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ABSTRACT:

A multipurpose chemical additive is newly developed for Warm Mix Asphalt. This new additive enables producing and applying at a temperature around 30 to 50 degrees in Celsius lower than an equivalent Hot Mix Asphalt. General dosage is around 0.5 to 1.0% by weight of asphalt, i.e. only 250 to 500g by weight of 1,000kg mix in case of 5% of asphalt content. Low dosage means cost effective even supposing that the unit price of the additive is a little high. This additive is effective for not only straight-run asphalt, but also any polymer modified asphalt and specific decoloring asphalt which are commercially available in Japan. And this additive is effective for any graded mixtures and for both virgin and RAP used mixtures. Furthermore, the thermal oxidative aging using this additive is evaluated in two ways. First, dense-graded mixtures with straight-run asphalt and this additive are compacted after 72-hour heated at 160oC. Second, dense-graded mixtures with 50% of RAP and this additive are compacted after 24-hour silo storage without anti-oxidant. Few changes in mixture properties are found in both cases. These effects are verified through many paving projects in Japan. For example, porous asphalt pavement with polymer modified asphalt is well paved under -1 degrees in Celsius in daily average temperature with light snow. These pavements are still in good condition compared to adjacent general pavements.

Development of the Multipurpose Chemical Additive for Warm Mix Asphalt

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1 INTRODUCTION

Conserving the global environment has been one of the major problems for a long time. Act on promotion of procurement of Eco-friendly goods and services by the State and other entities (Green Purchasing Law) has been in effect since May 31, 2000 in Japan and business operators and citizens in Japan are to endeavor to select Eco-friendly goods to the extent possible when purchasing or leasing goods and/or receiving the provision of services. The designated procurement items list which includes Eco-friendly goods is documented and items on the list are promoted to be used.

Paving works are same. For example, hot mix asphalt (HMA) with reclaimed asphalt pavement (RAP) has been on the list since March 2004 and warm mix asphalt (WMA) without RAP has been on the list since February 2010. WMA technologies has been studied since early 1990s in Japan and some commercialized technologies were developed. Most were oil-based technologies and few were chemical foaming technologies.

The Nippon Road had also two technologies for WMA but these had some disadvantages comparing to other products. The first is that these depend on asphalt, i.e. the oil-based technology is only for straight-run (non-modified) asphalt and the chemical foaming technology is only for modified asphalt. The second is that dosage depends on volume of newly adding asphalt in case of WMA with RAP. And the third is that total binder tends to increase in case of HMA and/or WMA with RAP because rejuvenator is required.

The authors have been developed a new multipurpose chemical additive for the use of WMA and overcame above disadvantages. This paper describes the outline of the additive, some examples of mix properties with this additive, some case studies and so forth.

2 BACKGROUND OF NEEDS FOR A MULTIPURPOSE ADDITIVE

2.1 Trends of HMA Production in Japan

Publish investment has been decreased and decreased since Japan's overheated stock and real estate markets had also been collapsed in early 1990s. Concerns about improvement of infrastructure including road buildings and pavement repairs declined at the same time. Figure 1 shows the amount of HMA production from 1984 to 2016 (Japan Asphalt Mixture Association 2018). Maximum total amount was about 80 million tons in 1992 and it falls to about one-half in 2016 according to the latest statistics.

On the other hand, HMA with RAP has been gradually increased ever since then. As a heavy black line in this figure shows, percentage of HMA with RAP was about 15% in 1992, it reached to 50% in 1998 and is about 77% in 2016.

