Development and Evaluation of a Warm Mix Asphalt Additive of Surfactant for Pre-mixing Asphalt

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ABSTRACT: It is an increasingly urgent worldwide issue to halt global warming, and the paving industry is responding to the call with the introduction of a variety of environmentally friendly paving methods. One of these is warm mix asphalt (WMA) technologies, which allow the temperature to be lowered during the manufacture of asphalt mixtures. In Japan, WMA technologies mainly employ techniques based on foaming agents and other related technologies and, to a lesser extent, oil and wax for viscosity modification. However, these methods are strongly dependent on elapsed time after mixing, and as such, require precise time and temperature controls. Another issue generally is that the viscosity modifiers and other additives must be added to each batch during the mixing process. In an attempt to resolve the above issues and reduce the tasks related to adding additives during mixing, the authors have focused on viscosity modification of WMA and have developed a WMA additive based on a surfactant that can be directly added to asphalt before manufacturing asphalt mixture (pre-mixed). The advantages of this WMA include its reduction of asphalt viscosity and the improvement of the slip properties of the asphalt and aggregate by the surfactant. These effects provide the desired level of compaction at a temperature 30ºC lower that usually required for asphalt mixing, which contributes to reducing fuel consumption during the process and the amount of CO_2 released. This report describes the asphalt characteristics and provides the results of tests its effectiveness as pavement.

KEY WORDS: WMA, surfactant, pre-mix

1. INTRODUCTION

The WMA currently used in Japan mainly consist of foamed mixes (methods in which a foaming additive is added to the mixture, causing a “bearing effect” due to the small cells created, and methods in which asphalt, steam and water are combined to create the foam), and controlled-viscosity mixes (in which wax, oil and other additives are added in order to adjust the mix viscosity). Of these, the foaming technologies are more commonly used. However, the effectiveness of the foaming methods depends on how much time has passed since mixing, so not only control of the mix temperature. Moreover, the viscosity control are generally troublesome, as the additives must be thrown into the mixture in a batch process.

In order to overcome these issues, authors have focused on viscosity control methods, and have identified a surfactant usable as a WMA additive that is more effective than conventional waxes and oils and that can be added directly to asphalt in advance. Herein, the nature of this surfactant is examined and its effectiveness is verified.

This report first describes the approach behind the selection of WMA and the mechanisms of selected WMA additive in reducing the manufacturing temperature. Next, the process of using the agent in test operations with actual equipment and the subsequent results are then presented.

2. DEVELOPMENT OBJECTIVES

The following objectives were established in order to resolve current issues in warm mix technologies while preserving the goal of reducing the temperatures used in WMA.

To reduce the asphalt mix manufacturing temperature by 30°C from the conventional temperature.
To be able to use the new material both directly in mixers at a plant (plant-mix) and by adding to asphalt before delivery (pre-mix).
To avoid any large influence on mixture characteristics in the region of service temperatures.

3. SELECTION OF SURFACTANT AS WMA ADDITIVE

Additive to be used in WMA must work with the asphalts in a temperature region lower than ordinary temperatures, and must not disturb the characteristics of asphalt mixture in the service temperature range.

Using an organic surfactant as a WMA additive, we were able to reduce the viscosity of the asphalt itself without affecting its characteristics and improve the workability of the asphalt mixture by acting on the interface between the asphalt and the aggregate.

The surfactant examined by the authors is a solid, thermally and chemically stable surfactant comprised of long chains of fatty acids. Its melting point depends on its composition. After trial and error, we ultimately selected a fatty acid derivative with a melting point of about 100°C. This material maintains its fluidity in the compaction temperature region but hardens in the service temperature region. As a result, above the melting temperature, it melts with the asphalt, while at lower temperatures, it takes a solid form. Therefore, it exerts no influence on the characteristics of the asphalt in the service temperature region, but above that region, melts easily into the asphalt, allowing warm-mix handling using any addition method.

