DISCUSSIONS ON ASSESSMENT AND QUALITY STANDARDS OF WATER-RETAINING CONCRETE BLOCK

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SUMMARY

In large cities in Japan, a phenomenon is growing where the atmospheric temperature in the city becomes higher compared to suburban areas. One countermeasure for it is the introduction of pavements to control the rise of road surface temperature. In interlocking block pavement, "water-retaining concrete block pavement," controls the rise of road surface temperature with the heat of vaporization produced when water evaporates. It has been developed and is being constructed in walkways, etc.

Japan Interlocking Block Pavement Engineering Association (JIPEA) is promoting newly established quality standards of water-retaining concrete block to help propagate this technology.

This paper describes the current situation of pavements that control the rise of road surface temperature in Japan, the method of performance evaluation of water-retaining concrete block, and the study results on quality standards, etc.

1. INTRODUCTION

In large cities in Japan, the average annual atmospheric temperature rose by approximately 2 to 3°C during the past 100 years (Tokyo, 2004). This is faster compared to an average rise of atmospheric temperature of approximately 0.6°C for the entire planet. In Tokyo in particular, the number of days where the maximum atmospheric temperature in summer exceeds 30°C and the number of nights when the minimum atmospheric temperature during nighttime is no lower than 25°C shows an increase, evidencing a progress of deterioration of the thermal environment.

In asphalt concrete pavements in Japan, the maximum road surface temperature rises up to approximately 60°C in the daytime under fine summer weather. Moreover, at night long-wave radiation heats the atmosphere released from asphalt concrete pavements accumulated during the daytime (Murai et al., 1998). For that reason, high temperatures on paved road surfaces constitutes one of the causes of warming in large cities. This is particularly important in Japan where the area paved with asphalt is approximately 10 to 20% of the total surface area.

Under such circumstances, the introduction of pavements for controlling the rise of road surface temperatures is being promoted in Japan. The intent is to improve the thermal environments in pedestrian areas and sidewalks in large cities. In interlocking block (ILB) pavement, "water-retaining concrete block pavement" controls the rise of road surface temperatures with the heat of vaporization produced when water evaporates by holding water in the pavement.

Figure 1 indicates applications of ILB pavement in Japan. ILB pavement has realized a downward trend after a peak of approximately 8.5 million m^2 in 1996 to approximately 4.3 million m^2 in 2004. Approximately 80% is in plazas and walkways.

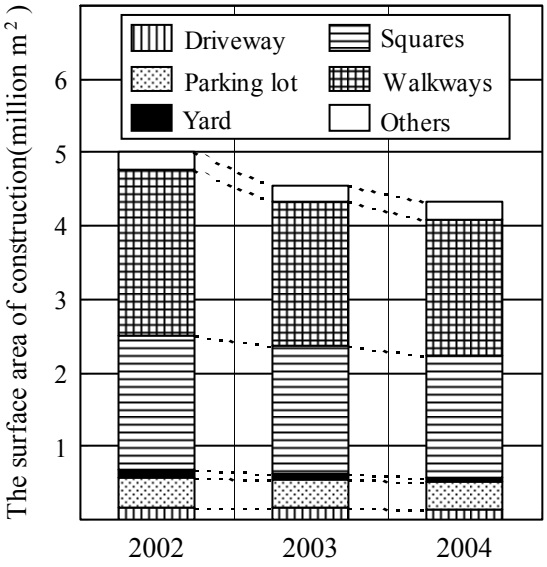


Fig. 1 Achievements of construction of ILB pavement in Japan

It is believed that in the future an increase in the surface area of water-retaining block pavement may contribute to improvement of thermal environments for pedestrians, etc. and control warming during summer, enabling an increase in ILB pavement.

From that point of view, JIPEA installed a "Committee for Studying Quality Standards of Water-retaining Block" composed of representatives of the industrial, administrative and academic circles, with a view to promoting water-retaining block pavement, and establishing quality standards by studying required performance, methods of performance evaluation and standard values.

This paper describes the current situation of pavement controlling the rise of road surface temperature in Japan, methods of performance evaluation of water-retaining block, and the results of study of quality standards, etc.

