EVALUATION OF PERFORMANCE OF WATER-RETENTIVE CONCRETE BLOCK PAVEMENTS

A. KARASAWA, K. TORIIMINAMI, N. EZUMI, K. KAMAYA

A. KARASAWA, Research & Development Center, TAIHEIYO CEMENT CORPORATION,
2-4-2, Osaku, Sakurashi, Chiba Prefecture, 285-8655, JAPAN
Tel: +81 43 498 3894 Fax: +81 43 498 3849 Email: akihiko_karasawa@taiheiyo-cement.co.jp
K. TORIIMINAMI, Research & Development Center, TAIHEIYO CEMENT CORPORATION
N. EZUMI, TAIHEIYO CEMENT CONCRETE PAVING BLOCK ASSOCIATION
K. KAMAYA, TAIHEIYO CEMENT CONCRETE PAVING BLOCK ASSOCIATION

SUMMARY

Japanese cities have rapidly become warmer in recent years, a phenomenon which is popularly called the "heat island" effect. While the average temperature of the Earth's surface has increased by 0.7ºC over the last century, the average temperature in Tokyo has increased by 3.0ºC, which is much higher than that in other major cities of the world. [1] The increase is particularly noticeable in summer and is accelerating each year to the point where it has become a matter of serious public concern. Against this backdrop, water-retentive pavement has begun to attract attention as a promising technology to alleviate this problem. The advantage of water-retentive concrete block pavement is that it can prevent the rise in temperature of the road surface through the removal of heat by the evaporation of moisture retained in pavement blocks; such water-retentive pavement has been installed at various sites including sideways, parks, and plazas, with a total area of over 200,000 square meters already installed (as of March 2006). With this background, the Japan Interlocking Block Pavement Engineering Association (JIPEA) published a quality performance standard and associated test methods for water-retentive concrete paving blocks in July 2005. [2]

However, as water-retentive concrete blocks have only a short history of development and installation, there are few empirical reports on their effectiveness in preventing the rise in temperature of the road surface. Therefore, the authors installed 15 types of water-retentive blocks that satisfy the quality performance standard and were produced by member manufacturers of the Taiheiyo Cement Concrete Paving Block Association (an industrial society comprised of Taiheiyo Cement and its user manufacturers) to measure the changes of various parameters in a real environment over time, including road surface temperature, amount of evaporation from road surface, and water content of cushion sand. This paper summarizes the analysis results of the study and describes the effects of "quality performance of water-retentive concrete blocks," "surface color of concrete blocks," and "existence of cushion sand and joint sand" on the road surface temperature.

1. QUALITY PERFORMANCE STANDARD FOR WATER-RETENTIVE CONCRETE BLOCKS

In July 2005, JIPEA established a quality performance standard and test methods for water-retentive concrete blocks aiming to encourage the use of water-retentive pavement. Table 1 lists some of the requirements extracted from the quality performance standard. As previously mentioned, water-retentive concrete blocks prevent the temperature of the road surface from rising by removing heat through evaporation of retained moisture. Therefore, the quality performance standard specifies two major properties for water-retentive concrete blocks: one is the water-retentive property to retain moisture within blocks and the other is the water-absorbing property to draw the moisture towards the top of the blocks. The water-retentive property is specified by the amount of water that can be retained in the water-holding test and water-retention capacity is calculated by Equation (1). The water-absorbing property is specified by the absorption height in the water-absorbing test, which is calculated by Equation (2). As the flexural strength for water-retentive blocks is categorized similarly to the case of standard interlocking blocks (5.0 N/mm^2 or higher) and permeable interlocking blocks (3.0 N/mm^2 or higher), water-retentive blocks may be used for the same applications as with these block products.