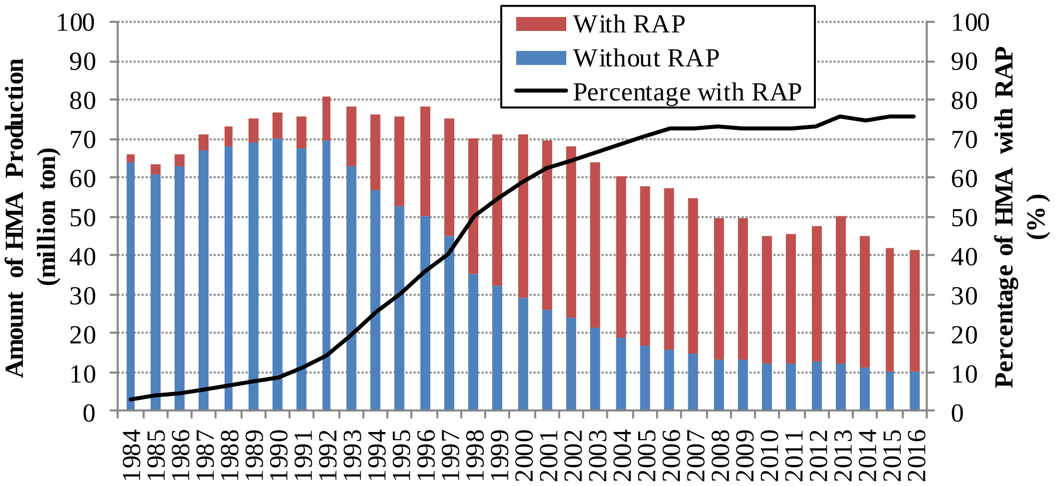

Figure 1. Amount of HMA Production in Japan (Japan Asphalt Mixture Association 2018)

As noted above, WMA without RAP was on the designated procurement items list in 2000. Virgin HMA was no longer main product at that time. WMA without RAP is one of the products of virgin HMA. It was said that percentage of WMA was under 1% of all HMA products.

2.2 Trends of Polymer Modified Asphalt in Japan

Japan has currently more than 1.2 million km road network. As shown in Figure 2, maximum number of large vehicles was about 21 million in 1991. Since then, severe rutting has been one of the major sources of concern for not only road authorities but also road users. Using polymer modified asphalt (PMA) is one of the solutions for that. PMA type I includes rubber as the modifier and PMA type II includes a kind of resin as the modifier. Both have become a general product in 1988. Since then totally seven PMA have been developed and used in Japan according to theirs purpose and application, as shown in Table 1. The amount of production of HMA using PMA was about 380,000 tons. It is about 11% of all HMA. And the amount was 480,000 tons and about 16% of all HMA, according to the latest statistics (Japan Modified Asphalt Association 2015). PMA usually used for virgin HMA or WMA. As already shown in Figure 1, about 23% of total production is virgin

HMA and this means that PMA is used for about 70% (=16/23) of virgin HMA.

From these, any additives for the use of HMA or WMA using virgin asphalt only was not needed. And development goal should be one additive for the use of HMA or WMA using PMA and HMA or WMA with RAP.

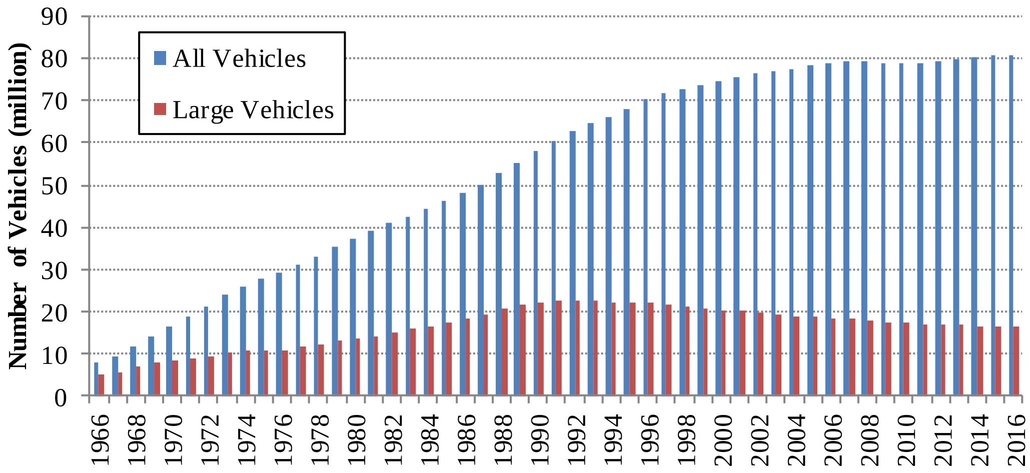

Figure 2. Number of Vehicles in Japan (Automobile Inspection & Registration Information Association 2017)

Table 1. Types of PMA and Its Application in Japan (Japan Modified Asphalt Association 2006)

Purpose	Application	Type I	Type II	Type III	Type III-W	Type III-WF	Type H	Type H-F
Permanent deformation	General road	Very good						
	Heavy duty road		Very good				Very good	Very good
	Heavy duty road and crossing			Very good	Good	Good	Good	Good
Wearing	Cold and snowy area	Very good	Very good	Good	Good	Good		
Water sensitivity	Concrete deck bridge		Good	Good	Very good			
Flexibility	Steel deck bridge		Good	Good		Very good		
Permeability	Surface						Very good	Very good
Available mixture		Dense-graded, fine-graded, coarse-graded mixtures					Porous asphalt mixture	