2. CURRENT SITUATION OF PAVEMENT CONTROLLING THE RISE OF ROAD SURFACE TEMPERATURE IN JAPAN

Pavements controlling the rise of road surface temperature in Japan include "water-retaining pavement" which controls the rise of road surface temperature with the heat of vaporization produced when water evaporates. The pavement holds water in it and the "solar radiation reflective pavement" controls the rise of road surface temperature by reflecting the near infrared rays with high efficiency to prevent accumulation of heat in the pavement.

As the water-retaining pavement, there are such types as (a) "Asphalt concrete based water-retaining pavement" realized by filling air voids of porous asphalt concrete with a water-retaining material, (b) "Cement concrete based water-retaining pavement" prepared by mixing or filling a water-retaining material into porous concrete, (c) "Block based water-retaining pavement" using water-retaining block.

The application of water-retaining pavement in Japan is mostly represented by asphalt with approximately 310,000 m^2 as of the end of March, 2006. Figure 2 indicates a conceptual drawing of asphalt concrete based water-retaining pavement.

As solar radiation reflective pavement, there are such types as (a) "Coated type" made by either spraying or coating a solar radiation reflective paint on the surface of the pavement, (b) "Filled type" prepared by filling the surface of the pavement with a solar radiation reflective material, and (c)

"Mixture type" realized by mixing a solar radiation reflective material into the mixture for surface layer. Most applications are the coated type with approximately 900,000 m^2 as of the end of March, 2005. Figure 3 indicates a conceptual drawing of coated type solar radiation reflective pavement.

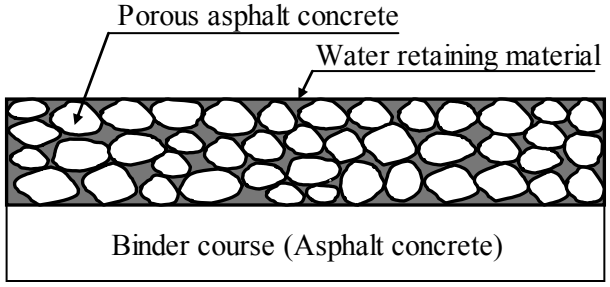


Figure 2. Asphalt concrete based water-retaining pavement

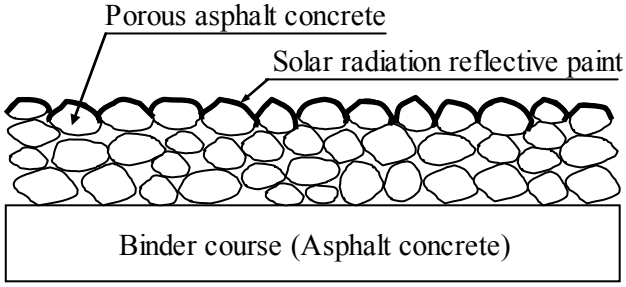


Figure 3. Coated type solar radiation reflective pavement

3. CHARACTERISTICS OF WATER-RETAINING BLOCK PAVEMENT

Water-retaining block pavement, which uses concrete block having a water retaining function in the surface layer, has a mechanism of absorbing and holding water, during rainy weather or sprinkling of water. It evaporates the water content from the surface under fine weather to control the rise of road surface temperature with the heat of vaporization of the water, as shown in Figure 4. The water retaining function is often secured by forming minute, continuous air voids.

Water-retaining block pavement has the possibility of holding a larger water capacity per unit volume, compared with asphalt concrete based water-retaining pavement. Therefore, this could help maintain reasonable road surface temperature and control its rise, as well as offer excellent durability and landscape appeal.

