Advanced Use of Environmentally-friendly Pavement Technologies

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ABSTRACT: In recent years, it has been desirable for asphalt pavement engineers to tackle environmental issues due to global warming. The main reason for such requirement is that asphalt paving works tend to generate carbon dioxide when producing asphalt mixtures at batching plants. In addition, the emission in urban areas may be related to “Urban Heat Island” which significantly affects pedestrians as well as asphalt surfaces in terms of temperature. In order to solve these problems, Warm-Mix Asphalt and Solar Heat-blocking Pavement technologies were developed to gain the following effects: the mitigation of greenhouse gas, the reduction of surface temperature and the prevention of pavement deterioration. This paper describes the practical effects of the two technologies through experiments and case studies. The following conclusions are drawn from this study. With respect to the Warm-Mix Asphalt, the laboratory results provide that a newly developed additive may be applicable for several types of asphalts, even for polymer modified asphalt. The results also show that the new additive may decrease the mixing temperature of the polymer modified asphalt to 110°C. With regard to the Solar Heat-blocking Pavement, the field results indicate that the reduction in surface temperature by use of the solar heat-blocking pavement is approximately 16°C. Finally, the application at airport taxiway reveals that the technology would be highly effective to the mitigation of rutting since the rate of rut depth is about a half, compared to dense-graded asphalt surface.

KEY WORDS: Warm-mix asphalt, production temperature, solar-heat-blocking pavement, airport taxiway, rut depth reduction.

1 INTRODUCTION

In recent years, it has been desirable for asphalt pavement engineers to tackle environmental issues due to global warming. The main reason for such requirement is that asphalt paving works tend to generate carbon dioxide when producing asphalt mixtures at batching plants. In addition, the emission in urban areas may be related to “Urban Heat Island” which significantly affects pedestrians as well as asphalt surfaces in terms of temperature. In order to tackle these problems, it is necessary to study more about environmentally-friendly technology related to asphalt pavement. Based on the public demand, Warm-Mix Asphalt and Solar Heat-blocking Pavement technologies were developed to gain the following effects: the mitigation of greenhouse gas, the reduction of surface temperature and the prevention of pavement deterioration. This paper describes the practical effects of the two technologies and their advanced uses through experiments and case studies.

2 WARM-MIX ASPHALT (WMA)

Recently, there is growing awareness that the use of warm-mix asphalt technology is highly effective for the reduction of production temperature in asphalt pavement (Huschek, 1994; Gabrera & Zoorab 1994, 1996). This technology has been applied to the several types of pavements such as dense-graded asphalt and reclaimed asphalt pavements. However, despite the fact that the production amount of porous asphalt mixture has been rapidly increasing due to its clear advantages such as the reduction of noise and water spray, the application of WMA technology to the polymer modified asphalt is not studied enough. Therefore, further development of warm-mix asphalt technology has been desired. In order to tackle this problem, the trial which might be related to the new development of warm-mix technology was conducted based on the micro-form technology. This section describes the Warm-Mix Asphalt technology focused on micro-form agent, and examines the advanced use for the polymer modified asphalt.

2.1 Basic concept of micro-form technology

Warm-Mix Asphalt technology enables production and compaction temperatures to be lower than those of the traditional HMA. There are mainly three types of the technology: organic (wax) additive, forming process and emerging U.S. technologies (FHWA, 2009). Of the Warm-Mix Asphalt technologies, the foaming technology developed can be generated and dispersed micro-forms in asphalt during HMA production by adding special additive. As a result, the micro-forms act as bearings so that good compaction can be achieved even at lower temperatures. Therefore, it will be possible to decrease the production temperature.

Figure 1 indicates the schematic of micro-form generation during compaction. The contents of the special additive are a forming agent, which generates the evaporation of crystallization water included, and a foam reinforcing agent.

