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Study on Laboratory Performance of Foamed Warm Mix SBS Modified Asphalt Mixture

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Abstract—In **order to determine the reasonable molding method, optimum molding temperature and laboratory performance of foamed warm mix asphalt mixture, Marshall compaction method and Superpave gyratory compactor(SGC) were used to mold the foamed WMA specimens and the reasonable and optimum molding temperature were confirmed according to the changing law of volume parameters. rutting test, beam bending test and freeze-thaw splitting test were used to evaluate the performance of foamed-warm mixed asphalt mixture and compared the results with conventional hot mix asphalt. The experimental results indicates that the superpave gyratory compacter is more suitable to design the foamed warm mix asphalt mixture and the foamed warm asphalt mixture has an excellent performance which can meet the requirements of standard specifications.**

Keywords—: Foamed Warm Mix Asphalt; gyratory compaction; molding temperature; mixture performance

I. INTRODUCTION

At present, most of asphalt pavement constructions are using the traditional hot mix asphalt (HMA), aggregate and asphalt are usually require to be heated to 150~162□, Heated to such high temperature, not only consumes a lot of energy, but also in the construction process will emit a lot of emissions, Seriously affect the quality of the surrounding environment and the workers health. With the rapid economic development and the environmental deterioration, the energy crisis and environmental protection has become globally problem to be solved urgently, "Energy saving and emission reduction" has become the theme of today's world, Based on the needs of survival and development, warm mix technology in pavement construction projects gradually increased[1-3].

The main goal of warm mix technology is to reduce the production and construction temperature of asphalt mixture during the construction process to achieve the "Energy saving and emission reduction.

At present, Several types of technologies have been developed and used in many countries to produce WMA[4-6], including the use of foaming additives such as Aspha-min, Advera, and WAM-FOAM; organic additives such as Sasobit and Asphaltan; chemical packages such as Evotherm; and surfactants such as Cecabase. Compared to these WMA technologies foamed WMA by water injection does not require to add special additives to the mixture. This makes it less expensive to produce in many places of the world.

During the past few years a large number of laboratory and field studies have been conducted to evaluate the performance of foamed WMA mixtures. A study carried out by Middleton and Forfylow[7]. suggests that the use of foamed WMA compared with the conventional hot mix can result in 42% reduction in energy consumption and 10% reduction in CO_2 ,SO_2 and NO_x emissions,and in the meantime, rutting and moisture susceptibility performance remains the same as the conventional HMA.

Feipeng Xiao and others [8]. Through a laboratory experiments have considered the different gradation, foaming water content and aggregate in wet and dry conditions based on the gyration numbers of different compaction temperature on the foamed warm mix asphalt mixture, to analyze the effect of rut and moisture stability, the results pointed out that the rut and TSR values of the foamed asphalt mixture at 102~118 molding temperature were not changed.

An evaluation study of rutting potential and moisture susceptibility of plant-produced foamed WMA mixtures containing high amounts of RAP (up to 50 percent) has been carried out by Hodo et al[9]. as part of a field demonstration project in Chattanooga, Tennessee. The study findings showed marginally acceptable performance with respect to moisture susceptibility. The authors suggested adding anti-stripping agents to improve the resistance to moisture-induced damage, if needed. Depending on the Hamburg Wheel Tracking and the Asphalt Pavement Analyzer test results, it was reported that rutting is not an issue.

A laboratory study was conducted by Ayman W. Ali and others[10], to assess the performance of Warm Mix Asphalt prepared using foamed asphalt binders (WMA-FA) and compare it to traditional Hot Mix Asphalt (HMA). Two aggregates and two asphalt binders and polymer modified were used in this study. The Indirect Tensile Strength (ITS), Dynamic Modulus (E*), Modified Lottman, and Asphalt Pavement Analyzer (APA) tests were used to assess the laboratory performance of the considered mixtures. The test results showed lower ITS values for the foamed WMA mixtures than for the HMA mixtures. The dynamic results of foamed WMA and HMA mixtures were close enough to each other without significant differences. The foamed WMA mixtures were slightly more susceptible to moisture-induced damage than the HMA mixtures.

