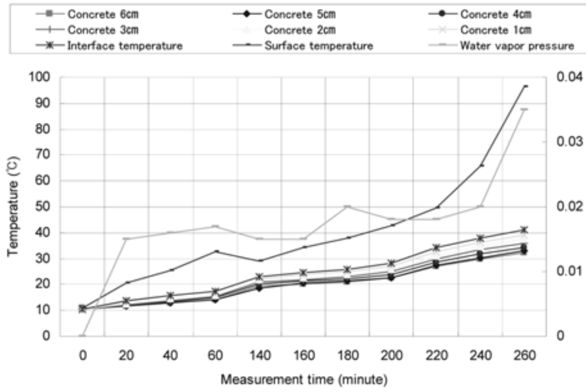

Fig. 11 Result of measuring ambient temperature and water vapor pressure in the polyurethane applied membrane (heat supply time: 20 minutes).

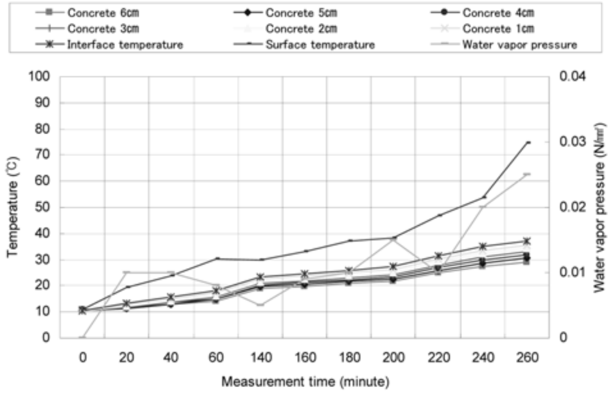

Fig. 12 Result of measuring ambient temperature and water vapor pressure in the polyurethane applied membrane (heat supply time: 20 minutes).

the experiment is because of the error in the overall experiment, in which the thermal source affected the aerator, although the heat should be supplied to the surface of the fluid-applied membrane only. Lastly, the reason that the deviation of the water vapor pressure change was not even in general, while the heat supply time was limited to 20 minutes, is construed to be due to the phenomenon manifested by the short heat supply time compared to the time required for the discharge of the water vapor pressure.

Figures 13 and 14 display the result of measuring the change in water vapor pressure in response to the change in the temperature inside the concrete while the heat supply time is controlled at 30 minutes.

They show that the temperature change inside the concrete while limiting the heat supply time to 30 minutes was similar to the case of limiting the heat supply time to 20 minutes. It can be seen that the water vapor pressure increases greatly around the interface temperature of 25~30°C. Additionally, comparing the results of the experiment controlling for the heat supply time to 20 minutes and 30 minutes, the deviation of the water pressure change was less for the case of heat supply time of 30 minutes in general. It is construed to be the result of the heat supplied evenly to the surface and interface of the fluid-applied membrane and the concrete inside as the heat supply time is longer.

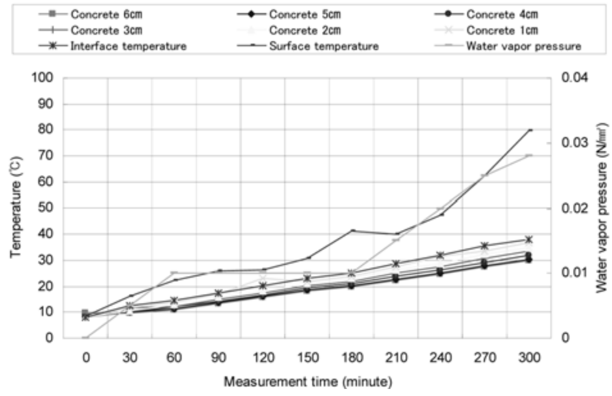

Fig. 13 Result of measuring ambient temperature and water vapor pressure in the polyurethane applied membrane (heat supply time: 30 minutes).

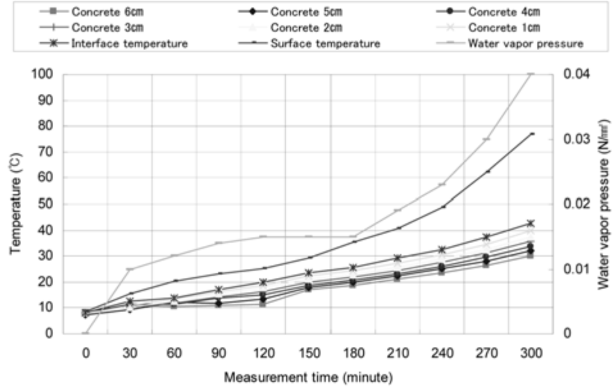

Fig. 14 Result of measuring ambient temperature and water vapor pressure in the polyurethane applied membrane (heat supply time: 30 minutes).