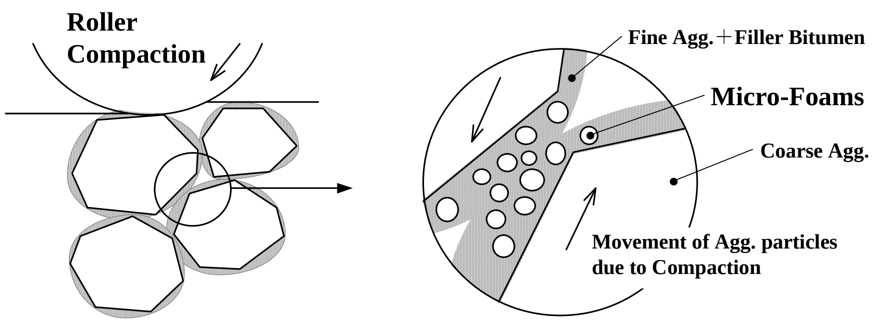

Figure 1: Concept of micro-formed WMA

Figure 2 shows the duration time of forming between the special additive used for micro-form technology and forming agent only. In this experiment, both the special additive and forming agent were added to asphalt (i.e. straight asphalt 60/80) at 130°C; the duration time of forming was compared. From this result, it was found that a volume of bitumen for special additive increases significantly due to the micro-foam generation and decreases to an original state after 120 minutes which is approximately 90 minutes longer than foaming agent only. Although the duration time was set to 2 hours, this time can be adjusting in practice.

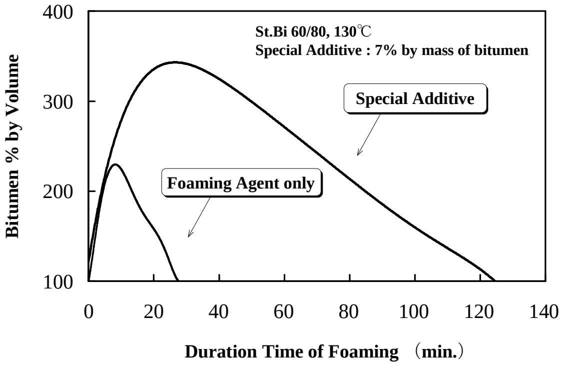

Figure 2: Micro-foam generation with a special additive

2.2 Temperature reduction and viscosity state

Based on the micro-form technology, the new additive was developed using the three agents: addictive for micro-form generation, viscosity reduction agent and reactive curing agent. By combining these, the new special additive for warm-mix asphalt was examined targeting a further reduction in production temperature, and the application to the polymer modified asphalt. In order to confirm the performance, several types of warm-mix agents were studied to see the changes in viscosity at different temperatures; the viscosity was examined by stirring the asphalts with thermometer. The result is shown in Figure 3.

		Additive[1] (% by wight of binder)	State of Asphalt[2] ← Temperature (℃) → 150 140 130 120 110 100 90 80 70 60	Penetration 1/10mm	Toughness N・m	Tenacity N・m
Straight Asphalt 60/80	No additive	–	Low viscosity / Middle / High	67	4.4	0.5
	Viscosity reduction agent (Oil type)	2%		116	2.4	0.2
	Viscosity reduction agent (Wax type)[3]			48	5.6	0.5
	Foam reinforcing agent[4]			154	2.3	0.3
	Additive agent (Micro-form 30℃)[5]			69	4.2	0.5
	Additive agent (Micro-form 50℃)[5]			72	4.0	0.5
	New additive agent[6]	6%		67	4.3	0.5
Modified Asphalt type II	No additive	–	Low viscosity / Middle / High	53	24.9	19.6
	Viscosity reduction agent (Oil type)	4%		128	13.2	12.4
	Viscosity reduction agent (Wax type)[3]			42	18.8	12.6
	Foam reinforcing agent[4]			145	12.8	12.0
	Additive agent (Micro-form 30℃)[5]			56	23.4	18.8
	Additive agent (Micro-form 50℃)[5]			58	23.7	19.9
	New additive agent[6]	10%		51	24.5	19.2
Polymer Modified Asphalt	No additive	–	Low viscosity / Middle / High	51	25.8	19.6
	Viscosity reduction agent (Oil type)	6%		118	16.4	14.3
	Viscosity reduction agent (Wax type)[3]			33	21.5	13.0
	Foam reinforcing agent[4]			138	15.0	12.3
	Additive agent (Micro-form 30℃)[5]			49	25.1	19.0
	Additive agent (Micro-form 50℃)[5]			54	23.0	17.7
	New additive agent[6]	18%		50	24.8	19.6

Notes: 1: Amount of additive is percent by wight of binder.
2: The state of asphalt was evaluated by visual inspection using thermometer. The degree of viscosity was ranked with the following order:Low<Middle<High.
3: Viscosity reduction agenet is a wax with melting point of 90℃ and can change the viscosity of binder.
4: Foam reinforcing agent can be kept the forming state for long duration.
5: Micro-form 30℃ and 50℃ are additive agents for WMA which can reduce the production temperature by 30℃ and 50℃, respectively.
6: The new additive agent consists of viscosity reduction agenet and reactive curing agent, based on the additive for micro-form WMA.
(In this case, the new additive without reactive curing agent was examined.)

