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Application of Warm-Mix Modified Asphalt Mixture in Highway Maintenance Project

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Abstract: Warm-mix asphalt (WMA) is a relative new technology that has been used in constructing asphalt pavements around the world. WMA offers many advantages, such as energy-saving, environmental advantage, construction cost reduction, extension of construction season, etc. Current and past researches have indicated satisfactory performance of WMA pavements. Continued application and the desire for improvement of performance of WMA have attracted great interests from pavement communities worldwide. In this research, laboratory and field evaluations were conducted to systematically study the behavior and performance of WMA mixtures modified with styrene-butadiene rubber (SBR) emulsion or epoxy resin. The results showed that the use of epoxy resin resulted in a significant change in the penetration characteristic of WMA, while the addition of styrene-butadiene rubber (SBR) emulsion improved the viscosity and temperature susceptibility of WMA mixtures. No significant changes were observed in WMA ductility. With the same aggregate gradation, SBR-modified WMA mixtures exhibited superior water stability and high-temperature performance to regular WMA mixtures and hot mix asphalt mixtures. Overall, SBR-modified WMA mixtures showed equal or better performances than conventional hot-mix asphalt mixtures did.

Key words: *Epoxy resin; Mix proportion; Modified warm-mix asphalt; Pavement-application performance; Styrene-butadiene rubber Emulsion.*

Introduction

The warm-mix technology was first introduced in Europe mainly for the purpose to reduce the viscosity of cementing material in the mixtures and thus to lower the mixing and compaction temperatures. The Warm-mix mixture technology based on the addition of emulsions into asphalt mixtures is widely used in China. This is a recently developed method in the United States, which allows a relatively wider temperature ranges for mixing operation and construction. During the production of asphalt mixtures, a condensed soap liquid made with a special emulsifier was directly sprayed into the mixing pot to produce warm-mix asphalt (WMA) mixtures. The construction and compaction equipment and processes used in this technology are basically the same as those used for other WMA mixtures.

It has been shown from past studies and projects that the WMA technology can lower the mixing and compaction temperatures, thus saving energy and reducing emission during construction. Because of the lower construction temperature requirement, it can extend the asphalt pavement construction season. As a result, the WMA technology has been increasingly recognized in the road construction.

Previous study conducted by Chen [1] indicated that styrene-butadiene rubber (SBR) and epoxy resin modified WMA exhibited improved performance compared to WMA without modifiers. The objective of this research was to study the mechanical properties and performances of WMA modified with two different additives, SBR emulsion and epoxy resin. It was hypothesized that the inclusion of the additives could further improve the performance of WMA pavements. The study was also to evaluate the effects of SBR emulsion and epoxy resin on the viscosity and workability of WMA.

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Literature Review

Several new technologies have been developed, originally in Europe, to lower the production and placement temperatures of hot-mix asphalt (HMA), which are generally referred to as WMA [2]. WMA has been used in all types of asphalt pavement, with a wide range of layer thicknesses and subjected to various levels of traffic.

There are two common ways for WMA classification. The first one is by the degree of temperature reduction as compared to HMA. The production temperatures within WMA can vary widely, from 20 to 30°C below HMA to temperatures slightly above 100°C. WMA technologies can also be classified by types of additives used, including those that use water and those that use some form of organic additive or wax to affect the temperature reduction. Processes that introduce small amounts of water to hot asphalt, either with a foaming nozzle or a hydrophilic material such as zeolite, are based on the fact that when a given volume of water turns to steam at atmospheric pressure, it expands significantly. The addition of organic additives can reduce the viscosity above the melting point of the organic additives.

Many processes have been developed. These processes include:

- The use of various additives, including Sasobit, a Fischer-Tropsch wax; Asphaltan-B, a refined Montan wax; Lincomont BS 100, a fatty acid amide; etc.
- Foaming process, including Asphalt-min, a synthetic

zeolite; ECOMAC, cold mix warmed before laying; etc.
- Other emerging technologies, such as Evotherm, hot aggregate coated with emulsion; Double-Barrel Green; Advera; etc.

Many advantages of the use of WMA technologies have been cited. These advantages included reduced emissions; reduced fuel and energy usage by 20 to 35 percent; the ability to pave in cooler temperature to extend the construction season; the ability to sustain longer distance hauling; the ability to incorporate higher percentage of recycled asphalt pavement (RAP); and reduced work exposure to fumes and high temperatures.