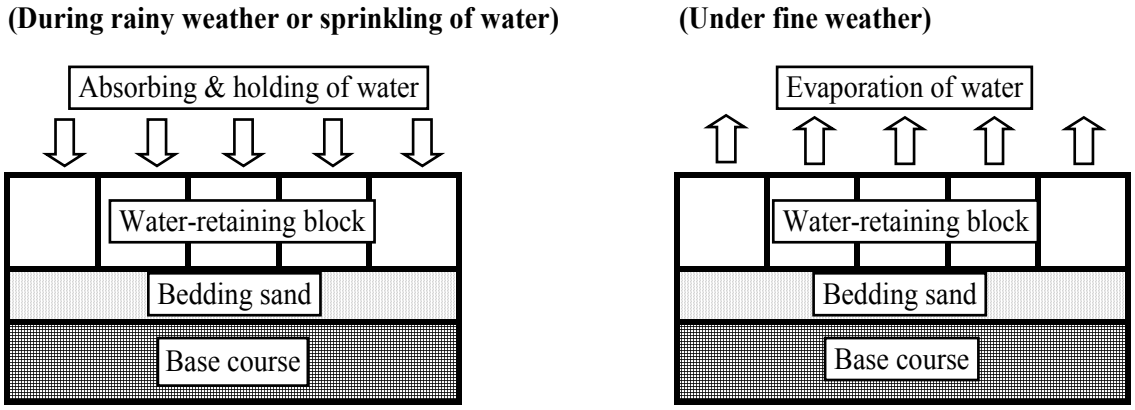


Figure 4. Water-retaining block pavement

4. PERFORMANCE EVALUATION OF WATER-RETAINING BLOCK

4.1 Required performance for water-retaining block

In order for water-retaining block pavement to road surface temperature, it needs rapid absorption and holding water in the water-retaining block body, plus efficient evaporation of the retained water from the surface of the block. Therefore, water-retaining block should absorb and hold water and efficiently

feed retained water to the surface. We studied methods to evaluate the performance of absorbing and holding water and a method to evaluate the performance of efficiently feeding the retained water to the surface.

4.2 Method of evaluation for water-retaining block

4.2.1 Water retaining test

Water retaining test evaluates the performance of water absorption and holding by water-retaining block. A water retaining test determines the water capacity per unit volume where a water-retaining block is immersed in water for 24 hours. The water capacity is calculated by formula (1).

$$\text{Water capacity (kg/m}^3\text{)} = \frac{\text{Wet mass of specimen (kg) - Dry mass of specimen (kg)}}{\text{Volume of specimen (m}^3\text{)}} \quad (1)$$

where,

Wet mass: Mass of the specimen measured immediately after the specimen absorbs water for 24 hours a temperature of 15 to 25°C in an apparatus shown in Figure 5. The specimen is cured for prescribed time in a chamber at a temperature of 15 to 30°C, and the water film on the surface of the specimen is wiped with a piece of wrung wet waste cloth.

Dry mass: Mass of the specimen measured after the specimen is dried up to a constant mass in a dryer set at a temperature of 105 ±5°C, and cooled to room temperature.

Volume: Volume of the specimen is calculated by measuring the thickness of the specimen at 3 points and the width and length at 2 points, by using slide calipers capable of measuring with an accuracy of at least 0.1 mm, determining the mean value of the respective measured values and multiplying the respective mean values by one another.

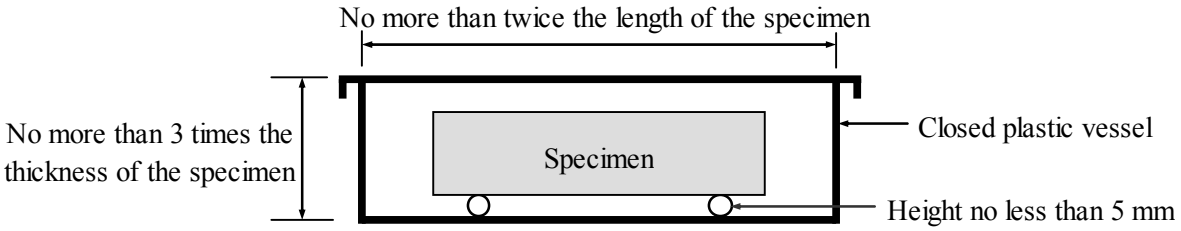


Figure 5. Schematic chart of an apparatus for producing a wet state

Because the wet mass of the specimen was expected to vary depending on the curing time in the apparatus as shown in Figure 5, a study was made on optimal curing time.

Figure 6 indicates the relationship between curing time and water capacity after 4 product specimens which absorbed water for 24 hours were installed in an apparatus as shown in Figure 5. The water capacity showed a tendency of becoming about

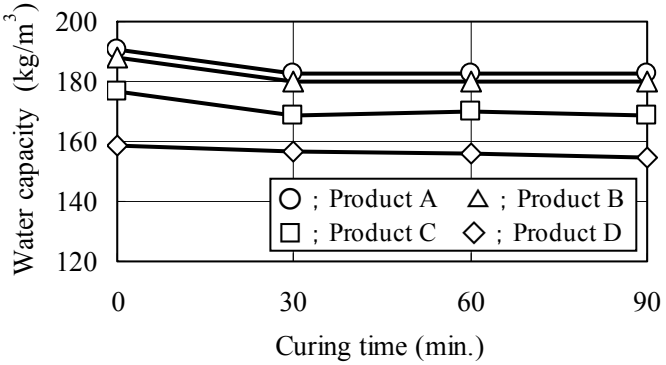


Figure 6. Relationship between curing time and water capacity

constant with no less than 30 minutes of curing. From this result, it was judged that 30 minutes is proper as curing time of the specimen.

