Establishment of Certification System for Road Surface Temperature Reduction Interlocking Concrete Blocks in Japan

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Abstract :

In 2015, the Japan Interlocking Block Pavement Engineering Association (JIPEA) established the Cool Block Pave®certification system for road surface temperature reduction interlocking concrete blocks. For promoting the use of this certification system, JIPEA has been refining the method for reproducing, in a laboratory setting,the effect of reducing the rise in road surface temperature at the work site. This paper describes a test method that can accurately reproduce this effect and the factors contributing to it.

Key Words : heat island, Cool Block Pave, effect of reducing the rise in road surface temperature, laboratory experiment

1. Introduction

The urban thermal environment in Japan has become worse due to the heat island effect. To help improve this environment, the following materials have been developed and introduced: water-retentive pavement material that reduces the rise in road surface temperature through latent heat transfer, and heat-shielding pavement material that reduces heat conduction by reflecting sunlight. The same materials have also been developed in the field of interlocking concrete blocks (ICBs), and they are currently used for sidewalks, parking lots and plazas. In 2015, the Japan Interlocking Block Pavement Engineering Association (JIPEA) established the Cool Block Pave®certification system (under their registered trademark) for the road surface temperature rise reduction type ICBs (hereinafter, Temperature Reduction ICBs). This system grants the Cool Block Pave® name to those blocks that have demonstrated a temperature reduction effect of at least 8°C compared to a dense-graded asphalt mixture. By 2017, 21 types (11 companies) of heat-shielding ICBs and 15 types (11 companies) of water-retentive ICBs were certified as Cool Block Pave®.

In this study, we inspected the Cool Block Pave® certified blocks at their installation sites and confirmed that the temperature reduction effect at the road surface exceeded that stipulated in the certification test. In addition, using the heat-shielding type blocks that have been certified as Cool Block Pave®and are expected to be used at the venues for the Tokyo Olympic and Paralympic Games, the following two subjects were investigated.

(1) How will the work site conditions be reproduced in a laboratory setting?

(2) What are the factors contributing to the temperature rise reduction effect?

The results showed that the work site conditions can be accurately reproduced by controlling the moisture state in the ICBs, and that the effect of reducingthe temperature rise varies with the surface lightness of the blocks.

2. Heat Island Effect and Overview of the Temperature Reduction ICBs

The heat island effect refers to the phenomenon in which urban temperatures are higher than suburban temperatures. The temperature rise, particularly during summer, has become a serious issue due to the degraded level of comfort in daily life. There are three causes of the heat island effect: artificial ground surface covering (decrease of green areas and increase of asphalt paving), increased anthropogenic exhaust heat (radiated from buildings, factories, automobiles, etc.), and dense urban environments (stagnation of air due to closely packed buildings).

As indicated above, one of the major causes of the heat island effect is the expanded use of asphalt paving in urban areas. The surface temperature of asphalt pavement risesto over 60°C in summer, causing discomfort to pedestrians and urban residents. Against this backdrop, the Temperature Reduction ICBs have attracted attention as a promising technology to significantly reduce the road surface temperature compared to asphalt pavement. These blocks are broadly divided into two categories: heat-shielding ICBs and water-retentive ICBs. The heat-shielding ICBpaving uses a specific material on the block surface that reduces the rise in road surface temperature by reflecting the sunlightin the daytime. Also, the reduction in radiation heat helps prevent hot and humid nights (Figure 2). On the other hand, the water-retentive ICB pavement prevents the rise in road surface temperature through the removal of heat by the evaporation of rainwater retained in the blocks (Figure 3). Thus, these two types of pavement have different mechanisms to prevent the rise in road surface temperature. Figure 4 shows the changes over time in the road surface temperature for these two pavements and asphalt pavement. The road surface temperature of the asphalt pavement rapidly increased up to 60°C the day after rainfall. On the other hand, the road surface temperature of the water-retentive ICB pavement remained low for the first three to four days while water was retained inside the blocks, but then it increased up to the same level as the ordinary ICB pavement. The heat-shielding ICB pavement showsa slightly higher temperature compared to the water-retentive ICB pavement the day after rainfall, and the temperature stays at the same level for a long time even under clear skies. These findings suggest that when choosing a type of pavement, consideration should be given to the practicality of physically watering the pavement during continuous clear skies.

