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Heat Control of Pavement Surface Temperature Using Recycled Materials

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ABSTRACT

The developed heat reflective pavements are constructed from open-graded asphalt concrete in which voids in the upper part of the pavement are filled with a cement mortar containing recycled materials such as pottery debris, glass cullet, roof tile debris, or oyster shell lime. The temperature reduction of the pavement surfaces at an open site was evaluated experimentally by taking measurements in summer. The results show that the maximum surface temperature of the pavements fell by about 8–10°C compared with that of an asphalt concrete pavement. It was found that the temperature reduction was due particularly to the increased solar radiation reflectance of the pavement surface.

Keywords. Heat ReflectingPavement, Asphalt Concrete Pavement, Pavement Surface Temperature, Recycled Material, Filling Mortar

1 INTRODUCTION

Asphalt concrete pavements generally tend to absorb solar radiation heat because they are black, and the surface temperature can rise to a maximum of over 60°C during the day in summer. These high temperatures will affect the durability of the pavement as well as the heat island phenomenon in urban areas.

In Mie Prefecture, oyster farming is a prosperous industry and discharges a large quantity of oyster shells. Some of the shells are pulverized in a factory after removing salt and utilized as oyster shell lime. In a previous study, the authors reported that heat reflecting pavements using oyster shell lime reduced the surface temperatures by up to about 12°C compared with dense-graded pavements (Ishiguro and Yamanaka, 2010; Ishiguro and Yamanaka, 2011). Crushed escallop and coral sand were also shown to be useful as a fine aggregate for the filling mortar of heat reflecting pavements (Ishiguro and Yamanaka, 2012).

In this study, heat reflecting pavements using recycled materials such as crushed pottery debris, glass cullet, and roof tile debris have been developed. All of the recycled materials were produced at factories located in Mie Prefecture. The reduction in the pavement surface temperature was evaluated by field experiments.

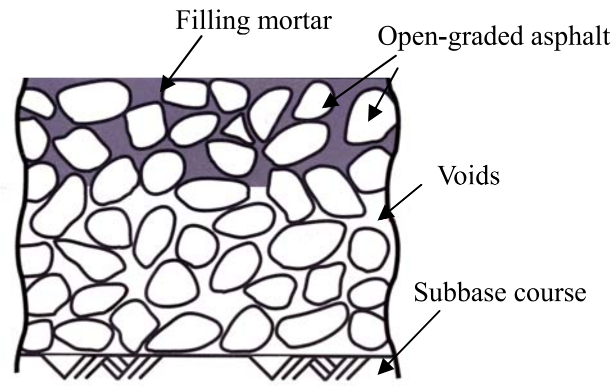

Figure 1.Cross section of the pavement.

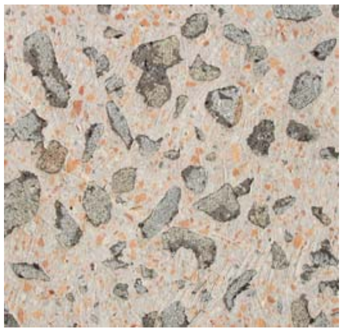

Figure2.Pavement surface patterns.

2 PAVEMENT STRUCTURES

A cross section of the pavement tested in this study is shown in Figure1. The 50-mm thick heat reflecting pavement is an open-graded asphalt concrete in which voids in the upper part of the pavement are filled with a cement mortar containing recycled materials. A maximum aggregate size of 20 mm is used for the open-graded asphalt concrete pavement. Figure2 shows the pavement surface patterns. The beautiful patterns are produced by grinding the pavement surface after the filling mortar has hardened. The results of a skid resistance test show that the British pendulum numbers(BPNs) of the pavements are larger than 45 and thus, the pavements have good skid resistance.

3 FILLING MORTAR PROPERTIES

Oyster shells, a waste product from oyster farming,are pulverized into a fine powder with a particle size of less than 2 mm to form the lime used as the fine aggregate for the filling mortar in this study. The other recycled materials such as the pottery debris, glass cullet, and roof tile debris are also pulverized into a fine powder with a particle size of less than 3 mm. Natural river sand is used as a control in this study. In the filling mortar mixture, Portland cement and the recycled materials are used as the binder and fine aggregate, respectively. Table 1 shows the properties of the filling mortars. As the pottery debris and oyster shell lime are lighter in color than the commonly used Portland cement, their inclusion in the mortar subsequently produces a mortar that is lighter in color. Consequently, the surface of the open-graded asphalt filled with this mortar has an increased solar reflectance, which results in a lower surface temperature.