A brief description of the selected WMA additive is provided in Table 1.

Table 1 Description of WMA additive

Item		Detail
Material properties	Dimenshional tandard @ 25°C	Powder
	Melting point	101°C
Summary	Effectiveness	Decrease viscosity + Surface-active between asphalt and aggregate
	Addtion method	Plant-mix and Pre-mix

4. VERIFICATION OF IMPROVED COMPACTION CHARACTERISTICS

4.1 Differences in WMA Additive Amount and Addition Methods

Compaction tests were performed with a gyratory compactor to verify the beneficial effects of the additive on compaction characteristics of this WMA.

The mixture was assessed as follows. The asphalt was mixed at ordinary manufacturing temperatures (160°C for Polymer Modified Asphalt Type 2 :PMA2), according to the number of gyrations required for the mixture to reach the Marshall standard density, while varying the amount of additive to the WMA. The compaction temperature was 130°C, 30°C lower than the conventional temperature. In order to obtain a constant compaction temperature, the mixture was compacted after putting in a constant temperature oven for 1 hr. Also, in order to reproduce the processes of pre-mixing and plant-mixing, two sequences of mixing were used; the WMA additive was added to the asphalt in one, and in the other, it was added directly in the mixer.

As shown in Fig.1, adding the WMA additive reduced the number of gyrations necessary to reach the Marshall standard density, i.e., it improved compaction. This improvement was more marked in pre-mixing than in plant-mixing. This is most likely because the dispersion of the additive was not very uniform in plant-mixing, so greater quantities of additive were needed in order to get the same effect as obtained in pre-mixing.

These results suggest that charges of 2.5% of the additive in plant-mixing or 1.5% in pre-mixing require the same number of mixer rotations to reach standard density under ordinary manufacturing conditions.

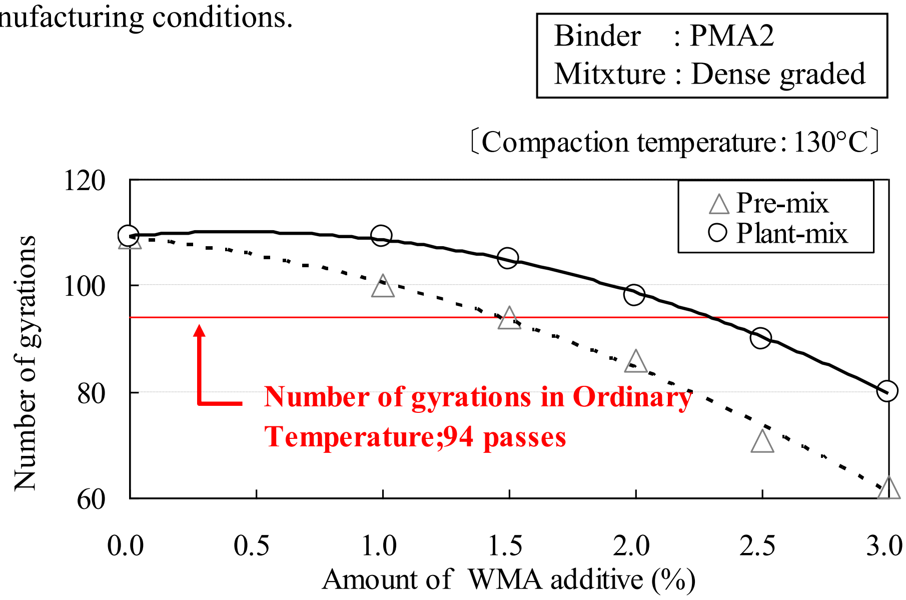

Figure 1 Number of gyrations of WMA mixture to reach the Marshall standard density vs for various amount of additive

4.2 Plastic flow resistance of WMA additives

Next, a wheel tracking test was performed to assess the plastic flow resistance of mixtures incorporating the additive. The manufacturing temperature, mixture type and amount of WMA additive were the same as those described in Section 4.1.

