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Surface Temperature of Asphalt Pavements with Colored Cement-Based Grouting Materials Containing Ceramic Waste Powder and Zeolite

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***Abstract*—**The heat island phenomenon and extremely hot summer climate are becoming environmental problems in Japan. Cool pavements reduce the surface temperature compared to conventional asphalt pavements in the hot summer climate and improve the thermal environment in the urban area. The authors have studied cement–based grouting materials poured into voids in porous asphalt pavements to reduce the road surface temperature. For the cement–based grouting material, cement, ceramic waste powder, and natural zeolite were used. This cement–based grouting material developed reduced the road surface temperature by 20 °C or more in the hot summer season. Considering the urban landscape, this study investigates the effect of surface temperature reduction of colored cement–based grouting materials containing pigments poured into voids in porous asphalt pavements by measuring the surface temperature of asphalt pavements outdoors. The yellow color performed the same as the original cement–based grouting material containing no pigment and was thermally better performance than the other color. However, all the tested cement–based grouting materials performed well for reducing the surface temperature and for creating the urban landscape.

***Keywords*—**Ceramic waste powder, natural zeolite, road surface temperature, asphalt pavements, urban landscape.

I. INTRODUCTION

ASPHALT and concrete pavements cover a high percentage of many urban areas and largely affect development of the heat island phenomenon and the hot nights when the temperature does not fall below 25 °C outdoors. In the hot summer climate, the surface temperature of asphalt pavements reaches over 60 °C. The road researchers and engineers have investigated and assessed the effect of surface temperature reduction on cool pavements. The water retaining pavements are open-graded asphalt pavements with a cement–based material poured into their voids. The cement–based grouting material has high water absorption to store water inside the material [1], [2]. On the other hand, the solar radiation reflective pavements are coated on the surface by using thin layer paint with a high solar reflectance [1], [2]. In Japan, it is usually defined that these cool pavements reduce the surface temperature by 10 °C or more, when compared with the conventional asphalt pavement with its surface temperature reaching 60 °C.

Many researches on the cool pavements to improve the thermal conditions in the urban environment and to reduce the energy consumption have been reported in the literature [1]–[19]. Santamouris [1] and Qin [2] have reviewed developments of the cool pavements to mitigate the urban heat island. Kinouchi et al. [6] have developed the paint–coated asphalt pavement with high albedo and low brightness using an innovative paint coating whose surface temperature is lower than that of the conventional asphalt pavement. Synnefa et al. [7], [11] have reported that the surface temperature of the off–white asphalt specimen with the highest solar reflectance was lower than the other colored asphalt specimens. They showed the difference in the solar reflectance of colored thin layer asphalt pavements. The use of cooling materials in the urban areas can contribute to the mitigation of the urban heat island [1], [2]. On the other hand, the authors have studied the utilization of ceramic waste materials discarded from electric power industries. Ceramic waste porcelain insulators are crushed and grinded into aggregates for construction materials [20], [21]. In the crushing and grinding processes, ceramic waste powder (CWP) is produced to constitute about 12% of the total mass of the ceramic waste porcelain insulators. The authors have also investigated the use of this CWP as a component of a certain type of water retaining pavements [22]–[24]. In the previous studies [22], [23], the cement–based grouting materials consisting of cement (C), CWP, and fly ash (FA) or natural zeolite (NZ) were poured into voids in the porous asphalt pavement, and the surface temperature was measured. Then, the cement–based grouting materials reduced the surface temperature by 10 °C or more in the summer season. After that, to reduce the surface temperature rise more, the mixing ratio of the CWP and the NZ in the cement–based grouting materials was investigated through measurements of their surface temperature using small samples in the outdoor environment [24]. The mixing ratio of 0.7:0.3 between the CWP and the NZ was suitable from the viewpoint of the thermal performance of the cement–based grouting material. In this study, pigments were added to the cement–based grouting materials and mixed to prepare colored cement–based grouting

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materials with material variations for the urban landscape design. After that, the surface temperature measurements in the outdoor environment were carried out as in the previous study [24].

