4.7 DEVELOPMENT OF COOL PAVEMENT WITH DARK COLORED HIGH ALBEDO COATING

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1. INTRODUCTION

It is considered that the dark surface of buildings and pavements is one of the major heat source causing the urban heat islands, as it absorbs more heat from the sun. In Japan, several kinds of cool pavement have been developed and their cooling effects were investigated. However, they have never been widely used in practice due to a limited effect in mitigating urban thermal environment.

Some of the heat island mitigation studies deal with the albedo increase of road and building surfaces (Sailor, 1995). It is not difficult to raise the albedo of the building roof as it can be attained by bright colored painting. For pavements, however, the brighter surface is not allowable for reasons of driving safety and visibility of white line, unless the brightness is less than that of the conventional asphalt and concrete pavements.

In this study, a new type of pavement is developed to satisfy both high albedo and low brightness by introducing the paint coating technology. By applying newly developed durable paint coating with high albedo and low brightness to the conventional asphalt pavement, the effectiveness of reducing pavement temperature and sensible heat flux is investigated by field measurements. Then, the impact of introducing high albedo pavement on the overall canopy albedo, canopy surface temperature and energy balance was investigated by applying canopy energy balance model in a real urban canopy setting.

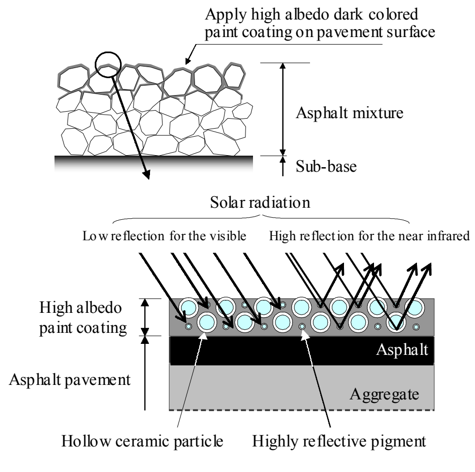

Fig.1. Schematic view of paint-coated asphalt pavement

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2. DEVELOPMENT

2.1 *Concept*

A new type of pavement is developed to satisfy both high albedo and low brightness with the innovative paint coating technology. The function of this pavement is based on a thin paint coating on the surface of the conventional dark asphalt pavement, which gives quite high reflectivity for the near infrared and low reflectivity for the visible (Figure 1). This results in the dark colored pavement surface while achieving much higher albedo. The fine hollow ceramic particles are included in the paint to expect additional effects on reducing thermal conduction and heating of the coat.

As the high brightness of road surfaces deteriorates the visibility of painted lane markings, the target brightness as represented by the L* value (a brightness index) is set to approximately 40 and under.

2.2 *Results of laboratory experiment*

In the laboratory experiments, trial paint coatings of more than a hundred types with the combination of different pigments and modifiers were tested. By this procedure, we found some types of pigment and paint coating structure are effective in achieving higher reflectivity, lower brightness and suppressing the surface temperature.

The reflectivity is measured for a number of metal plates coated with different types of paint. The highest albedo was more than 50% with the L* value around 40. Figure 2 indicates the reflectivity with wavelength

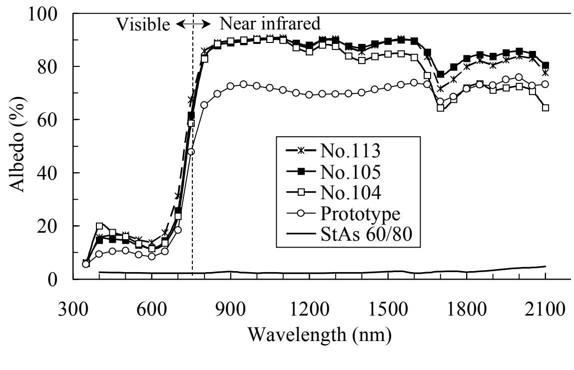

Fig.2. Reflectivity with wavelength

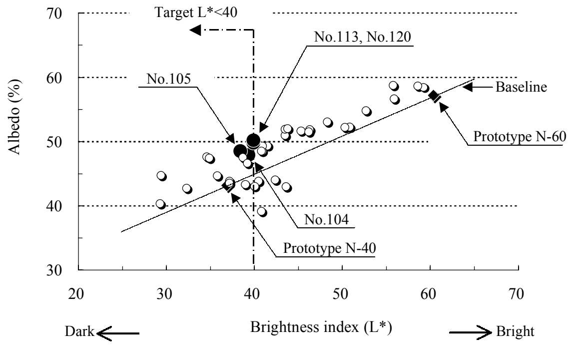

Fig.3. Relation between L* value and albedo

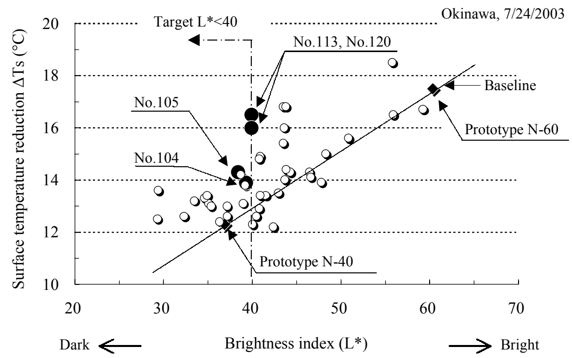

Fig.4. Relation between L* value and surface temperature reduction (ΔTs)