In 2005, the National Center for Asphalt Technology (NCAT) of USA conducted laboratory studies to evaluate the Asphalt-Min® and Sasobit® for use in the warm mix technology [3, 4]. The main objective was to determine if theses technologies were applicable to typical paving operations and environmental conditions commonly found in the United States, especially the performance of the mixes in quick traffic turn-over and high temperature conditions. It was concluded from these studies that the use of these technologies could improve the compactability of mixtures in both the Superpave Gyratory Compactor (SGC) and vibratory compactor. An overall reduction in air voids was observed. Improved compaction was noted at temperatures as low as 88°C. They did not affect the resilient modulus of an asphalt mix nor did they increase the rutting potential of an asphalt mix as measured by the Asphalt Pavement Analyzer.

In a research to evaluate the installation of WMA to compile experiences and offer recommendations for future use in Virginia, three trial pavement sections were installed using warm mix technologies in 2006 [5]. Two used the Sasobit technology, and the third employed the Evotherm technology. Mix designs of the materials, mixture production, and pavement placement were documented. Typical mixture designs and construction practices were used so that performance under typical construction conditions could be evaluated. The study indicated that WMA could be successfully constructed using conventional HMA paving practices and procedures with only minor modifications to account for the reduction in temperature. It also recommended that additional monitoring of constructed sections be performed to evaluate long-term performance.

Following the field evaluation, a laboratory study was conducted to evaluate the performance of the WMA mixture using the Sasobit technology [6]. The evaluation included comparisons of various performance parameters between the WMA and HMA mixtures. Performance parameters evaluated were compactibility, volumetric properties, moisture susceptibility, rutting resistance, and fatigue performance. From the study, the authors stated that few differences were found between the HMA and WMA mixtures evaluated. The performance of WMA and HMA was similar when evaluated for moisture susceptibility, rutting potential, and fatigue resistance.

Another laboratory study was carried by You and Goh [7] to investigate the performance of a WMA made with synthetic zeolite technology. A control HMA mixture, WMA with 0.3% of synthetic zeolite, and WMA with 0.5% of synthetic zeolite were used in this study. Asphalt mixtures were compacted using Superpave Gyratory Compactor and were subjected to dynamic modulus test. It was found that the overall performance of WMA in terms of dynamic modulus increased when compared the control HMA mixture.

Giuliani and Merusi [8] conducted an extensive laboratory study to investigate the effects of different types of wax on the flow and viscoelastic properties of bitumen. Five different organic additives, including both natural and synthetic waxes, were used to make eleven bitumen-wax mixes and their rheological properties were evaluated. It was discovered that changes in viscosity functions depended on the chemical structure of wax as well as on its physical characteristics. However, the viscosity of all blends at 120°C was lower than the viscosity of the base bitumen.

Evaluation of Properties of WMA with or without Modifiers

Equipments and Materials

Equipments

Equipments used in this study included SYD-2801 penetration test apparatus (penetrometer); SYD-4508C ductility tester; SYD-2806E automatic asphalt softening-point tester; and CF-B standard constant temperature water bath.

Materials

A common asphalt material AH-70# was used, which had the following properties: a penetration of 65 at 25°C, a softening point of 50°C, and ductility over 100*cm* at 25°C. Other materials included Evotherm warm-mix agent, bisphenol-A epoxy resin E44, epoxy curing agents JN13-T-31, and anionic SBR emulsion.

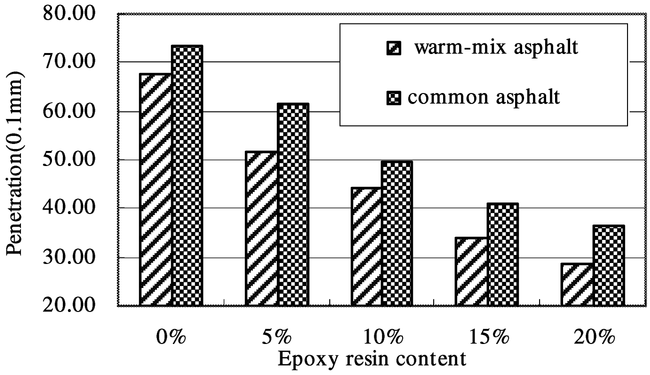
Experimental Program

The mix design and mixing procedure of WMA mixture prescribed in the Technical Specification for Construction of Highway Asphalt Pavement were followed. The warm-mix agent to asphalt ratio was 1:9 and the acidic solution had PH values between 3.5 and 2.5. The following processes and controls were used in producing the asphalt mixtures:

- Heat the base asphalt to a temperature between 130 and 140°C and keep it within the range,
- Slowly add the warm-mix agent into the liquid asphalt while stirring the mixture until no air bubbles indicating that moistures in the mixture have evaporated,
- Add either the SBR emulsion or the epoxy resin into the WMA mixture, and
- Keep stirring the mixture again until the consistency met the requirement for mould-cast operation.