2.3 Study about Another Option

The authors understand that foaming technologies for WMA are mainly used in the United States (NAPA 2007). The Nippon Road imported one of the foaming technologies from USA about eight years ago and made some tries to produce WMA with the foaming process. Finally, the Nippon Road decided that the foaming technology is not applicable as WMA in Japan because it was hard to decrease producing and paving temperature about 30 degree in Celsius comparing to generally produced HMA and asphalt pavement laid using this technology ‘moved’ slightly after opened to traffic. This phenomenon sometimes led to rutting in early stage.

3 BRIEF DESCRIPTION OF DEVELOPED CHEMICAL ADDITIVE

Figure 3 shows developed chemical additive. It is white and solid and flake form at ambient temperature and melting point is 53 degree in Celsius. This additive is easy to dissolve in any asphalt, so it is not necessary to extend mixing time when producing WMA. This additive has high-temperature stability, then it is applicable for silo storage and long-distance hauling of produced mixtures. pH is 7.1, i.e. this is neutral. No need to care about environmental affairs due to acidity and alkalinity, if this additive leaks from pavement after service.

Figure 3. Developed Chemical Additive

Actual dosage depends upon mixtures and asphalt contents, and general dosage is 0.5% to 1.0% by weight of asphalt. So only 250g to 500g addition is required to produce 1,000 kg of WMA with this additive when asphalt volume is 5.0%.

Figure 5 shows effects to asphalt penetration according to dosage of this additive and Figure 6 shows effects to asphalt softening point. In these figures, 0.0% of dosage mean the original values of asphalt used. Penetrations are slightly increase with dosage of additive. But it seems that the impacts are limited when dosage is under 1.0%. Softening points show almost same values of the original asphalts. Thus this additive is not a modifier of asphalt.

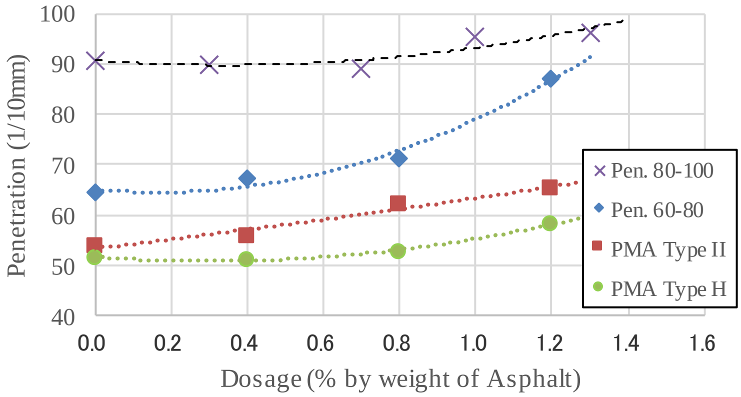

Figure 4. Effect to Penetration of Asphalt

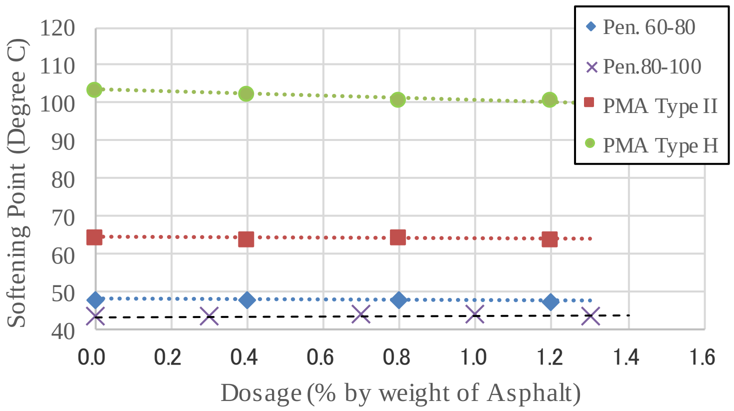

Figure 5. Effect to Softening Point of Asphalt

4 CASE STUDIES

4.1 Mix Design of Dense-graded Asphalt Mixture

The Marshall mixture design method is still adopted in Japan. Figure 6 shows the comparison of air voids of cylindrical specimen. Selected aggregates measured to meet dense-graded mixture requirement. PMA type II is used in this case with a purpose of higher deformation resistance. Recommended mixing temperature of this PMA is 170 to 185 degree in Celsius and recommended compaction temperature is 160 to 170 degree in Celsius. Some trial mix are mixed at 178 degrees in Celsius and compacted at 168 degrees in Celsius. According to the Marshall method, OAC is 4.9% and shows 3.6% air voids. No additive is used in this stage. Specification of air voids for dense-graded mixture is 3 to 6%. This mixture meets all specifications including air voids. This is referred as 'general HMA' in Figure 6.

