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Effect on Surface Temperature Reduction of Asphalt Pavements with Cement–Based Materials Containing Ceramic Waste Powder

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***Abstract*—**The heat island phenomenon becomes one of the environmental problems. As countermeasures in the field of road engineering, cool pavements such as water retaining pavements and solar radiation reflective pavements have been developed to reduce the surface temperature of asphalt pavements in the hot summer climate in Japan. The authors have studied on the water retaining pavements with cement–based grouting materials. The cement–based grouting materials consist of cement, ceramic waste powder, and natural zeolite. The ceramic waste powder is collected through the recycling process of electric porcelain insulators. In this study, mixing ratio between the ceramic waste powder and the natural zeolite and a type of cement for the cement–based grouting materials is investigated to measure the surface temperature of asphalt pavements in the outdoor. All of the developed cement–based grouting materials were confirmed to effectively reduce the surface temperature of the asphalt pavements. Especially, the cement–based grouting material using the ultra–rapid hardening cement with the mixing ratio of 0.7:0.3 between the ceramic waste powder and the natural zeolite reduced mostly the surface temperature by 20 °C and more.

***Keywords*—**Ceramic waste powder, natural zeolite, road surface temperature, water retaining pavements.

I. INTRODUCTION

IN the urban area, asphalt and concrete pavements cover a high percentage and largely affect the development of the heat island phenomenon. The heat island phenomenon and hot nights when the temperature does not fall below 25 °C outdoors become environmental problems. In the hot summer climate, the surface temperature of conventional asphalt pavements reaches over 60 °C. As the countermeasure in the field of road engineering, cool pavements such as water retaining pavements and solar radiation reflective pavements with the surface temperature rise reducing function have been constructed. The water retaining pavement consists of open graded asphalt pavement (porous asphalt pavement) and a cement–based material poured into voids in the porous asphalt pavement. In general, the cement–based grouting material has high water absorption of, e.g., 40–80% by mass. The solar radiation reflective pavement is coated on the road surface by thin layer paint with a high solar reflectance. These cool pavements reduce the surface temperature by 10 °C and more, when compared with the surface temperature of the conventional asphalt pavement at 60 °C.

There are many reports on the cool pavements to improve the thermal conditions in the urban environment and to reduce the energy consumption [1]–[16]. Santamouris [10] and Qin [14] have reviewed on the actual developments using cool pavements to mitigate the urban heat island. Kinouchi et al. [4] have developed an asphalt pavement with high albedo and low brightness using an innovative paint coating. Their field measurements show that the maximum surface temperature of the paint–coated asphalt pavement is lower than that of the conventional asphalt pavement. Synnefa et al. [5], [9] have developed colored thin lay asphalt pavements with higher solar reflectance. Their results of field measurements show that an off–white asphalt sample having the highest solar reflectance has the greatest difference from the conventional asphalt sample. Nakayama and Fujita [8] have investigated on the surface temperature of water–holding pavements. The temperature of their water–holding block was 5–20 °C lower than that of the other engineered pavements after rain. On the other hand, the infinite use of resources to meet consumer demand in the growing economy will cause the continual increase in the industrial waste. Material recycling is an attractive solution in the industrial waste disposal because the availability of landfill is limited. Ceramic porcelain insulators discarded from electric power industries can also be industrial wastes. The authors [17], [18] have studied the utilization of ceramic waste aggregates for construction materials. In the recycling process of ceramic porcelain insulators through crushing and grinding, ceramic waste powder, which is collected by a dust chamber, also constitutes about 20% of the total mass of the ceramic waste. The authors [19], [20] have also investigated the utilization of ceramic waste powder as a part of components in water retaining pavements. In the previous field tests [19], cement, ceramic waste powder, and fly ash or natural zeolite were used for cement–based grouting materials. Then, the cement–based grouting materials reduce the surface temperature by 10 °C and more in the hot summer climate.

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In this study, to enhance the surface temperature rise reducing function, mixing ratio between the ceramic waste powder and the natural zeolite and a type of cement for the cement–based grouting materials are investigated through the measurements of their surface temperature using small samples in the outdoor.