Five different amounts of modifiers (SBR emulsion or epoxy resin emulsion) were used in this study 0, 5, 10, 15, and 20%. The WMA mixtures, as well as the conventional HMA, were then subjected to three standard tests, penetration test, softening point test, and ductility test. The test results were analyzed to evaluate the effects of the SBR and epoxy resin on the conventional HMA and the WMA and to determine the optimum mix design.

Analysis of Test Results



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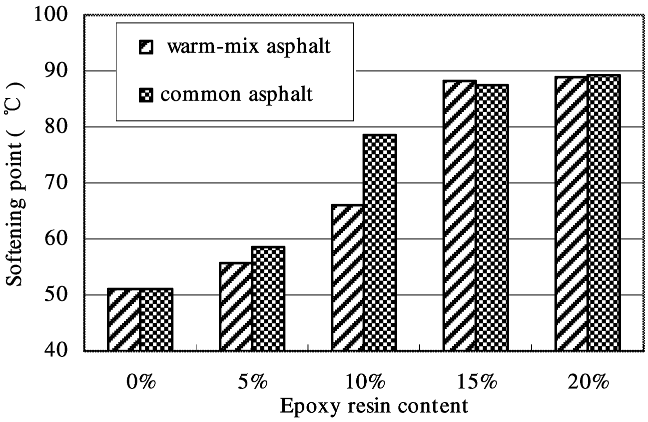

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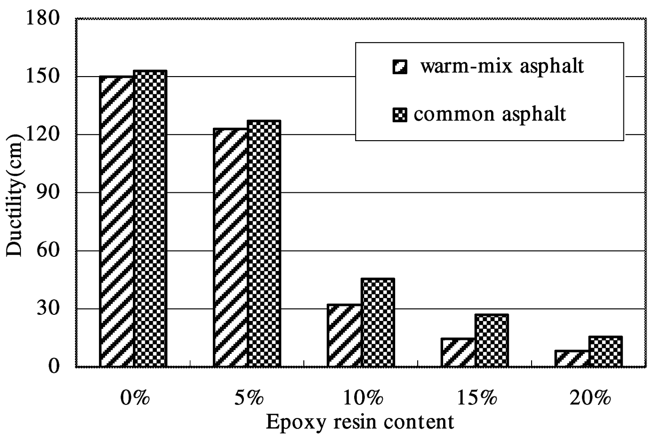

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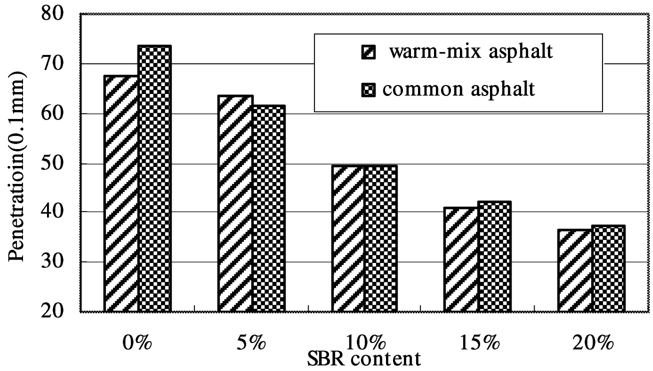
Fig. 1. Comparison of Penetration, Softening Point, and Ductility Test Results for WMA and HMA Mixtures Containing Various Percentages of Epoxy Resin (a) Penetration at 25°C, (b) Softening Point, and (c) Ductility at 25°C.



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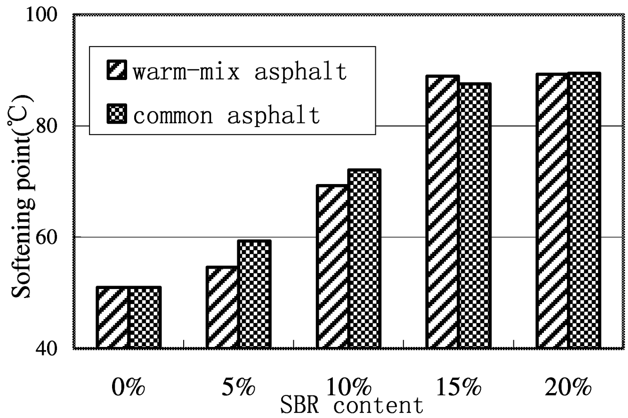