4.2.2 Water absorption test

Water absorption test has been devised for the purpose of evaluating the performance of efficiently feeding held water to the surface through water-retaining block. A water absorption test consists of determining the suction height of water. This is done by dipping a dry water-retaining block in water for prescribed time at a depth of 5mm from the bottom face, as shown in Figure 7. The suction height is calculated by formula (2), and rounded to an integer.

$$\text{Suction height (\%)} = \frac{\text{Sucked mass of specimen (kg) - Dry mass of specimen (kg)}}{\text{Wet mass of specimen (kg) - Dry mass of specimen (kg)}} \times 100 \qquad (2)$$

where,

Sucked mass: Mass of the specimen after a dry water-retaining block is dipped in water for prescribed time at a depth of 5 mm from the bottom face.

Dry mass: Same as formula (1).

Wet mass: Same as formula (1), (curing time for dripping excess water of the specimen: 30 minutes).

Because the suction mass of the specimen was expected to vary depending on the dipping time in water of the specimen, a study was made on optimal dipping time. Figure 8 indicates the relationship between dipping time and suction height of the specimen on 4 different types of product. The suction height showed a tendency of becoming about constant with a dipping time of about 30 minutes.

From this result, it was judged that 30 minutes is proper as dipping time in water.

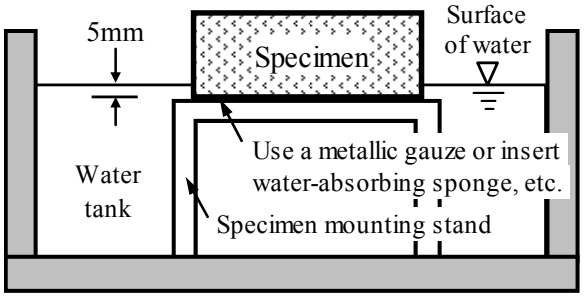


Figure 7. Schematic chart of water absorption test apparatus

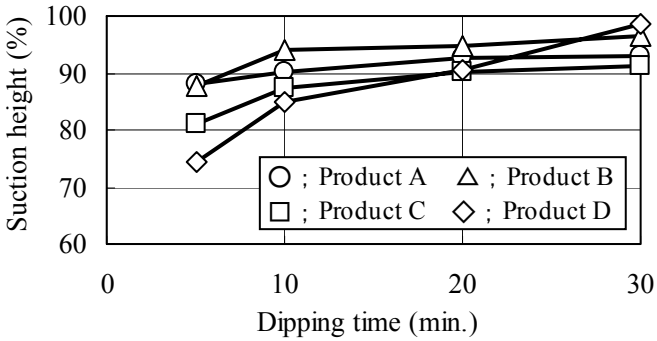


Figure 8. Relationship between dipping time and suction height

4.3 Results of evaluation of water-retaining block

4.3.1 Water capacity

The evaluation of the water capacity was implemented on water-retaining blocks of 18 different manufactures in Japan. The test methods used were those just described. The curing time of the specimen in the apparatus indicated in Figure 5 was set for 30 minutes. In addition, evaluation was made also on ordinary block pavers from 17 different manufactures in Japan for the sake of comparison.

Figure 9 indicates the measured results of water capacity of water-retaining blocks, while Figure 10 shows the measured results of water capacity of ordinary blocks. As water-retaining blocks, products

with a water capacity of 175 to 200 kg/m^3 were the largest in number. About 70% of the total number was represented by products with a water capacity no less than 150 kg/m^3. On the other hand, as ordinary blocks, products with a water capacity of 75 to 100 kg/m^3 and 100 to 125 kg/m^3 was the largest in number, and all products showed a water capacity no more than 150 kg/m^3.

From those facts, it seems appropriate to use 150 kg/m^3 as border value, when distinguishing between water-retaining blocks and ordinary blocks by water capacity.