II. CEMENT–BASED GROUTING MATERIALS

A. Materials and Mixtures

The cement–based grouting materials consist of cement (C), ceramic waste powder (CWP) supplied from The Kanden L&A Co., Ltd., Japan, and natural zeolite (NZ) produced in Izumo, Shimane, Japan. In this study, two types of cement, i.e., ultra–rapid hardening cement (UHC) ultra–rapid hardening cement (UHC) and high early strength Portland cement (HPC) produced by Sumitomo Osaka Cement Co., Ltd., Japan were used. The color is creamy in UHC and gray in HPC. The chemical and physical properties of the powder materials used are shown in Table I. The chemical composition of the UHC was not available due to confidential business information. The specific gravity and the specific surface area in Blaine of the CWP are 2.43 and 1810 cm^2/g. The particle size of the NZ was less than 200 μm. The specific gravity and the specific surface area in Blaine of the NZ are 2.30 and 6770 cm^2/g.

TABLE I
CHEMICAL AND PHYSICAL PROPERTIES

Properties	HPC	UHC	CWP	NZ
Chemical compositions (wt.%)				
SiO_2	20.42	NA	70.90	70.15
Al_2O_3	4.84	NA	21.10	12.28
Fe_2O_3	2.61	NA	0.81	1.16
CaO	65.26	NA	0.76	1.98
MgO	1.32	NA	0.24	0.53
SO_3	2.98	NA	–	–
Na_2O	0.23	NA	1.47	1.93
K_2O	0.37	NA	3.57	2.38
TiO_2	0.27	NA	0.33	0.17
P_2O_5	0.22	NA	–	–
MnO	0.07	NA	–	0.06
SrO	0.06	NA	–	–
S	–	NA	–	–
Cl	0.008	NA	–	–
Loss on ignition	1.18	0.80	–	9.25
Specific gravity	3.13	3.05	2.43	2.30
Specific surface area (cm^2/g)	4600	5230	1810	6770

For a water retaining pavement, the required ability of the cement–based grouting material poured into the porous asphalt pavement is principally fluidity and water absorption. The aim of this study is of the mixing ratio between the ceramic waste powder and the natural zeolite and a type of cement for the cement–based grouting materials. The mixture proportions of the cement–based grouting materials by mass ratio are shown in Table II. The mixing ratio between the ceramic waste powder and the natural zeolite was varied. The water–to–cement ratio (w/c) by mass was kept constant at 1.3 and 1.1 for the combination with and without the NZ, respectively, because the fluidity was controlled within a range of the flow time recommended by road constructors in Japan. The addition of the NZ decreased the fluidity due to the viscosity. Furthermore, when the UHC was used, an air entraining and high–range water reducing agent supplied from BASF Japan Ltd., Japan and a setting retarder were added to constitute 3% and 0.4% of the UHC by mass, respectively. The cement–based grouting materials were mixed by using an electric hand mixer with a mixing time of 3 min.

TABLE II
MIXTURE PROPORTIONS OF CEMENT–BASED GROUTING MATERIALS

Name	HPC	UHC	CWP	NZ
JG	–	0.50	0.50	–
JGZ0505	–	0.50	0.25	0.25
JGZ0703	–	0.50	0.35	0.15
HG	0.50	–	0.50	–
HGZ0703	0.50	–	0.35	0.15

B. Test Methods

A fluidity of the cement–based grouting materials was evaluated by the falling flow time, which was measured by a method using a P–type funnel with a volume of 1725 ml according to JSCE–F 521 [21]. The fluidity test was immediately carried out in a room at 20±2 °C and 60±10% RH after each cement–based grouting material was mixed.

A water absorption test was carried out on three cylindrical specimens of 50 mm diameter and 100 mm height for each cement–based grouting material. The water absorption test was conducted at 2 days for specimens using the UHC, and 4 days for specimens using the HPC. After the specimens were fully submerged in water for 1 h, they were dried in an oven under 60 °C for 24 h. Then, the water absorption ratio was calculated by using the mass difference before and after the oven–dry.

A compression test was carried out on three cylindrical specimens of 50 mm diameter and 100 mm height for each cement–based grouting material. The compression test was conducted at 3 days for specimens using the UHC, and 4 days for specimens using the HPC. The specimens were cured in a room at 20±2 °C and 60±10% RH until each test was conducted. A compressive load was applied by using a 500 kN capacity universal testing machine under a constant loading speed of 0.1 N/mm^2/s according to JSCE–G 505 [22].