As shown in Fig. 2, the Dynamic Stability (DS) decreased as the amount of additive was increased. DS was observed to decrease more in the pre-mixed asphalt mixture than in the plant-mixed asphalt mixture. This was most likely due to influence of the solidified WMA additive, and indicates that effects from the additive on mix conditions can not be ignored in cases of excessive amounts of additive. From these results, we determined the upper limits for the amounts of the additive as 2.5% in pre-mix and 3.0% in plant-mix if DS is at least 3000.

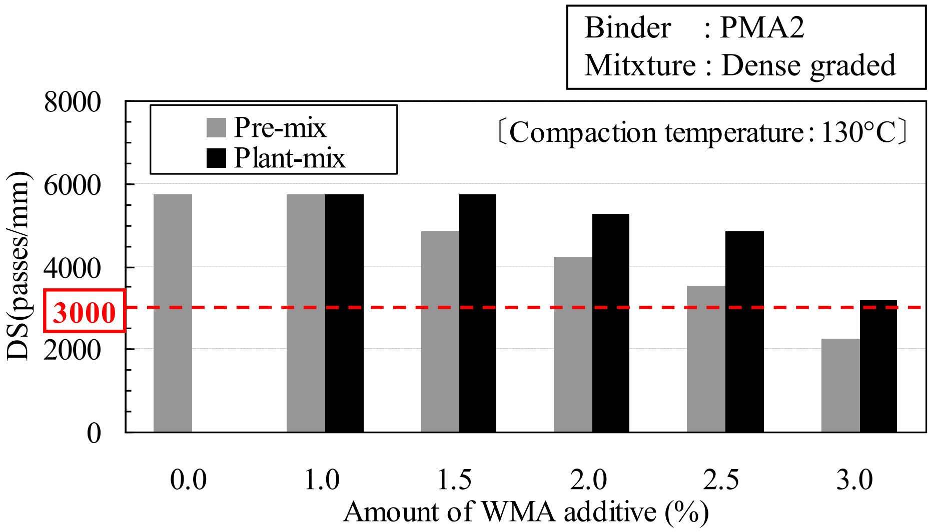

Figure 2 Dynamic Stability (DS) vs amount of additive

4.3 Observations of the mechanisms of action of the WMA additive

The WMA additive used in the present study allowed the mixing temperature to be reduced by 30°C. The following describes our investigation of the mechanisms of action of the additive in the melt and solid states.

1) Melt state (internal and external lubrication effects)

The WMA additive used in this study is a surfactant, and provides two benefits: 1) it reduces the viscosity of melting asphalt (enhancing internal lubrication) and 2) it improves the sliding properties of the asphalt-aggregate interface (enhancing external lubrication).
The temperature-viscosity curve for PMA2 is shown in Fig. 3. The curve indicates that adding the WMA additive shifts the viscosity to the left, the lower temperature portion, due to the improvement of internal lubrication. The shift amounts to only about 12°C even at the level of 3% of the additive.