Figure 3: Asphalt state and temperature

The three types of asphalt (i.e. straight asphalt 60/80, modified asphalt type II and polymer modified asphalt) were examined with different warm-mix agents. As can be seen from the results, the new additive clearly shows higher performance than other additives, in terms of temperature. For straight asphalt, the new additive showed the possibility that production temperature may be decreased to 100°C as the increase in viscosity was confirmed at around 100°C. Almost the same result was obtained for the modified asphalt type II. Despite the fact that other additives show the increase in viscosity at around 110°C, the asphalt with the new additive reached the same state at around 100°C. For polymer modified asphalt, this trend is more pronounced for the new additive than other additives. While there was an increase in viscosity of the new additive at around 110°C, other additives reached to the same state at 120 to 130°C. Therefore, these results may provide the possibility for further reduction in production temperature and the application to the polymer modified asphalt.

2.3 Temperature reduction and coating in mixtures

Coating in mixes is an important factor affecting the life cycle of asphalt pavement. However, there is concern that whether or not good coating state is achieved, especially in the case of Warm-Mix Asphalt since the asphalt mixture is produced at lower temperatures. In order to confirm good asphalt coating state to aggregates (i.e.wettability), the three types of asphalt were examined at different mixing temperatures using micro-form based WMA (i.e. 30°C and 50°C reduction types) and the new additive. The wettability was evaluated by the visual inspection of 5 volunteers; the percentages of the wettability determined from questionnaire were averaged. The result is presented in Figure 4.

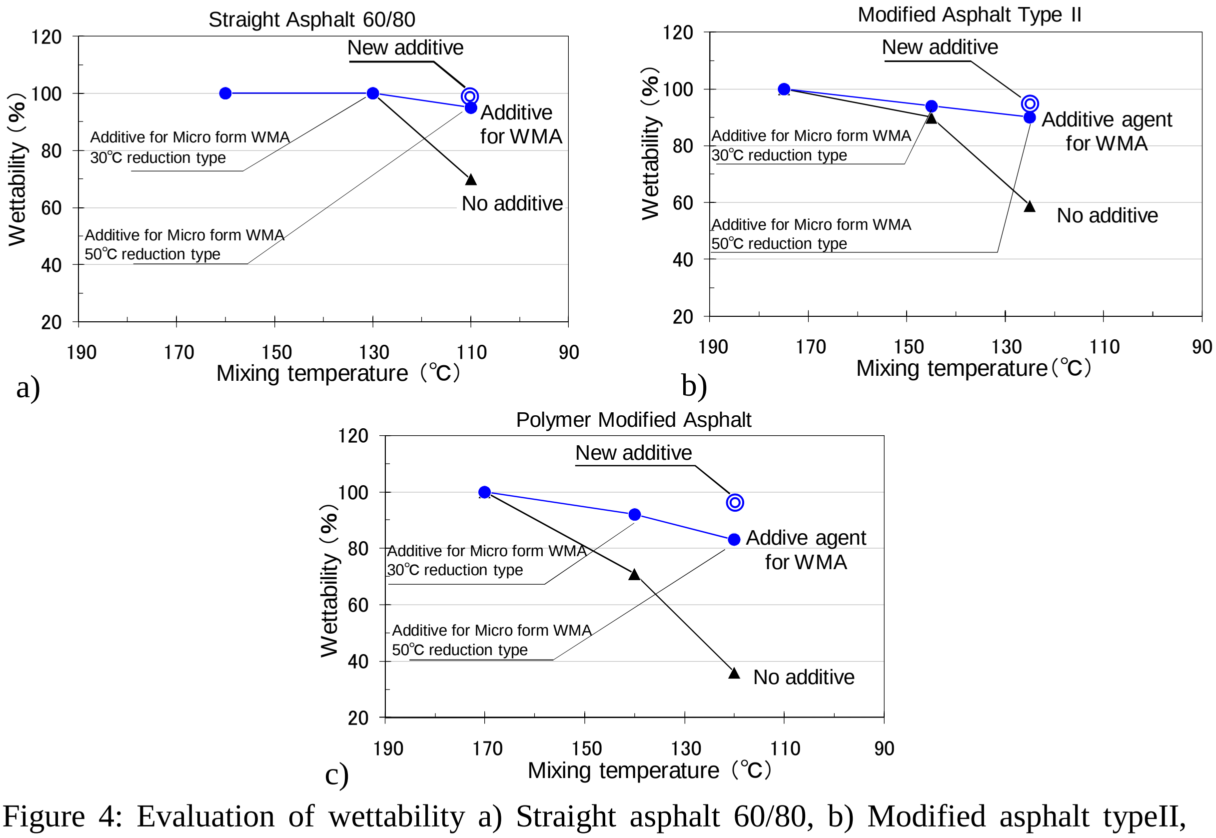

Figure 4: Evaluation of wettability a) Straight asphalt 60/80, b) Modified asphalt typeII, c) Polymer modified asphalt.