Table 1. Quality performance standard of water-retentive concrete blocks (excerpted in part)

Water retention	Water absorption	Flexural strength (N/mm^2)
$0.15 g/cm^3$ or more	Absorption height of 70% or more,in 30minutes	3.0 or more
		5.0 or more

For other specifications of the standard as well as the consequences and grounds of the study, refer to the paper of Yamamoto, "Discussions on Assessment and Quality Standards of Water-retaining Concrete Block."

$$\text{Water-retention capacity } (g/cm^3) = \frac{\text{Damp mass (g)} - \text{Absolute dry mass (g)}}{\text{Volume of water-retentive concrete block } (cm^3)} \quad \text{------------------------------} \quad (1)$$

$$\text{Absorption height } (\%) = \frac{\text{Absorption mass (g)} - \text{Absolute dry mass (g)}}{\text{Damp mass (g)} - \text{Absolute dry mass (g)}} \times 100 \quad \text{-----------------------} \quad (2)$$

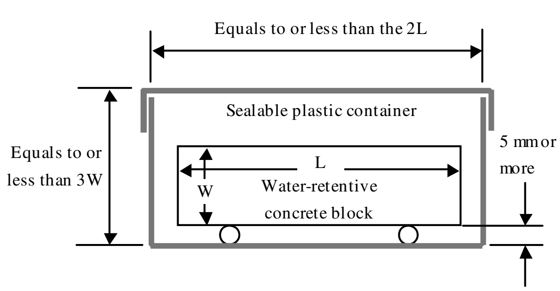

Figure 1. Schematic diagram of equipment for damping the blocks

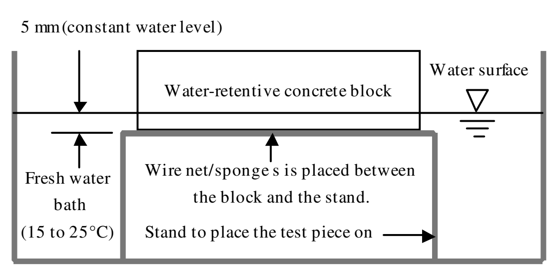

Figure 2. Schematic diagram of water absorption test

where:

Damp mass:
The mass resulting from the following series of processes: 1) immerse the block in clear water of 15 to 25ºC for 24 hours, 2) remove and put the block into a plastic container (shown in Figure 1) at a room temperature of 15 to 30ºC for 30 minutes for draining, 3) wipe any visible water film with a well wrung-out cloth, and then 4) immediately measure the weight.

Absolute dry mass:
The mass measured after first drying the block to a constant mass in a drying oven with temperature set at 105 ±5ºC and then cooling the block to room temperature.

Absorption mass:
The mass resulting from the following series of processes: 1) set the test piece in the water-absorbing test setup shown in Figure 2, 2) remove the test piece after waiting for 30 minutes, 3) drain the test piece until it stops dripping, 4) wipe any visible water film with a well wrung-out wet cloth, and then 4) immediately measure the weight.

2. FIELD TESTS TO VERIFY THE EFFECTIVENESS OF TEMPERATURE RISE SUPPRESSION

2.1 Outline of Experiment

Field tests were performed to verify the effects of "quality performance of water-retentive concrete blocks," "surface color of concrete blocks," and "existence of cushion sand and joint sand" on the road surface temperature. The experiment was conducted during mid-summer in Japan, for the one month period from August 10 to September 9, 2005, at the test site shown in Photo 1, and various measurements were continuously carried out. The experiment is outlined below.

Photo 1. Outdoor test site

2.1.1 Pavement type

Table 2 lists the quality performance parameters and geometries of the pavement surface materials subjected to the experiment. A total of 15 types of different water-retentive concrete blocks were used, all of which satisfied the previously noted quality performance standard. Among the 15 types, 11 were non-permeable and 4 were permeable. The permeable concrete blocks were the products from actual production lines and each block type was from a different manufacturer. The concept of how to provide water-retentive and -absorbing properties (e.g., use of water-retentive aggregate, percentage of air void, and adjustment of void diameter) is different for each type and so the resulting materials used, mix proportions, and surface colors are different. Standard interlocking blocks, permeable interlocking blocks, and dense grade asphalt were selected as the pavement materials for the experiment. For standard interlocking blocks, 12 different surface colors were used with the same mix proportion.