5.3 Result of water vapor pressure measurement by the temperature change at the interface between the concrete substrate and fluid-applied membrane

Figure 15 shows the result of measuring water vapor pressure change in response to the temperature change at the interface between the concrete substrate and fluid-applied membrane while the heat supply is controlled at 20 minutes. Although the

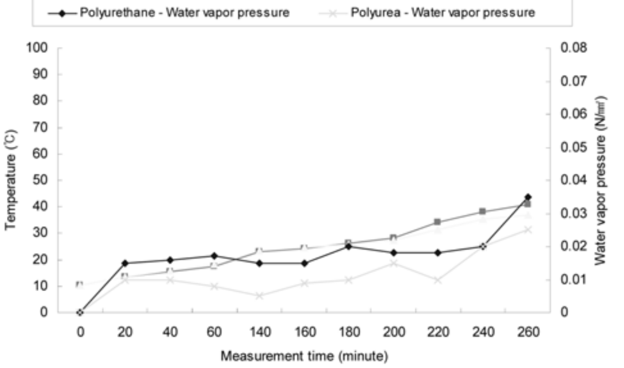

Fig. 15 Result of measuring ambient temperature and water vapor pressure of each specimen (heat supply time: 20 minutes).

temperature change at the interface was measured similar with respect to the height of the thermal source for these two test specimens, every measurements of the water vapor pressure of polyurethane specimen was about 0.01 N/mm^2 greater than that of polyurea specimen on the average.

Figure 16 shows the result of measuring water vapor pressure change in response to the temperature change at the interface between the concrete substrate and fluid-applied membrane while the heat supply is controlled at 30 minutes. The temperature change at the interface was measured similar with respect to the height of the thermal source for these two test specimens, just like the aforementioned case of the heat supply controlled at 20 minutes, and the water vapor pressure change was similar for these two specimens. Additionally, it was found that the water vapor pressure increased greatly around the interface temperature of 25~30°C. Nevertheless, the reason for the difference between the case of controlling the heat supply time at 20 minutes and this case of water vapor pressure change is construed by the following explanation. When heat is supplied adequately to the fluid-applied membranes, the difference in the water vapor pressure due to the thickness of these membranes becomes insignificant. Lastly, the trend of water vapor pressure change in response to interface temperature change is more similar than the trend of water vapor pressure change in response to temperature change at the surface or inside the concrete, and it is deemed that the interface temperature of the fluid-applied membrane affects water vapor pressure greater.

5.4 Result of water vapor pressure measurement by the temperature change in the surface of the moisture-proof layer (fluid-applied membrane) of concrete

Figure 17 shows the result of measuring water vapor pressure change in response to the temperature change at the surface of the fluid-applied membrane while the heat supply is controlled at 20 minutes. It shows that the temperature change at the surface was measured similar with respect to the height of the thermal source for these two test specimens at the initial stage of the experiment, but the difference in the temperature of the surface layer of these two specimens was quite conspicuous around the measurement time of 200 minutes. This is construed due to the difference in the heat conductivity of the materials used for these two specimens.

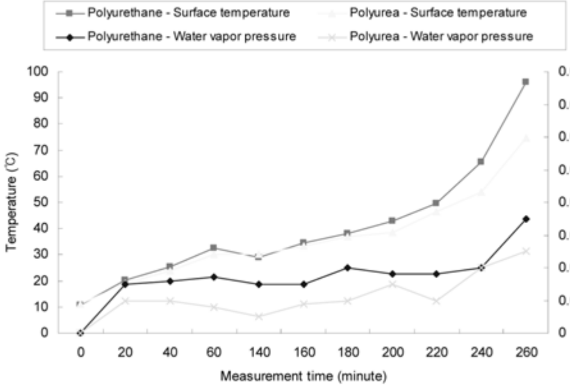

Fig. 17 Result of measuring ambient temperature and water vapor pressure of each specimen (heat supply time: 20 minutes).