The results clearly show that the new additive has good wettability to aggregates even when producing asphalt mixtures at lower temperatures. Although the wettability of mixture with existing micro-formed WMA was also secured more than 80% in the three binders, these can be recovered to more than 95% by using the new additive. In addition, this trend is more pronounced for polymer modified asphalt than straight asphalt and modified asphalt type II. Therefore, these results may verify that the new additive will gain good coating state.

2.4 Temperature reduction and mixture quality

In this study, the authors are thinking of applying the new additive to the site after a number of trials. However, before applying to the practice, the quality of mixture has to be ensured in the laboratory. Therefore, the mixture quality of ϕ 100 mm porous asphalt specimens which add the new additive was examined looking at the two factors: air voids and Marshall stability. In this case, polymer modified asphalt was used to make the specimens; mixing and compaction temperatures were 110°C and 90°C, respectively. A series of experiment was conducted by changing an amount of the new additive. Although the reactive curing agent was not applied to see the general trend for the compactablility, it was added only in the case of 15% of the additive, to examine the effect of the reactive curing agent. The results are presented in Figures 5 to 6.

As can be seen from Figure 5, the result indicates a general decrease in air voids with increase in the new additive. However, it should be noted that the percentage of air voids yields at around the specified value. In addition, such trend did not change even adding the reactive curing agent at 15% in the amount of the additive. Therefore, it can be said that the new additive agent does not affect the air voids of mixtures.

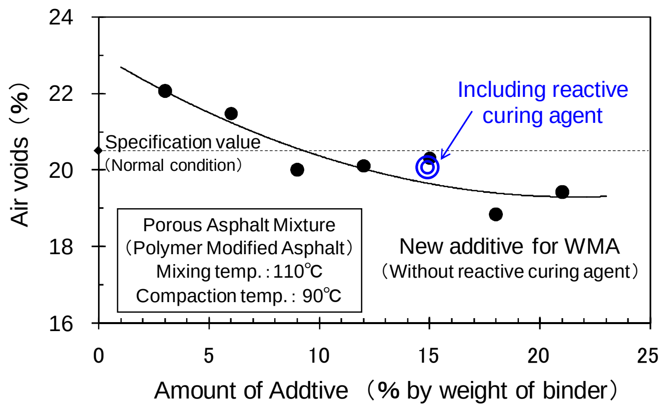

Figure 5: Measurement result for air voids

In terms of Marshall stability, as presented in Figure 6, the general trend is almost identical with the result of air voids. The Marshall stability shows steady decrease with increase in the new additive. Although these values are lower than the specified value which was manufactured under normal condition (i.e. mixing temperature: 170°C, compaction temperature 150°C), it can be seen that reactive curing agent can recover the marshall stability to the specified value. Therefore, this result may provide the evidence that mixture quality with the new additive will be ensured by adding the reactive curing agent.

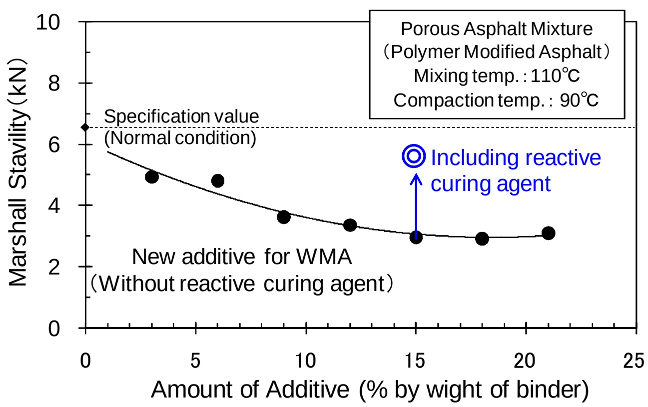

Figure 6: Measurement result for Marshall Stability

3 SOLAR HEAT-BLOCKING PAVEMENT

The reflective solar radiation technology has been developed to mitigate rising temperatures during the summer season (Kinoshita, 1998). In recent years, this technology has been applied to road pavements. In general, the pavement surface which has solar reflective technology is called "Solar Heat-blocking Pavement" in Japan (Yoshinaka et al. 2003, 2005).