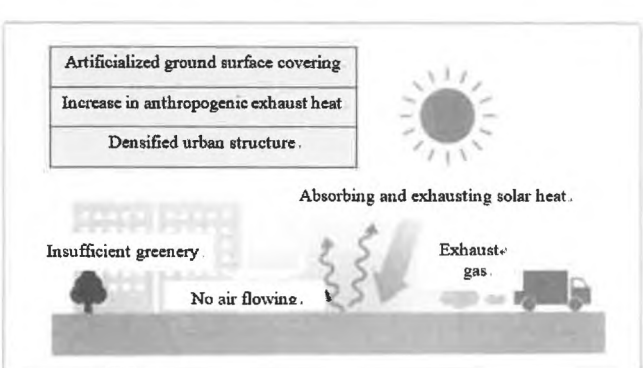


Figure 1. Causes of heat island effect

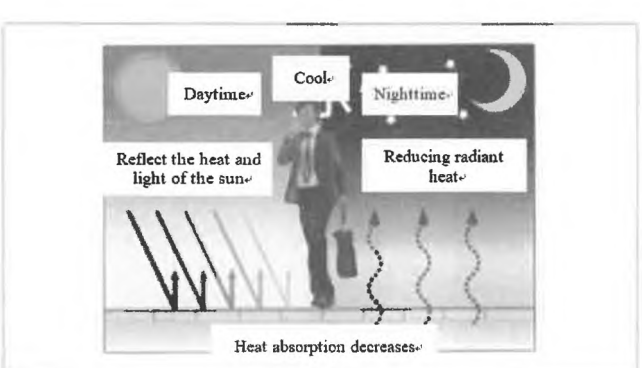


Figure 2. Heat-shielding ICB

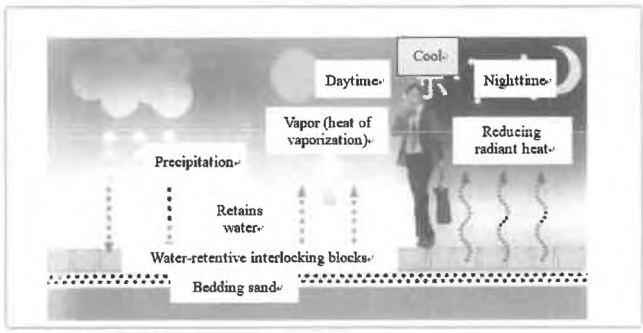


Figure 3. Water-retentive ICB

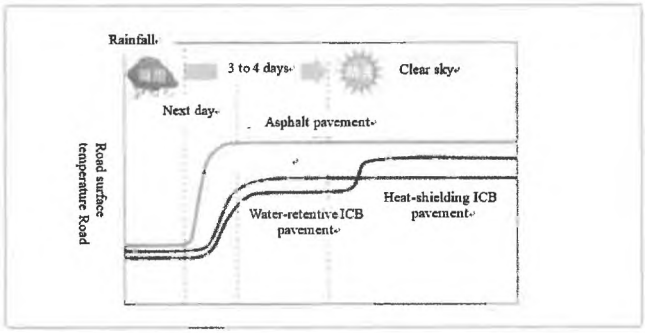


Figure 4. Conceptual image of road surface temperature changes over time

3. Quality Standard for Thermal Properties of Temperature Reduction ICBs

3.1 Quality standard for water-retentive ICBs

As the use of water-retentive ICBs became prevalent in the 2000s, JIPEA established the quality standard shown in Table 1 and the test methods shown in Figure 5 and Figure 6. [1] The standard stipulates that on a sunny day after rainfall, the practical target for the effect of reducing the rise in road surface temperature shall be at least 10°C lower than that of asphalt pavement. To ascertain this effect, an experiment was conducted by constructing a pavement of water-retentive ICBs from block manufacturers at the field experiment site shown in Photo 1, and their water content and absorption height were determined in the laboratory.



Photo 1. Field experiment setting

Table 1. Quality standard for water-retentive ICBs

Water retention	Water absorption
0.15 g/cm^3 or more	Absorption height, 70% or more of the specimen thickness at 30 min into the test

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

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

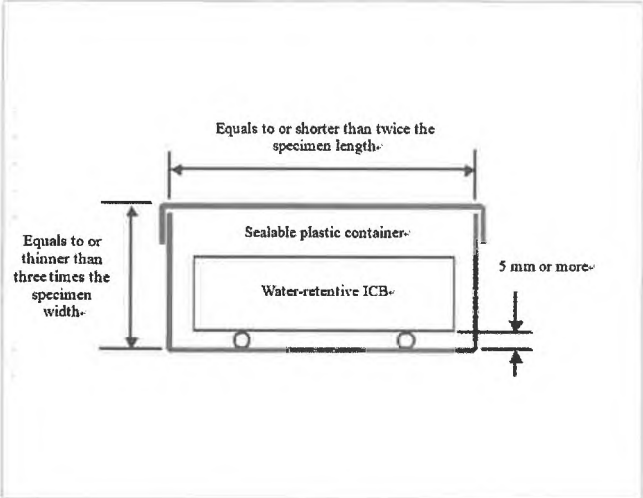


Figure 5. Equipment for damping the blocks.

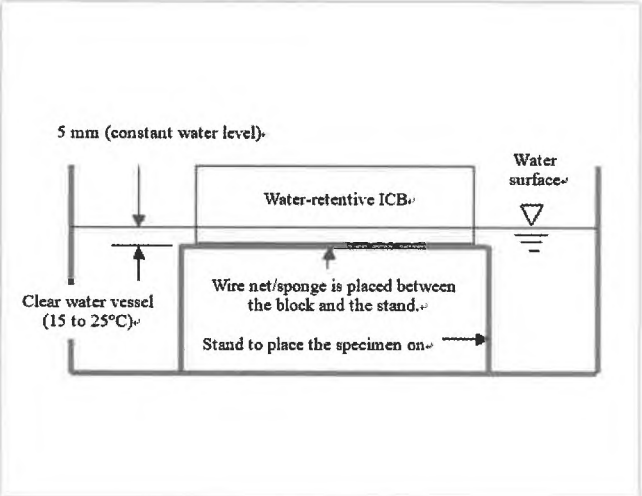


Figure 6. Water absorption test equipment

Where:

Damp mass:

The mass resulting from the following series of processes: 1) immersing the specimen in clear water of 1525±2°C for 24 h; 2) removing the specimenfrom the water and placing it in a plastic container (shown in Figure 5) for 30 min at a room temperature of 1530±2°C to allow it to drain; 3) wiping off visible water film with a wrung-out wet cloth; and 4) immediately measuring the weight.

Absolute dry mass:

The mass measured after first drying the block to a constant mass in a drying oven at a set temperature of 105±5±2°C and then cooling the specimen to room temperature.