Figure 18 shows the result of measuring water vapor pressure change in response to the temperature change at the surface of the moisture-roof layer (fluid-applied membrane) while the heat supply is controlled at 30 minutes. The result shows that the temperature change at the surface was measured similar with respect to the height of the thermal source for these two test specimens throughout the experiment. However, there was a significant difference in water vapor pressure change between these two specimens.

6. Analyses

6.1 Temperature change by the depth of the concrete substrate

Figure 19 shows the temperature change inside the concrete by its depth.

No apparent temperature inside the concrete is observed within the range of measured depth of 10~60 mm. Thus, it is deemed that the temperature of a concrete substrate exposed to air and direct sunlight is affect by the sunlight only within 2 mm of depth from the surface. Accordingly, it is anticipated that the water vapor pressure, which is generated within 2 mm of con-

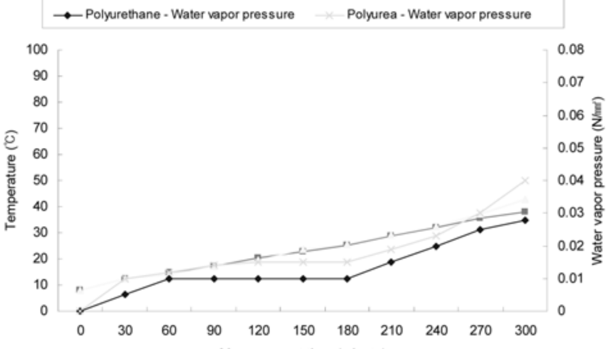

Fig. 16 Result of measuring ambient temperature and water vapor pressure of each specimen (heat supply time: 30 minutes).

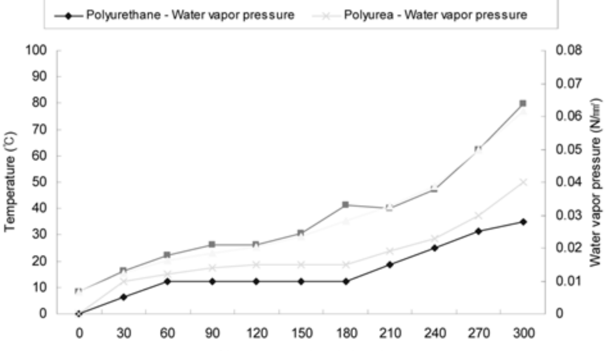

Fig. 18 Result of measuring ambient temperature and water vapor pressure of each specimen (heat supply time: 30 minutes).

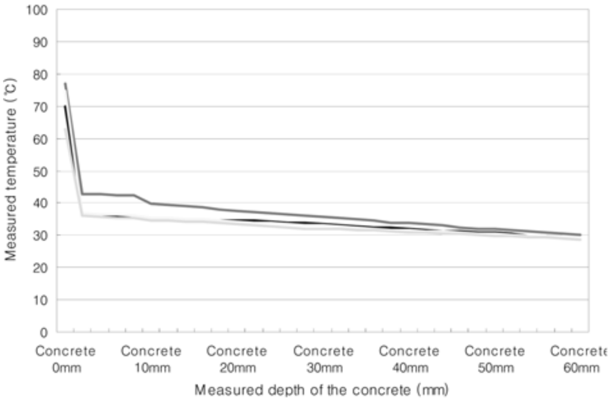

Fig. 19 Result of measuring temperature change inside the concrete by its depth.

crete depth, i.e. at the interface between the concrete substrate and the fluid-applied membrane, will have an influence on the fluid-applied membrane.

6.2 Relationship between ambient temperature and surface temperature of the fluid-applied membrane

The relationship between ambient temperature and surface temperature of fluid-applied membrane is depicted in Fig. 20 based on the result of an outdoor measurement. The figure shows a deviation of about 10^{o}C for the surface temperature of the fluid-applied membrane under the condition of the same ambient temperature. This is reasoned by the fact that the sunlight reaching the ground surface is blocked, refracted, and reflected due to the cloud or dust in the air so as to change the magnitude of sunlight heat.

6.3 Relationship between surface temperature of the moisture-proof (fluid-applied membrane) layer and interface temperature of concrete

The relationship between surface temperature of water-proof (fluid-applied membrane) layer and the interface temperature of the concrete is depicted in Fig. 21 based on the result of a laboratory measurement. This result was consistent regardless of the materials used for the water-proof layer (fluid-applied membrane), and it indicates that the heat conductivity of each material is almost the same irrespective of the physical properties of the materials. This result is obtained when adequate heat is supplied to the surface of the water-proof (fluid-applied membrane) layer.