Table 1.Properties of the filling mortars containing recycled materials

	Aggregate	Particle size (mm)	W/C (%)	Aggregate –cement ratio	Compressive strength (MPa)	
					7 days	28 days
A	Roof tile debris	0–3	95	2:1	16.1	25.9
B	Natural river sand	0–5	50	2:1	32.9	44.3
C	Pottery debris	0–3	83	2:1	17.0	27.0
D	Glass cullet	0–2.5	55	2:1	24.3	35.9
E	Oyster shell	0–2	110	2:1	6.97	9.61

4 FIELD EXPERIMENTS

The pavements were constructed at the university testing site located in Tsu city, Mie Prefecture, as shown in Figure3, to monitor the surface temperature in summer. The dense-graded pavement (F), with a maximum aggregate size of 20 mm, used as the control and the oyster shell section (E) were both constructed in June 2011. The heat reflecting pavements (A–D), filled with a cement mortar containing various recycled materials, were constructed in June 2012. The pavements are 50-mm thick and placed on a 100-mm-thick crushed stone bed. After the filling mortar in the heat reflecting pavementshad hardened, the surfaces were subject to grinding treatments. The temperature measurements were conducted in late July 2012 via thermocouples attached to the pavement surfaces; a data logger recorded the temperature at 1 min intervals. The air temperature and solar radiation intensity were monitored at the same time. There was no rainfall during the measurement period.

The temperature changes of the heat reflecting pavement surfaces are shown in Figure 4.

A: Roof tile debris section (0.75×0.75 m) B: Natural river sand section (0.75×0.75 m)
C: Pottery debris section (0.75×0.75 m) D: Glass cullet section (0.75×0.75 m)
E: Oyster shell section (1.5×1.5 m) F: Dense-graded asphalt section (1.5×1.5 m)

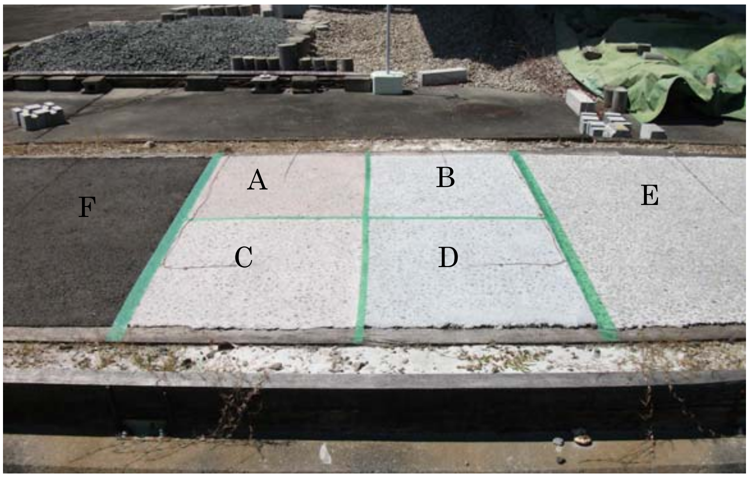

Figure3.View of the pavements.