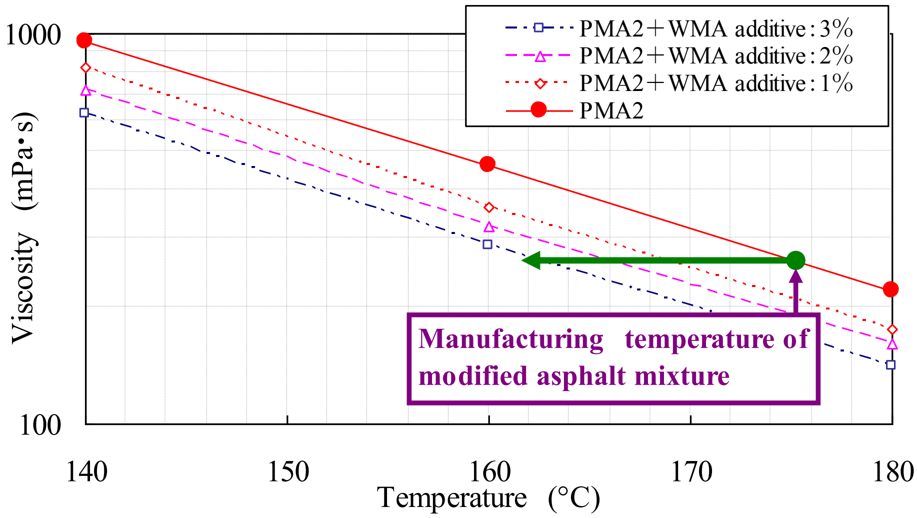

Figure 3 Temperature-viscosity curves for PMA2 with WMA additive

The developed additive is made up of polar radicals consisting of lipophilic groups of long-chain fatty acids and short chains. In the melting asphalt, polar radicals (positively charged) with high affinity to the aggregate particles' surfaces (negatively charged surfaces of silica and other minerals) appear to adsorb the additive, giving rise to the exterior lubrication effect by increasing the concentration of the additive in the vicinity of the aggregate surface.

Thus, we attribute the effectiveness of this additive in lowering the temperature not only to its enhancement of internal lubrication but also to the synergistic combination of the above factors.

2) Solid state

The additive disperses evenly throughout the asphalt when the asphalt is melting at a high temperature, but at lower temperatures where solidification begins to occur, the additive agglutinates and disperses in the form of particles, with lowered effectiveness on the asphalt properties.

5. TRIAL PAVING

5.1 Outline of trial

A trial was conducted with ordinary paving equipment in order to confirm the improvement in compaction afforded by the additive in laboratory tests. Existing asphalt mixture in a yard was overlaid with modified asphalt mixture incorporating the additive.

An overview of the test installation is provided in Table 2. Here, the objective was to verify the benefit in workability at temperatures 30−50°C lower than conventional manufacturing temperatures for the modified asphalt mixture and to assess the influence of the additive on the mixture conditions.

Table 2 Outline of trial paving

Construction condition	Date	January 2008
	Construction area	Width×Length×Thickness 2m×8m×5cm ×three Lane
	Zone	1 Lane: (WMA additive : 0%) Manufacturing temperature 125°C(50°C lower)
		2 Lane: (WMA additive : 2.5%) Manufacturing temperature 125°C(50°C lower)
		3 Lane: (WMA additive : 2.5%) Manufacturing temperature 145°C(30°C lower)
Manufacturing condition	Mixture type	Dense graded RAP : 30% Binder : PMA2
	Mixing time	DRY : 7sec, WET : 35sec(1 Lane), 45sec(2 Lane and 3 Lane)
	Addition method	Plant-mix

5.2 Determination of the amount of the WMA additive

The additive was directly thrown into the mixer of plant (plant-mix), because the volume of asphalt to be used was small. In order to determine the optimal amount of additive, a test was conducted to examine the compaction characteristics of the mixture. The test conditions are same as Section 4.2. As shown in Fig. 4, compaction characteristics obtained in a mix with an additive fraction of 2.5% were similar to those obtained under ordinary manufacturing conditions, so this was used for the trial paving. The mixing conditions were similar to those seen in mixtures prepared under normal manufacturing conditions.