In the design of asphalt mixture, it is very important to determine the appropriate molding method, because different molding methods are obtained different volume parameters. Many scholars have studied the compaction properties of the mixture. Wang Changheng et al[11]. discussed the difference between SGC and Marshall compaction method in terms of molding method, volume calculation method and optimum asphalt content determination, short-term aging. And through the analysis pointed out that In the design process of asphalt mixture, asphalt absorption and the using of four volume systems to calculate the volume indicators should be considered.

The aim of this study is to determine the optimum molding method and optimum molding temperature of foamed WMA mixture by using different molding methods. then for the designed mixture will evaluate the performance of foamed WMA at high temperature, low temperature cracking and resistance to moisture damage and compare the results to traditional HMA.

II. MATERIALS INFORMATION AND MIX DESIGN

A. Asphalt binder

This study used Styrene–Butadiene–Styrene (SBS) polymer modified asphalt produced in Jiangsu Province, China for the generation of foamed asphalt binders and subsequent testing. Table 1 summarizes the various properties of the asphalt binders, tested in accordance to the Superpave mix design specifications and the Chinese standard JTJ 052-2000[12][13].

TABLE I. ASPHALT PROPRIETIES TEST RESULTS

Properties	SBS modified asphalt	
	Requirements	Test results
Penetration (25 °C,100 g,5 s)/0.1 mm	30～60	46.4
Penetration indicators （PI）	/	0.3
Ductility ((15 °C, 5 cm/min)/cm	≥25	34.1
Softening point（TR&B）/ °C	≥60	80
density（15°C）/(g/cm3)	N.A.	1.030
Solubility（trichloroethylene）/（%）	≥99	99.3
PG grade	N.A.	PG70-22

B. Production of foamed WMA

Foamed WMA used 3% of water by weight of asphalt binder and for SBS modified asphalt foaming temperature was 170 °C for asphalt and 30 °C for water. Figure 1 shows the result of SBS asphalt mixture After foaming process.

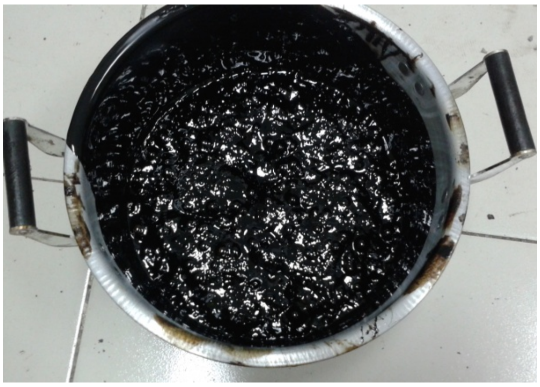

Fig1.asphalt binder After foaming

TABLE II. AGGREGATE AND MINERAL POWDER DENSITY TEST RESULTS

Test items	1#	2#	3#	4#	mineral powder
Apparent density，g/cm3	2.854	2.884	2.916	2.933	2.713
Bulk density，g/cm3	2.798	2.824	2.831	2.842	---
Water absorption（%）	0.69	0.75	1.04	1.10	---

C. Aggregates

Four classes of basalt aggregate and Limestone mineral powder were used in this study. Produced in Wujiang City,jiangsu province ,china and tested accordance to the Chinese specification for construction of highway asphalt pavement JTJ032-2004 and AASHTO M323. The aggregate and mineral powder density test results are shown in Table 2.

III. ASPHALT MIXTURE GRADATION DESIGN

Since the foamed warm mix asphalt is not a new material but just to increase the asphalt foaming process to reduce its viscosity and improve the mixture workability, hence mixture design will not be different from hot mix[15]. Therefore, asphalt mixture gradation design and asphalt binder content will meet the standard of conventional hot-mix asphalt mixture design method.The Marshall mix design method was used in the selection of aggregate gradation and determination of asphalt binder content.

This study used Sup-20 mixture type, produced in jiangsu province, china, mixture gradation and asphalt binder content are shown in Table3 and Table4.