II. COLORED CEMENT–BASED GROUTING MATERIALS

A. Materials and Mixtures

The materials used for the cement–based grouting material in this study were an ultra–rapid hardening cement (UHC) produced by Sumitomo Osaka Cement Co., Ltd., Japan, CWP supplied from The Kanden L&A Co., Ltd., Japan, and natural zeolite produced in Izumo, Shimane, Japan. The chemical and physical properties of the CWP and the NZ used are shown in Table I. 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 is 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	CWP	NZ
Chemical compositions (wt.%)		
SiO_2	70.90	70.15
Al_2O_3	21.10	12.28
Fe_2O_3	0.81	1.16
CaO	0.76	1.98
MgO	0.24	0.53
SO_3	–	–
Na_2O	1.47	1.93
K_2O	3.57	2.38
TiO_2	0.33	0.17
P_2O_5	–	–
MnO	–	0.06
SrO	–	–
S	–	–
Cl	–	–
Loss on ignition	–	9.25
Specific gravity	2.43	2.30
Specific surface area (cm^2/g)	1810	6770

For a cement–based grouting material poured into the porous asphalt pavement, the required ability is principally fluidity and water absorption. In the previous study [24], the mixing ratio of 0.7:0.3 between the CWP and the NZ was found effective for the surface temperature reduction. Also, the water–to–cement ratio (w/c) by mass was kept constant at 1.3 because the fluidity was controlled within the range of flow times (9 to 13 s) recommended by road constructors in Japan. Furthermore, when the UHC was used, the workability during infiltration should be needed due to its quick chemical reaction and hardening. Therefore, an air entraining and high–range water reducing agent and a setting retarder were added to constitute 3% and 0.4% of the UHC by mass, respectively as with the previous study [24]. In this study, to prepare colored cement–based materials, red, yellow, blue and green, each pigment was added by 2% of the UHC by mass and then mixed. The cement–based grouting materials were mixed by using an electric hand mixer with a mixing time of 3 min.

B. Test Methods

The fluidity of the cement–based grouting materials was evaluated by the falling flow time using a P–type funnel with a volume of 1725 ml according to JSCE–F 521 [25]. The fluidity test was immediately carried out in a room at 20±2 °C and 60±10% RH or in an ambient room temperature after each cement–based grouting material was mixed.

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

A compression test was carried out on three cylindrical specimens of 50 mm in diameter and 100 mm in height with each cement–based grouting material by using a 500 kN capacity universal testing machine. The compression test was conducted at the age of three days. A compressive load was applied at a constant stress speed of 0.1 N/mm^2/s according to JSCE–G 505 [26].

TABLE II
TEST RESULTS OF CEMENT–BASED GROUTING MATERIALS

Name	Flow time (s)	Water absorption ratio (%)	Compressive strength (N/mm^2)
JGZ	9.63	34.7	8.00
JGZ-Red	10.08	42.6	5.85
JGZ-Yellow	9.86	42.9	5.49
JGZ-Blue	–	37.9	3.76
JGZ-Green	–	37.8	4.05

C. Test Results of Colored Cement–Based Grouting Materials

The test results of the colored cement–based grouting materials including without any pigment are shown in Table II. The flow time of each cement–based grouting material except the JGZ–Blue and the JGZ–Green was within 9 to 13 s, which satisfied the range of flow times recommended by road constructors in Japan. All the cement–based grouting materials, including the JGZ–Blue and the JGZ–Green, were easily poured into voids in the porous asphalt pavement. The maximum water absorption was observed for the JGZ–Red and the JGZ–Yellow. In contrast, the maximum compressive strength was observed for the JGZ [24]. Generally, the water absorption and the compressive strength contradict each other. However, in these test results, its trend was not observed. The compressive strength over 5 N/mm^2 is recommended for the serviceability in the traffic road. However, in this study, the colored cement–based grouting materials are intended for use in sidewalks and other area without traffic loading, considering the urban landscape. Therefore, it can be said that the compressive strength is not particularly limited.