3.1 Basic concept

The function of this pavement is based on higher reflectivity for near infrared rays and lower reflectivity for visible rays. In general, reflectivity for solar and infrared rays is represented by "albedo" (Kinouchi et al. 2003). Higher albedo means that pavement surface reflects infrared rays on the surface, whereas lower albedo indicates that pavement easily absorbs infrared rays. Therefore, the pavement surface which has lower albedo would result in the increase of surface temperature. To avoid the absorption of the infrared rays on the surface, the basic concept of this technology is to coat specific materials which reflect both solar ray and infrared ray, on the pavement surface (see Figure 7).

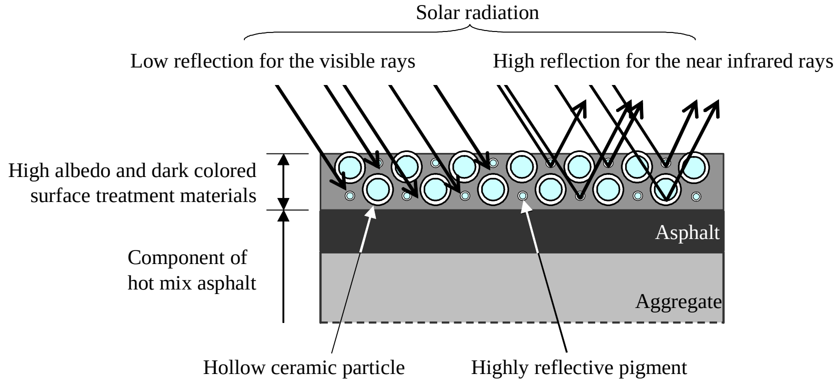

Figure 7: Schematic of Solar Heat-blocking Pavement

3.2 Properties of solar heat-blocking pavement

In order to examine albedo characteristics, comparison between Solar Heat-blocking Pavement, which is set to L*40 as brightness index, and conventional pavement (i.e. dense graded asphalt pavement with Straight asphalt 60/80 only and with normal paint L*40) was conducted. The result is shown in Figure 8.

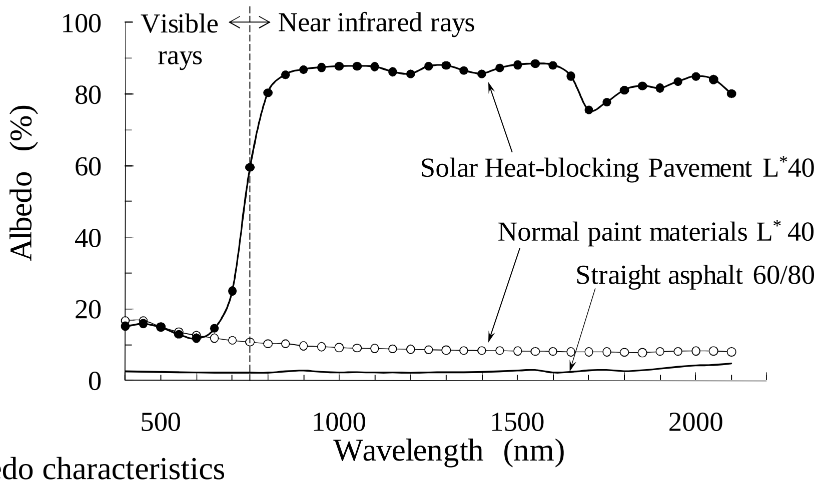

Figure 8: Albedo characteristics
(Solar Heat-blocking Pavement, normal paint materials, straight asphalt)

The result shows that there are clear differences between the Solar Heat-blocking Pavement and conventional painting materials. Conventional painting materials have almost the same or less degree of reflective ratio within whole wavelength. However, for Solar Heat-blocking Pavement, the reflective rate of near infrared rays in the wavelength is much higher than others. This indicates that Solar Heat-blocking Pavement has higher albedo, despite the fact that the normal paint materials recognized as L*40, have the same brightness index as the Heat-blocking Pavement.