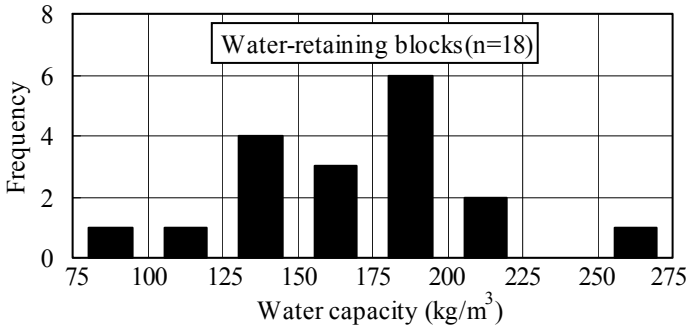


Figure 9. Measured results of water capacity of water-retaining blocks

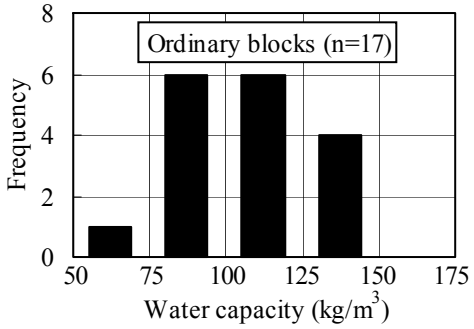


Figure 10. Measured results of water capacity of ordinary blocks

4.3.2 Suction height

The evaluation of the suction height was implemented on water-retaining blocks of 15 different manufactures in Japan. The test method was the same as that of water absorption test previously described. The dipping time of the specimen was set for 30 minutes. In addition, evaluation was made also on ordinary blocks of 17 different manufactures in Japan for the sake of comparison.

Figure 11 indicates the measured results of suction height of water-retaining blocks. Figure 12 shows the measured results of suction height of ordinary blocks. As water-retaining blocks, products with a suction height of 90 to 100% was the largest in number, and about 70% of the total number was represented by products with a suction height no less than 70%. On the other hand, as ordinary blocks, products with a suction height of 30 to 40% was the largest in number, and about 90% of the total products showed a suction height under 70%.

From those facts, it seems appropriate to regard the value of 70% as a border, when distinguishing between water-retaining blocks and ordinary blocks by suction height.

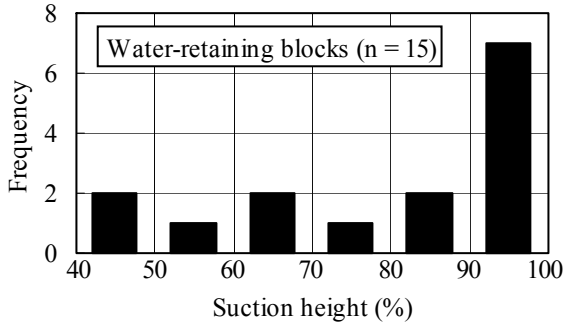


Figure 11. Measured results of suction height of water-retaining blocks

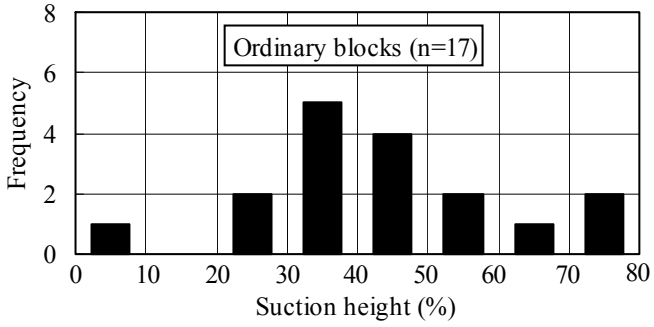


Figure 12. Measured results of suction height of ordinary blocks

4.4 Verification of road surface temperature rise controlling effects of water-retaining block

4.4.1 Indoor irradiation test

To evaluate the road surface temperature rise controlling effects of water-retaining block indoors, measurement was made of the surface temperature of the specimen and the amount of evaporation of water, by irradiating the specimen kept in wet condition by the method indicated in the water retaining test described earlier, by means of a beam lamp simulating solar light. The outline and an example of specifications of the irradiation test apparatus are as shown in Figure 13 and on Table 1.