Table 2. Quality performance and physical parameters of the surface course materials

		Concrete block paving				Asphalt paving
Type of surface course material		Water-retentive concrete blocks (15 types)		Standard ILB (12 types)	Permeable ILB (1 type)	Dense-graded asphalt mixture (13) (1 type)
		Non-permeable (11 types)	Permeable (4 types)			
Para-meter	Water retention (g/cm^3)	0.153 to 0.267	0.158 to 0.222	0.098	0.101	Stamping: 50 (times) Air void: 3.8% Saturation: 77.0 (%) Stability: 10.5 (kN) Flow value: 29 (1/100 cm)
	Absorption height (%)	71 to 100	72 to 98	24	38	
	Flexural strength (N/mm^2) *1	3.52 to 5.51	3.96 to 5.04	8.75	5.15	
	Permeability coefficient (cm/s)	–	2.99 x 10^{-3} to 2.90 x 10^{-2}	–	1.03 x 10-1	
	Surface color	Various colors	Various colors	Various colors	Color of cement	
	Surface lightness (L*) *2	41.20 to 69.29	41.49 to 75.75	37.93 to 72.37	55.11	32.13
Size		Rectangular solid of 98 (W) x 198 (L) x 60 (T) mm, or 300 (W) x 300 (L) x 60 (T) mm		Rectangular solid of 98 (W) x 198 (L) x 60 (T) mm		–
Production method		Dry cast production with high vibration compaction				Produced in plant

*1: Indicates the strength at the start of the experiment.
*2: Indicates the color L of L*a*b*. Indicates it is dry as L*.

2.1.2 Pavement structure

Regarding the structure of pavement, a typical structure commonly used for sidewalk pavements in Japan was adopted [3], [4]. As shown in Figure 3, the structural cross section of all the concrete block pavements is the same from the cushion layer and below. The structural cross section of dense graded asphalt pavement is shown in Figure 4. The area of each pavement was set to 1 x 1 m square and heat insulating material of 10 cm width (styrofoam insulation) was used between adjacent pavements. Land sand (fineness modulus 2.61, coefficient of water absorption 1.73%, and fine grain content 1.34%) was used as the cushion material for concrete block pavements. The width of joint gaps was set to 3 mm and the joint gap was filled by silica sand (fineness modulus 1.94, coefficient of water absorption 0.25%). The stretcher bond pattern, which is typically used for sidewalk pavements, was used.

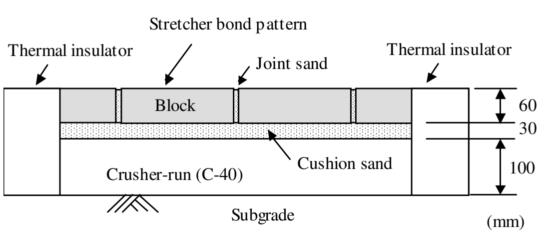

Figure 3. Structural cross section of concrete blocks – 1

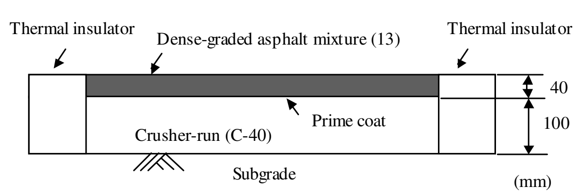

Figure 4. Structural cross section of concrete blocks – 2

2.1.3 Measurement items

In this experiment, changes over time of "road surface temperature," "amount of evaporation from the road surface," and "water content of cushion sand" was measured. For the measurement of road temperature, thermocouple elements were embedded at a depth of 5 mm below the road surface and the data was recorded at 1-hour intervals using a data logger. The amount of water evaporation was measured using a closed chamber type water evaporation measuring device. Water content of cushion sand was measured by inserting a probe of a soil water content measuring system into the cushion sand layer through a hole of 20 mm diameter drilled from the surface to the bottom of one of the blocks. Whenever measurement was not made, the hole was closed by a rubber plug. The measurement was made at a block near the center of the 1 x 1 m area.