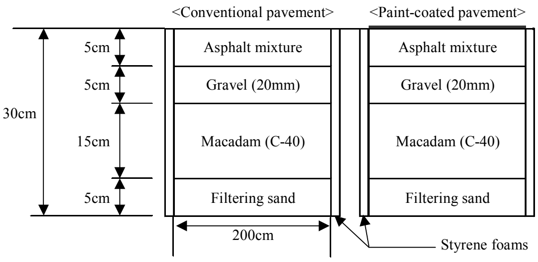

Fig.5. Schematic diagram of vertical structure

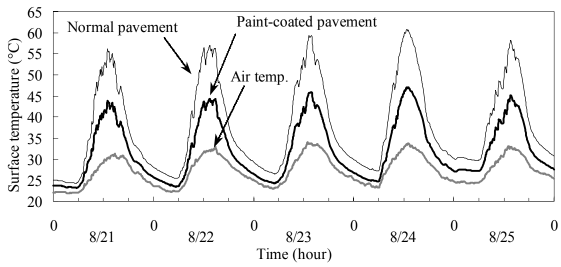

Fig.6. Surface temperature variation of conventional and developed asphalt pavement in August, 2003.

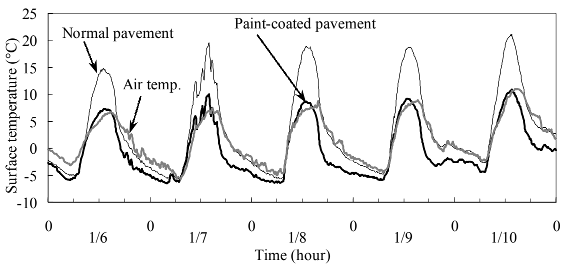

Fig.7. Surface temperature variation of conventional and developed asphalt pavement in January, 2003.

for selected trial paint coatings. The reflectivity is low for the visible and it changes significantly across the wavelength 750nm, achieving stably high reflectivity beyond it. The results indicate that the average reflectivity of No.113, for example, is 86% for the near infrared (750-2100nm wavelength) and 23% for the visible (350-750nm). The albedo and the L* value of those selected coatings range from 44 to 51% and 37 to 41, respectively.

The trial plates underwent the ultra-violet radiation exposure test, which enables the evaluation of changes in color, brightness and reflectivity after the exposure to the ultra-violet radiation for the duration equivalent to 3,000 hours. It is found that the changes in albedo and the L* value are very limited.

2.3 *Field measurement*

The temperatures of asphalt coated by selected paints were measured in the field yards located in Tsukuba and Okinawa, the latter has been exposed to larger solar radiation. In the Okinawa field measurement, test pieces with dimensions of 30cm square and 5cm thick were placed on existing asphalt surfaces. The surface temperature was continuously measured using thermocouples.

Figure 3 summarizes the relation between the L* value and corresponding albedo for each coating of the test piece. Two prototypes are the initially developed coatings, and other circles represent further developed test coatings. Blacked circles are considered to have high quality in terms of brightness and albedo. The maximum reduction of surface temperature for each piece (ΔTs) from the conventional asphalt pavement on a sunny clear day (24th of July, 2003) was plotted against the L* value (Figure 4). It is judged that pieces labeled as No.104, 105, 113 and 120 exhibit relatively high performance in reducing the surface temperature.

Another field measurement has been conducted in Tsukuba City located about 50 km north-east of Tokyo. Larger test pieces with more realistic layered structure were installed as shown in Figure 5. Meteorological elements such as solar radiation, atmospheric radiation, air temperature, relative humidity and wind velocity at a height of 300 cm above the pavement were measured along with the substrate temperatures at several depths in the pavement.