III. SURFACE TEMPERATURE MEASUREMENTS

A. Specimens and Test Method

Porous asphalt pavements with the size of 300 × 300 mm and the thickness of 50 mm were prepared, in which a straight asphalt binder, ST60/80, was used, and the void ratio was designed to be 23%. Before pouring each cement–based grouting material, a T–type thermocouple was embedded in each pavement at a depth of 5 mm from the top surface to measure the surface temperature of each pavement. After that, each cement–based grouting material was poured into voids in the porous asphalt pavement and vibrated on the surface. Finally, the surface was treated with a rubber rake to observe the aggregates. In this paper, the thermal performance of six specimens listed in Fig. 1 including the porous asphalt pavement (PoAs) was reported.

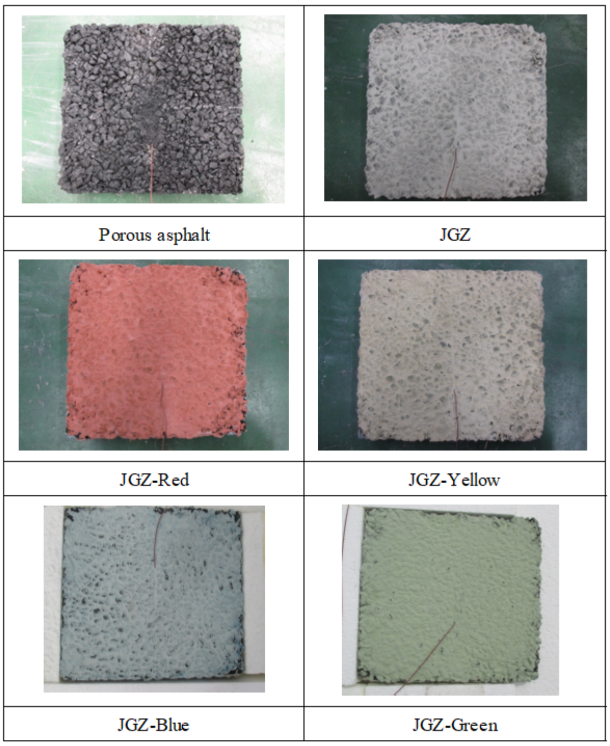


Fig. 1 List of specimens reported in this study

The specimens were placed at the rooftop of the research building of Kindai University in Yao, Osaka, Japan as shown in Fig. 2. The surroundings of each specimen except the top surface were covered by styrene foam as a thermal insulator. To measure the atmospheric temperature (AT), a T–type thermocouple was 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 25 days from July 16 to August 9 in 2016. Herein, specimens of PoAs, JGZ, JGZ–Red and JGZ–Yellow were prepared in 2015 and their surface temperature measurements started from September 2 in 2015 and continued until this work is conducted. The measuring results were partially reported in [24]. Specimens of JGZ–Blue and JGZ–Green were prepared in 2016 and measured together with the other specimens.

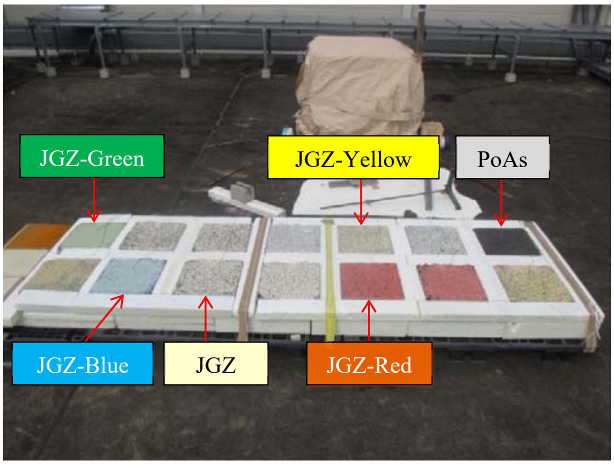


Fig. 2 Test setup at the rooftop of the research building at Kindai University in Yao, Osaka, Japan