C. Test Results of Cement–Based Grouting Materials

The test results of the cement–based grouting materials are shown in Table III. The flow time of each cement–based grouting material was within 9 to 13 s, which is a range of the flow time recommended by road constructors in Japan. They can be easily poured into voids in porous asphalt pavements. The maximum water absorption ratio was obtained in the specimen JGZ0703, and almost same level was observed in the specimen HGZ0703. The water absorption ratio of the other specimens was less than that of those specimens. It can be seen that the water absorption and the compressive strength are contrary to each other. The water absorption and the compressive strength were varied with the ratio between the CWP and the NZ, but no trend was observed in the mixing ratio of these materials. The compressive strength is recommended over 5 N/mm^2 for the traffic serviceability. From the compressive strength results, the curing time provided in this study sufficiently enables to open for traffic. When the cement–based grouting material is supplied for sidewalks and other area without heavy traffic loading, the opening can become earlier than the curing time provided in this study.

TABLE III
TEST RESULTS OF CEMENT–BASED GROUTING MATERIALS

Name	Flow time (s)	Water absorption ratio (%)	Compressive strength (N/mm^2)
JG	9.63	34.7	8.00
JGZ0505	10.67	37.7	7.62
JGZ0703	10.41	41.5	6.48
HG	10.85	29.3	7.45
HGZ0703	9.81	39.7	5.38

III. SURFACE TEMPERATURE MEASUREMENTS

A. Specimens and Test Method

In this study, 11 specimens of porous asphalt pavements with the size of 300 × 300 mm and the thickness of 50 mm were totally prepared. For the porous asphalt pavements, straight asphalt binder (ST60/80) was used, and its void ratio was designed as 23%. The surface temperature of each pavement was measured by a T–type thermocouple embedded at a depth of 5mm from the top surface. Each cement–based grouting material was poured into voids in the porous asphalt pavement and was vibrated on the surface. Finally, the surface was treated with a rubber rake. In this paper, the thermal performance of only six specimens listed in Fig. 1 including the porous asphalt pavement was reported. The results of the other five specimens with the addition of some color pigments will be shown in the near future.

The specimens were set at the rooftop of the research building of Kindai University at Yao, Osaka, Japan as shown in Fig. 2. Surroundings of each specimen except for the top surface were covered by styrene foam as a thermal insulator. To measure the atmospheric temperature, a T–type thermocouple was also fixed at a height of 1.5 m from the surface of the rooftop. The surface temperature of the specimens was recorded at 1 h intervals and monitored for sixty days from September 2 to October 31 in 2015.

B. Surface Temperature Distributions

The daily precipitation in September, 2015 recorded in Yao City, which was available from Japan Meteorological Agency, is shown in Fig. 3. In the beginning of September, eight days with the rain were recorded. Therefore, the surface temperature distributions of each pavement for six days without the rain from September 18 to 23 are shown in Figs. 4 (a)-(f). In Fig. 4 (a), the atmospheric temperature (AT) and the surface temperature of the porous asphalt pavement (PoAs) are presented. In the other figures, the surface temperature of each pavement with the cement–based grouting material and the porous asphalt pavement and the surface temperature difference between each pavement and the porous asphalt pavement are shown.

From Fig. 4 (a), during six days, the surface temperature of the porous asphalt pavement over 60 °C was recorded for one day. In Japan, a water retaining pavement is needed to reduce the surface temperature by 10 °C and more, as compared with a conventional asphalt pavement, which reaches over 60 °C. From Figs. 4 (b)-(f), these pavements with the cement–based grouting materials satisfy the surface temperature reduction by 10 °C and more. Especially, in the pavements using the UHC, the surface temperature reduction was observed by 20 °C and more. Furthermore, in October, 2015, no daily precipitation was continuing for 15 days (October 11 to 26). It can be said that the surface temperature reduction of the cement–based grouting materials developed in this study lasts without rain water or additional water sprinkling.