It is found that the paint-coated asphalt pavement shows about 15°C lower surface temperature than that of the conventional one at the maximum (Figure 6). It must be noted that even in the nighttime the surface of the paint-coated asphalt is cooler for more

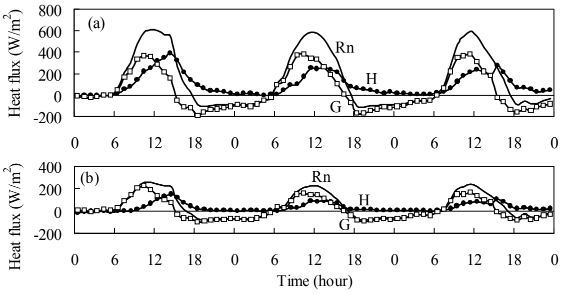

Fig.8. Energy balance of (a) conventional pavement and (b) paint-coated pavement for August, 2002.

than 2°C. In the winter, the surface temperature of the paint-coated pavement is slightly lower than that of the conventional one even below the freezing point (Figure 7), and it may result in the delay of snowmelt.

Figure 8 shows the energy balance of the conventional and paint-coated asphalt pavements. The sensible heat flux (H) is estimated from Louis's scheme (Louis, 1979) with the roughness length $z_0=3x10^{-4}$ m, which was verified to give a satisfactory estimate. The heat flux into the ground (G) is derived by subtracting H from the measured net radiation (Rn). The surface albedo was referred to the result of laboratory experiments. It is found that a significant reduction can be found by applying high albedo coatings for the sensible heat flux and the heat flux into the ground.

3. IMACT ON URBAN ATMOSPHERE

3.1 *Outline*

The high albedo pavement reflects more solar radiation back to the sky. If it is widely used for the urban canopy floor, surrounding buildings absorb part of the reflected solar radiation, which in turn could increase the wall temperature and sensible heat fluxes from the wall. Thus, the impact of introducing high albedo pavement on the overall canopy albedo and energy balance was investigated by applying a canopy energy balance model developed by Kanda et al. (2004a) to a real urban canopy setting. The dependency of the overall canopy albedo, sensible heat flux and canopy surface temperature on the canopy configuration and floor albedo was investigated, and the efficiency of introducing the high albedo pavement is discussed.

3.2 *Model explanation*

The energy balance model used in this study is the *s*imple *u*rban energy balance *m*odel for *m*eso-cale simulations (SUMM), which consists of a 3-D theoretical radiation scheme (Kanda et al., 2004b) and the conventional heat transfer expression that uses a network of resistances. SUMM allows one to readily calculate the energy balance and surface temperature at each face of the urban canopy (i.e., roof, floor, and four vertical walls) without time-consuming iterations. This model was validated by the surface temperature of canopy facets and heat fluxes measured in a reduced-scale hardware canopy model experiment. In addition, the parameters related to the thermal properties for the asphalt pavement of the canopy floor were determined by comparing simulation results of asphalt surface temperature in a horizontally open situation with the data of field measurement in Tsukuba (Table 1). Other thermal properties of walls and roof used in simulations are also listed in Table 1.

Table 1. Summary of parameters

	Floor	Walls*	Roof*
Heat capacity($J/cm^3/K$)	2.2	2.1	2.1
Conductivity(W/m/K)	0.7	1.6	1.6
Emissivity	0.98	0.98	0.98
Albedo	0.1-0.7	0.2	0.2

*Nunez and Oke (1976)

The outer meteorological boundary conditions including the downward shortwave and longwave radiation were given from Moriwaki and Kanda (2003) as an hourly average for sunny days in July 2002 measured at the height of 29m over a densely built-up residential area in Tokyo. The inner temperature of buildings and the bottom temperature of the canopy floor are assumed to be a constant.

The urban canopy geometry in the simulation assumes an infinitely extended regular array of buildings with square horizontal cross-section and uniform surface properties, and streets with asphalt pavement. The canopy geometry is characterized by the horizontal dimension of buildings (W), the height of buildings (H) and the width of streets (L). W is set to 10m in all simulations, and the plane area index ($\lambda_p=W^2/(W+L)^2$) and frontal area index ($\lambda_f=WH/(W+L)^2$) are used to define canopy geometry.

3.3 *Results*

Figures 9 and 10 show the total sensible heat flux (TSH) at the reference height (29m) and the area-weighted temperature of four wall facets and floor surface (AT) for four cases of floor albedo (α=0.1, 0.3, 0.5 and 0.7) with the canopy configuration H=10.5m and W=10m. It is found that both TSH and AT are significantly reduced with increased albedo for the smaller plane area index (L=20m, λ_p=0.1111). However, the smaller λ_p case gives larger sensible heat flux for the floor albedo below around 0.3.

