Paving Method to Control Heat-Island Phenomena and its Effects — Study on Water Retaining Pavement and Solar Radiation Reflective Pavement

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ABSTRACTS: Toward the heat environment improvement of the city, the pavement that reduces road surface temperature is being developed, including water retaining pavement and solar radiation reflective pavement. This study evaluated of these pavements from the latent heat effect of water retention and the reflectivity of pavement colors, with regard to the energy transfer of solar radiant energy absorbed to the road surface and then emitted into the air.

This study found the following:

1. The effects of road surface temperature reducing pavements can be arranged in order of reflectivity. It was found that a temperature reduction of about 10 degrees or more could be ensured with a reflectivity of approximately 30 percent or more.
2. Water retaining pavement has a high road surface temperature reduction effect due to its reflectivity and latent heat. In conditions where reflectivity is ensured, a temperature reduction effect of approximately 5 degrees or more (field test) can be expected in addition to the effect of reflectivity, and the persistence of this effect is also improved.
3. The effect of a solar radiation reflective pavement with the same reflectivity was about 10 degrees (laboratory test), which allows the pavement to be used as a temperature reduction pavement with dark colors.
4. The effects of road surface temperature reducing pavement could be arranged in the order of the amount of heat storage in the pavement.

KEY WORDS: Heat-island phenomena, water retaining pavement, solar radiation reflective pavement, latent heat, reflectance, storage of heat.

1 INTRODUCTION

It is generally known that the surface temperature of asphalt pavement increases significantly in summer, which is considered to be a cause of heat island phenomena in urban areas. This is because asphalt pavement easily accumulates solar radiation heat, causing the pavement temperature to increase. As an effort to prevent this, water retaining pavement, which retains and evaporates rainwater, and solar radiation reflective pavement, which reflects solar radiation, are being developed.

In this paper, with regard to paving technologies that reduce road surface temperature, the effects of water retention and colors on the transfer of solar radiation energy input from the sun to the road surface and output to the atmosphere are recognized, and the paving methods effective in preventing heat-island phenomena in the entire urban areas are evaluated based on the results of laboratory and field tests.

2 FACTORS THAT REDUCE ROAD SURFACE TEMPERATURE

In the previous studies on the road surface temperature-reducing effects, based on net solar radiation, sensible heat, latent heat, and soil heat flux were studied from an energy transfer standpoint. In this paper, with the focus on the latent heat effect of water retention and the reflection effect of pavement colors, the effects of water retaining pavement and solar radiation reflective pavement are studied.

3 LABORATORY TEST OF ROAD SURFACE TEMPERATURE-REDUCING PAVEMENT

3.1 Overview of Water Retaining Pavement

Water retaining pavement prevents the road surface temperature from increasing. It's the mechanism of this pavement that retaining water is evaporated by solar radiation and so that evaporation latent heat is removing.

Many types of water retaining pavement are semi-flexible types that use water retaining cement milk, and therefore, the pavement surface has a whiter finish than the conventional pavement. Water retaining pavement produces two types of road surface temperature-reducing effects: the effect obtained by reflecting input solar radiation and the effect obtained by increasing latent heat through the evaporation of retained water with heat transferred to the road surface as soil heat flux. In addition, water retaining pavement has the effect of reducing the temperature of the atmosphere around the road surface because the reduction of the road surface temperature reduces infrared radiation and sensible heat.

3.2 Measurement of the Road Surface Temperature-reducing Effects of Water Retaining Pavement

3.2.1 Test Method

First, the temperature-reducing effects of water retaining pavement were evaluated based on the assumption that no moisture was retained (it had not rained for a long time). Next, the combined effect of colors and water retention was evaluated under the conditions where the water retention effect was the greatest in summer.

The test used water retaining pavement, porous concrete pavement (green) and drainage pavement (top: 20 mm and 13 mm), and dense-graded asphalt pavement.

First, the temperature of each specimen was measured with a halogen light until the equilibration temperature (about 60ºC) was reached. Next, the same measurement was made with the specimens immersed and saturated in water.