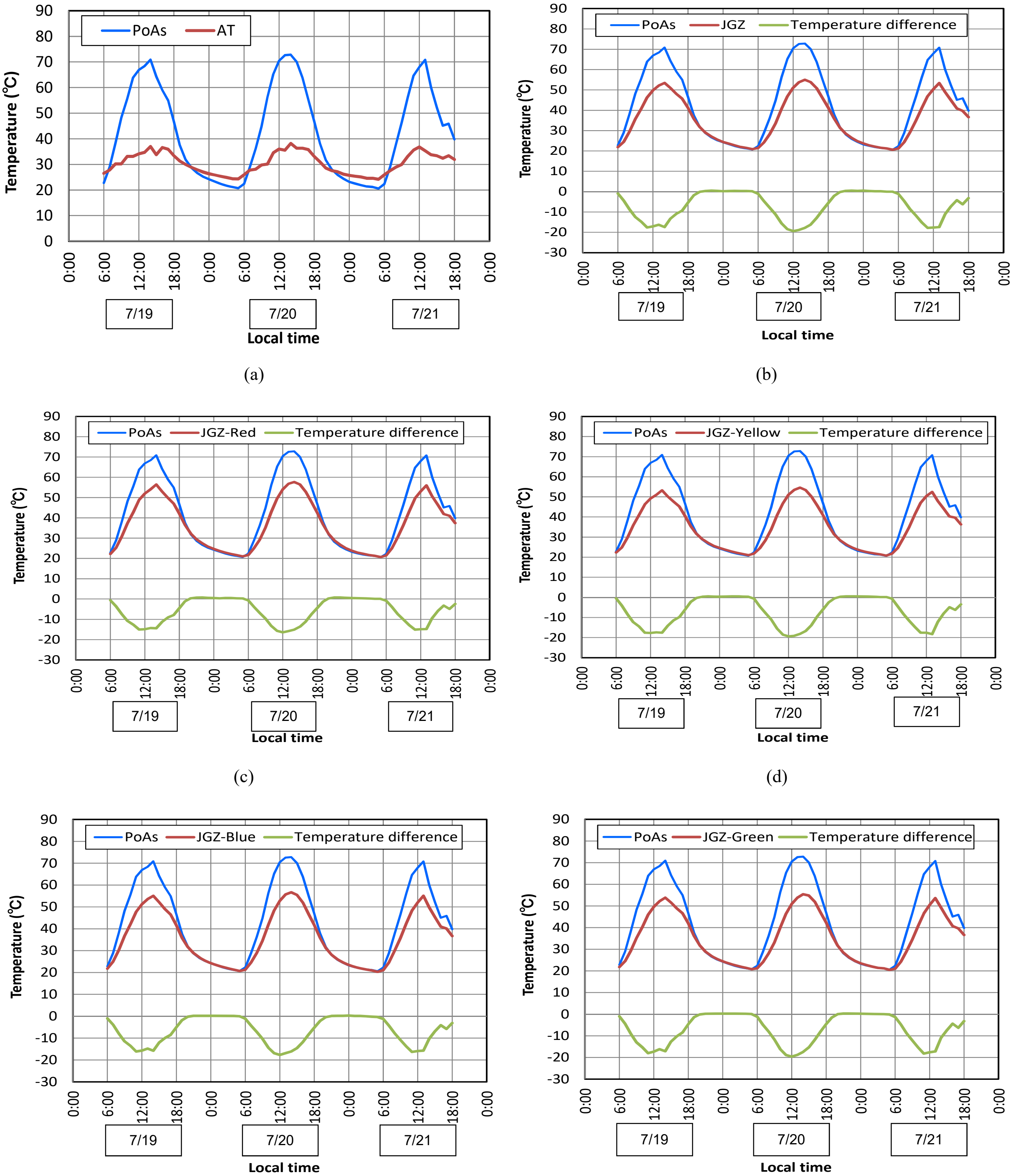
B. Surface Temperature Distributions

The rainfall was recorded for only five days during the measurements from July 16 to August 9 in 2016 in Yao City, Osaka, Japan. In this summer, extremely hot days at temperature over 35 °C or greater continued. The surface temperature distributions of each specimen, for example, for three days from July 19 to 21 without rainfall, are shown in Fig. 3. In Fig. 3 (a), the PoAs and the AT are presented. In the other figures, the surface temperature of each specimen with the cement–based grouting material and the PoAs and the surface temperature difference between each specimen and the PoAs are shown. The surface temperature distributions in the colored cement–based grouting material are almost the same as those in the JGZ without any pigment.