3.3 Effect of temperature reduction

In order to examine the effect of temperature reduction, dense graded asphalt pavement and solar heat-blocking pavement were compared in the field. Figure 8 shows the surface temperature of the two surfaces. The maximum surface temperature of the Solar Heat-blocking Pavement was approximately 42°C, despite the fact that the maximum temperature of conventional pavement was around 58°C; the difference between the two surfaces was about 16°C. Therefore, the result clearly shows the advantage of the Solar Heat-blocking Pavement for the reduction in surface temperature during the summer season.

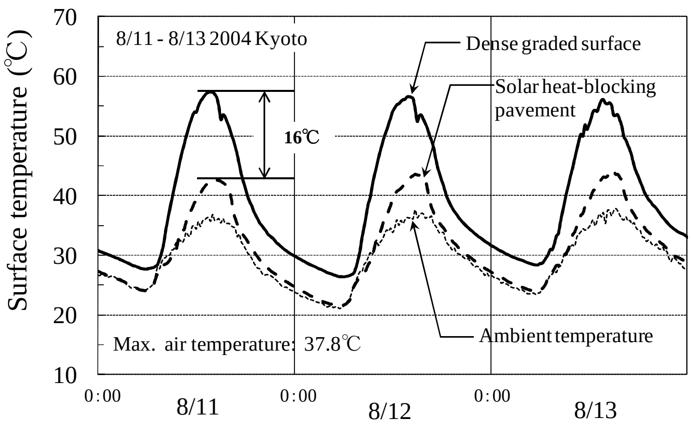

Figure 9: Surface temperatures of solar heat-blocking pavement and dense grade surface

3.4 Application to the airport taxiway

In general, the growth of rut depth depends on surface temperature (Yoder, 1975). Therefore, the reduction in rut depth on the asphalt surface can be expected by use of Solar Heat-blocking Pavement. In order to examine this effect, it was constructed at the taxiway of Narita International Airport (Hayakawa et al. 2008, 2009). The number of landing is 532 times per day in average, as of 2007; the details of aircraft usage at the airport are presented in Figure 10.

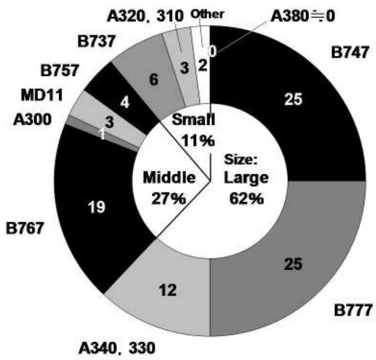

Figure 10: Details of aircraft that use Narita International Airport

In this trial, the temperatures of the two surfaces were examined: conventional dense-graded asphalt and solar heat-blocking pavements. In addition, thermocouples were set to within the pavements (set depth: 20 mm, 80 mm and 200 mm below surface); the temperatures were measured for three years. The schematic of the cross section is shown in Figure 11.

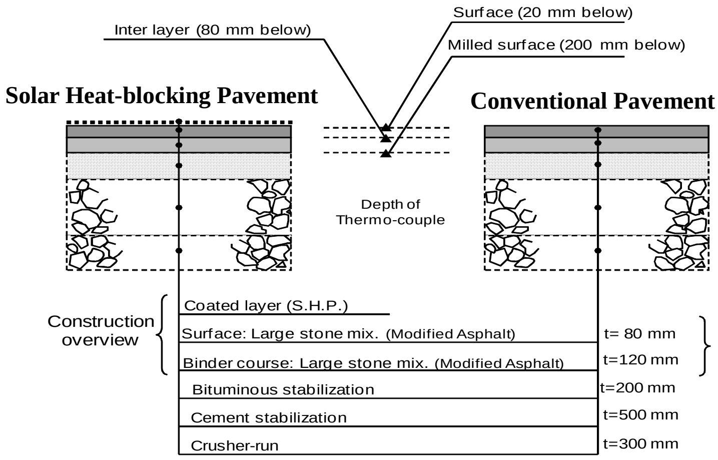

Figure 11: Cross section of pavements

3.4.1 Measurement results of the surface temperatures

Figure 12 shows the measurement results of the temperatures for conventional dense-graded pavement and solar heat-blocking pavement. In this result, the maximum temperature in each month is recorded. As can been seen from the result, the reduction in temperature was shown not only at the surface, but this trend is also seen in 200 mm below the surface. Also, it was understood that this function is maintained for three years.