Figures 11~13 show the dependency of TSH, AT and the overall canopy albedo (CA) on the floor albedo and canopy configuration. TSH, AT and CA is more sensitive to the floor albedo for the smaller frontal area index. TSH for the higher floor albedo (α=0.5) is less sensitive to the plane area index than the lower albedo case (α=0.1). AT is mostly influenced by the frontal area index and floor albedo. AT is reduced with increased albedo even though the wall surface temperature is slightly increased due to the

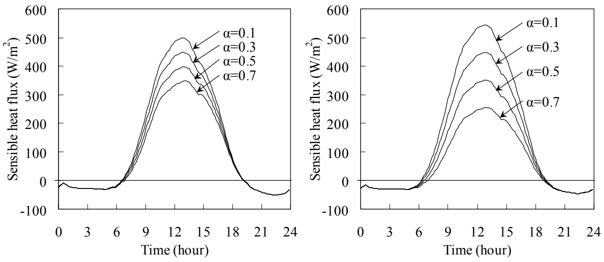

Fig.9. Total sensible heat flux from whole canopy layer with H=10.5m and W=10m. (Left: L=10m, right: L=20m)

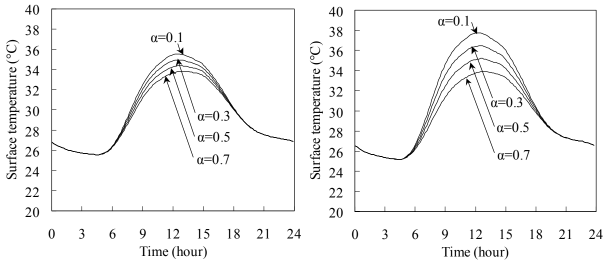

Fig.10. Averaged surface temperature of wall and floor with H=10.5m and W=10m. (Left: L=10m, right: L=20m)

higher incident solar radiation reflected from the canopy floor. CA for α=0.5 is much dependent on the plane area index than that for α=0.1. If it is assumed that the same upper boundary condition holds for any canopy configurations, it can be said that smaller plane area index and frontal area index become effective in increasing overall canopy albedo when the canopy floor albedo is higher.

4. IMACT ON HUMAN THERMAL SENSATION

The high albedo pavement is considered to reduce the air temperature near the ground and the longwave radiation emitted from the pavement surface. On the other hand, it must be considered that the pavement surface reflects more solar radiation, and it may increase the thermal stress on the human body walking or standing on it. Thus, a preliminary test was carried out to reveal the impact on the thermal sensation by letting 6 volunteers stand on the paint-coated pavement and conventional pavement under the summer outdoor environment.

Thermal sensation, comfort sensation and sensation regarding the thermal impact on the feet were declared. WBGT was also monitored during the test. It is found that the high albedo pavement gives cooler sensation than the conventional one, which may be resulted from the mitigated heat conduction through the feet and the upward longwave radiation.

5. REFERENCES

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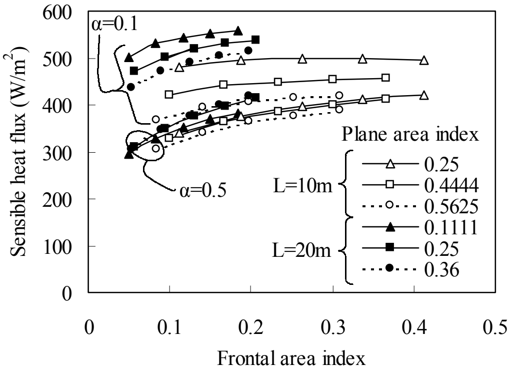

Fig.11. Total sensible heat flux (TSH) from whole canopy layer (W=10m, L and H are variable).

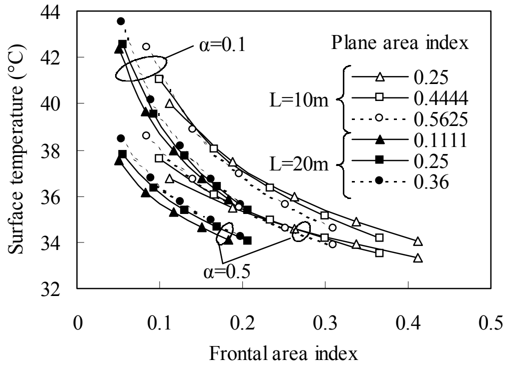

Fig.12. Area-averaged surface temperature (AT) of walls and floor (W=10m, L and H are variable).

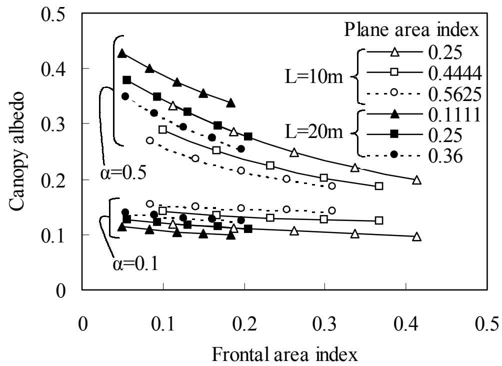

Fig.13. Canopy albedo (CA) at noon for whole canopy layer (W=10m, L and H are variable).

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