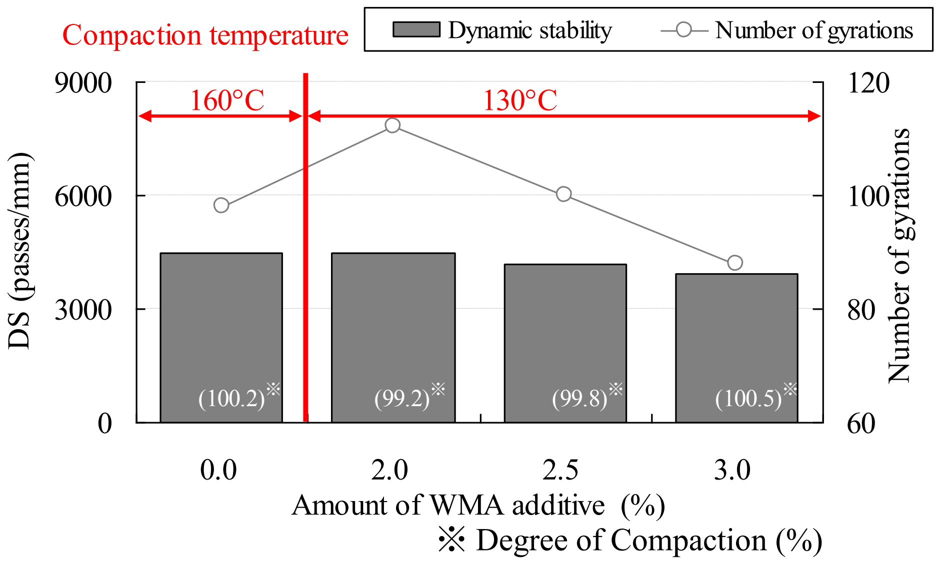

Figure 4 Amounts of WMA additive vs mixture properties

5.3 Manufacturing and application conditions

Wet mixing time with the additive was increased from the ordinary length by 10 to 45 sec, in order to make sure that dispersion was complete.

The mixture was loaded on a dump truck and driven for 30 min. After that, it was paved using an asphalt paver.

5.4 Density test with core boring

The degree of compaction found in the core borings from three lanes of the test pavement is presented in Fig. 5. The compaction reached a mean of 99% in 3 Lane, where the WMA additive had been added and mixing occurred at 30°C below the conventional temperature. A compaction was obtained that was quite similar to that obtained under ordinary mixing conditions.

The results from 1 Lane and 2 averaged a little below 98% compaction. There was a detectable benefit from the additive even when the mixing temperature had been reduced by 50°C.

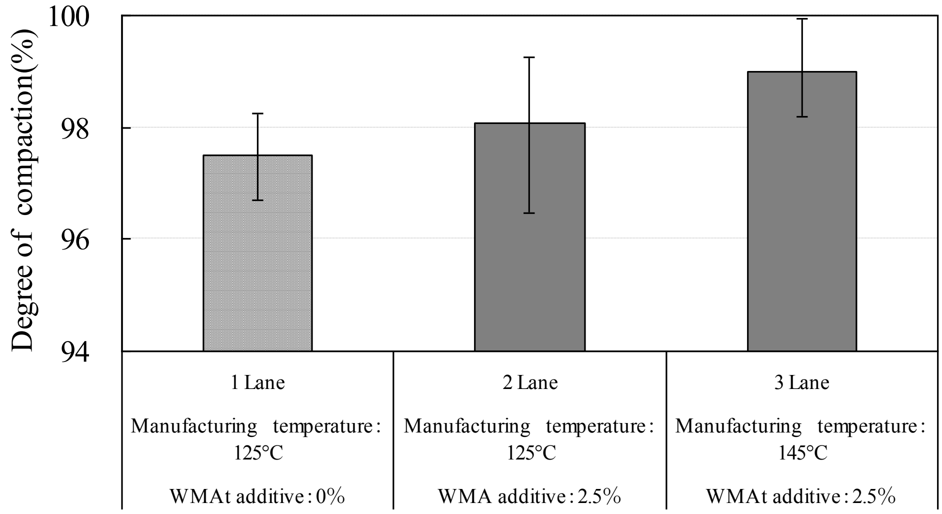

Figure 5 Results of compaction indicated by core borings

6. TEST ON ACTUAL ROADWAY

It had been established in laboratory and trial paving that appropriate levels of WMA additive allow manufacture of asphalt of satisfactory quality at 30°C lower than the conventional temperature. This mixture including the additive was therefore applied to an actual roadway in order to examine its performance in actual traffic.