From Fig. 3 (a), the surface temperature of the PoAs was recorded over 70 °C due to the extremely hot days. In Japan, cool pavements such as water retaining pavements and solar radiation reflective pavements are needed to reduce the surface temperature by 10 °C or more, as compared with a conventional asphalt pavement, which is at 60 °C. From Figs. 3 (c)-(f), these specimens with the colored cement–based grouting materials achieve the surface temperature reduction by 10 °C or more. It can be said that the colored cement–based grouting materials developed have almost same performance on the surface temperature reduction with the JGZ of the original cement–based grouting material as shown in Fig. 3 (b).

C. Surface Temperature Differences

From the surface temperature distribution of each specimen during the measuring period from July 16 to August 9 in 2016, the temperature difference between each pavement and the PoAs was calculated. The relationships between the surface temperature difference of each specimen and the surface temperature of the PoAs are shown in Fig. 4. For the specimens of JGZ, JGZ–Red, and JGZ–Yellow, the temperature difference measured from September 2 to October 31 in 2015 is also shown in each figure. The temperature difference shown in those figures is in the period from 6:00 AM to when the PoAs recorded the maximum temperature in daytime. It can be seen that the surface temperature difference and the surface temperature of the PoAs have a linear trend for each specimen with the cement–based grouting material. These relationships were also observed in the previous study [22], [23].



(a)

(b)

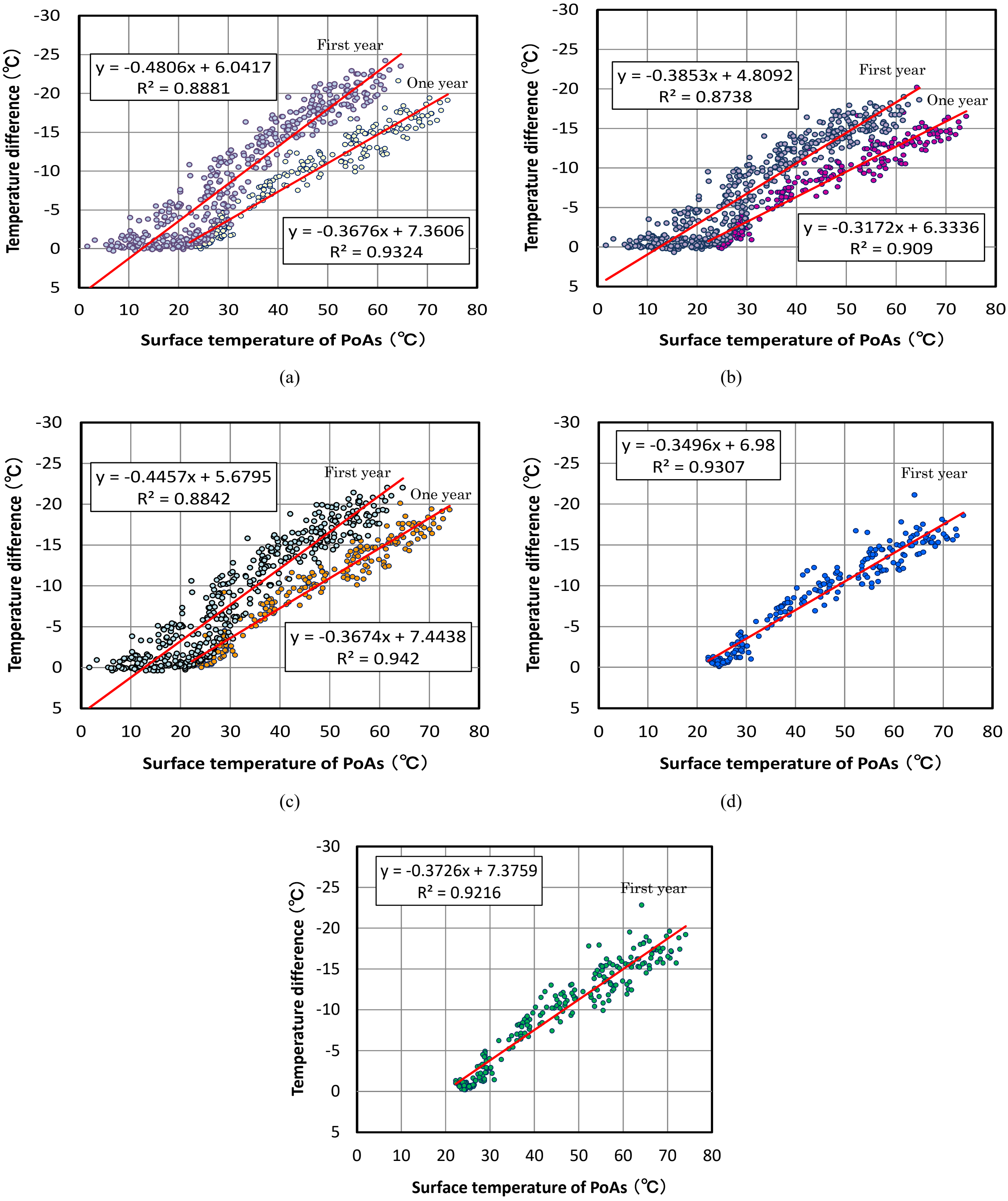
(c)