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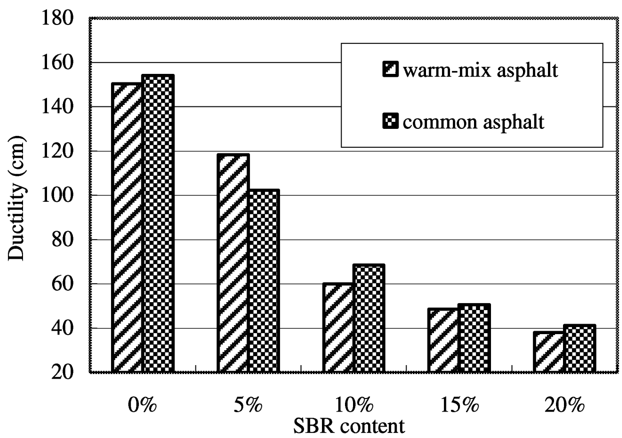

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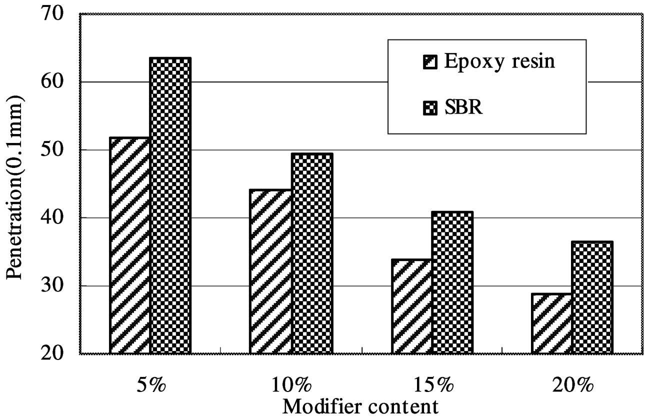
Fig. 2. Comparison of Penetration, Softening Point, and Ductility Test Results for WMA and HMA Mixtures Containing Various Percentages of SBR (a) Penetration at 25°C, (b) Softening Points, and (c) Ductility at 25°C.

Properties of WMA Modified by Epoxy Resin

Results of the penetration test, the softening point test, and the ductility test for both HMA and WMA mixtures containing various percentages of epoxy resin are presented in Fig. 1. From Fig. 1(a), it is observed that, for both WMA and HMA, the penetration decreases with increasing percentage of epoxy resin in the mix. It is also noted that, containing same percentage of epoxy resin, the WMA mixture has lower penetration than HMA does. As shown in Fig. 1(b), opposite trend is observed for softening point. For both WMA and HMA, the softening points increase as the percentages of epoxy resin increase, up to 15%. When the content of epoxy resin increases from 15 to 20%, no significant changes are observed. Also, for most cases, no significant differences on softening point



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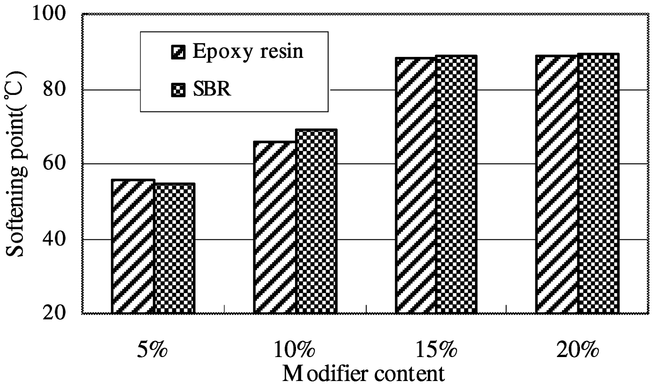

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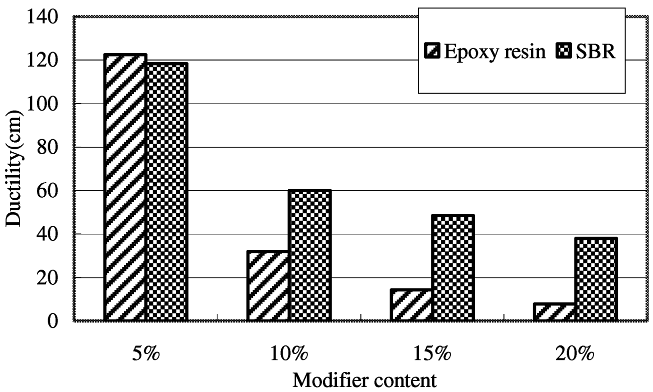

(c)

Fig. 3. Comparison Penetrations, Softening Points and Ductility of Warm-Mix Asphalt with the Two Different Modifiers (a) Penetration at 25°C, (b) Softening Point, and (c) Ductility at 25°C.

are presented between WMA and HMA. Fig. 1(c) shows that addition of epoxy resin reduces the ductility significantly. A huge reduction in ductility is noted when the epoxy resin content increases from 5 to 10%. In general, the HMA exhibits slightly higher ductility, especially at higher epoxy resin contents.

