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Original Research Paper

Testing and assessing the performance of a new warm mix asphalt with SMC

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ABSTRACT

Warm mix asphalt (WMA) is a new technology which asphalt mix is produced and placed at normal temperature. It has advantages including low cost, environmentally friendly, haul-convenience, and so on. WMA has been widely tested and applied in the USA in the last decade, but it has just started in China. Recently, a new WMA using a new plastic-macromolecule-normal temperature additive, which was called "SMC" by the production company, was introduced as asphalt modifier. Based on discussing the strength forming process of this new WMA with SMC, a series of laboratory tests, including Marshall stability test (MST), boiling test (BT), modified immersion Marshall test (MIMT), freeze-thaw splitting test (FTST), rutting test (RT), low-temperature bending test (LTBT), and abrasion loss test (ALT), were conducted in this study to assess the performance of this WMA and the capability of applying it on low volume roads in China. SMC modified asphalt mixed under normal temperature is used in testing samples. It was found that this WMA product exhibited merits on its strength, which was about 6.7 kN bigger than the requirement of 5.0 kN in the JTG F40-2004, on high-temperature stability, which is about 1100 times/mm greater than the requirement of 600–1000 times/mm in the JTG F40-2004, and on its storage stability. Based on these indicators, it is recommended that this product could be used for low volume low class roads construction. However, due to the relatively lower water resistance and low-temperature cracking resistance, this product is suggested to be applied first in the areas with warm weather and little rainfall. In order to improve the performance of this WMA with SMC, further research on this SMC asphalt modifier should be continued.

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1. Introduction

Warm mix asphalt (WMA) is a new kind of energy saving and environmental protection material, which has broad application prospects. D'Angelo et al. (2008), Federal Highway Administration (FHWA) (2013), CDR Staff (2014) pointed out that WMA has attracted a considerable amount of attention in the USA and Europe over the last decades. Hurley and Prowell (2006) found that warm mix is about 25% of the total asphalt production in the USA in 2012, more than 4 times of that of 2009. The key issue of applying WMA is the asphalt modifier, which allows lowering the producing and placing temperature of asphalt mix. Chen et al. (2009), Guo et al. (2010), Liu et al. (2011), Pei and Xing (2010), Pei et al. (2011), Qin et al. (2010), Zhang et al. (2011) and Zhou et al. (2010) studied the compaction properties, the construction technology and the road performance of WMA. According to their studies, the benefits of WMA are evident: low cost, less gas and particle emissions in paving process, and thereby more environment friendly, a longer time period for construction, longer hauling distance etc. Their study results also show that the construction temperature of WMA is lower than that of HMA. WMA has better high-temperature stability as well, but some other researches done by Li et al. (2010), Sun et al. (2011), Xiao et al. (2010), Yu et al. (2011) found that WMA's cracking resistance at low temperatures, fatigue resistance and water stability would be changed slightly. In order to improve the performance of WMA, some additives should be mixed into this mixture, and the SBS asphalt modifier is commonly used in the USA as the WMA's additive. The SBS asphalt modifier presents stability in engineering practice. However, due to its expensiveness, the SBS based WMA has been widely used for pavement surface repair, but seldom used in new pavement construction in China. Recently, a new plastic-macromolecule-normal temperature additive, which was called “SMC” by the production company, was invented by a Chinese company, and a new WMA technology using this SMC as asphalt modifier was put into some roads construction practice, and this modifier is about 30% of the price of SBS asphalt modifier. Although, the price of the SMC asphalt modifier is significantly lower, this SMC asphalt modifier is not suitable for high volume roadways, since the strength of the materials is questionable (Ai et al., 2014). In contrast, experiment results indicate that this SMC asphalt modifier is a satisfactory choice for low volume and low class pavement construction.

To conduct this research, the strength forming process of this new WMA with SMC is first discussed, and followed by detailed description of properties of testing materials. Then the laboratory testing methods are described in detail and results are presented. Conclusions and discussions are addressed at the end of this paper.

2. Strength forming process of WMA with SMC

It is important to understand the strength forming process in this research. Similar to HMA, the cohesion of the material C and internal friction φ are the 2 factors affecting the strength of the WMA. However, the WMA is differing from the HMA because the cohesion of the material C and internal friction φ are prone to change. The material strengths at early and late stages of the paving are different. In general, the forming of the strength of WMA is comprised of the following four phases, as illustrated in Fig. 1.