(d)

(e)

(f)

Fig. 3 Surface temperature and temperature difference distributions (a) PoAs and AT, (b) JGZ, (c) JGZ–Red, (d) JGZ–Yellow, (e) JGZ–Blue, and (f) JGZ–Green



(a)

(b)

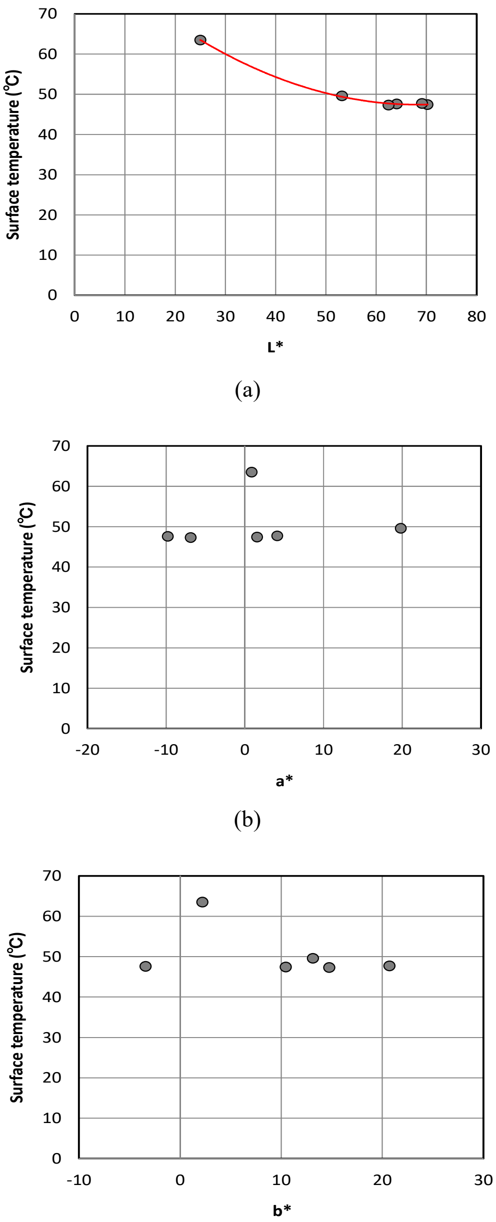
(c)