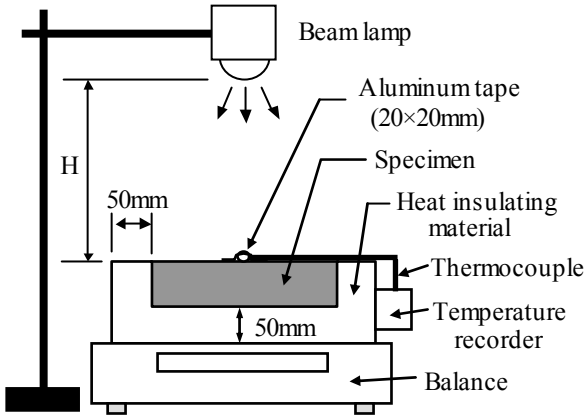


Figure 13. Outline of irradiation test apparatus

Table 1. Example of specifications of irradiation test apparatus

Item	Example of specifications
Beam lamp	Diffusion type; Beam angle 30°; BRF110V150W
Thermocouple	Resolution 0.1°C
Temperature recorder	Accuracy ±1°C
Balance	Minimum indication 0.1g; Weighing capacity 5,000g or over
Heat insulating material	Foaming polystyrol

Three different types of specimen were prepared, i.e. water-retaining block, ordinary block and dense grade asphalt concrete, and the dimensions of the specimens were set for 200 x 100 x 60 mm. On the water-retaining block, measurements were made on 12 different types of specimens with different water capacities and brightness.

The height H of the beam lamp from the top face of the specimen was set at 250 mm at which the surface temperature of the specimen of dense grade asphalt concrete comes to approximately 60°C in 4 hours, after the start of irradiation with the beam lamp. The measurement of surface temperature was made by covering 4 side faces and the bottom face of the specimen in wet state with a 50 mm-thick insulating material, and by fixing a thermocouple at the center on the top face of the specimen by means of aluminum tape (20 x 20 mm). The measurement of the amount of evaporation of water was made by placing the specimen, etc. on a balance and measuring the mass every 30 minutes after (the start of) irradiation of the lamp. The ambient temperature during the test was set for approximately 20°C, and the ambient humidity was set for approximately 60%.

Figure 14 shows an example of relationship between the irradiation time of beam lamp and the surface temperature, while Figure 15 indicates an example of relationship between the irradiation time of beam lamp and the amount of evaporation of water (Taiheiyo cement concrete paving block association, 2005). The water capacity of the water-retaining block is no less than 150 kg/m^3, and the suction height is no less than 70%. The water-retaining block indicated a tendency of being better capable of controlling the rise of surface temperature, with a larger amount of evaporation of water, compared with the dense grade asphalt concrete and the ordinary block.

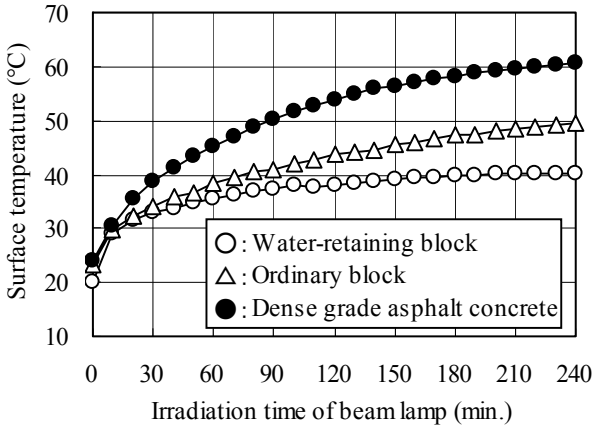


Figure 14. Relationship between irradiation time of beam lamp and surface temperature

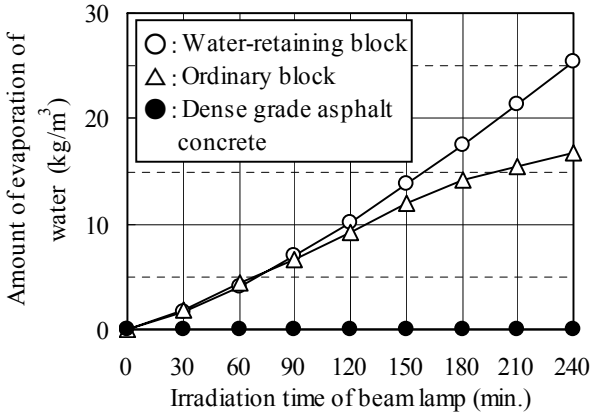


Figure 15. Relationship between irradiation time of beam lamp and amount of evaporation of water