Absorption mass:

The mass resulting from the following series of processes: 1) placing the specimen in the water absorption test setup shown in Figure 6; 2) removing the specimenfrom the test setup after waiting for 30 min; 3) draining the specimen until it stops dripping; 4) wiping off visible water film with a wrung-out wet cloth; and 5) immediately measuring the weight.

3.2 Quality standard for ICBs

The use of heat-shielding ICBs became widespread around the end of 2010. For this reason, JIPEA established the quality standard shown in Table 2 and associated test methods shown in Table 3 and Figure 7 for the Temperature Reduction ICBs. [2] This quality standard designates and specifies a certaintype of ICB (proven to have the effect ofreducing the road surface temperature compared to asphalt pavement) as the Temperature Reduction ICBs. This includes the water-retentive ICBs that were alreadystandardized and the heat-shielding ICBs that had become prevalent. Namely, (1) ordinary ICBs, (2) permeable ICBs and (3) water-retentive ICBs, all with the ability to reduce the road surface temperature rise. This quality standard designates only those blocks as the Temperature Reduction ICBs, namely those blocks that successfully demonstrate the ability to reduce the road surface temperature by at least 8°C when the surface temperature of the dense-gradedasphalt mixture is increased to 60°C in the laboratory lamp radiation test (hereinafter, "Laboratory Test"). The difference between "at least 8°C" mentioned above and "at least 10°C" specified for the water-retentive ICBs is due to the slightly less effective temperature reducing effect of the heat-shielding ICBscompared to the water-retentive ICBs (Figure 4).

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Table 2. Quality standard for the Temperature Reduction ICBs

Type		Temperature Reduction value(˚C)	Technique
Temperature Reduction ICBs	Ordinary ICBs	At least 8˚Clower, compared to the dense-graded asphalt mixture	A(Heat-shielding type)
	Permeable ICBs		
	Water-retentive ICBs		B(Water-retentive type)

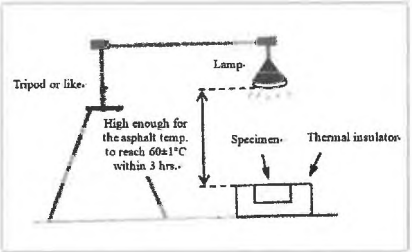


Figure 7. Radiation test equipment

Table 3. Details of Laboratory Test for Temperature Reduction ICBs

	Technique A (Heat-shielding type)	Technique B (Water-retentive type)
Specimen size	100 (d) × 60 or 80 (h) mm cylinders taken from the blocks	
Reference specimen	Dense-graded asphalt mixture	
Radiation lamp	Xenon lamp (radiation dose: 850 W/m^2) (Refer to Figure 7)	
Lamp height	High enough for the temperature of the reference specimen to reach 60±1˚C within 3 h (Refer to Figure 7)	
Ambient temperature	30±1˚C	
Ambient humidity	50±5% RH(Not mandatory)	50±5% RH (Mandatory)
Specimen curing time	The specimen is left to stand in the absolute dry condition for 5 h at 30±1˚C	The specimen is immersed in water of 30±1˚C for 1 h, then it is removed from the water, and water dripping from the surface is wiped away, after which it is left to stand for 5 h at 30±1˚C, 50±5% RH
Measurement time	Three hours of consecutive radiation	
Temperature measurement interval	Thermocouple elements and data loggers are used to measure the surface temperature of the specimen at 10-min intervals	

Note that the quality standard for the water-retentive ICBs remains in effect even after the publication of this new quality standard. Compared to the ordinary ICBs, the water-retentive ICBs have a larger water content resulted from stored rainwater, and thus it is assumed that a certain number of pavement architects and clients will require the water-retentive type of pavement even if the Temperature Reduction value is below the standard value.

4. Cool Block Pave® Certification System

In 2015, JIPEA initiated the Cool Block Pave® certification system based on the quality standard draft for the Temperature Reduction ICBs mentioned above. The procedure of this certification system is illustrated in Figure 8 below: a JIPEA member applies for certification with JIPEA, a JIPEA-designated testing institute tests the blocks, and JIPEA issues a Cool Block Pave® certificate for the blocks if the test results satisfy the quality standard for the Temperature Reduction ICBs (Table 2). This system helps pavement architects and clients choose a highly effective Temperature Reduction ICB. The system is also beneficial forJIPEA member companies as it helps prevent the circulation of nonconforming blocks in the market.

By 2017, 21 types (11 companies) of heat-shielding ICBs and 15 types (11 companies) of water-retentive ICBs were certified as Cool Block Pave®.