(d)

(e)

Fig. 4 Surface temperature difference between each specimen and the PoAs (a) JGZ, (b) JGZ–Red, (c) JGZ–Yellow, (d) JGZ–Blue, and (e) JGZ–Green

From these relationships, the surface temperature of each specimen, when the surface temperature of the PoAs is at 60 °C, reduces by 14.7 °C for JGZ, 12.7 °C for JGZ–Red, 14.6 °C for JGZ–Yellow, 14.0 °C for JGZ–Blue, and 15.0 °C for JGZ–Green in 2016. When the surface temperature reduction of the JGZ, JGZ–Red, and JGZ–Yellow in 2015 is compared with that in 2016, unfortunately, the effect of the surface temperature reduction decreased by 8.1 °C for JGZ, 5.6 °C for JGZ–Red, and 6.5 °C for JGZ–Yellow as shown in Figs. 4 (a) to (c). This might be due to the ageing deterioration such as the color change on the specimen surface. As reported in [11], the off–white color having the high solar reflectance appears to have the lower temperature than the other colors, such as yellow, beige, red, and green. In the measurement conducted after one year, the yellow color still shows the same temperature reduction as the JGZ. Although the blue and green colors showed a better reduction in the first year, the effect of the surface temperature reduction due to the ageing deterioration will be continuously observed for these specimens.



(a)

(b)

(c)

Fig. 5 Surface temperature and color measurements (a) L* (lightness), (b) a* (redness–greenness), and (c) b* (yellowness–blueness)

D. Color Space Values and Surface Temperature

The CIElab color space expressed in L*a*b* on the surface of each specimen was measured by using the color–difference meter (CR-20 Color Reader, KONICA MINOLTA) to study the relationships between the color space and the surface temperature. The L* value indicates the lightness from black to white. The a* and b* values represent redness–greenness and yellowness–blueness, respectively. The color measurements of the specimen surface with the surface temperature of each specimen at the same time are listed in Table III. The color data are the average of five independent measurements and values of the reference white. Furthermore, the relationships between the surface temperature and the color data are shown in Fig. 5.

From Fig. 5 (a), there is a certain trend that the surface temperature nonlinearly decreases with the lightness, but the surface temperature of specimens using the cement–based grouting materials had almost the same values as shown in Table III. In contrast, the surface temperature has no trend with the a* and b* values as shown in Figs. 5 (b) and (c), respectively. The color measurement and the surface temperature measurement will be continuously carried out to study the ageing deterioration in the future.

TABLE III
SURFACE TEMPERATURE AND COLOR SPACE VALUES

Name	Surface temperature (°C)	L*	a*	b*
PoAs	63.5	25.0	0.9	2.2
JGZ	47.4	70.2	1.6	10.5
JGZ-Red	49.6	53.2	19.8	13.1
JGZ-Yellow	47.7	69.1	4.1	20.7
JGZ-Blue	47.6	64.1	-9.8	-3.4
JGZ-Green	47.3	62.5	-6.9	14.8

IV. CONCLUSIONS

In this study, the thermal performance of the asphalt pavements with the colored cement–based grouting materials was investigated for creating the urban landscape through the outdoor tests. The main conclusions are:

(1) The colored cement–based grouting materials achieved the surface temperature reduction by 10 °C or more, when compared with a porous asphalt pavement at 60 °C. The colored cement–based grouting materials have the better performance on the surface temperature reduction.

(2) However, for the JGZ, JGZ–Red, and JGZ–Yellow, which were measured for one year, the effect of the surface temperature reduction decreased. It might be due to the ageing deterioration such as the color change on the specimen surface.

(3) The results of the color space L*a*b* measured with the color–difference meter revealed a trend that the surface temperature nonlinearly decreased with the lightness. However, the surface temperature of specimens using the cement–based grouting materials developed in this study showed almost the same values. In contrast, the surface temperature had no trend with the a* and the b* values. The color measurement, including the surface temperature measurements, will also be continuously carried out to

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study the ageing deterioration in the future.

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