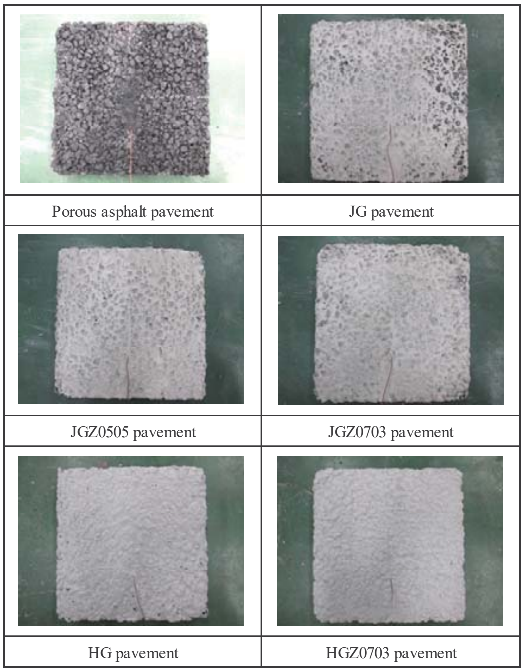

Porous asphalt pavement
JG pavement
JGZ0505 pavement
JGZ0703 pavement
HG pavement
HGZ0703 pavement

Fig. 1 List of specimens reported in this study

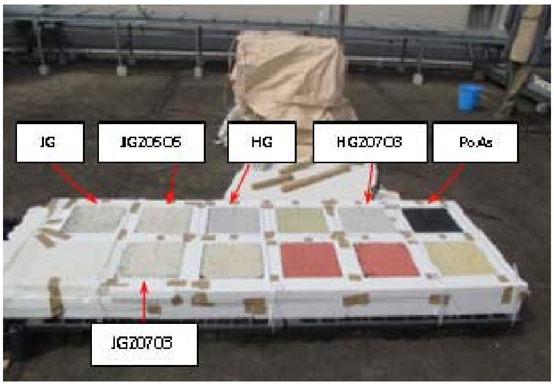


Fig. 2 Test set–up at the rooftop of the research building of Kindai University at Yao, Osaka, Japan

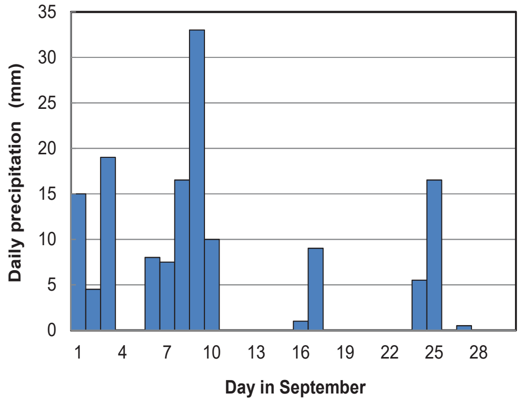
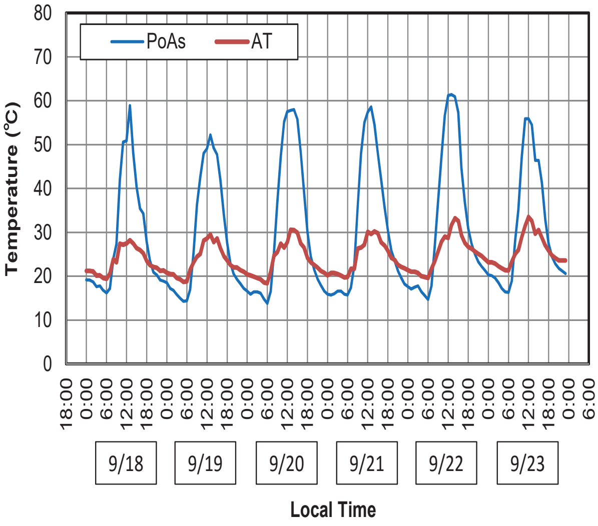
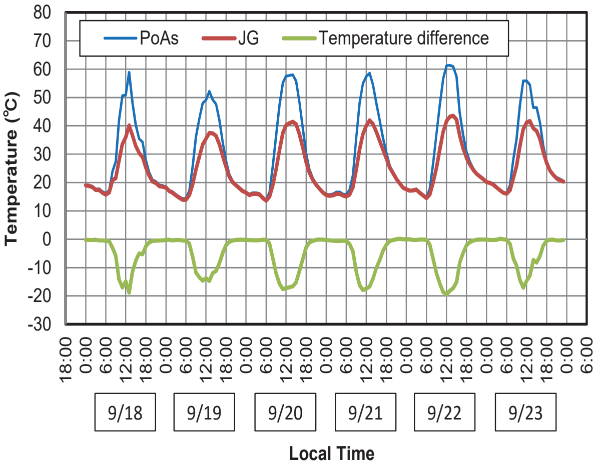