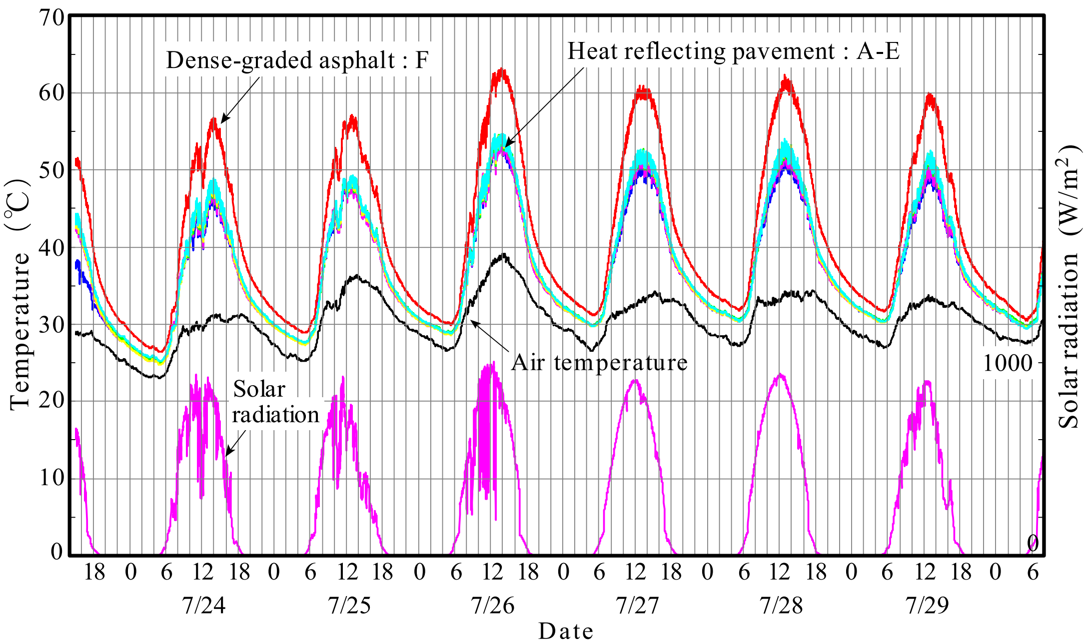

Figure4. Temperature changes on the pavement surface.

The surface temperature of the black dense-graded asphalt reached a maximum of 63.1°C on July 26, whereas the surface temperature of the heat reflecting pavements did not exceed 54.3°C. The heat reflecting pavements were up to about 9°C lower than that of the dense-graded pavement on a fine day. This temperature reduction is a result of the higher solar reflectance due to the lighter colored mortar. Consequently, this also leads to an increase in the durability of the pavement.

The maximum surface temperatures and temperature differences from that of the dense-graded pavement are summarized in Table 2. The maximum measured daily temperatures of the heat reflecting pavements fell by about 8–10°C compared with that of the dense-graded asphalt. The maximum temperature of the pavement using the pottery debris was a little lower than that using the other recycled materials. The variations in the temperature difference are partly due to the variations in the surface colors of each pavement. It was found that the heat reflecting pavement using natural river sand was effective in keeping the pavement cool in summer. The results of the field experiments show that the surface temperatures of the heat reflecting pavements under summer sunlight irradiation decreases both during the day and at night and that this acts to reduce the urban heat island effect.

Table 2. Maximum surface temperatures of the pavements

Date	Dense-graded asphalt(°C)	Heat reflecting pavement (°C) (Temperature difference)				
	F	A	B	C	D	E
2012.7.26	63.1	54.3 (−8.8)	54.2 (−8.9)	53.4 (−9.7)	53.5 (−9.6)	54.3 (−8.8)
2012.7.27	60.9	52.6 (−8.3)	52.3 (−8.6)	51.1 (−9.8)	51.8 (−9.1)	52.4 (−8.5)
2012.7.28	62.3	53.6 (−8.7)	53.6 (−8.7)	52.3 (−10.0)	52.7 (−9.6)	54.1 (−8.2)
2012.7.29	60.0	52.0 (−8.0)	51.8 (−8.2)	50.4 (−9.6)	50.8 (−9.2)	51.7 (−8.3)

Table 3. Skid resistance of the pavements (BPN)

Heat reflecting pavement					Dense-graded asphalt
A	B	C	D	E	F
73	80	77	77	79	86

The skid resistances of the pavements were tested in accordance with ASTME 303 (Standard Test Method For Measuring Surface Frictional Properties Using The British Pendulum Tester). The test results are summarized in Table 3 and show that the BPN value of the heat reflecting pavements are higher than the value of 45 required for highway use and that the pavements have good skid resistance.

5 CONCLUSIONS

Heat reflecting pavements using recycled materials have been developed, and the temperature reduction effect was evaluated by field experiments. The results of this study are summarized as follows.

1) The surface temperatures of the heat reflecting pavements are about 8–10°C lower than that of the dense-graded asphalt pavement. This is due particularly to the increase in the solar radiation reflectance.
2) The heat reflecting pavement filled with mortar containing pottery debris is lighter in color and has a higher solar reflectance compared with those of other recycled materials.
3) Beautiful patterns were produced by grinding the pavement surface after the filling mortar had hardened.
4) The heat reflecting pavements using recycled materials are environmentally friendly and contribute to promoting the effective use of waste products.

6 REFERENCES

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