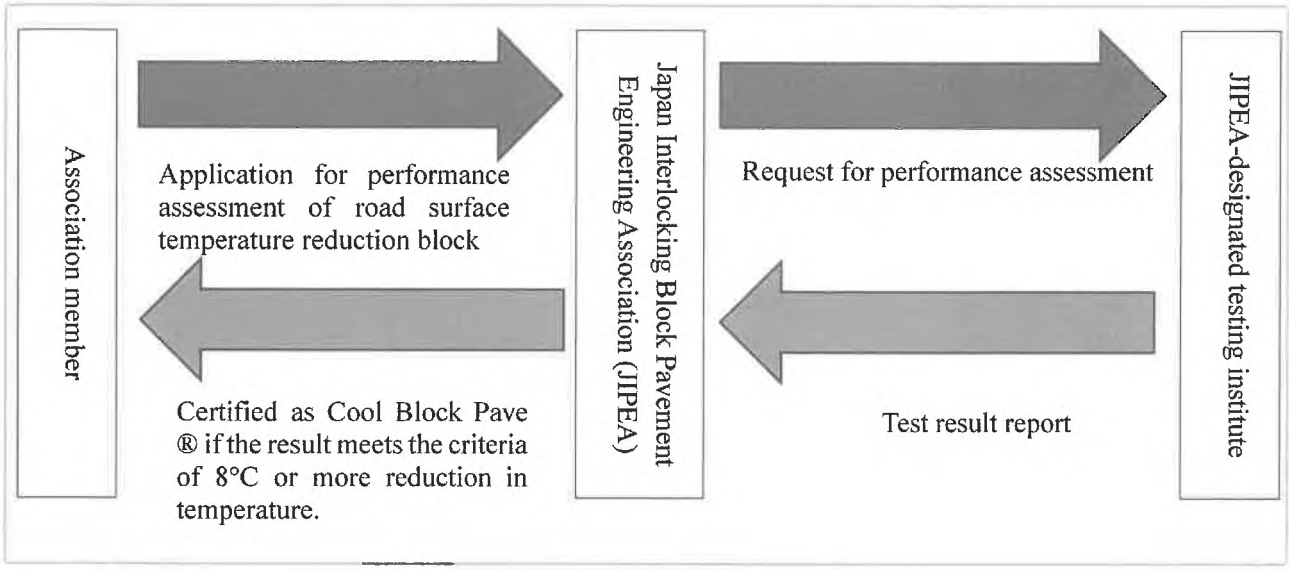


Figure 8. Schematic diagram of Cool Block Pave® accreditation system

5. Issues with Quality Standard for Temperature Reduction ICBs

In the Laboratory Test, Temperature Reduction was measured under test conditions prepared so that the results would approximate the assumed results at the work site. The road surface temperature data collected from the Cool Block Pave® certified blocks at the work sites by JIPEA member companies shows that the results of the water-retentive ICBs in the Laboratory Test approximated the data from the work sites. Lately, however, it was found that the Temperature Reduction in the heat-shielding ICBs was larger in the work site results compared to the results in the Laboratory Test. As an example, the measurement resultsobtained from the heat-shielding ICBs certified as Cool Block Pave® and manufactured by a JIPEA member company are shown in Figure 9 (Laboratory Test) and Figure 10 (work site). A comparison shows that the result of the Laboratory Test is 2.3ºC lower than that from the work site. In other words, the Laboratory Test does not accurately reflect the road surface temperature rise reduction effect obtained at the work site.

6. Resolution of Issues with the Quality Standard

The reason that the reduction effect was undervalued by the Laboratory Test is likely due to the damp condition of the laboratory specimen. As shown in Table 3, the Laboratory Test method for the heat-shielding ICBuses the specimen in an absolute dry condition. Since the mechanism of the road surface temperature reduction in the heat-shielding ICBis reflection of sunlight, as shown in Figure 2, it is indeed appropriate to use an absolute dry specimen to determine the effect of solar reflectance. However, ICBs are manufactured using the vibration-compression immediately stripped dry cast method, and thus theyhave water-retentive properties compared to the dense-graded asphalt mixture. Therefore, the heat-shielding ICBs at the work site can only become absolutely dry under many continuous sunny days in summer. Otherwise, the blocks at the work site are assumed to retain a certain amount of moisture. This suggests that the heat-shielding ICBs are also capable of reducing the rise in road surface temperature by removing the heat through the evaporation of retained moisture, just like the water-retentive ICBs. JIPEA experimentally verified this assumption.