2.2 Experimental Results and Discussion

The following sections describe and discuss the test results of the experiment conducted under three series of weather conditions: 1) total amount of rainfall of 14 mm from 02:00 to 08:00 on August 13, 2005, 2) clear skies on August 14 (the next day) with the highest temperature of 33.8°C recorded for the month at 14:00, and 3) clear skies for the next 8 days until August 21.

2.2.1 Effect of concrete block surface color on road surface temperature

Figure 5 shows the relationship between the block surface lightness and road surface temperature of the standard interlocking block measured on the day after rain (at 14:00 on August 14). From past study results, it is known that the heat balance on the ground surface satisfies Equation (3).[5]

$$R_n = S\,(1-\alpha) + L\downarrow - L\uparrow = H + \ell E + G \qquad (3)$$

where:

R_n: Net amount of radiation heat received by the ground surface

S: Solar radiation (direct and reflected components)
α: Reflection factor for solar radiation (albedo)
L↓: Atmospheric radiation
L↑: Earth radiation
H: Sensible heat transfer by convection
ℓE: Latent heat transfer by vaporization
G: Heat transfer within the ground by conduction

Figure 5 shows that there is a correlation, i.e., the higher the block surface lightness, the lower the road surface temperature of the standard interlocking block pavement; the road surface temperature of white blocks is lower than that of black blocks by 5.1°C. This is because parameter α (reflection factor for solar radiation) is large when the block surface lightness in Equation (3) is high.

As the surface colors of concrete blocks used for the experiment are all different, the effect of different surface colors cannot be ignored in comparing the road surface temperatures. So, except for the dense graded asphalt pavement, correction was applied to the surface temperature of concrete block pavements so that it is referenced to the block surface lightness of 64 using a multiple regression equation with surface lightness and air temperature set as the explanatory variables. The road surface temperatures of concrete block pavements indicated in the following paragraphs are the values after correction to the lightness of 64. Note that the surface lightness reference of 64 was selected in order to match it with the surface lightness of water-retentive asphalt pavement (to fill water-retentive cement grouting), which is about 64.

2.2.2 Effectiveness of temperature rise suppression by water-retentive concrete block pavement (natural water supply system)

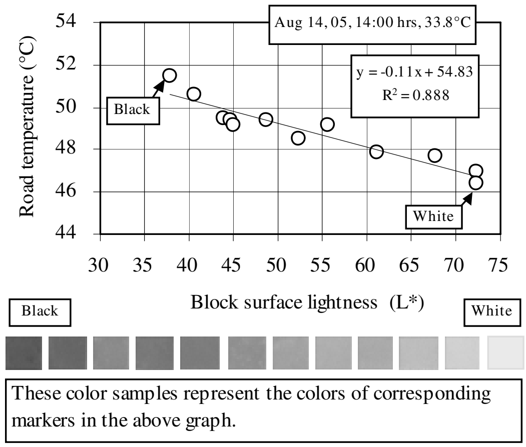

Figure 5. Relation between the block surface lightness and the road temperature of standard ILB

Figure 6 compares the road surface temperatures of different pavements for the day after rain (at 14:00 on August 14, at 33.8ºC air temperature) and 8 days after the rain (at 12:00 on August 21, at 31.9ºC). While the road surface temperature of the dense grade asphalt pavement was increased by 56.1ºC the day after the rain, the road surface temperature increase for the 15 types of water-retentive concrete block pavements was in the range of 39.5 – 48.9ºC. In other words, water-retentive concrete block pavements successfully suppressed the temperature rise by 7.2 to 16.6ºC compared to the dense grade asphalt pavement under the weather conditions of the day after rain and at 33.8ºC air temperature. It was also noted that water-retentive concrete block pavement is more effective in suppressing the rise in surface temperature than standard interlocking blocks and permeable interlocking blocks.