Other specimens are made with the new chemical additive. This additive is used after introducing asphalt during mixing. Dosage is 0.8% by weight of asphalt, i.e. only 0.5g for about 1,200g mixture. To confirm the effect of this additive both mixing and compaction temperatures have been changed as showed in Table 2.

Specification of air voids of dense-graded mixture is 3 to 6% in Japan. Air void of general HMA is 3.6%. On the other hand, air voids of WMA with this additive are 2.7%, 2.7%, 2.9% and 3.3% when compaction temperatures are 170, 150, 130 and 110 degree in Celsius respectively. This result indicate that this additive can improve the compactability of asphalt mixture and enables compaction temperature drop more than 50 degree in Celsius relative to general HMA.

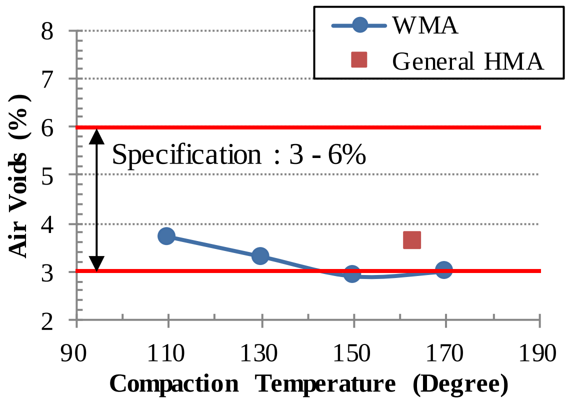

Figure 6. Comparison of Air Voids of Cylindrical Specimen

Table 2. Mixing and Compaction Temperatures when new additive is used

	Mixing Temperature (degree in Celsius)		Compaction Temperature (degree in Celsius)	
Case 1	175	(-3)	170	(+7)
Case 2	155	(-23)	150	(-13)
Case 3	135	(-43)	130	(-33)
Case 4	115	(-63)	110	(-53)
General HMA	178		163	

Note: Number in a parenthesis means temperature difference relative to general HMA

4.2 Field Test Pavement

The authors conducted small test pavements to confirm the temperature drop efficiency of this additive at a private field in Tsukuba, Japan. Dense-graded mixture, coarse-graded mixture and porous asphalt mixture were constructed. Maximum aggregate sizes are 13mm, 20mm and 13mm, respectively. Test section had 2.8m in width and 90m in length. Thickness was 5cm. Table 3 shows mix design results for each mixture. The new additive is not used in mix design stage. After some trial mix, dosages of the additive are decided as 0.7%, 0.5% and 0.7% by weight of asphalt, respectively. And target temperature drop of mixing are 30 degree in Celsius in every case.

Table 3. Mix Design Result

	Dense-Graded	Coarse-Graded	Porous Asphalt
Asphalt used	Pen. 60-80	Pen. 60-80	PMA Type H
Asphalt Content (%)	5.5	4.7	4.8
Air Void (%)	3.9	3.9	20.5
Density (g/cm^3)	2.387	2.416	1.980
Stability (kN)	10.9	10.6	6.4
Mixing Temperature (degree in Celsius)	152	152	170

All mixtures were produced at a batch plant. This test filed was at adjacent to the asphalt plant, so paving works were carried out after one hour hauling to simulate general paving works at public roads. MF43WD asphalt finisher made by Mitsubishi was used to spread the produced asphalt mixtures. The SW650 tandem roller with 7 tons made by Sakai was used for the first compaction and the TX701 pneumatic-tired roller with 15 tons made by Sakai was used for the finishing compaction. A steel-tired roller is generally used for the first compaction in Japan, however it was not able to use due to the narrow filed width. Table 4 shows a series of measured temperatures of asphalt mixtures at each construction stage. Mixture production temperatures and spreading temperatures are almost on target and/or below target.