First, in the storage phase, since the mixture is not yet subject to external forces, the WMA is still loose, and the aggregates are separated from each other. In this phase, the strength is not yet formed, and both C value and φ value are small.

In the construction phase, under the influence of compaction machinery and vehicle load, mineral aggregate particles begin to form embedded structure. Forces generated within the frictional resistance are a major source of strength. In this phase, C value retains small while φ value increases.

In the initial use phase, the heavily-loaded traffic should be restricted during this phase. With the volatilization of the organic solvents in the WMA, the asphalt gradually becomes denser, making them bond to aggregates even tighter. Meanwhile, the mixture is compacted by repeated traffic load, the air voids are reduced and the strength is significantly increased. During this phase, the C value is increasing while φ value stays large.

In the use phase, this pavement should be completely open to traffic at this time. With the effect of natural environment and vehicle loads, the final strength of the mixture is formed when all the organic solvent are volatilized. Thus, both the C value and φ value are large.

According to the above described process, the WMA shows a distinguishing property in terms of strength form comparing to HMA. Therefore, the evaluation of WMA performance must be implemented based on these properties.

3. Determining testing materials

The newly developed SMC asphalt modifier is a type of solvent bitumen which is made of a special oil dilution. The major lab

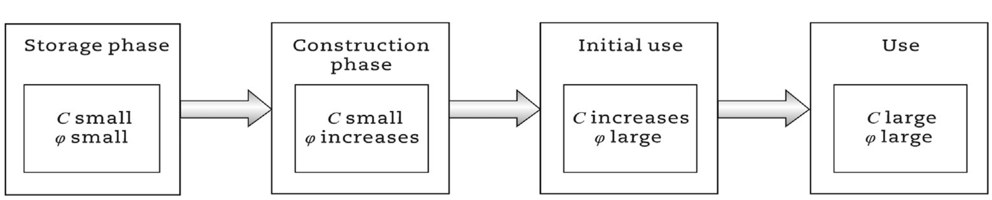

Fig. 1 – Strength forming process of WMA.

testing results of this SMC modified asphalt are shown in Table 1. The organic solvents of SMC asphalt modifier are volatile. Referencing the T0651-1993 test method in JTG E20-2011, the mass loss rate testing of this SMC modified asphalt was carried out. Fig. 2 illustrates the mass loss rate under room temperature (about 25 °C), 60 °C temperature thermostat oven, and 110 °C thermostat oven. According to Test Methods of Aggregate for Highway Engineering (JTG E42-2005), the coarse aggregates used in this study were conglomerate rolling gravel with a crushed value of 18.8% and the Los Angeles wear rate 22.5%. Fine aggregates were machinery sand between 0 and 2.36 mm, and the equivalent weight of which was 84.1%. Fillers were constituted of ore powder from grinded limestone.

The aggregate gradation is based on JTG F40-2004 in this study. The 5 different types of grading curves are determined based on the AC-13 gradation range. As illustrated in Tables 2 and 3 of these gradations are close to the upper level, lower level, and middle level of AC-13, respectively. The remaining 2 groups employed typical S-shape and reverse-S-shape gradation, respectively. The properties of different groups of gradations are listed in Table 2. The Marshall tests are used to determine the optimal quantity of each gradation, respectively, as shown in Table 3.

The final step is to select the WMA samples. First, the WMA samples are made under the same optimum asphalt content and the same number of compaction molding. In order to ensure the compaction quality, 75 for both sides are needed and recommended by the product company. Then the modified immersion Marshall test is employed to test the stability of the samples. To generate unbiased results, 6 samples for each group are produced, respectively. By placing the samples in 25 °C ± 1 °C constant temperature water bath for 30 min, the mean air voids and Marshall stabilities for different gradations of the tested WMA samples are summarized in Table 4. Based on the results presented in Table 4, in order to ensure the mixture has a minimum air void without compromising the strength, the reverse-S-shape gradation and an asphalt content of 5.0% are selected to conduct further studies.

Table 1 – Major performance indicator of SMC modified asphalt.