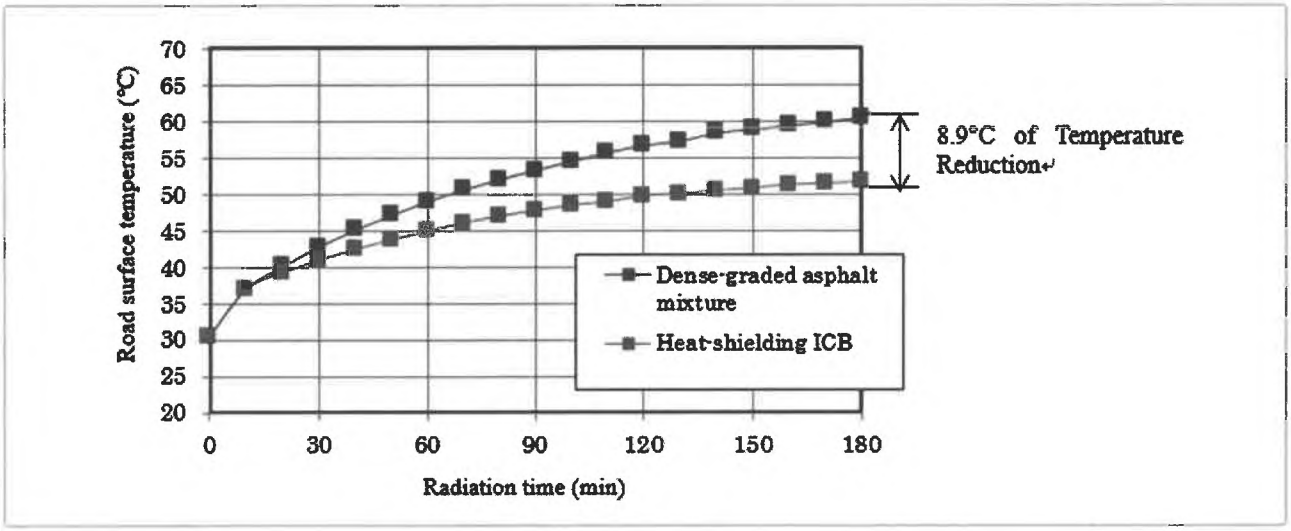


Figure 9. Laboratory Test result of the heat-shielding ICB

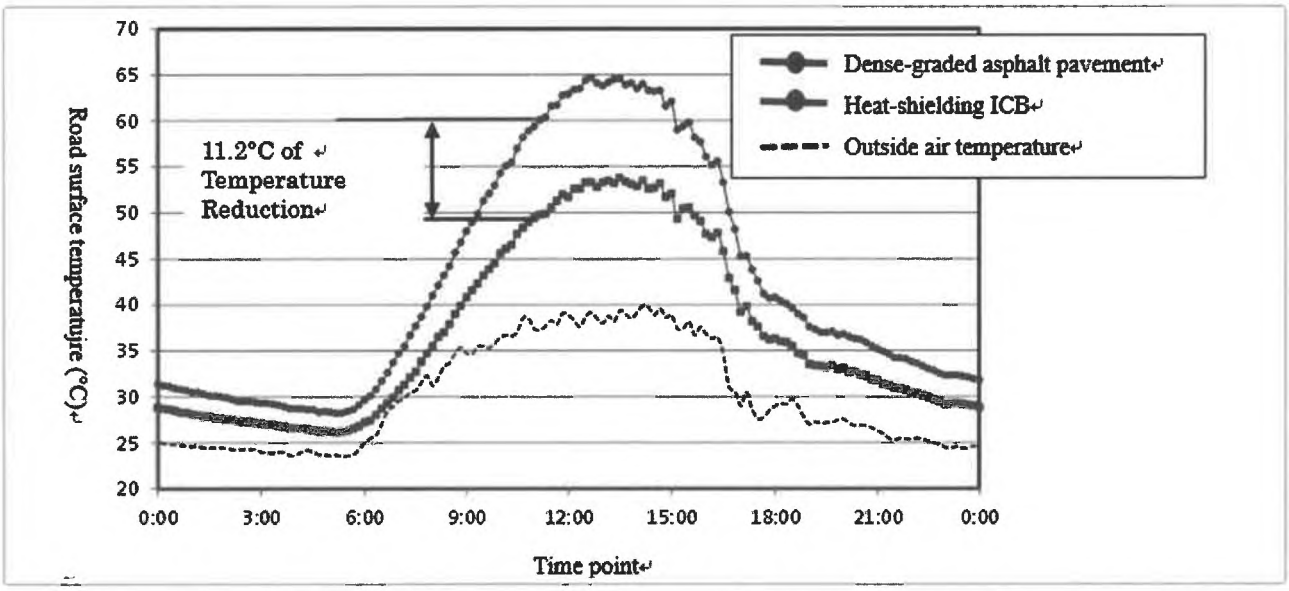


Figure 10. Measurement results of the road surface temperature of the heat-shielding ICB in the worksite.

6.1 Field verification experiment

First, it was necessary to experimentally determine if moisture evaporated from the heat-shielding ICB at the work site. [3] For the experiment, the sidewalk pavement shown in Figure 11 and Figure 12 was constructed, and heat-shielding ICBs, water-retentive ICBs and dense-graded asphalt mixture were installed on the surface of the pavement. Next, changes over time in the amount of water that evaporated from the road surface were measured using a water evaporation measuring device (Nikkiso, Tokyo, Japan) on the day after rainfall. The results are shown in Figure 13. There was no evaporation from the dense-graded asphalt pavement during the entire day. On the other hand, in response to the temperature, humidity and wind speed, water evaporated from the water-retentive ICBpavement. Water also evaporated from the heat-shielding ICB pavement in an amount about 2050% of that from the water-retentive ICB pavement. It was verified that the heat-shielding ICB pavement effectively reduces the rise in road surface temperature by using the heat of vaporization, as in the case of the water-retentive ICB pavement.

The evaporation rate from the water-retentive ICBpavement was 2000 g/m²·24 h in this experiment. If the water-retentive ICB has a water content of 0.15 g/cm³ as specified in the quality standard, a 60-mm-thick block should have a water content of 9000 g/m². Based on the above data, the number of days expected to be effective in reducing the rise in road surface temperature through evaporation from the water-retentive ICBis calculated as 9000/2000 = 4.5 days, in the case of continuous sunny days in summer. In Tokyo, the frequency of occurrence of "continuous sunny days without rain" is rather low due to numerous sudden showers and localized torrential rains in summer. Thus, the water-retentive ICBs basically have a high potential to reduce the rise in road surface temperature throughout the summer.

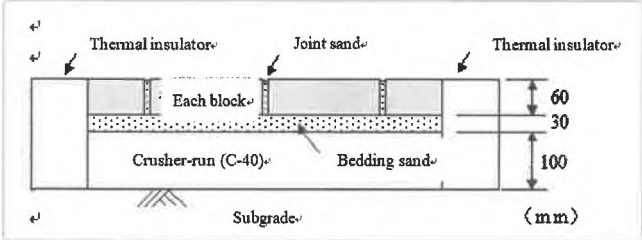


Figure 11. Structures of heat-shielding type ordinary ICB pavement and water-retentive ICB pavement