Table 4. Measured Temperatures of Asphalt Mixtures at Each Construction Stage

	Dense-Graded Mixture	Coarse-graded Mixture	Porous Asphalt Mixture
Target Production Temperature	122 (-30)	122 (-30)	140 (-30)
Production Temperature	122 (-30)	119 (-33)	140 (-30)
Mixture Temperature After Hauling	123	123	140
Spreading Temperature	101 (-39)	100 (-40)	98 (-57)
First Compaction Temperature	80	78	88
Finishing Compaction Temperature	52	54	75

Note: Unit is degree in Celsius. Number in a parenthesis means temperature difference relative to general HMA

Six cores with 100 mm in diameter are sampled at each mixture site and measured their densities and air voids. And percent of lab-compacted densities are calculated. These results are shown in Table 5. Percent of lab-compacted density means density of WMA core divided by lab-compacted HMA specimen's density. These results show three WMA are well compacted even though production temperature is dropped 30 degree relative to general HMA.

Table 5. Density and air voids of Sampled 100mm Cores

	Dense-Graded Mixture	Coarse-graded Mixture	Porous Asphalt Mixture
Density (g/cm^3)	2.421	2.450	2.051
Air Voids (%)	4.2	4.0	19.4
Percent of lab-compacted density (%)	98.1	98.2	99.0

4.3 Construction Work at a National Road

The Nippon Road made a contract on a national road in Tokyo. This was a construction for wire common conduct. The wire common conduct was buried under a road in service and pavement should be restored daily to open traffic. This work was carried out at night. So actual construction hours were very limited. Taking consideration of shortening the construction hours, it sometimes faces higher temperature of HMA. The Nippon Road decided to adopt WMA. And as previously noted, this WMA should be included RAP due to Green Purchasing Law.

As a result of mix design, WMA with 50% RAP was adopted for asphalt stabilized base material for the base course, coarse-graded mixture for binder course and dense-graded mixture for surface course. Table 6 shows the mixture properties and conditions. Every mixture is WMA with RAP, but no rejuvenator is used because this new additive also acts like a rejuvenator (Endo et.al. 2016).

Table 6. Asphalt Mixtures Properties and Conditions

	WMA for Surface Course	WMA for Binder Course	WMA for Base Course
Asphalt Content (%)	5.2	4.7	4.0
Air Void (%)	3.8	3.9	6.7
Lab-compacted Density (g/cm^3)	2.402	2.414	2.365
Production Temperature (°C)	132 - 140		
Compaction Temperature (°C)	124 - 130		
Penetration of Adding Asphalt (1/10mm)	Pen.80-100		
Additive Content (%)	0.8 (by weight of asphalt)		
RAP Content (%)	50		
Rejuvenator	N/A		

This was two-year long project. General HMA with RAP was also in this work. Figure 7and Figure 8 show temperature drop comparison between HMA with RAP and WMA with RAP after placing binder course and surface course. HMA data were collected during winter season and average air temperature was 3.1°C. And WMA data were collected during fall season and average air temperature was 11.2 °C. Red dotted line shows a target temperature to enable opening for traffic. 20 minutes reduction for binder course construction and 15 minutes reduction for surface course construction in case of WMA with RAP comparing to HMA with RAP. Taking account for the air temperature, it is expected that WMA with RAP has more reduction of construction hours effect.

Table 7 shows the percentage of lab-compacted density of filed sampled cores of HMA with RAP and WMA with RAP. Specification of percentage is 96% or above. All cases meet this specification and WMA with RAP are well compacted like HMA with RAP even though WMA with RAP were produced and constructed about 30°C temperature decrease comparing to HMA. HMA with RAP property was not noted in this paper, rejuvenator was used. These facts show that developed new additive act well as not only warm-mix additive but also rejuvenator. Other mixture properties like stability, rutting resistance and so forth were on same levels.