Figure 7 shows the relation between the amount of water evaporation from the surface and the road surface temperature of different pavements measured on the day after water was sprayed over the pavements by using a sprinkler (water was sprayed from 08:00 to 09:00 on August 29 at a rate of 30 mm/hour and measurements were made at 12:00 on August 30, at the condition of 30.3ºC air temperature and 66% RH, and wind speed of 3 m/s). The amount of water evaporation from the 15 types of water-retentive pavements was generally higher than that of standard interlocking block pavement or permeable interlocking block pavement and the trend was that the greater the amount of water evaporation from the pavement, the lower the road surface temperature. Many past studies have shown that the parameter lE (latent heat transfer by vaporization) in Equation (3) plays a major role in suppressing the temperature rise of a road surface when water-retentive pavement is used, the present experiment confirmed this finding. While the degree of correlation is not so high in Figure 7, it is affected by the fact that the 15 types of water-retentive concrete blocks had differing thermal conductivities and thermal capacities, thus giving different values of G (heat transfer within the ground by conduction) in Equation (3).

Secondly, Figure 6 indicates that water-retentive concrete block pavements successfully suppressed the rise in temperature by 1.9 to 5.8ºC compared to the dense grade asphalt pavement even eight days after the rain, although by a lesser amount than the next day after rain. This is assumed to be because the water content in the pavement body reduces over time, thus also reducing the amount of evaporation from the road surface. Focusing on the relation between road surface temperatures of the next day and 8 days after the rain regarding water-retentive concrete block pavements, the pavements having lower surface temperature on the next day also exhibited lower temperatures for

8 days after the rain. In other words, the water-retentive concrete blocks that are more effective in suppressing the rise in temperature on the day after rain are likely to maintain the effect for a longer period of time.