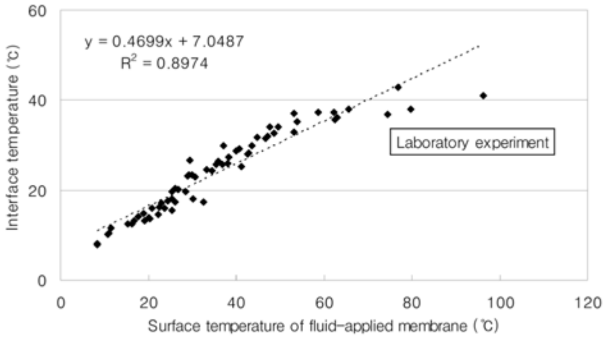

Fig. 21 Relationship between surface temperature of water-proof (fluid-applied membrane) layer and the interface temperature of the concrete.

6.4 Relationship between ambient temperature and water vapor pressure

The data for the comparison of water vapor pressure vs. ambient temperature are depicted in Fig. 22 based on an outdoor experiment. The range of measured temperature and measured water vapor pressure was about 11^{o}C and 0.2 N/mm^{2}, respectively. The result of this experimental measurement indicates that the ambient temperature and water vapor pressure exhibited values very similar to aforementioned theoretical values, and it is found that water vapor pressure of about 0.2 N/mm^{2} on the daily average is generated inside the concrete due to the ambient temperature.

6.5 Relationship between surface temperature and water vapor pressure

Figure 23 shows the relationship between surface temperature of the fluid-applied membrane and water vapor pressure. It can be seen that the correlation was rather low. Especially, the relationship was particularly low at low temperature. This is construed by the fact that it requires some time for the heat to reach the interface while the surface temperature results in a rapid increase in the water vapor pressure in the initial stage of the experiment. Thus, it is deemed that the inference of the change in water vapor pressure by the change in surface temperature is rather difficult.

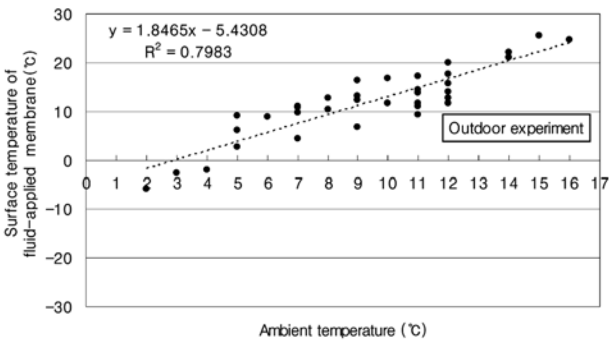

Fig. 20 Relationship between ambient temperature and surface temperature of fluid-applied membrane.

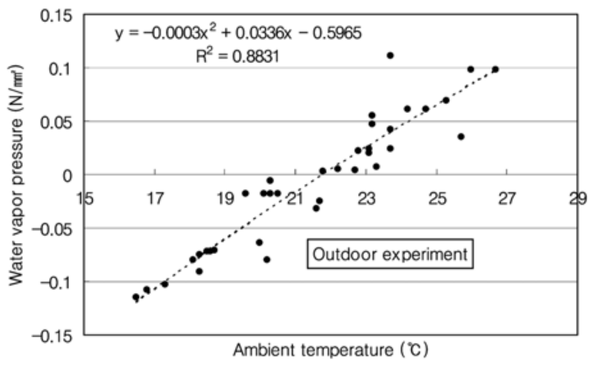

Fig. 22 Relationship between water vapor pressure vs. ambient temperature.

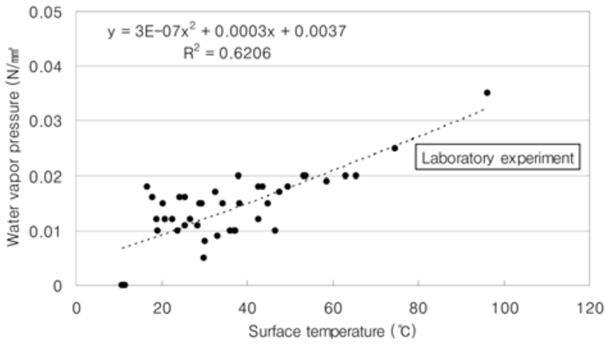

Fig. 23 Relationship between surface temperature of the fluid-applied membrane and water vapor pressure.