Fig. 3 Daily precipitation in September, 2015 recorded in Yao City



(a)



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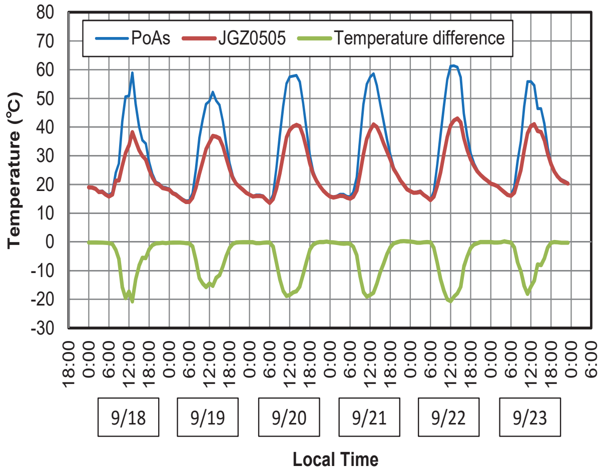

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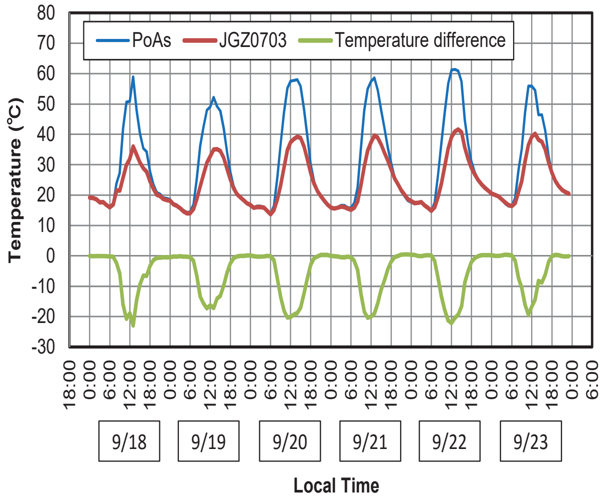

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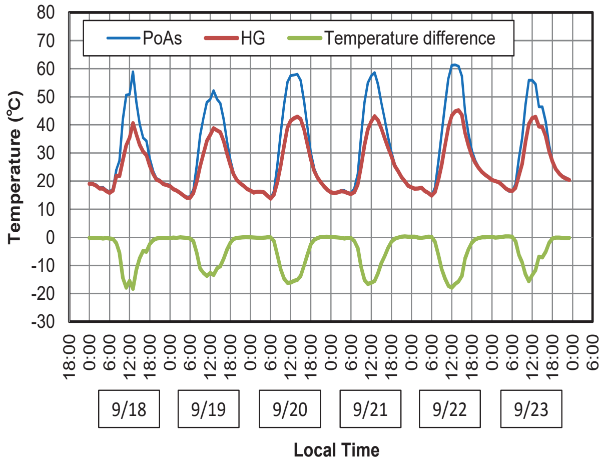
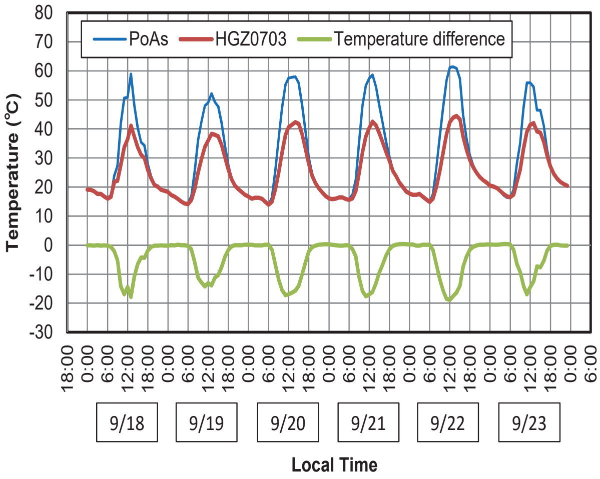
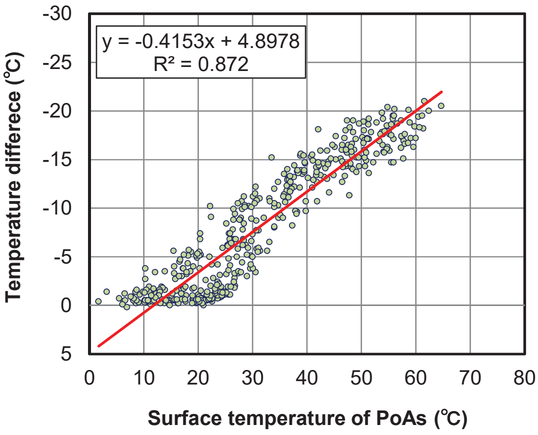