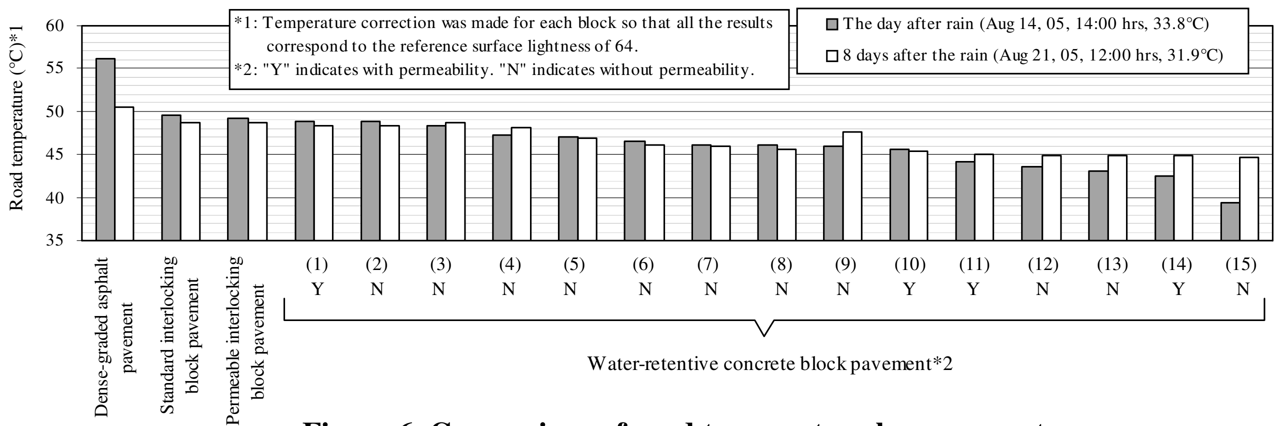

Figure 6. Comparison of road temperature by pavement

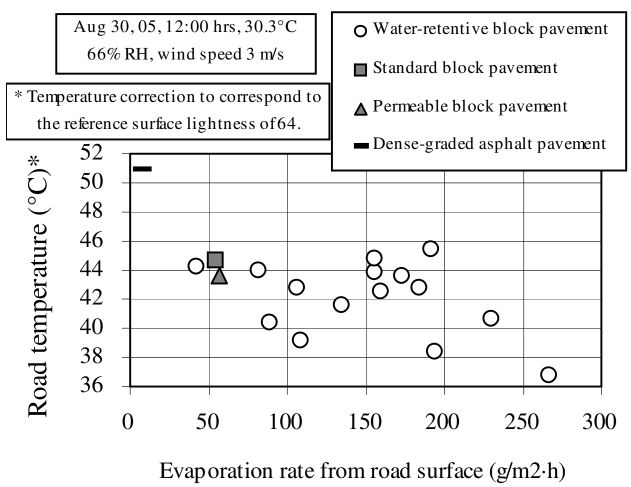

Figure 7. Relation between evaporation from the surface and road surface temperature on the day after spraying

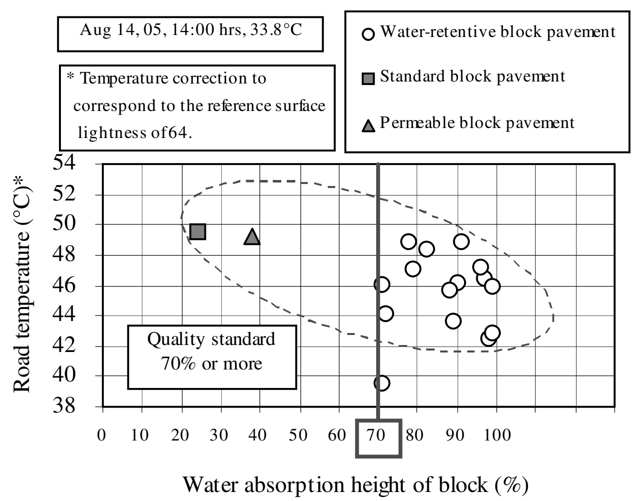

Figure 8. Relation between absorption height and road surface temperature on the day after rain

2.2.3 Effect of quality performance of water-retentive concrete blocks on road surface temperature

(1) Effect of water content and absorption height

Figure 8 shows the relation between absorption height and road surface temperature of the blocks measured on the day after rain (at 14:00 on August 14). These plots generally show that water-retentive concrete blocks whose absorption height is higher have a lower road surface temperature. This is probably because water-retentive concrete blocks whose absorption height is higher can evaporate more moisture from the road surface and thus can effectively remove heat and prevent temperature rise. Figure 9 is a histogram of pore size distribution measured by mercury intrusion porosimeter for the type #15 water-retentive concrete block in Figure 6 and a standard interlocking block. Compared to the standard interlocking block, this water-retentive concrete block has a large number of pores of diameter in the range of 0.003 μm – 400 μm; these pores are thought to contribute to the high evaporation rate through capillary action.

Figure 10 shows the relation between the water content of blocks and road surface temperature on the day after rain. These plots generally indicate that water-retentive blocks whose water content is higher have a lower road surface temperature. This is probably because water-retentive concrete blocks with higher water content have higher specific heat leading to a smaller value of G (heat transfer within the ground by conduction) in Equation (3), in addition to their high absorption height by which more moisture evaporates from the road surface. However, it should also be noted that there are some water-retentive concrete block types that showed a high road surface temperature even though their water content was more than 0.20 g/cm^3, as indicated outside of the dashed area in Figure 10. This could be due to some thermal characteristics of water-retentive material contained in the blocks, so further analysis is required.

(2) Effect of permeability

As shown in Figure 6, there is no apparent correlation between the permeability of water-retentive concrete blocks and road surface temperature. Also, among water-retentive concrete blocks that are permeable, no correlation is observed between the degree of permeability (permeability coefficient) and road surface temperature. This is probably because the pore diameter that contributes to permeability is different from that which contributes to evaporation by capillary action.