6.6 Relationship between interface temperature and water vapor pressure

The data for the comparison of water vapor pressure and the temperature at the interface between the concrete substrate and fluid-applied (water-proof) membrane is depicted in Fig. 24 based on an indoor experiment. The range of measured temperature change and measured water vapor change was about 35^{o}C and 0.03 N/mm^2, respectively. This is explained by the influence of the temperature generated at the interface between the concrete substrate and fluid-applied (water-proof) membrane on water vapor pressure, and the measured values are somewhat higher than aforementioned theoretical value. It is construed that a part of the heat supply installed to measure the water vapor pressure was inflowed to raise the water vapor pressure a little. However, the figure shows that the temperature at the interface between the concrete substrate and fluid-applied (water-proof) membrane is correlated closer to the change in water vapor pressure compared to the temperature inside the concrete and the surface temperature of the water-proof (fluid-applied membrane) layer.

7. Conclusions

This study measured the change in water vapor pressure occurring at the interface between the concrete and water-proof (fluid-applied membrane) layer in response to the change in temperature and aging (hardening) of the concrete, and the following conclusions are derived.

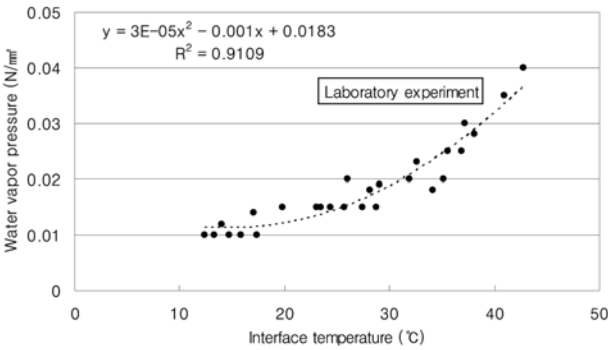

Fig. 24 Relationship between water vapor pressure and the temperature at the interface between the concrete structure and fluid-applied (water-proof) membrane.

1) The result of measuring the change in water vapor pressure in the fluid-applied membrane exposed to the air in response to the change in ambient temperature affirmed that they are correlated proportionally.

2) The result of measuring water vapor pressure in the setting of annual average temperature of 10^{o}C in Seoul based on a laboratory experiment revealed that the temperature at the interface between the concrete and the fluid-applied (water-proof) membrane layer raised up to about 40^{o}C and that the water pressure at the interface was simultaneously measured at about 0.03 N/mm^2.

3) When the temperature at the interface between the concrete and the fluid-applied (water-proof) membrane layer increased from 30^{o}C to 35^{o}C, about 0.01 N/mm^2 of water vapor pressure was observed. When the interface temperature increased from 35^{o}C to 40^{o}C, about 0.005 N/mm^2 of water vapor pressure was generated. Additionally, it was found that the water vapor pressure increased greatly (rapidly) around the interface temperature between 25~30^{o}C.

4) As the temperature at the interface between the concrete and the fluid-applied (water-proof) membrane layer increased, the water vapor pressure increased constantly. Additionally, the change in water vapor pressure was affected by the change in the interface temperature greater than by the change in surface temperature of the fluid-applied membrane layer.

References

1. Hwang, B. J., et al., “Fundamental Study of Mortar Property Using Discarded Wood Material,” *Journal of Architectural Institute of Korea*, Vol. 23, No. 2, 2003.

2. Oh, B. H., *Causes and Counter-Measures for the Types of Cracking and Water-Leaking of Concrete Structures*, Hanjin Construction Technology, 2003.

3. Lee, M. S., et al., “Evaluation of Water-Sealing of Concrete by Using the Theory of Water Absorptivity,” *Journal of Architectural Institute of Korea*, Vol. 17, No. 2, 2001.

4. Lee, M. S., “Investigation of Water-Absorption Performance of Cement-Mortar Heterogenous Composite,” *Journal of Architectural Institute of Korea*, Vol. 21, No. 11, 2005.

5. 小池迪夫, et al., “Water-Retaining Condition of Concrete by the Degree of Dryness Right after the Concrete Placement,” *Journal of Architectural Institute of Japan on Structure*, No. 412, 1990.

6. Korea Meteorological Administration, http://www.kma.go.kr, Highest and Lowest Daily Temperature by the Month, 2005.