Moreover, Figure 16 indicates the relationship between the water capacity of the specimens and the surface temperature after 4 hours of irradiation by the lamp. The relationship between the surface temperature and the water capacity showed that the larger the water capacity, the lower the surface temperature, although there is some dispersion in that relationship. Especially, with water-retaining block with a water capacity of 150 kg/m^3 or greater, the surface temperature was conspicuous compared with the dense grade asphalt concrete and the ordinary block.

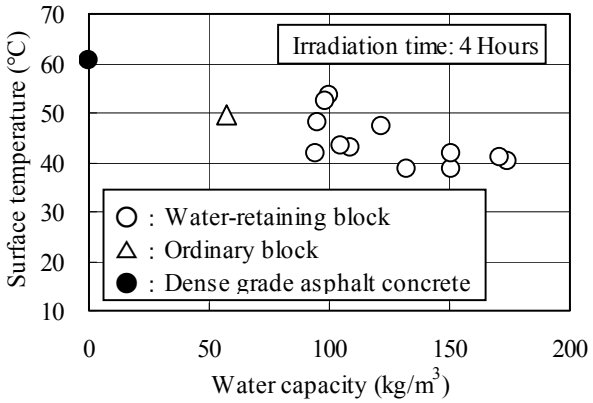


Figure 16. Relationship between water capacity and surface temperature

4.4.2 Measurement of road surface temperature of actual pavement

To verify the road surface temperature rise controlling effect of water-retaining block pavement in outdoors, we constructed pavement of 1 m^2 each by using the types of material indicated on Table 2, and measured the road surface temperature. The measurement of road surface temperature was made by drilling a hole with a diameter of approximately 2 mm and a depth of approximately 5 mm in the pavement, and installing a thermocouple there. The section of the pavement is as shown in Figure 17.

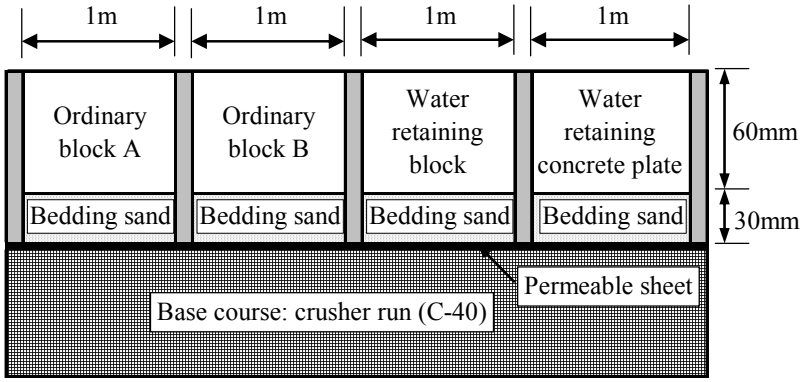


Figure 17. Section of pavement

Table 2. Specimen characteristics

Type	Water capacity (kg/m^3)	Suction height (%)
Ordinary block A	84	42
Ordinary block B	26	43
Water-retaining block	182	95
Water-retaining concrete plate	119	78
Dense grade asphalt concrete	0	0

Figure 18 shows the results of measurement of temperature in the case of fine weather days consecutively after a precipitation of approximately 167 mm during a period of 28 hours. The water-retaining block pavement showed a tendency of a maximum road surface temperature of about 10°C lower compared with dense graded asphalt concrete, and also lower than that of the ordinary blocks A, B and the water-retaining concrete plate. Furthermore, the water capacity of the water-retaining block was 150 kg/m^3 or over, and the suction height was no less than 70%, thus showing the highest value in both water capacity and suction height among the pavement materials submitted to the measurement.

From those facts, it was assumed that the road surface temperature rise controlling effects due to absorption and holding of water become superior as the water capacity and the suction height increase.

From the results of the road surface temperature rise controlling effects described above, it can be expected that the water-retaining block has ability of to control road surface temperature rise because it has a water retaining capacity and suction height at no lower than a certain level.