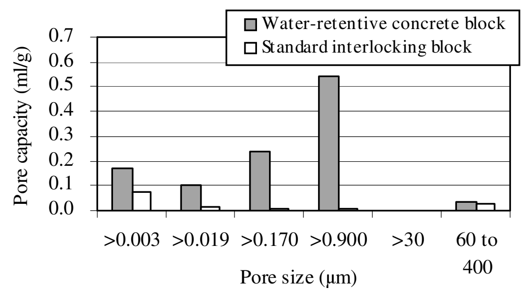

Figure 9. Histogram of pore size distribution of the blocks

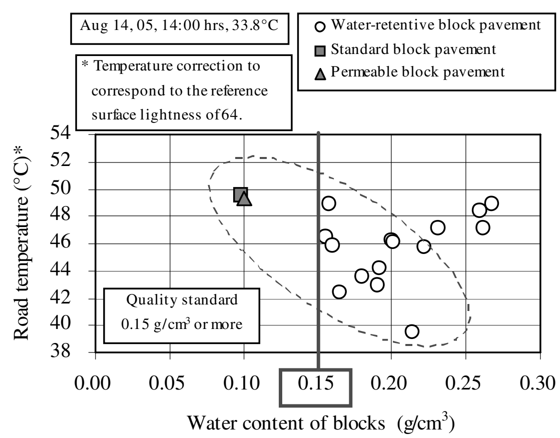

Figure 10. Relation between water content of blocks and road surface temperature on the day after rain

2.2.4 Effect of cushion sand and joint sand on road surface temperature

(1) Effect of cushion sand

Figure 11 shows changes over time of cushion sand water content under sunshine after water was sprayed over the pavements by using a sprinkler at a rate of 30 mm per hour from 08:00 to 09:00 on August 29. The water-retentive concrete block pavement in the figure is that of the type #15 in Figure 6. While the water content of cushion sand decreased over time in both water-retentive and standard interlocking concrete block pavements, the rate of decrease was higher in the water-retentive block pavement. In addition, it was confirmed that the rate of decrease in cushion sand water content was generally higher in the blocks that had a higher rate of evaporation from the road surface.

From the above results, the water content of cushion sand is thought to contribute to the sustainability of the suppression of temperature rise of the road surface of water-retentive concrete block pavements.

(2) Effect of joint sand

Using the concrete block pavement of type #8 in Figure 6, two different installations were made, i.e., the gap was filled with gap sand for one installation, and not for the other. The resulting road surface temperature is compared in Figure 12. There was no difference in road surface temperature between the installations with and without joint sand for both the day after rain (at 14:00 on August 14, at 33.8ºC air temperature) and 8 days after rain (at 12:00 on August 21, at 31.9ºC). This is probably because the total area of the joint gaps (3 mm width) on the road surface accounts for only 4% of the area of water-retentive concrete blocks (in a rectangular shape of 98 mm W x 198 mm D) and thus the effect of water content and water-absorbing property of joint sand on the road surface temperature is relatively small.

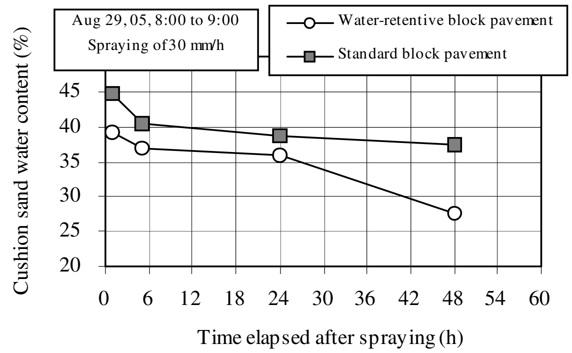

Figure 11 Changes over time of cushion sand water content after spraying

Nevertheless, joint sand is an important paving material for water-retentive concrete block pavements as well as for other concrete block pavements because it ensures secure engagement between blocks and protects the blocks from damage by providing sufficient separation between them.