3.2.2 Test Results

Table 1 shows the results of measuring the colors of the specimens. The light source is limited to the visible light region of 0.3 to 0.7 μm, and therefore, the effect of solar radiation can be evaluated.

The road surface temperature-reducing effect of each pavement was evaluated based on a temperature difference measured after three hours, when the surface temperature of dense-graded asphalt pavement reached around 60°C. Figure 1 shows the relationships between the temperature-reducing effect and reflectance, and between the temperature-reducing effect and brightness.

Table 1: Results of Color Measurement

Type of pavement	Reflectance (%)		Elements of the Munsell color system		
	Wet	Dry	Hue	Brightness	Intensity
Water retaining pavement	23.7	45.3	4.7Y	7.4	0.7
Porous concrete pavement	6.2	10.1	7.8GY	3.6	1.3
Drainage pavement (20 mm)	2.9	3.1	8.7PB	2.0	0.0
Drainage pavement (13 mm)	3.3	3.5	8.2PV	2.1	0.7
Dense-graded asphalt pavement	3.4	4.0	8.6YR	2.2	2.2

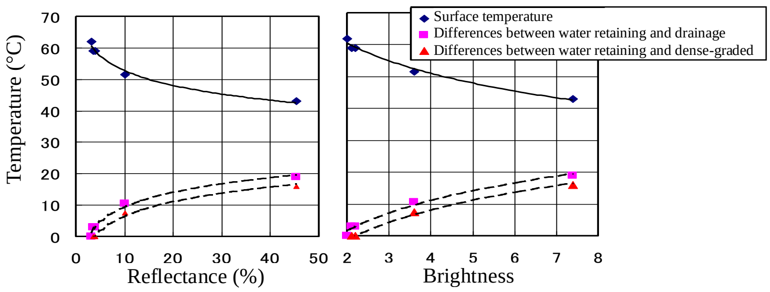

Figure 1: Relationships between the Temperature-reducing Effect, and Reflectance and Brightness (in a Dry State)

From this figure, it can be seen that the temperature decreases more significantly as the reflectance or brightness increases, and an effect of 15 to 20°C can be obtained when the reflection is 30% or more. The same results were obtained with the reflectance and brightness, so after this test, evaluation was made from the reflectance.

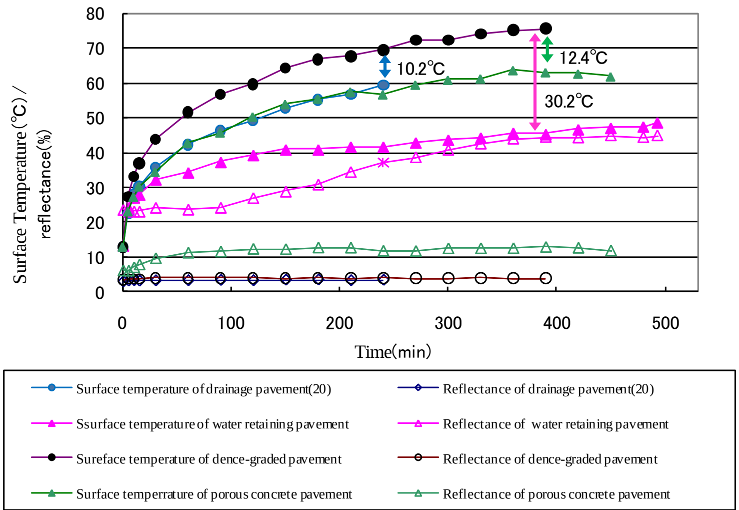

Figure 2: Relationships between Temperature-reducing Effect and Reflectance (Wet State)

Figure 2 shows the results of the test where water-saturated water retaining pavement was irradiated by a halogen light. The surface of the water retaining pavement became dry about 6 hours after irradiation, and its reflectance returned to the reflectance it has in a dry state. Evaluation was made based on differences in the road surface temperature between dense-graded asphalt pavement and other types of pavement at the time when the reflectance of each specimen became constant. Figure 3 shows the results of evaluating the latent heat effect of water retaining pavement along with the results of evaluating the reflection effect shown in Figure 1.