Performance indicator		Testing result
Flash point (°C)		230
Cohesiveness (80 °C) (Pa·s)		0.73
Volatility (110 °C, 7 d, mass loss) (%)		12.27
Adhesion (Grade)		4
Evaporation residue	Penetration (25 °C, 100 g, 5 s) (0.1 mm)	27.4
	Penetration index	−0.151
	Softening point (°C)	65.1
	Ductility(25 °C, 5 cm/min)(cm)	55.7
	Elastic recovery 25 °C (%)	35.5

Note: these experimental conditions in this table are recommended by the product company.

4. Experiment design

Based on the inherent properties of WMA, the strength performance, water stability, high-temperature stability, low-temperature cracking resistance, and storage stability are concerned. Seven standard tests are performed referring to Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011) to assess the performance of the above aspects of the selected WMA. These tests include Marshall stability test (MST), boiling test (BT), modified immersion Marshall test (MIMT), freeze-thaw splitting test (FTST), rutting test (RT), low-temperature bending test (LTBT), and abrasion loss test (ALT). The brief description of these tests is presented as the following.

4.1. *Marshall stability test*

MST is conducted to assess the strength performance of the WMA. Since 2 strengths, the initial strength and the final strength, are concerned, and 2 different MSTs are designed, respectively. To test the initial strength, the SMC asphalt modifier is first heated to 120 °C, and then mixed with the unheated aggregates under room temperature. By molding according to the standard Marshall compaction molding method, the unmolded sample is released into the thermostatic water bath 60 °C for about 30–40 min. The initial strength is measured through this stability. To test the final strength, the mixtures are made conforming to the same process. However, they are placed into the test oven at 110 °C for 24 h in the form of uniform paving layer before unmolded. By repeating the water bath process, the measured stability is the final stability as described by Yang et al. (2007) in their paper.

4.2. *Boiling test*

Since the WMA is mixed at room temperature, unheated aggregates exhibit lower adhesiveness than that of the HMA. In addition, the diluent leads to a lower cohesiveness than normal HMA. The cohesiveness between the asphalt and

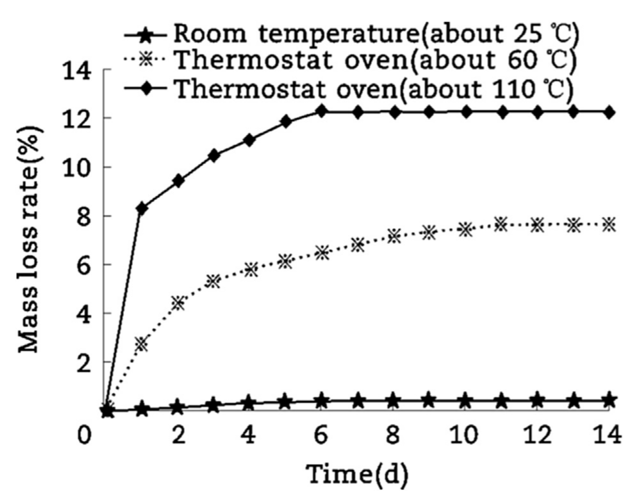

Fig. 2 – Mass loss of SMC modified asphalt.

Table 2 – Gradation of mixture.

Gradation type	Sieved mass percentage (mm/%)									
	0.075	0.15	0.3	0.6	1.18	2.36	4.75	9.5	13.2	16
Close to upper level	8	14	18	26	35	47	66	83	100	100
Close to mid-level	6	10	13	19	26	37	53	76	95	100
Close to lower-level	4	6	9	12	18	27	40	70	90	100
S-shape	5	8	11	14	22	35	57	82	98	100
Reverse-S-shape	7	13	17	25	33	40	50	72	91	100

Table 3 – Optimal asphalt contents for different gradations.

Gradation type	Close to upper level	Close to mid-level	Close to lower-level	S-shape	Reverse-S-shape
Optimal asphalt content (%)	5.0	4.5	4.0	5.0	5.0

Table 4 – Mean air voids and Marshall stabilities for different gradations.