(e)

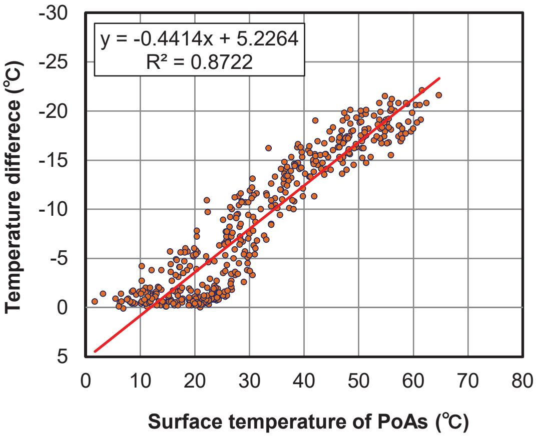


(f)

Fig. 4 Surface temperature and temperature difference distributions (a) Porous asphalt pavement and atmospheric temperature, (b) JG pavement, (c) JGZ0505 pavement, (d) JGZ0703 pavement, (e) HG pavement, and (f) HGZ0703 pavement



(a)



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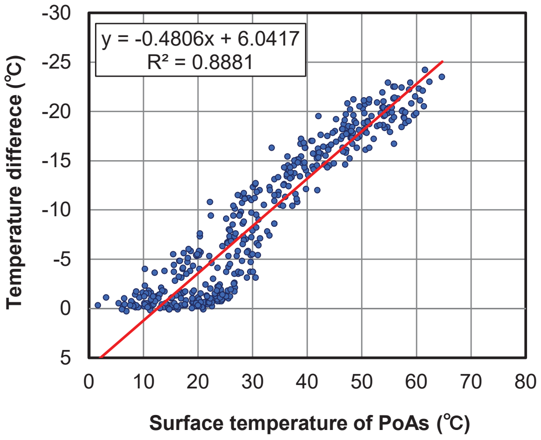
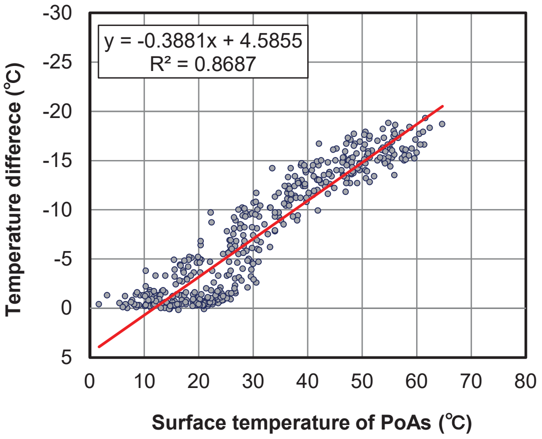


(c)