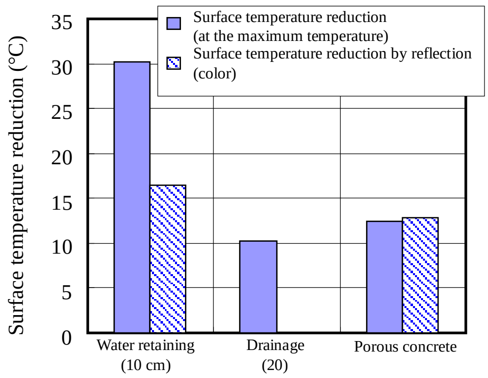

Figure 3: Temperature-reducing Effects of Reflection and Latent Heat

From these figures, it can be seen that the effect of the latent heat of water retaining pavement was almost the same as the effect of the reflection, about 15ºC. In addition, it was confirmed that the temperature-reducing effect of drainage pavement was about 10ºC, but this is probably because the water retained in voids evaporated.

3.3 Overview of Solar Radiation Reflective Pavement

Solar radiation reflective pavement is formed by a solar radiation reflective and heat-shielding material consisting of heat reflective pigment, and such like applied on the surface of the pavement, and has the effect of reducing the road surface temperature. Solar radiation that has reached the road surface and atmospheric radiation are reflected, causing the road surface temperature to decrease. This reduces soil heat flux and infrared radiation from the road surface, causing the atmospheric temperature on the road surface to decrease.

3.4 Measurement of the Road Surface Temperature-reducing Effects of Solar Radiation Reflective Pavement

3.4.1 Test Method

The temperature-reducing effect of the solar radiation reflective material was evaluated, using a plate to which the heat-shielding material was applied, based on relationships between the surface temperature and reflectance. The tests were carried out with black, white, and gray specimens, with and without the solar radiation reflective material. The tests were carried out in the same method as in 3.2.

3.4.2 Test Results

Figure 4 shows the test results. The temperature-reducing effect of the solar radiation reflective material with the same color (reflectance) was about 10ºC. This is probably because the reflection in the infrared radiation region decreased the surface temperature. In other words, it was found that a temperature-reducing effect of 10ºC or so can be expected by using special coating (infrared reflection coating), even in the dark color region, where the reflectance is 20% or less and the infrared absorption is typically high.

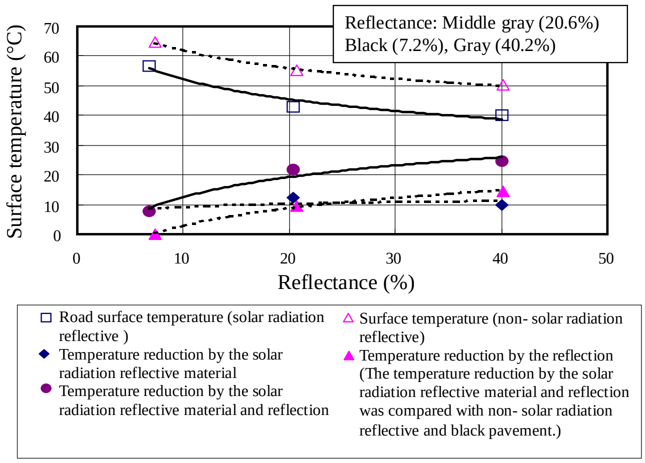

Figure 4: Relationships between Temperature-reducing Effect and Reflectance (Solar Radiation Reflective Pavement) Wet State)

4. TEST CONSTRUCTION

The road surface temperature-reducing effect obtained by the laboratory test based on the solar reflection and water retaining capability was verified by a field test.

4.1 Overview of Test Construction

The test was carried out at six sites (3.0 × 3.5 m per site) using water retaining pavement (5 cm) (white and gray), water retaining pavement (10 cm) (white), drainage pavement, solar radiation reflective pavement (drainage pavement/white), and semi-flexible pavement. In addition, the existing dense-graded asphalt pavement was used for control site.