3. CONCLUSIONS

The following findings were obtained from the field tests conducted to evaluate the effects of suppressing the rise in temperature of the road surface:

1) The higher the block surface lightness (L*), the lower the road surface temperature of concrete block pavements.
2) Using 15 types of different blocks that satisfy the quality performance standard for water-retentive blocks, the target pavements successfully suppressed the temperature rise by 7.2ºC to 16.6ºC compared to the dense grade asphalt pavement under the weather conditions of the day after rain and at 33.8ºC air temperature. (Correction was made for each block so that all the results correspond to the reference surface lightness of 64.)
   It was generally found that water-retentive block pavements having higher evaporation rate were lower in road surface temperature.
3) Water-retentive concrete blocks that were more effective in suppressing temperature rise on the day after rain were likely to maintain the effect for a longer period of time.
4) Water-retentive blocks having higher absorption height showed a lower road surface

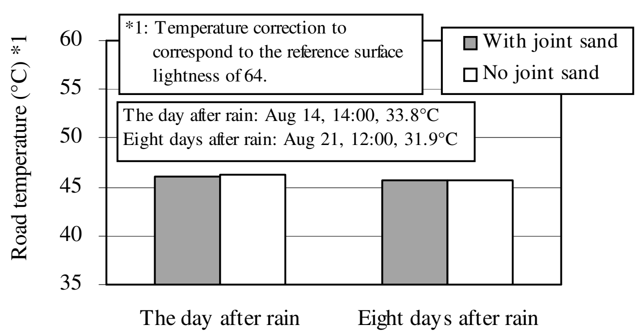

Figure 12 Comparison of road temperature with or without joint sand

temperature.

5) Water-retentive block pavements having higher water content showed a lower road surface temperature. However, some blocks showed a high road surface temperature in spite of their high water content. This could be due to some thermal characteristics of the water-retentive materials contained in these blocks.

6) No correlation was found between the permeability of water-retentive concrete blocks and road surface temperature. Also, among water-retentive concrete blocks that were permeable, there was no correlation between the degree of permeability (magnitude of permeability coefficient) and road surface temperature.

7) The water content of cushion sand may contribute to the sustainability of the suppression of rise in temperature of the road surface of water-retentive concrete block pavements.

8) With water-retentive concrete block pavements having joint gaps of 3 mm width, no difference was observed in the road surface temperatures between the installations with and without gap sand.

4. FUTURE ISSUES

This experiment helped to identify some essential conditions required for establishing water-retentive concrete block pavement that can efficiently suppress the rise in temperature of road surfaces. As colorful landscape design is possible with water-retentive concrete block pavements, they are mainly used in areas frequented by many people including sideways, parks, and plazas, and such applications are expected to grow in the future. Past studies have shown that water-retentive asphalt pavements with water-retentive cement grouting effectively reduce the thermal radiation load on the human body, in addition to suppressing the temperature rise of the road surface for alleviating the heat island effect. [6] This study on the effect of thermal loads on humans should be evaluated also in the field of water-retentive concrete block pavements, with reference to the results of the present study.

5. REFERENCES

1. Japanese Climate in the 20th Century, May 2002, The Meteorological Agency.
2. Quality Performance Standard for Concrete Blocks for Water-retentive Pavement, July 2005, Japan Interlocking Block Pavement Engineering Association.
3. Manual for Design and Construction of Asphalt Pavement, July 1997, Japan Road Association.
4. Design and Construction Guidelines for Interlocking Block Pavement, July 2000, Japan Interlocking Block Pavement Engineering Association.
5. Masamitsu Arita, Hiroshi Okamoto, Toshio Koike, Masanori Nakai, Takehiko Fukushima, Tsuyoshi Fujino, January 2000, Atmosphere Environment, Tokyo Denki University Press.
6. Tsuyoshi Fujino, Hiroo Nagashima, Tadashi Suganuma, Tsuyoshi Tsujii, March 2005, Application of Water-retentive Pavements to Theme Parks and Effect of Heat Load Reduction, Pavement, Vol. 40, No. 3.