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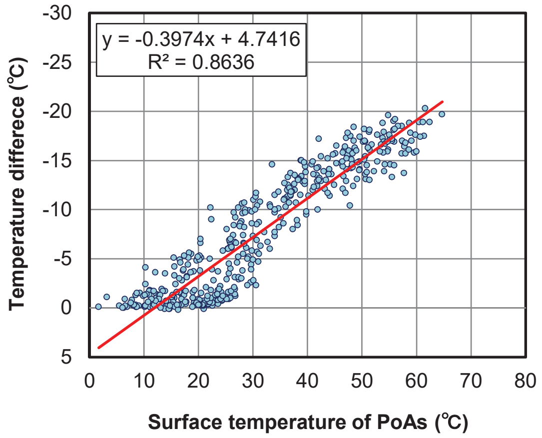

(e)

Fig. 5 Surface temperature difference between each pavement and the porous asphalt pavement (a) JG pavement, (b) JGZ0505 pavement, (c) JGZ0703 pavement, HG pavement, and (e) HGZ0703 pavement

C. Surface Temperature Properties

From the surface temperature distribution of each pavement during the test period from September 2 to October 31 in 2015, the surface temperature difference between each pavement and the porous asphalt pavement was calculated. The relationships between the surface temperature difference of each pavement and the surface temperature of the porous asphalt pavement from 6:00 A.M. to the time when the porous asphalt pavement recorded the maximum temperature in daytime are shown in Figs. 5 (a)-(e). It can be seen that the surface temperature difference and the surface temperature of the porous asphalt pavement have a linear trend for each pavement with the cement–based grouting material. These relationships were also observed in the previous field measurement [20]. From these relationships, the surface temperature of each pavement, when the surface temperature of the porous asphalt pavement is at 60 °C, reduces by 20.0 °C for JG, 21.3 °C for JGZ0505, 22.8 °C for JGZ0703, 18.7 °C for HG, 19.1 °C for HGZ0703. The high surface temperature reduction was observed. Particularly, the surface temperature of pavement using the UHC with creamy color was reduced more than that using the HPC with gray color. Furthermore, the addition of the NZ used, which is also creamy color, was effective solution for the surface temperature reduction. The efficiency of the surface temperature reduction depends on the higher solar reflectance [5], [6]. From the test results, the mixing ratio of 0.7:0.3 between the CWP and the NZ is suitable from the viewpoint of the thermal performance. On the other hand, from the economical viewpoint, the use of the HPC is effective, because the HPC is lower cost than the UHC. Consequently, it can be said that the pavements measured in this study contribute to the mitigation of the urban heat island and to improve the urban environment.

IV. CONCLUSIONS

In this study, the thermal performance of the asphalt pavements with the cement–based grouting materials was investigated through the outdoor tests. The following conclusions can be drawn.

1) All of the cement–based grouting materials tested were confirmed to effectively reduce the surface temperature of the asphalt pavement. Especially, the cement–based grouting material using the ultra–rapid hardening cement reduced the surface temperature by 20 °C and more, when the surface temperature of the porous asphalt pavement was at 60 °C.
2) From a range of the addition of the natural zeolite tested, the mixing ratio of 0.7:0.3 between the ceramic waste powder and the natural zeolite was suitable from the viewpoint of the thermal performance. From the economical viewpoint, the use of the high early strength Portland cement is also effective.
3) The cement–based grouting materials developed in this study have great potential in reducing the surface temperature and contribute to the mitigation of the urban heat island phenomenon. Also, the ceramic waste powder collected in the recycling process of the ceramic porcelain insulator wastes can be utilized.

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REFERENCES

[1] T. Gustavsson, “Variation in road surface temperature due to topography and wind”, *Theoretical and Applied Climatology*, vol. 41, 1990, pp. 227–236.

[2] N. K. Bansal, S. N. Garg, and S. Kothari, “Effect of exterior surface color on the thermal performance of buildings”, *Building and Environment*, vol. 27, 1992, pp. 31–37.

[3] T. Asaeda and V. T. Ca, “Characteristics of permeable pavement during hot summer weather and impact on the thermal environment”, *Building and Environment*, vol. 35, 2000, pp. 363–375.

[4] T. Kinouchi, T. Yoshinaka, N. Fukae, and M. Kanda, “Development of cool pavement with dar colored high albedo coating,” *In: Fifth Conference for the Urban Environment*, 2004.

[5] A. Synnefa, M. Santamouris, and I. Livada, “A study of the thermal performance of reflective coatings for the urban environment”, *Solar Energy*, vol. 80, 2006, pp.968–981.