Table 2 shows the measurement items in the test site and Figure 5 shows the measuring instruments and measuring points.

Table 2: Test and Measurement Items

Measurement Item	Measuring point	Measuring instrument	Frequency
Temperature/humidity	1.5 m above the ground	Self-recording instrument	Every 15 minutes
Solar radiation			
Rainfall	Sides of the test sites	Rain gauge	Continuous measurement
Road surface temperature	Pavement surface (only ① and ③)	Radiation thermometer	Every 15 minutes
	1.0, 2.5, and 7.5 cm below the pavement surface	Thermocouples	Every 15 minutes
Temperature/humidity	Pavement surface 30 cm above the Pavement surface	Thermo-hydrometer	Every 15 minutes

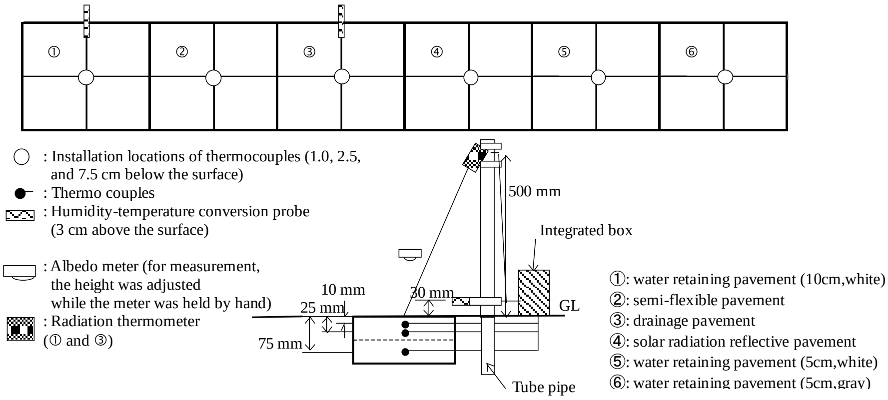

Figure 5: Measuring Instruments and Measuring Points

4.2 Test Results and Considerations

4.2.1 Results of Measurement of Road Surface Temperature in Summer

Figure 6 shows an example of the results of measuring the road surface temperature in summer. Table 3 shows the results of measuring the reflectance of each pavement. In addition to the reflectance in wet and dry states, the table includes the reflectance measured when the difference in the road surface temperature from the drainage pavement was the largest.

To verify the temperature-reducing effect of water retention, water equivalent to a rainfall of about 20 mm/h was sprayed for one hour in the early morning of the measurement day.

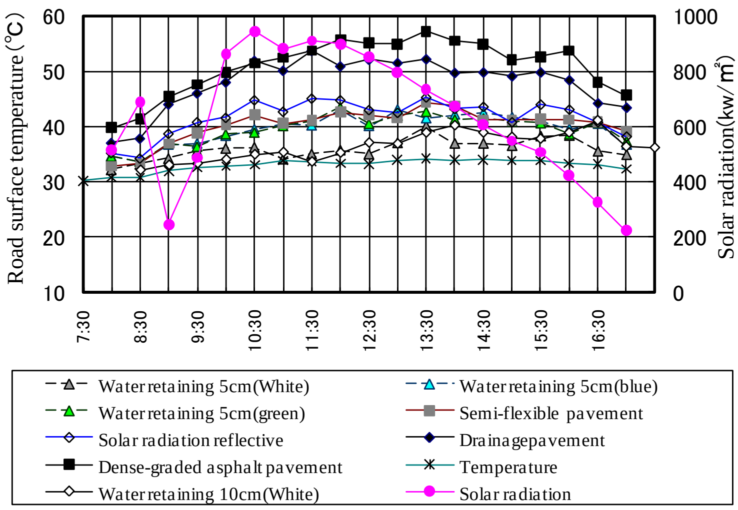

Figure 6: Results of Measurement of Road Surface Temperature and Solar Radiation in Summer