From analysis of the test results, it appears that the addition of 10% epoxy resin has the most significant effects on the properties of both the WMA and HMA mixtures. Therefore, 10% epoxy resin content has been selected as the optimal content in this study.

Properties of WMA Modified by SBR Emulsion

Results of the penetration test, the softening point test, and the ductility test for both HMA and WMA mixtures containing various percentages of SBR emulsion are presented in Fig. 2. Overall, it is observed that the effects of the SBR emulsion on WMA and HMA mixtures are very similar to those of epoxy resin. With the increasing percentage of SBR emulsion, the penetration decreases; the softening point increases; and the ductility decreases. Again, the 10% SBR emulsion content was determined to be the optimal content.

Comparison between Modification Results of Two Different Modifiers

From Figs. 1 and 2, it is apparent that both the SBR emulsion and the epoxy resin had significant effects on the properties of WMA. A comparison of the relative effects of these two modifiers on properties of WMA mixtures is shown in Fig. 3.

Fig. 3(a) clearly indicates that, at the same percentages, epoxy resin can improve the penetration of the WMA more than the SBR emulsion can (lower penetration values). From Fig. 3(b), no significant differences are observed on the softening point for the WMA containing either the SBR emulsion or epoxy resin. However, at percentages higher than 5%, the WMA mixtures modified by SBR show higher ductility, as shown in Fig. 3(c). Also, the rate of decrease in ductility with increasing percentage of modifiers is smaller for the SBR modified WMA as compared to that of epoxy resin modified WMA.

From the analysis, it is clear that both the SBR emulsion and the epoxy resin significantly modified properties of WMA, and each had its own unique advantages. The results also confirmed that, by improving the viscosity and temperature performance while inducing less reduction in ductility, the positive effects of SBR emulsion exceeded those of epoxy resin [9, 10].

Evaluation of Pavement Performance of WMA Pavement, with or without Modifiers

Marshall Stability Experiments

Materials Preparation

The procedure for preparation of WMA mixtures differed slightly from that for HMA mixtures. The specific steps for preparation of the WMA mixtures in this study were as follows:

1. Fully wet a 50 milliliter paper cup and then weighed/measured the amount of additive in accordance with the mix design proportion, which would be described in the next section;
2. Placed the heated aggregate into a preheated mixing pot to make a dry mix to reduce heat loss;
3. Used a mixing shovel to pull the dry mixed aggregate material into a slope so that the bottom of the mixing pot is exposed;
4. Poured the hot asphalt (the temperature is the same as that of HMA) into the exposed bottom of the mixing pot;
5. Lowered the mixing impeller down to a level appropriate for

Table 1. The Gradation for Asphalt Mixture AC-13.

Sieve Size (*mm*)	Gradation Proportion %
13.2-16.0	5
9.5-13.2	18.5
4.75-9.5	23.5
2.36-4.75	16
1.18-2.36	10.5
0.6-1.18	7.5
0.3-0.6	5.5
0.15-0.3	3.5
0.075-0.15	4

the beaker/paper cup to get into; poured the modifiers on the asphalt surface, and, at the same time, tried to avoid contaminating the aggregates;

6. Lowered the mixing impeller and began stirring; kept stirring for about 2 minutes;
7. Raised the mixing impeller a little higher; add mineral powder (unheated) and kept stirring once again.

Determination of Appropriate Mixing and Compaction Temperatures for WMA

The use of modifiers, such as SBR emulsion and epoxy resin, in the WMA resulted in an increase in viscosity, which, in turn, would affect the mixing and compaction temperatures. In other words, the mixing and compaction temperatures for WMA mixtures might not be suitable for of modified WMA mixtures. It is a well known fact that, at a fixed compaction temperature, the air void volume in the mixture will be lower as the asphalt binder content increases. As the compaction temperature decreases, the air voids in the mixture will increase. Therefore, to keep the air void in proper ranges, a low compaction temperature will result in higher asphalt binder content, which will be detrimental to high-temperature stability of the mixture.