6.1 Summary of roadway experiment

The roadway test is summarized in Table 3. The surface layer consisted of enhanced dense grade asphalt mixture(aggregate top size 13mm) including 30% recycled asphalt mixture and the WMA additive, mixed at a temperature 30°C lower than the conventional temperature.
A 40m section of this pavement (the control zone) was re-paved from the binder course up for comparison with the rest of the pavement. The construction was completed with standard equipment for pavement work. The right lane was paved first, and then the left lane was paved. A high volume of additive was used, so it was added at the manufacturing plant of polymer modified asphalt, and the modified asphalt was loaded on a tank truck with a specified amount of additive, resulting in pre-mixed asphalt.

Table 3 Summary of test installation on actual roadway

Construction condition	Date	September 2008
	Method	Cut and overlay (thickness=5cm)
	Design traffic	N5 (250 ≦ t < 1000 pedestal/day・direction)
	Zone	Maintenance work : No.0～No.7+10 975m^2(HMA)
		Test zone : No.7+10～No.10+10 390m^2(WMA)
Manufacturing condition	Mixture type	Dense graded RAP:30% Binder : polymer modified asphalt
	Mixing time	Control zone ; DRY : 7sec,WET : 35sec Test zone ; DRY : 7sec,WET : Right lane 35sec,Left lane 45sec
	Addition method	Pre-mix

6.2 Determination of the amount of the WMA additive

A laboratory test was performed in the same method as trial paving in order to determine the appropriate amount of additive to use. The same degree of compaction was obtained at an additive fraction of 2.5% as under ordinary manufacturing conditions, so this fraction was chosen to be used for the roadway test.

6.3 Manufacture of asphalt mixture and results of roadway test

The manufacture of the asphalt mixture is presented as a flowchart in Fig. 6.

For the right lane, the first lane to be paved, the wet mixing time for the asphalt with the additive was set at 35 sec, the same as used in the control zone. When the second rolling was performed with a pneumatic tire roller, flushing was observed in some spots on surface. This was judged to be caused by insufficient mixing of the new asphalt incorporating the additive with the old, recovered asphalt, due to the lower manufacturing temperature. Therefore, the wet mixing time was lengthened by 10 sec to ensure that the asphalt was adequately mixed in preparation for paving the left lane of the test zone. The left lane showed an excellent finish, with no flushing.

Thermographs of the temperature conditions during finishing are shown in Fig. 7, and indicate about a 30°C difference in the temperatures between the test zone and the control zone, nearly identical to the temperature difference when the each mixture were discharged to the trucks. The lower temperature reduced the heat radiated from the mixture and resulted in a distinctly cooler work environment.