Table 3: Reflectance Measurement Results

Type of pavement	Color	Reflectance (%)		
		Wet	Dry	When measured
Water retaining pavement (5 cm)	White	31.6	52.8	42.2
	Gray	18.4	40.0	29.2
	Blue	15.8	36.8	26.3
	Green	15.1	35.4	25.3
Water retaining pavement (10 cm)	White	32.9	57.1	39.0
Semi-flexible pavement	White	22.5	47.6	41.4
Drainage pavement	Black	2.6	4.2	4.2
Solar radiation reflective pavement	White	39.7	40.7	40.8
Dense-graded asphalt pavement	Black	4.4	8.4	8.4

4.2.2 Road Surface Temperature-reducing Effect in Summer

Figure 7 shows the relationships between the road surface temperature-reducing effect and reflectance in summer. Though the weather was fine on the measurement day, we decided that the water retaining pavement and solar radiation reflective pavement could exercise sufficient performance through the spaying of water before measurement. In comparison to drainage pavement, the temperature-reducing effect was evaluated based on the largest temperature difference.

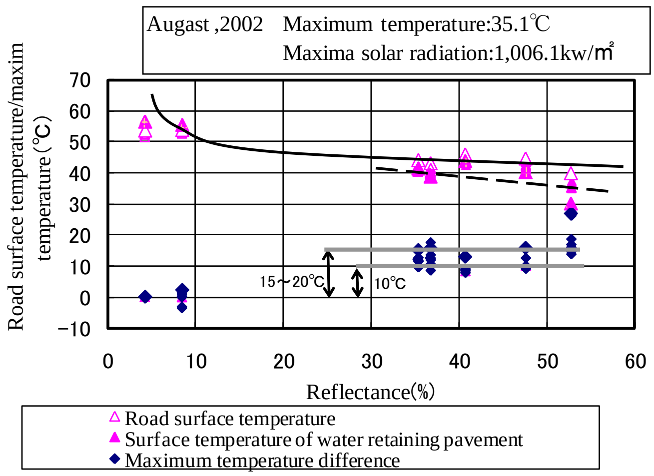

Figure 7: Relationships between the Road Surface Temperature and Reflectance

In the figure, the solid line indicates the trend in the road surface temperature of pavement without water retaining capability, and the dotted line indicates the trend in the road surface temperature of water retaining pavement. From this figure, it can be seen that the road surface temperature-reducing effect was about 10ºC when the reflectance was 35% or more. In addition, it is considered to be possible to add an effect of 5 to 10ºC by adding water retaining capability to pavement with sufficient reflection.

4.2.3 Maintenance of the Road Surface Temperature-reducing Effect of Water Retaining Pavement

The maintenance of the road surface temperature-reducing effect of water retaining pavement was evaluated with the largest difference in the surface temperature (1 cm below the surface) from the drainage pavement of 12ºC or more as a standard (Figure 8).

The result found that when a sufficient amount of water was retained and the intensity of solar radiation was around 1,000 kW/m^2, the temperature difference of 12ºC or more, which was set as a standard, was held for about 7 days or more. The result also found that the temperature difference was maintained for only 4 days with semi-flexible pavement with little water retaining capability, and it was difficult to achieve a temperature difference of 12ºC or more with solar radiation reflective pavement (drainage pavement/white).

More specifically, it was found that it was possible to increase the temperature-reducing effect by about 10ºC by ensuring sufficient reflectance, and further increase the temperature-reducing effect by about 5 to 10ºC by adding water retaining capability, as well as increasing its maintenance.