Although increasing the compaction temperature might help reducing the required asphalt content the use of too high a compaction temperature would lose the many benefits provided by the WMA technology significantly [11, 12]. In this study, the optimum mixing and compacting temperatures were determined by making testing samples at different mixing and compacting temperatures with the optimum asphalt-binder content of HMA mixtures. From analyses of the variation of temperature-air-voids data, the Marshall Stability and Marshall Flow numbers, the optimal mixing and compaction temperatures were determined to be 130 and 120°C, respectively. Table 1 presents the gradation of asphalt mixture AC-13 used in this research.

Mix Design Proportions of Epoxy Resin Modified WMA Mixture

As discussed in previous sections, the optimal epoxy resin content was 10%. With 10% epoxy resin content, WMA mixtures with five different asphalt-binder contents, 6.0, 6.5, 7.0, 7.5, and 8.0% were prepared. The Marshall compaction method was used to fabricate the samples at a compaction temperature of 120°C (double-side 75×2 times). Bulk specific gravity (relative density) of each asphalt mixture was measured under the saturated surface dry condition. Relationships between the asphalt-binder content and bulk specific gravity, stability, flow number, air voids volume (VV), voids filled with asphalt (VFA), and voids in the mineral aggregate (VMA) were established. Table 2 shows the Marshall Test results of WMA mixtures containing 10% of epoxy resin. From these analyses, the design asphalt-binder content was determined to be 7.5% [13].

Mix Design of SBR Modified WMA Mixtures

Following the same process and testing conducted for epoxy resin modified WMA described in the previous section, the design asphalt-binder content for the SBR modified WMA was 7.5%, with 10% of SBR emulsion. The test results are shown in Table 3.

Discussion of Results

Results of Marshall Stability and other parameters are presented in Table 4. Please note that two asphalt contents, 7.5 and 6.5%, and only epoxy resin were used in this analysis. As can be seen from this table, all properties and parameters for the modified WMA and modified HMA are not significantly different.

Comparison of Pavement Performance Indices of Modified WMA Mixture and Modified HMA Mixture

Freeze-Thaw Splitting Experiment

Eight cylinder test samples, 101.6*mm* in diameter and 63.5*mm* in height, were fabricated by Marshall Compactor with a 50-blow compaction effort. The eight samples were divided into two groups, with each group containing four samples. Group 1 samples were left untreated and were used as the control samples. Group 2 samples were subjected to Vacuum Saturation treatment. The test sequences were as follows:

- Subjected the samples to a vacuum pressure of 730 to740*mmHg*

Table 2. The Results of Marshall Tests on WMA Mixtures Mixed with 10% of Epoxy Resin.

Test Index	Asphalt Binder Content, %	Marshall Stability, *kN*	Flow Value *mm*	Air Voids Volume VV, %	Voids Filled with Asphalt VFA, %	Voids in The Mineral Aggregate VMA, %
Test Results	6.5	11.87	1.29	4.3	75.12	17.29
	7	13.38	1.87	3.14	81.88	17.32
	7.5	15.98	2.01	4.06	84.16	19.1
	8	13.24	2.36	3.09	83.98	19.27
	8.5	12.03	4.05	3.06	84.88	20.21
Technical Requirements	/	>8	1.5～4.0	3～5	/	>14

Table 3. The Results of Marshall Tests on WMA Mixtures Mixed with 10% of SBR Emulsion.

Tested Indexes	Asphalt Binder Content, %	Marshall Stability, *kN*	Flow Value *mm*	Air Voids Volume VV, %	Voids Filled with Asphalt VFA, %	Voids in the Mineral Aggregate VMA, %
Test Results	5.5	12.96	1.96	6.95	64.52	19.58
	6	15.92	1.81	3.58	79.76	17.7
	6.5	14.78	1.94	3.61	80.71	18.73
	7	13.36	2.1	4.2	79.22	20.19
	7.5	12.03	2.48	5.1	84.38	20.3
Technical Requirements	/	>8	1.5～4.0	3～5	/	>14

Table 4. Comparison between Data of Marshall Tests on Warm-Mix Modified Asphalt Mixture and Hot-Mix Modified Asphalt Mixture.