[6] A. Synnefa, M. Santamouris, and K. Apostolakis, “On the development, optical properties and thermal performance of cool colored coatings for the urban environment”, Solar Energy, vol. 81, 2007, pp. 488–497.

[7] M. Scholz and P. Grabowiecki, “Review of permeable pavement systems”, *Building and Environment*, vol. 42, 2007, pp. 3830–3836.

[8] T. Nakayama and T. Fujita, “Cooling effect of water–holding pavements made of new materials on water and heat budgets in urban areas”, *Landscape and Urban Planning*, vol. 96, 2010, pp. 57–67.

[9] A. Synnefa, T. Karlessi, N. Gaitani, M. Santamouris, D. N. Assimakopoulos, and C. Papakatsikas, “Experimental testing of cool colored thin layer asphalt and estimation of its potential to improve the urban microclimate,” *Building and Environment*, vol. 26, 2011, pp. 38–44.

[10] M. Santamouris, “Using cool pavements as a mitigation strategy to fight urban heat island–A review of the actual developments,” *Renewable and Sustainable Energy Review*, vol. 26, 2013, pp. 224–240.

[11] D. Yinfei, S. Qin, and W. Shengyue, “Highly oriented heat–induced structure of asphalt pavement for reducing pavement temperature”, *Energy and Buildings*, vol. 85, 2014, pp. 23–31.

[12] M. Hendel, M. Colombert, Y. Diab, and L. Royon, “Improving a pavement–watering method on the basis of pavement surface temperature measuremnts”, *Urban Climate*, vol. 10, 2014, pp. 189–200.

[13] Y. Qin and J. E. Hiller, “Understanding pavement–surface energy balance and its implications on cool pavement development”, *Energy and Buildings*, vol. 85, 2014, pp. 389–399.

[14] Y. Qin, “A review on the development of cool pavements to mitigate urban hear island effect”, *Renewable and Sustainable Energy Reviews*, vol. 52, 2015, pp. 445–459.

[15] M. Hendel and L. Royon, “The effect of pavement–watering on subsurface pavement temperatures”, *Urban Climate*, vol. 14, 2015, pp. 650–654.

[16] J. Yang, Z. H. Wang, and K. E. Kaloush, “Environmental impacts of reflective matrerials: Is high albedo a ‘silver bullet’ for mitigating urban heat island?”, *Renewable and Sustainable Energy Reviews*, vol. 47, 2015, pp. 830–843.

[17] H. Higashiyama, M. Sappakittipakorn, M. Sano, O. Takahashi, and S. Tsukuma, “Charateristics of chloride ingress into mortars containing ceramic waste aggregate,” *Journal of Material Cycles and Waste Management*, vol. 17, no. 3, 2015, pp. 513–521.

[18] H. Higashiyama, M. Sappakittipakorn, M. Mizukoshi, and O. Takahashi, “Mechanical properties and chloride diffusion of ceramic waste aggregate mortar containing ground granulated blast-furnace,” *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, vol. 9, no. 9, pp. 843–848.

[19] H. Higashiyama, M. Sano, F. Nakanishi, O. Takahashi, and S. Tsukuma, “Development of water absorption asphalt pavement having surface temperature rise reducing function and verification by field tests,” *Hosou, Kensetsutosho*, vol. 51, no. 1, 2016, pp. 19–23 (in Japanese).

[20] H. Higashiyama, M. Sano, F. Nakanishi, O. Takahashi, and S. Tsukuma, “Field measurements of road surface temperature of several asphalt pavements with temperature rise reducing function”, *Case Studies in Construction Materials*, vol. 4, 2016, pp. 73–80.

[21] Japan Society and Civil Engineering, “Test method for flowability of grout mortar for prepacked concrete (P–type funnel method), JSCE–F 521–1999,” *Standard Specifications for Concrete Structures*, *Test Methods and Specifications*, 2005, p. 209 (in Japanese).

[22] Japan Society and Civil Engineering, “Test method for compressive strength of mortar and cement paste sing cylindrical specimens, JSCE–G 505–1999,” *Standard Specifications for Concrete Structures*, *Test Methods and Specifications*, 2005, pp. 247– 248 (in Japanese).