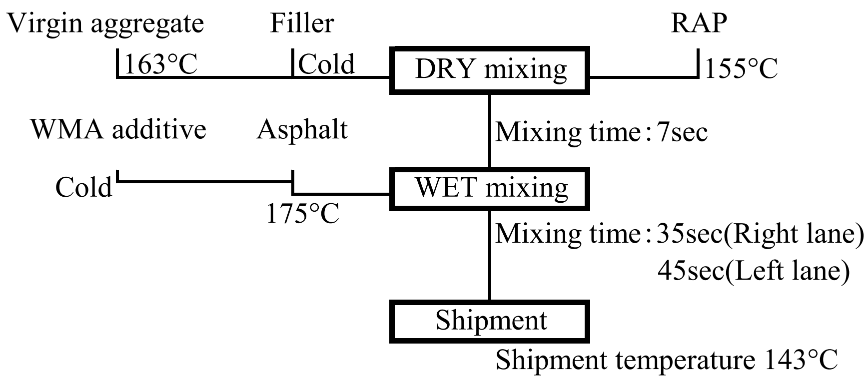

Figure 6 Manufacturing process of the asphalt mixture

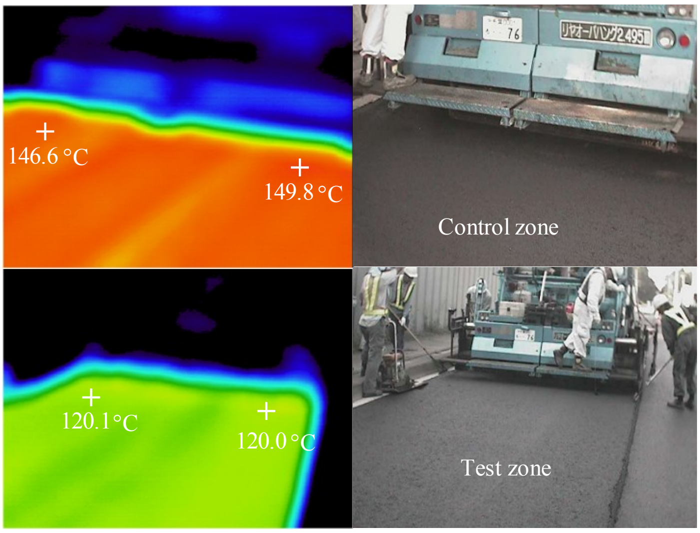

Figure 7 Thermographic temperature measurements

6.4 Results of quality confirmation tests

The results of quality testing of the test pavement and of a follow-up survey 1 year after construction are shown in Table 4. Similar or greater levels of compaction had been obtained in the test zone than in the control zone. It was verified that sufficient compaction was obtained with the warm-mix asphalt additive and the 30°C lower manufacturing temperatures.

Comparison of the mix conditions showed slightly lower levels of DS when the additive was used, but DS in both the right and left lanes showed levels above 3000, indicating that this mixture is usable on heavily traveled roadways. Comparison within the test zone indicated better mixing in the left lane, whose had a longer wet mixing time. It is supposed that the mixing state is improved, that is to say, the additive in new asphalt and the old asphalt in RAP is uniformly dispersed. These findings indicate that the wet mixing time should be extended slightly in terms of using the mixtures which include recycled aggregate.

The additive was added into the tank truck, but it takes good solubility. Therefore there was no issues with the addition method.

6.5 Results of follow-up survey

As indicated in Table 4, Test zone using the additive was shown as same quality and mixture properties as control zone.

Table 4 Results of quality test in actual roadway and follow-up survey

Item		Control zone	Test zone	
			Left lane	Right lane
Quality	Degree of compaction (%)	98.8	99.1	99.1
	Roughness (mm)(after the construction)	0.8	0.7	0.8
Mixture Property	DS (passes/mm)	4846	4200	3500
	Marshall stability test (kN)	15.2	14.5	13.6
	Immersion marshall stability test(48h) (%)	91.4	90.8	90.0
	Dending fracture strain$\times 10^{-3}$ (-)	4.2	4.1	4.0
Follow-up survey	Rutting volume (mm)(after 1 year)	6.4	4.7	4.7
	Cracking ratio (%)(after 1 year)	0	0	0

7. SUMMARY

The following results were obtained from this study.

1) A chemical compound having both the effect of reducing the viscosity of asphalt itself during low-temperature conditions and the effect of activating the asphalt-aggregate interface was selected as a WMA additive.
2) Using the appropriate amount of the selected WMA additive enables us to obtain the specified degree of compaction with modified asphalt mixtures, even when lowering the manufacturing temperature by 30°C.
3) If an appropriate amount of the selected WMA additive is added, it was shown not to exert influence on properties of asphalt mixture.

8. CONCLUSION

This report presents the effective use of a newly identified surfactant as a WMA additive in both laboratory experiments and test applications. Laboratory results also indicate that this additive confers similar performance improvements to straight asphalts. Future studies will involve testing of this additive to verify its effects in a variety of asphalt mixtures and under additional application conditions.

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