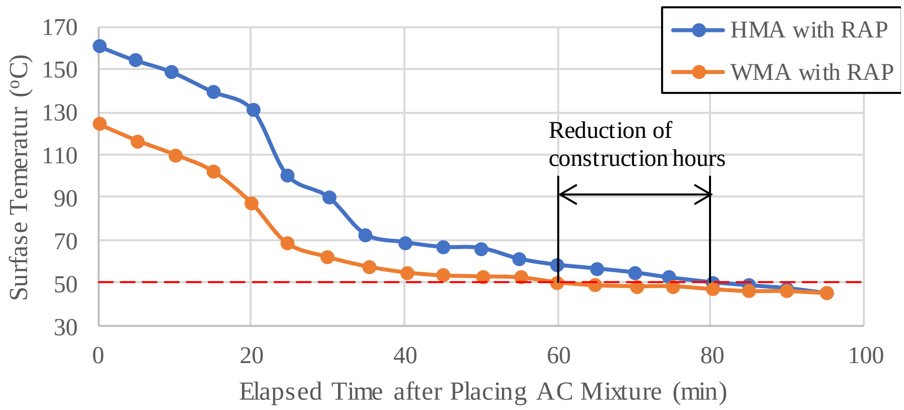

Figure 7. An example of Surface Temperature Drop after Placing Binder Course

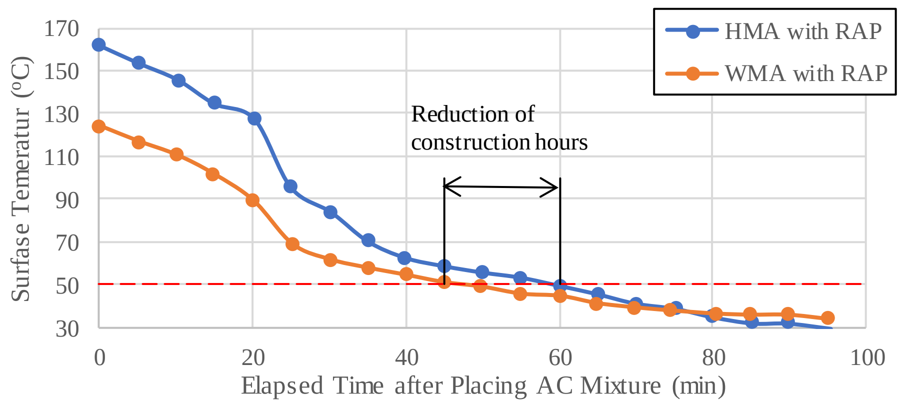

Figure 8. An Example of Surface Temperature Drop after Placing Surface Course

Table 7. Percentage of Lab-compacted Density of Filed Cores

	#	Asphalt Stabilized Material	Coarse-graded Mixture	Dense-graded Mixture
WMA with RAP	1	100.4	98.7	96.6
	2	101.4	101.5	96.9
	3	101.4	99.5	97.6
	4	101.2	101.3	98.5
	Ave.	101.1	100.3	97.4
HMA with RAP	1	98.9	100.3	97.5
	2	102.5	102.1	99.5
	3	100.5	101.0	98.5
	4	100.6	101.1	98.5
	Ave.	100.6	101.1	98.5

4.4 Other Projects

Some examples of other projects are shown in Table 8. This list summarized in 2012 and old data because this additive was developed in 2010 and the authors eagerly collected such data at that time. After that, the authors had few interested in these records because this additive is communized within the Nippon Road. As well-known, WMA has other aspect, i.e. it enables longer distance hauling than HMA and also enables enough compaction of pavement during cold weather. Fiscal year in Japan starts in April and ends in next

March. It is said that this leads to more construction works in winter season. This list includes such cases.

Table 8. Examples of Other Projects (As of 2012)

Area	Mixtures	Asphalt	Amount of Production (tons)
Osaka	Coarse-graded, Asphalt Stabilized	Pen.60-80	2,300
Ibaragi	Coarse-graded, Asphalt Stabilized	Pen.60-80	9,000
Fukushima	Dense-graded	PMA Type II	500
Kanagawa	Dense-graded	PMA Type II	2,000
Hiroshima	SMA	PMA Type II	200
Hiroshima	SMA	PMA Type II	300
Kouchi	Porous asphalt pavement	PMA Type IH	100
Hokkaido	Porous asphalt pavement	PMA Type IH	780
Fukushima	Coarse-graded, Asphalt Stabilized	Pen.60-80, PMA Type II	11,000
Tokushima	Coarse-graded, Asphalt Stabilized	Pen.60-80	300
Kouchi	SMA	De-colored Asphalt	200
Iwate	Dense-graded with RAP	Pen. 60-80	430
Other	Dense-graded with RAP	Pen. 60-80	4,000

5 CONCLUSIONS

This paper concludes like followings.

- A new chemical additive for WMA was developed.
- This additive does not affect to asphalt properties.
- This additive can use for any asphalts including polymer modified asphalt.
- This additive can use for any asphalt mixtures.
- General dosage of this additive is only 0.4 – 0.8% by weight of asphalt.
- This additive enables 30 – 50 °C temperature decrease comparing to general HMA.
- This additive acts like rejuvenator when this is used for WMA and/or HMA with RAP.
- Some case studied are shown to understand above features.

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