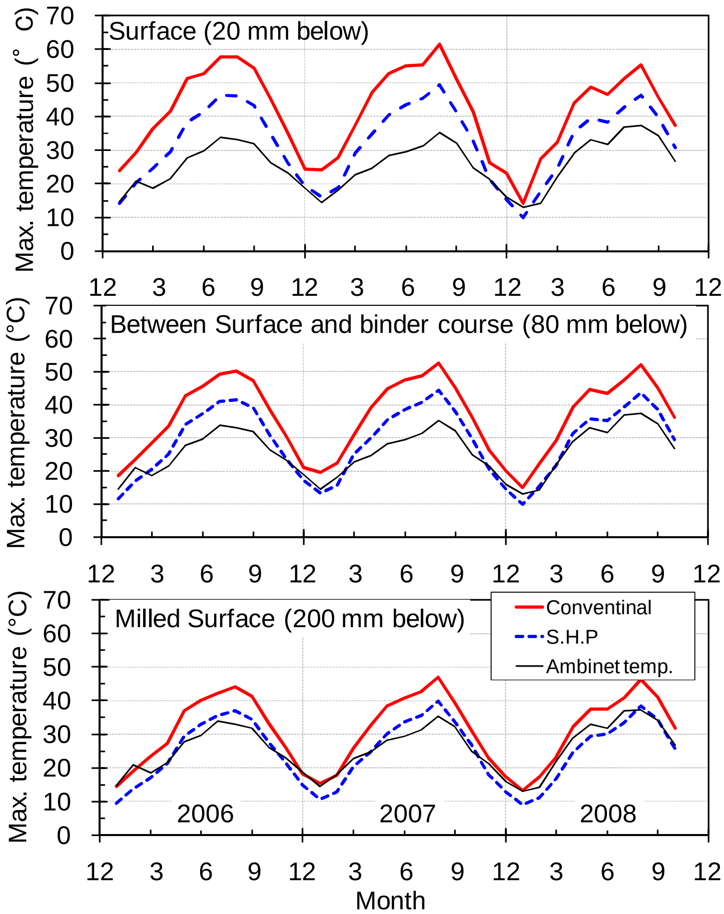

Figure 12: Surface temperatures in different depth

3.4.2 Measurement result of rut depth

Rut depth for the two surfaces (i.e. dense-graded pavement and solar heat-blocking pavement) was also measured in regular monitoring in parallel with surface temperature measurement. The rut depth in transverse direction was measured using 3 meter transverse profilemeter. Figure 13 presents the result of the monitoring for three years. Comparison of the solar heat-blocking pavement and dense graded pavement allows the effect of the solar reflective technology for the reduction of rut depth to be proved. From this result, it was found that solar heat-blocking pavement is highly effective for the mitigation of rutting as the reduction in rut depth was seen through the regular monitoring.

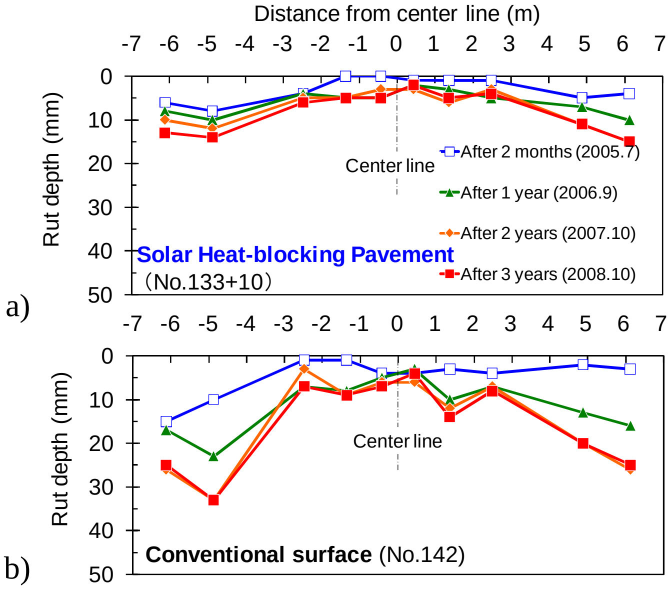

Figure 13: Result of rut depth in transverse direction a) Solar Heat-blocking Pavement, b) Conventional dense graded pavement

Also, an interesting feature of solar heat-blocking pavement was found through this trial. As can be seen in Figure 14, the solar heat-blocking pavement can reduce the maximum rut depth to a half, compared to that of dense graded pavement. In addition, it should be noted that the solar heat-blocking pavement presents gradual increase in the rut growth, despite the fact that the dense graded pavement shows steady increase in the rut depth. As a result, a clear difference is evident between solar heat-blocking pavement and dense graded pavement.