Gradation type	Air void (%)	Marshall stability (kN)
Close to upper level	5.0	5.62
Close to mid-level	5.2	5.76
Close to lower-level	5.5	4.40
S-shape	5.1	4.91
Reverse-S-shape	4.8	5.67

aggregates is particularly important and is tested through BT, which is similar to the T0616-1993 method in JTG E20-2011. The experiment equipment include WMA, a 1000 mL beaker, a glass rod, some distilled water, and an electric cooker. First, 800 mL distilled water is injected in the 1000 mL beaker and is heated to boiling. 250 g WMA is placed into the boiling water and stirred with a glass rod at 1 r/s for 3 min, as shown in Fig. 3. After ceasing the heating, the floating bitumen is removed to avoid secondary wrap cover. When the water is cooled down, the mixture is poured onto newspaper and the bitumen wrap rate is observed visually.

4.3. *Modified immersion Marshall test*

This experiment refers to the conventionally used MIMT for cold patch asphalt mixture. First, the Marshall test samples are divided into 2 equivalent groups. One group is placed into a 25 °C constant temperature bath for 48 h while the other group is not processed. The stabilities of the 2 groups are then measured. The ratio of the former to the latter is the residual stability.

Fig. 3 – Illustration of boiling test.

4.4. *Freeze-thaw splitting test*

The MIMT has some limitations, in the 48 h water immersion test, water is unable to completely penetrate into the interior of the sample when the WMA has small air voids. In other words, the process prevents the water from eroding the membrane of the asphalt. Other risks include that the air voids in real pavement is greater than that of the lab test, and the damage of which cannot be tested from the MIMT and that the water in the MIMT is static, which cannot simulate the effect of wheels rolling and suction pressure. The FTST can effectively improve the water saturation degree by being saturated in vacuum, and therefore is the ideal test to simulate the freezing and thawing cycle in the real world. In FTST, the repeated temperature gradient emulsifies the asphalt membrane, reflecting the most unfavorable scenario that water damages the asphalt membrane (Feng et al., 2007). Like MIMT, 2 groups of WMA samples are adopted for testing. One group is tested under repeated FTST and the other is not. The ratio between splitting tensile strength ratio is used to evaluate temperature water stability of the WMA.

4.5. *Rutting test*

A characteristic of WMA is that the strength and deformation resistance changes as the temperature changes. When the temperature rises, the viscosity of the asphalt lowers and the adhesion between aggregates weakens. Consequently, the shear resistance of the pavement surface decreases. Especially, the shear failure occurs at the initial stages after construction due to the relative weak adhesion between aggregates. With the increment of traffic load and time, the strength of the WMA finally forms when the organic solvent becomes volatile. According to the analysis of the phases of WMA properties, the RTs are conducted for initial and final phases, respectively. The rutting test plates are made as the requirement of national standard T0719-2011 in JTG E20-2011.

The rutting depth for the initial stage is measured under the testing that the temperature of 60 °C and a wheel-pressure of 0.7 MPa. The final stage rutting depth is tested from the rutting plates that are heated for 24 h in an oven under 110 °C in the form of paved layer.

4.6. Low-temperature bending test

The LTBT is used to test the tensile strength or resistance to deformation (Hao et al., 2000). Since the rutting plate formed under normal temperature is unable to cut the small beam, the rutting plate, which is derived from WMA being heated under 110 °C for 24 h, is used to make the small beam. The size of the trabecular is 250 mm × 30 mm × 35 mm. The load is spanned onto the center of the small beam at the speed of 50 mm/min. Under the temperature of −10 °C, the maximum bending tensile strain is measured.

4.7. Abrasion loss test

A significant characteristic of WMA is its storability. Usually, the WMA is produced and then hauled to the paving location. The concern is that if the WMA is able to remain loose until it is being used (Yu, 2012). This research borrows the ALT, proposed by Kim et al. (2009), which was initially used to evaluate cold mix asphalt (CMA), to assess the looseness and compaction of the WMA. The mixture is made of asphalt being heated to 120 °C and aggregates under normal temperature. 1000 g mixtures are extracted and made the Marshall sample by 20 times compaction on both sides at 15 °C. The unmolded sample is weighed as Q_1. After being kept at 15 °C for 4 h, the sample is then placed into the Los Angeles abrasion machine with the steel ball being default. After rotating 100 times, the heaviest piece of all from the rollers is weighed as Q_2. The abrasion loss rate (q) is calculated as follow

$$q = \frac{Q_1 - Q_2}{Q_1} \times 100\%$$

5. Results

5.1. Strength performance

In this segment, 6 WMA specimens were made and divided into 2 groups, and each group with 3 specimens was used to test the initial strength and final strength respectively. The tested results are summarized in Table 5. Apparently, the initial stability of WMA at room temperature is between 1.4 kN and 1.5 kN, which is unable to meet its HMA standards. However, due to the volatility of diluent and repeated vehicle loading, the strength grows. The final strength is about 6.7 kN, which does not meet the requirement 8 kN for expressways and first-class highways. However, it meets the requirement of low volume and low class roads, and the stability of which is 5 kN in JTG F40-2004.