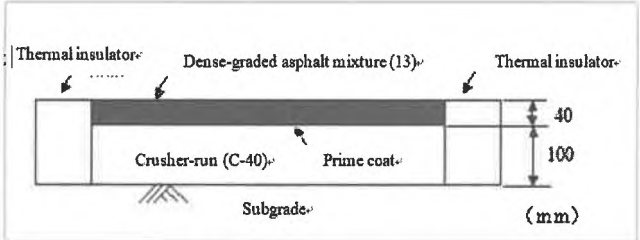


Figure 12. Structure of dense-graded asphalt pavement

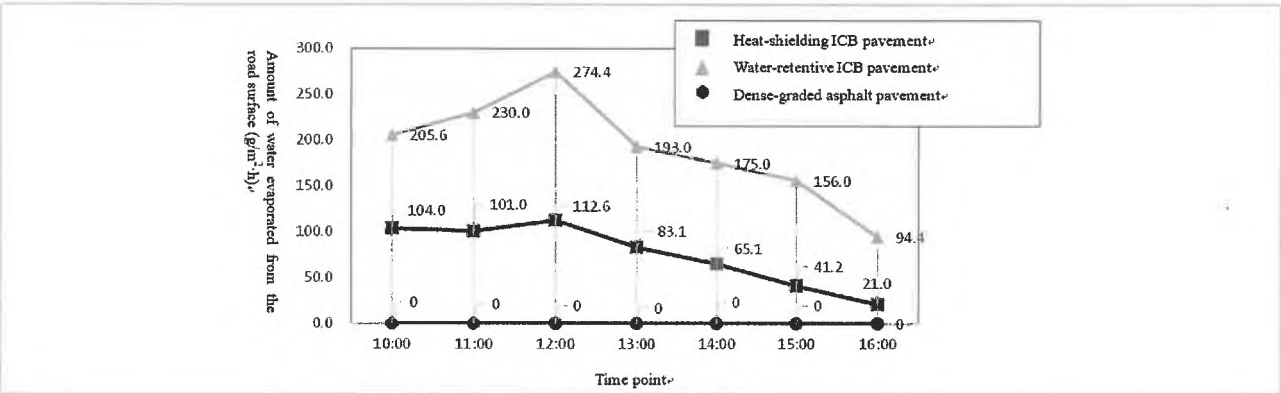


Figure 13. Measurement results of amount of water evaporated from the road surface of various pavements

6.2 Laboratory verification experiment

Next, we determined the relationship between the Temperature Reduction value and Technique A (absolute dry specimen) or Technique B (damp specimen) in the Laboratory Test by using the same heat-shielding ICBs. The heat-shielding ICBs subject to this experiment were three types of blocks from three member companies, including Company S shown in Figure 9 and Figure 10 above. The results are shown in Figure 14. The Temperature Reduction values of all the heat-shielding ICBs are larger with Technique B than with Technique A. Regarding the blocks of Company S, Temperature Reductionat the time of Cool Block Pave® certification was 8.3°C, while the result of the laboratory verification experiment using Technique A (absolute dry specimen) was 8.9°C. The Laboratory Test demonstrates high reproducibility. The result of the Laboratory Test using Technique B (damp specimen) was 11.6°C, while at the work site it was 11.2°C (Figure 10), demonstrating that the work site value was accurately reproduced in the laboratory using Technique B (damp specimen).

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Regarding Company I and Company T, the resultsobtained at the work sites were accurately reproduced in the Laboratory Test using Technique B (damp specimen). This demonstrates that for the heat-shieldingICBs, it is also possible to reproduce the resultsobtained from the work site in the laboratory using Technique B, not Technique A.

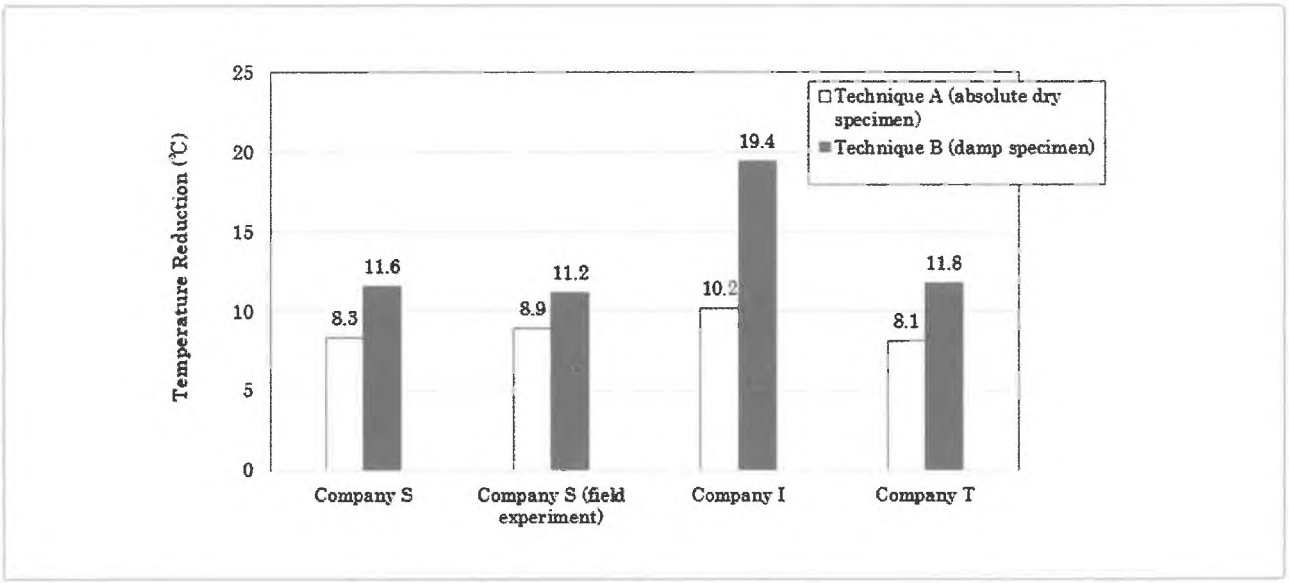


Figure 14. Laboratory demonstration experiment results

7. Relationship between the Surface Lightness and the Temperature Reduction Value

During the preparation of the quality standard for the water-retentive ICBs, the relationship between the surface lightness (L* of the L*a*b* color system) and the road surface temperature of the ordinary ICBwas determined at the field experiment site (Photo 1). The measurement was conducted after eight consecutive days of clear skies with a temperature of 30°C or above. The water content of the block is deemed to be similar to the absolute dry condition of TechniqueA. The results are shown in Figure 15.