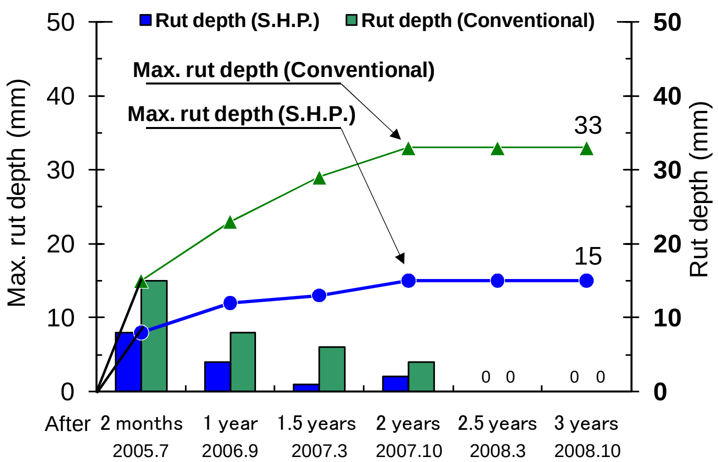

Figure 14: Changes in the maximum rut depth for three years

4 CONCLUSIONS

The results presented in this paper provids the possibility for the advanced use of Warm-Mix Asphalt and Solar Heat-blocking Pavement. Based on the results from the laboratory experiment and field trial on the two technologies, the following conclusions can be drawn:

- The new additive developed for WMA has a potential to decrease the production temperature of asphalt mixtures which use straight asphalt and modified asphalt type II up to 100°C since the changes in viscosity was seen at lower temperatures.
- The same trend as straight asphalt and modified asphalt type II was seen in polymer modified asphalt. The new additive may enable the production temperature of porous asphalt mixture to be lower than 110°C as approximately 95% of wettability was obtained in the porous asphalt mixture.
- In terms of mixture quality, the air voids and Marshall stability of porous asphalt mixture yielded at around specification value even when adding the newly developed additive; detailed investigations looking at mixture properties would be necessary for the future.
- With regard to the performance of Solar Heat-blocking Pavement, the reduction of surface temperature is approximately 16°C compared to conventional dense graded asphalt pavement due to the prevention of solar radiation.
- This technology would be effective to the mitigation of rutting as the rate of rut depth was approximately a half, compared to the dense graded asphalt surface at the airport taxiway.

REFERENCES

Gabrera, J.G. and Zoorob, S.E. 1994 *Design of Low Energy Hot Rolled Asphalt.* European Symposium on Performance and Durability of Bituminous Materials, pp.289-308.

Gabrera, J.G. and Zoorob, S.E. 1996 *Field Performance of Low Energy Hot Rolled Asphalt*. Second National Conference on Bituminous Mixtures and Flexible Pavements, pp.130-150.

Hayakawa, I., Yoshinaka, T. and Motida, S. 2008 *On the Effectiveness of Heat Blocking Pavement at the airport taxiway*. Proc. of Japan Society for Civil Engineer Kantou Region Conference, Vol. V (In Japanese).

Hayakawa, I., Uematsu, S., Sekita, M. and Yoshinaka, T. 2009 *The application of solar heat-blocking pavement to airport taxiway targeting the prevention of rutting*. Journal of Pavement, Vol 44-8, pp 9 (In Japanese).

Huschek, S. 1994 *Moglichkeiten zur Verringerung der Misch- und Einbautemperatur von Asphalt*,asphalt, pp.46-49 (in German).

Kinoshita, K. 1998 *A Solar radiation reflective paint to improve the efficiency of cooling and heating*. Industrial Material, Vol.46, No.5, pp.35-38 (in Japanese).

Kinouchi, T., Yoshinaka, T., Fukae, N. and Kanda, M. 2004 *Development of Cool Pavement with Dark Colored High Albedo Coating*. American Meteorological Society, 5th Conference on Urban Environment, No4.7.

Yoder, E.J. and Witzak, M. W. 1975 *Principles of Pavement Design*. New York, NY, Wiley and Sons.

Yoshinaka, T., Kinouchi, T. and Fukae, N. 2003 *Study on higher performance of solar radiation reflective pavement*. Proc. of 25th Japan Road Conference, No.09P04, (in Japanese).

Yoshinaka, T. 2005 *Study on Pavement Technology targeting improvement of Atmospheric Thermal Environment*. D.Eng Thesis, Nagaoka Institute of Technology (in Japanese).