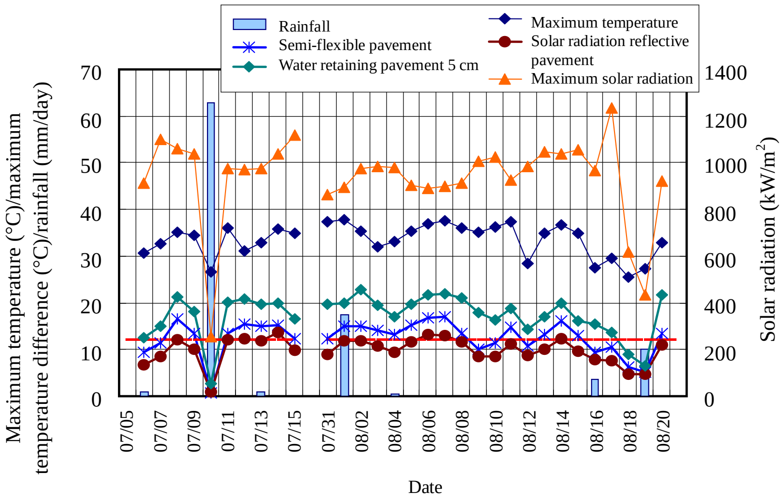

Figure 8: Changes in Road Surface Temperature Reduction in Summer

5 EFFECT OF REDUCING THE STORAGE OF HEAT IN PAVEMENT THROUGH THE REDUCTION OF PAVEMENT TEMPERATURE

The pavement temperature increases when the pavement is heated by solar and atmospheric radiation. Heat stored in pavement heats the atmosphere and pedestrians around the pavement. So far, water retaining pavement and solar radiation reflective pavement have been studied with the focus on the latent heat and long-wave radiation respectively, but it is not appropriate to carry out evaluations simply with these indicators because various factors affect atmospheric temperature and sensory temperature in a complicated manner. However, the storage of heat in pavement constitutes a major factor affecting long-wave radiation and sensible heat, and therefore, it is considered to be an effective indicator in evaluating the effect of road surface temperature-reducing pavement.

For the above-mentioned reason, the study was carried out with the focus on the pavement temperature (storage of heat).

Figure 9 shows a typical change in the road surface temperature on a sunny day and the inner temperature distribution of the pavement. With regard to the surface and binder courses (t = 10 cm), the shaded area in the figure was converted to the amount of heat by using the following formula, and the resulting values were used as an indicator for evaluating the pavement. The shaded area of right figure shows the reducing effect of the surface temperature and the shaded area of left figure shows the reducing effect of the inner temperature.

(Storage of heat) = (Specific heat) × (Density) × (Temperature) × (Thickness) × (Unit area)

In this evaluation, which was carried out on typical sunny days in summer, fall, and winter, water retaining pavement (5 cm), semi-flexible pavement, and solar radiation reflective pavement were compared with drainage pavement. Figure 10 shows the interior temperature measured at noon in summer and winter and Table 4 shows the calculation results of the storage of heat.

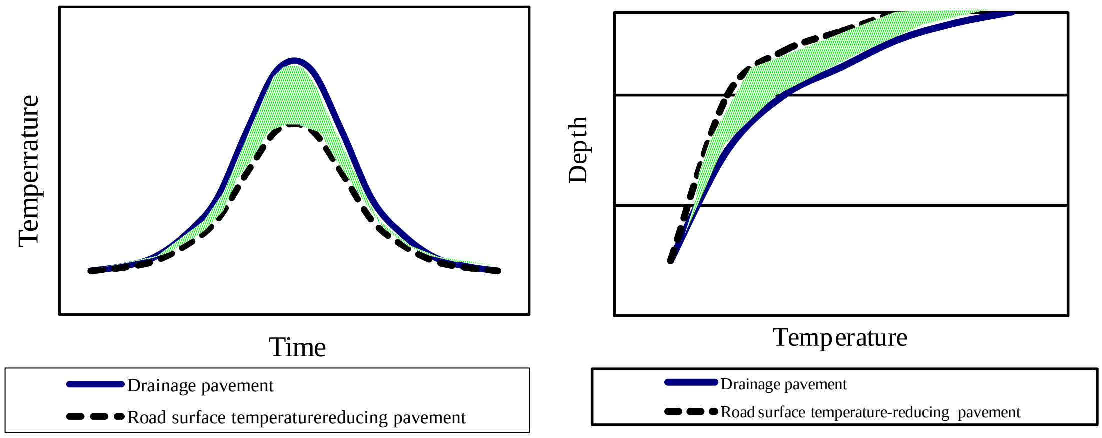

Figure 9: Pattern Diagram of the Effects of Reducing the Surface and Inner Temperatures