It can be seen from the figure that there is a high correlation between the block surface lightness and the road surface temperature, i.e., the road surface temperature decreases linearly with increasing surface lightness. As in the case of the road surface temperature reduction mechanism in the heat-shielding ICBs, this is related to the fact that the reflection factor for solar radiation (albedo) in the ordinary ICB increases with increasing surface lightness.

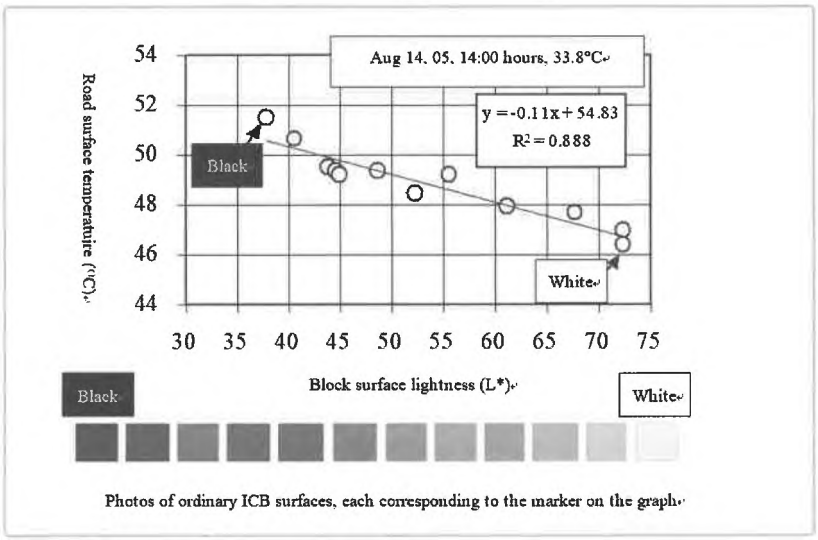


Figure 15. Relation between the surface lightness and road surface temperature of the ordinary ICB in the field experiment site

7.2 Laboratory experiment

For the heat-shielding ICBs of Company S, Company I and Company T (used in "6.2 Laboratory verification experiment") and the ordinary ICBs (not Temperature Reduction types) of these three companies, the following properties were measured: surface lightness (L* in the L*a*b* color system) and the temperature reduction using Technique A (absolute dry specimen).

Then, the relationship between these properties was evaluated. The results are shown in Figure 16. In both the heat-shielding ICBs and ordinary ICBs, the temperature reduction tended to increase linearly with the increase in surface lightness. Regarding the slope of the approximate straight line, that of the heat-shielding ICB is gentle compared to the ordinary ICB. This indicates that when the surface lightness is high and its color is close to white, the difference in temperature reduction between the heat-shielding ICBand the ordinary ICB is small, but when the surface lightness is lower and closer to black, the temperature reduction is larger in the heat-shielding ICB. This is due to the specific material used in the surface of the heat-shielding ICB; the material has the thermal property of high reflectivity against sunlight.

An example of the relationship between the sunlightwavelength and reflectance in the specific heat-shielding ICB material is shown in Figure 17. The characteristics of this material are such that the sunlight within the infrared region (wavelength of 800 nm or more) is effectively reflected. Since there is a large amount of heat in the sunlight in the infrared region, by reflecting this light, the road surface temperature in the heat-shielding ICB pavement is preventedfrom rising, compared to the ordinary ICB pavement. Thus, if the above-mentioned material is used in black-colored ICBs, it produces thermal properties close to those of white-color ICBs, because the material can increase the reflection of sunlight. Such thermal properties of the specific heat-shieling material influence the relationship between heat-shielding ICBs and ordinary ICBs shown in Figure 16.