Table 5 – Results of Marshall stability test.

Strength	Initial	Final
Stability (kN)	1.44	6.69
	1.41	6.72
	1.40	6.68

Fig. 4 – Results of boiling test.

5.2. WMA cohesiveness

In the boiling test, as the temperature rises, the black floats gradually increase. In addition, some oil-like materials are observed on the top of water film. Approximately 20% of the total area has come off from the WMA surface and some aggregates are exposed. As shown in Fig. 4, the cohesiveness of the WMA is not satisfactory. According to JTG E20-2011, the cohesiveness is the Grade 3, which is normal.

5.3. Immersion residual stability

In this segment, 6 WMA specimens were made and divided into 2 groups. The first group with 3 specimens was used to test the 30 min immersion stability, and the second group with another 3 specimens was used to test the 48 h immersion stability. The results of this modified immersion Marshall test are shown in Table 6. The residual stability of the WMA is about 37%, indicating that the residual stability is low and the water resistance is very poor.

5.4. Tensile strength ratio

As shown in Fig. 5, the testing sample is damaged during the immersion phase. The FTST cannot be completed.

Table 6 – Results of modified immersion Marshall test.

Parameter	30 min stability (kN)	48 h stability (kN)	Residual stability (%)
Result	5.74	2.12	36.93
	5.62	2.09	37.19
	5.57	2.02	36.27

Fig. 5 – Results during FTST.

Fig. 6 – Failed rutting test (initial phase).

5.5. *High-temperature stability*

When the organic solvent is not volatilized at the initial phase, the rutting depth of the first group by 3 testing samples reaches 25 mm by the middle of the testing, and the test cannot be finished, as shown in Fig. 6. After the organic solvent is volatilized at the final phase, the 45 min rutting depth, 60 min rutting depth, and dynamic stability of the second group by 3 testing samples are shown in Table 7, respectively. The JTG F40-2004 requires the dynamic stability between a minimum threshold of 600 times/mm and 1000 times/mm varying by climate zones.

Table 7 – Results of rutting test (final phase).

Parameter	45 min rutting depth (mm)	60 min rutting depth (mm)	Dynamic stability (times/mm)
Result	3.397	3.932	1177
	3.402	4.018	1023
	3.386	3.894	1244

Table 8 – Results of bending test.

Parameter	Damage loading (N)	Mid-span deflection (mm)	Maximum bending strain (10^{-6})
Result	640	0.31	1627
	621	0.28	1470
	611	0.27	1417

Table 9 – Results of bending test.

Parameter	Original weight (g)	Max-piece-weight after abrasion (g)	Abrasion loss (%)
Result	998.4	720.8	27.8
	995.6	704.2	29.3
	996.9	725.8	27.2

5.6. *Low-temperature cracking resistance*

The results from bending test by 3 samples are shown in Table 8. The JTG F40-2004 requires a minimum of 2000×10^{-6} for maximum bending strain. All the 3 indicators of the testing samples are relatively low.

5.7. *Storage stability*

From the testing results of the 3 samples, the abrasion loss is about 28% according to Table 9. A high loss rate implies a good looseness but poor compaction and vice versa. This rate is acceptable based on the CMA standard, which is 5%–20% according to Cui (2006), so the storage stability of this WMA is poor.

6. Conclusions

From the testing results, it can be seen that the tested WMA products exhibit certain aspects of merits whereas exist some problems. The application of this WMA product on low volume low class roadway is appropriate based on its strength, high-temperature stability, and good storage stability. However, the limitation of this product is its water resistance and low-temperature cracking resistance. Therefore, it is suggested that this product to be applied first in the areas with warm weather and less rainfall.

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