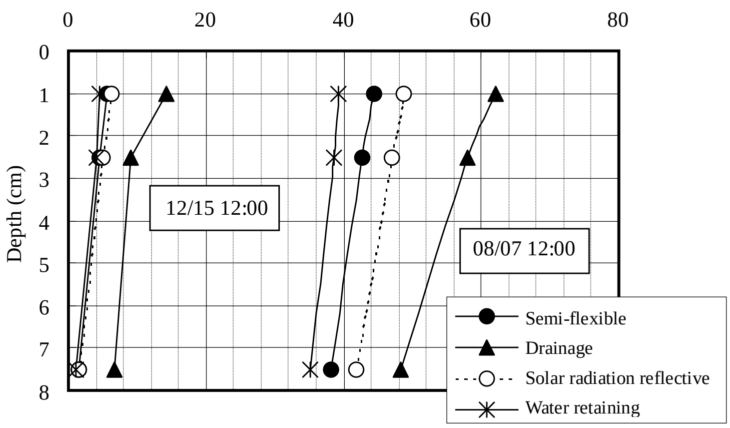

Figure 10: Example of Measurement of Inner Temperature of Pavement

Table 4: Storage of Heat in Pavement (Differences from the Drainage Pavement: $kJ/m^2 \cdot h$)

Type of pavement	Summer		Fall		Winter	
	Storage of heat	Difference	Storage of heat	Difference	Storage of heat	Difference
Drainage pavement	34,043	—	32,020	—	29,836	—
Semi-flexible pavement	33,224	805	31,318	656	29,473	363
Solar radiation reflective pavement	33,426	603	31,492	547	29,542	294
Water retaining pavement	32,911	1,119	31,145	894	29,435	401

From the table, it can be seen that in all the seasons, the differences in the storage of heat of water retaining pavement, semi-flexible pavement, and solar radiation reflective pavement are larger in this order. The storage of heat in semi-flexible pavement was almost the same as that in solar radiation reflective pavement, but the storage of heat in water retaining pavement is larger than that of the other two by about 25 to 40%. This is presumably because these differences in the storage of heat represent the effects of reducing the road surface temperature and heat source energy.

It has been reported that it is possible to decrease the sensory temperature by about 2.5ºC by reducing heat source energy of 1 MJ/m^2·h. However, it is considered to be necessary to further investigate and study how the amount of heat energy reduced affects the ambient temperature and sensory temperature.

6 SUMMARY

As a result of this study, the following findings were made:

1) The effects of road surface temperature-reducing pavement can be studied based on the reflectance, and as a rule, a temperature-reducing effect of about 10ºC can be obtained by setting the reflectance to 30% or more.
2) Water retaining pavement has a high road surface temperature-reducing effect because of its reflection and latent heat effects. In addition to the original effect, a temperature-reducing effect of about 5ºC or more (field test) can be expected when the reflectance is sufficient, and the maintenance of effects are improved .
3) The temperature-reducing effect of solar radiation reflective pavement is about 10ºC (laboratory test) when the reflectance is the same, and it can be used as a dark color temperature-reducing material.
4) The effects of road surface temperature-reducing pavement can be studied based on the storage of heat in pavement, and there is a need to recognize how this affects the ambient temperature and so on in the future.

About ten years have passed since the pavement technologies that reduce road surface temperature were begun to apply to actual roads. The problem of basic performance for pavement is hardly caused. And the durability in the effect of the road temperature decrease is about 3 to 5 years though it depends on the quantity of its decrease. The evaluation of the road temperature decrease on the actual roads is very difficult because the location of the building, traffic, and the weather etc. are different. The road surface temperature-reducing pavement is a technology effective to ease heat-island phenomena, which are one of the most serious environmental issues in urban areas, and it is considered to be important to quantify its effects and establish objective indicators to carry out evaluations.

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