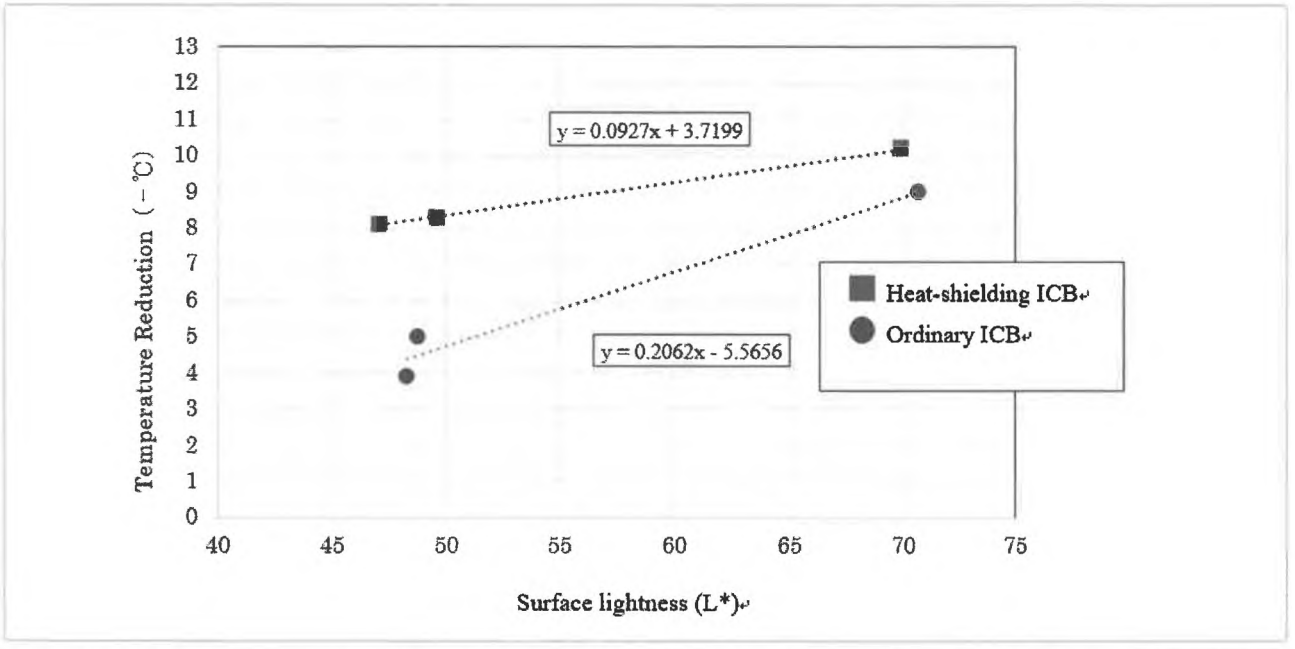


Figure 16. Relation between the Heat-shielding ICB surface Lightness and road surface temperature in the field test site

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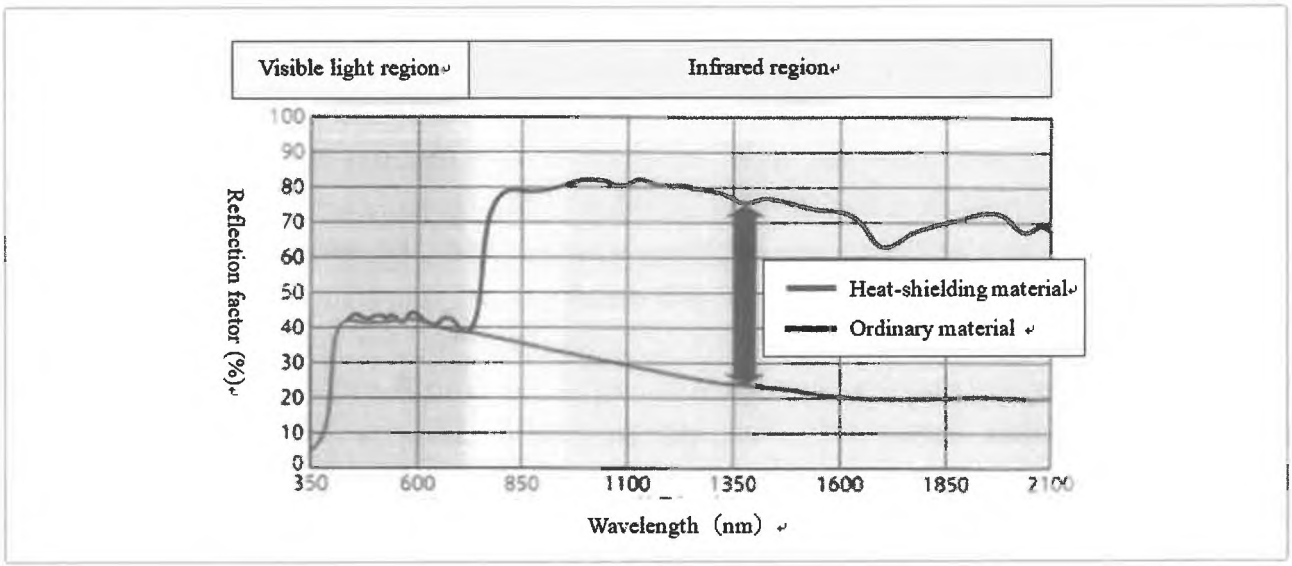


Figure 17. Example of relation between the sunlight wavelength and reflectance in the specific heat-shielding material used in the heat-shielding ICB

8. Conclusions

The following findings were obtained from this study.

(1) In the conventional Laboratory Test using Technique A (absolute dry specimen) for evaluating the road surface temperature rise reduction effect of the heat-shielding ICB, it was unrealistic to reproduce the effect observed at the work site in summer. We managed to reproduce the effect by adopting Technique B (damp specimen) used in the Laboratory Test for evaluating the water-retentive ICB into the Laboratory Test for evaluating the heat-shielding ICB.

(2) For both the heat-shielding ICB and ordinary ICB, the effect of reducing the temperature rise in the road surface increases with the increase in surface lightness (closer to white). This indicates that when the lightness of the block surface is high and its color is close to white, the difference in the temperature reductionbetween the heat-shielding ICB and the ordinary ICB is small, but when the surface lightness is lower and closer to black, the temperature reduction of the heat-shielding ICB becomes larger.

9. Concluding Remarks

In 2017, JIPEA issued a revised version of the "Interlocking Block Pavement Engineering Design and Construction Guidelines," which includes the quality standard and test methods for the Temperature Reduction type of ICB, as well as the description of the Cool Block Pave® system, a technical mainstay in the Association, to actively promote its use. The Laboratory Test described in the present report proves that by controlling the moisture state in the specimen, the effect of reducing the road surface temperature rise at work sites in summer can be accurately reproduced in the laboratory setting. This finding will be utilized and included in the next version of the Guidelines. In addition, JIPEA is promoting research such as on pavement with landscaping or design, technology to reduce environmental burden and technology supporting universal design. JIPEA is continuing to create a good road environment for people in and outside Japan, including those coming from around the world to enjoy the 2020 Tokyo Olympics. [4]



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