Tested Indexes	Asphalt Binder Content, %	Marshall Stability, *kN*	Flow Value, *mm*	Air Voids Volume VV, %	Voids Filled with Asphalt VFA, %	Voids in the Mineral Aggregate VMA, %
Hot-Mix Modified Asphalt Mixture (Mixed with Epoxy Resin)	7.5	16.15	2.67	3.52	83.25	20.52
Warm-Mix Modified Asphalt Mixture (Mixed with Epoxy Resin)	7.5	15.98	2.01	4.06	84.16	18.1
Hot-Mix Modified Asphalt Mixture (Mixed with Epoxy Resin)	6.5	15.71	2.47	3.64	82.41	20.68
Warm-Mix Modified Asphalt Mixture (Mixed with Epoxy Resin)	6.5	14.78	1.94	3.61	80.71	18.73

Table 5. The Results of Wheel-Tracking Experiments.

	Mixture Type	Dynamic Stability DS(times/*mm*)
Wheel-Ttracking Experiment	Traditional Hot Asphalt Mixture	1,032
	WMA Mixture	1,550
	WMA Mixture with 10% of Epoxy Resin	2,387
	WMA Mixture with 10% of SBR Emulsion	2,254

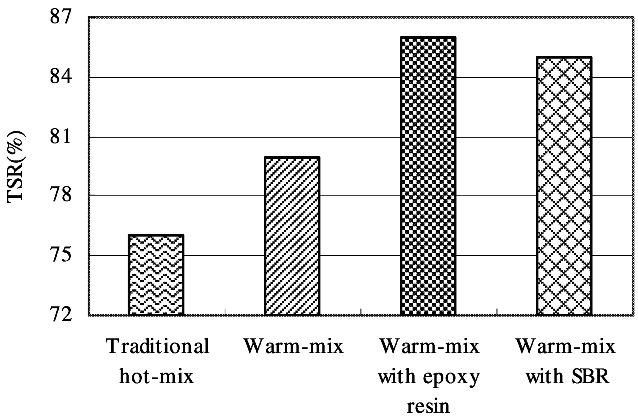

Fig. 4. The Results of the Freeze-Thaw Splitting Experiment.

of mercury for 15 minutes;

- Immersed the four samples into a water tank at ambient temperature for 0.5hr;
- Froze the saturated samples in a temperature of -18°C for 16hrs;
- Placed the frozen samples into a water bath at a constant temperature of 60°C for 24hrs;

All eight samples, including the four untreated Group 1 samples, were then immersed into a water bath at a constant temperature of 25°C for more than 2hrs. Finally, all eight specimens were subjected to splitting tensile strength tests at a loading rate of 50*mm/min*; and their corresponding tensile strength ratios (TSR) were calculated. Comparisons of the TSR of the specimens are shown in Fig. 4. It can be observed that WMA, with or without the modifiers had higher TSR than the HMA had, indicating a better resistance to water and freezing-thawing damage. The warm mix agent has an excellent anti-striping performance [14].

It is also observed that the use of SBR emulsion or epoxy resin could further increase the TSR values, and thus improve the anti-striping performance of the mixtures. With an original asphalt mixture AC-13, the modified WMA can increase the value of TSR by 5 to 10%.

Wheel-Tracking Experiment

Testing apparatuses included STLJ-4 asphalt mixture mixer; HYCZ-1 wheel-tracking specimen molding machine; HYCZ-1 automatic wheel tracking tester, and others. Test specimens, with the design asphalt content of 7.5%, had a size of 300 × 300 × 50*mm*. Samples were subjected to wheel tracking tests under a wheel pressure of 0.7*MPa* at a temperature of 60°C.

Test results are presented in Table 5, in which, the Dynamic Stability (DS) was used in representing the performance of the asphalt mixtures and had an unit of number of times of applications per *mm*. From this table, it is clear that WMA performed significantly better than HMA did. The performances were furthered improved by the addition of SBR emulsion or the epoxy resin. The degrees of improvement, in term of increasing of DS, were found to be similar for both the use of SBR emulsion or epoxy resin additives.

Table 6. Deflection Data of Test Road Paved with SBR Modified WMA Mixtures.

Number	Readings (1/100*mm*)		Deflection (1/100*mm*)		Number	Readings (1/100*mm*)		Deflection (1/100*mm*)	
	Left Wheel	Right Wheel	Left Wheel	Right Wheel		Left Wheel	Right Wheel	Left Wheel	Right Wheel
1	2	1	4	2	11	1	2	2	4
2	3	4	6	8	12	2	3	4	6
3	3	3	6	6	13	2	3	4	6
4	1	1	2	2	14	3	2	6	4
5	3	3	6	6	15	2	4	4	8
6	1	2	2	4	16	3	3	6	6
7	2	3	4	6	17	2	3	4	6
8	4	3	8	6	18	3	2	6	4
9	4	3	8	6	19	2	4	4	8
10	3	1	6	2	20	2	3	4	6

Table 7. Deflection Data of Test Road Paved with SBR Modified HMA Mixtures.