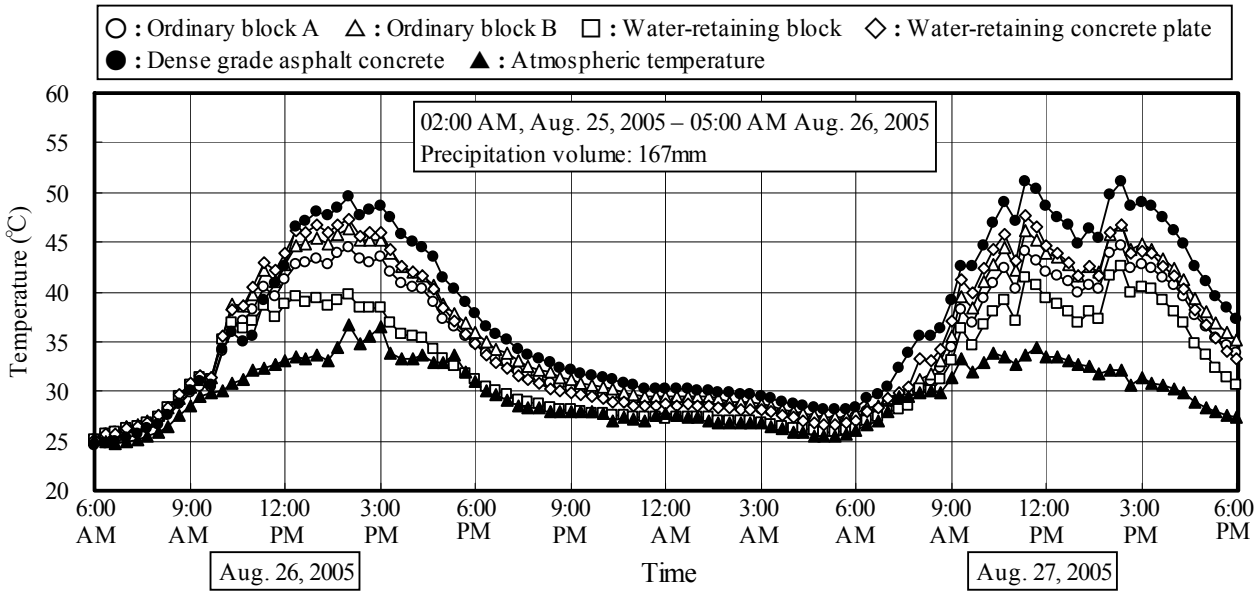


Figure 18. Results of measurement of temperature (after precipitation)

5. QUALITY STANDARDS OF WATER-RETAINING BLOCK

On the basis of the results of evaluation of water capacity and suction height and the results of evaluation of road surface temperature rise controlling effects, the reference values as indicated on Table 3 were selected for the quality standards of water-retaining block. As for skid resistance value, bending strength and tolerance of dimensions, the existing standard values of interlocking block established by JIPEA have been retained.

Table 3. Quality standards of water-retaining block

Application	Thickness (mm)	Water capacity (kg/m^3)	Suction height (%)	Skid resistance value(1) (BPN)	Bending strength(2) (N/mm^2)	Tolerance of dimensions (mm)	
						Width, Length	Thickness
Walkways	60	150 or more	70% or more (After 30 minutes)	40 or more	3.0 or more (17.0 or more)	±2.5	+4.0 -1.0
Pedestrians' roads(3)	80						
Parking lot, Driveway	80			60 or more	5.0 or more (32.0 or more)	±2.5	±2.5

Note (1): The skid resistance value is a value measured by using a British pendulum tester.
Note (2): The test conditions of bending strength are supporting at 2 points and loading at one point at the center, span of 160 mm, and loading speed of 0.8 ~ 1.0 MPa/min (increase of edge stress degree).
The values in ( ) show compressive strengths. It applies in the case where no bending test can be made for reason of block shape, etc.
Note (3): Includes pedestrian roads open to travelling of control vehicles with a total weight of 80 kN or under and restricted general vehicles.

6. CONCLUSIONS

It is hoped that the quality standards established by this study may help promote quality and increased use of water-retaining block. Water-retaining block has only a short history of is still developing from the technical viewpoint, and is expected to grow into products of better quality with in the future. Furthermore, the quality standards themselves will have to be reviewed with the progress of technology.

7. REFERENCES

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