Number	Reading (1/100*mm*)		Deflection (1/100*mm*)		Number	Reading (1/100*mm*)		Deflection (1/100*mm*)	
	Left Wheel	Right Wheel	Left Wheel	Right Wheel		Left Wheel	Right Wheel	Left Wheel	Right Wheel
1	1	1	2	2	11	1	2	2	4
2	2	4	4	8	12	2	3	4	6
3	3	4	6	8	13	2	3	4	6
4	1	2	2	4	14	2	2	4	4
5	3	2	6	4	15	1	1	2	2
6	1	3	2	6	16	3	2	6	4
7	4	2	8	4	17	1	2	2	4
8	1	3	2	6	18	2	1	4	2
9	1	3	2	6	19	1	1	2	2
10	2	1	4	2	20	2	3	4	6

Discussion of the Experimental Results

From the above tests, it can be generally stated that the WMA exhibited engineering properties better than those of HMA mixtures. The WMA showed higher TSR and DS values. These values were further improved with the additions SBR emulsion or epoxy resin modifiers. The use of WMA in pavement construction should enhance its performance.

Field Evaluation of a Test Pavement

To further evaluating and validating the effects of modifiers to the pavement performance, a test pavement was constructed on a section of the Huang-pu Road in Guangzhou City. From bottom to top, the pavement structures consisted of 15*cm* of graded crushed-stone cushion layer; 20*cm* of cement-stabilized gravel sub-base layer, 36*cm* of cement-stabilized crushed-stone base layer; and a 10*cm* asphalt layer including 6*cm* of coarse-grained asphalt concrete at the lower part and 4*cm* of medium-grained asphalt concrete on the upper part.

Detailed attention was paid during the preparation of the foundation and construction of successive layers to provide uniform conditions for both the HMA section and the WMA section. Prior to the placing asphalt layers, the surface of underneath layer was cleaned and a tack coat was uniformly applied to aid the bonding between the base and the asphalt layers. Again, the commonly used AC-13 was used as the base asphalt. Only SBR emulsion was used in the test road evaluation. The ratios of the warm mix agent, SBR emulsion, and the AC-13 asphalt were 1:1:10. Asphalt mixtures were mixed on site, with tight quality control. Asphalt was heated at a temperature of 130°C and the heating temperatures of the mineral aggregate were controlled between 120 and 140°C. Quality control tests were conducted for both the WMA and HMA mixtures daily.

A 200-meter segment was selected from each of the two test pavements, SBR modified WMA and SBR modified HMA pavements. Deflection testing was conducted on these two 200-m test segments, using a 540*mm* long Benkelman Beam. The applied load was 200*g* and two readings were taken at each location using a centesimal meter. Results of the deflection tests are shown in Tables 6 and 7 for the SBR modified WMA test section and the SBR modified HMA test section, respectively. The average deflection value of SBR modified WMA pavement was 5.1 (0.01*mm*), and the average deflection value of modified HMA pavement was 4.05 (0.01*mm*). It is apparent that the SBR modified WMA pavement had a higher deflection than SBR modified HMA had. However, both deflections met China's current specification requirement.

Recent field evaluation indicated good performances, with no major distresses observed. Good bonding conditions were noted between surface and base layers, and no stripping was observed. Field testing and observations indicated that pavement constructed with SBR modified WMA performed equally well with that constructed with SBR modified HMA pavement.

Conclusions

Based on the research conducted in the laboratory and in the field for modified WMA mixture, the conclusions can be summarized as follows:

1. The WMA mixture, without modifiers, can be mixed at 120°C and compacted at 100°C, and the Marshall mix design method is appropriate for determining the mix proportions of WMA. As the viscosity changes with the addition of different amount of modifiers, an optimal asphalt-binder content of need to be determined. The optimal temperatures for mixing and compacting operation can be determined as demonstrated in this study.
2. As demonstrated in the filed test section construction, WMA had its advantages in urban road construction and ultra-thin asphalt concrete overlays to solve the issues of environmental concerns and the problem of quick temperature loss.
3. Compared to WMA mixtures without modifiers, the addition of SBR emulsion modifier or epoxy resin results in an increase in the viscosity, thus a decrease in mixing temperature. However, the mixing temperature is still a little higher than that of WMA without modifiers.
4. SBR modified and epoxy resin modified WMA performed similarly in the filed as their counterpart HMA pavement.

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