TABLE III. SUP-20 DESIGN GRADATION

Mixture type	The following sieve size（mm） percentage passing (%)									
sup-20	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
combined gradation	100.0	93.3	69.5	38.4	28.3	21.2	15.6	9.9	7.3	4.9

TABLE IV. PROPORTION OF AGGREGATES AND ASPHALT CONTENT RATIO

Asphalt binder content (%)	Aggregate type and proportion (%)				
	1#	*2#*	*3#*	*4#*	*Mineral powder*
4.5	20	32	18	29	1.0

IV. SPECIMENS DESIGN

A. Determination of optimum molding method of foamed WMA

Marshall compaction method and supperpave gyratory compactor(SGC) were used to mold the sup-20 mixture at different temperatures, 100,110,120,130,140,150. Experimental results for specimens air voids and molding

temperature under different molding methods are shown in Table 5 .Figure3. to explore the different molding methods sensitive to compaction temperature value by using the determined temperature on both sides(right and lift) of every 10□ measure the air voids changing rate and then
the average values were calculated to make comparison.

TABLE V. THE AIR VOIDS OF MOLDING SPECIMENS UNDER DIFFERENT MOLDING TEMPERATURES

Molding method	Molding temperature（℃）					
	100	*110*	*120*	*130*	*140*	*150*
SGC	5.6	4.6	4.2	3.9	3.8	3.7
Marshall	5.8	4.8	4.4	4.3	4.3	4.2

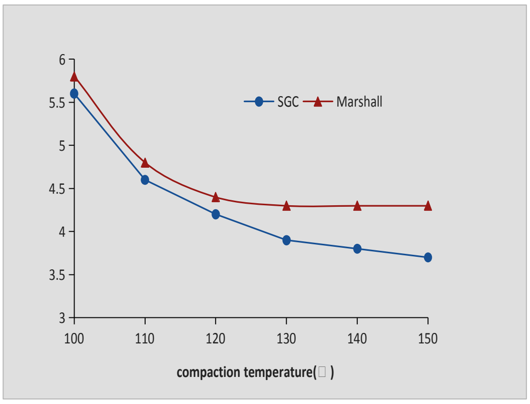

Fig2 specimens air voids and molding temperature under different molding methods

From the Table5 and Figure 2 we can found that. Due to superpave gyratory compactor（SGC）molding force is higher than the Marshall compactor force and the kneading effect is more easily to make the particles mixture compact together, so the gyratory compactor specimens air voids values are less than that of Marshall specimens. For the sup-20 mixture the Left slope range are [120~110]and[120~100], and the right slope range are [120~130]、[120~140]and[120~150].

For Marshall compaction method, the left changing rate of average value was 4.75%, and the right changing rate of average value was 0.8%, while for superpave gyratory compactor, the left changing rate of average was 6.25%, and the right changing rate of average value was 1.5%.

The Comparison result shows that the gyratory compaction molding method is more sensitive to the compaction temperature than that of Marshall molding method.

From the above analysis,the gyratory compaction molding method is more sensitive to the compaction temperature, which is more favorable to control the volume indicators of foamed warm mix asphalt mixture. Therefore, it's recommended to use the superpave gyratory compaction method to mold the foamed warm mix specimens.

B. Determination of optimum molding temperature of foamed WMA

this paper used superpave gyratory compaction method to determine the optimum molding temperature of foamed warm mix, Experimental procedure as follows supperpave gyratory compactor(SGC) used to mold the foamed WMA and HMA specimens at different temperatures, 110,120,130,140,150 □ for Foamed WMA mixture and at 165 □ for HMA mixture.Then after making the specimens and testing the corresponding volume indicators through comparative analysis, the foamed warm mix SBS modified asphalt mixture optimum molding temperature was determined.

Foamed warm mix asphalt and hot mix asphalt specimens volume indicators results at different molding temperatures are shown in Table6, Figure 3.

TABLE VI. FOAMED WARM MIX ASPHALT AND HOT MIX ASPHALT SPECIMENS VOLUME INDICATORS RESULTS

Asphalt type	SBS modified asphalt		
	Compaction temperature	*Gsb*	*VV*
Foamed warm	110□	2.408	4.6
	120□	2.422	4.2
	130□	2.418	3.9
	140□	2.426	3.8
	150□	2.431	3.7
Hot mix	165□	2.422	4.0

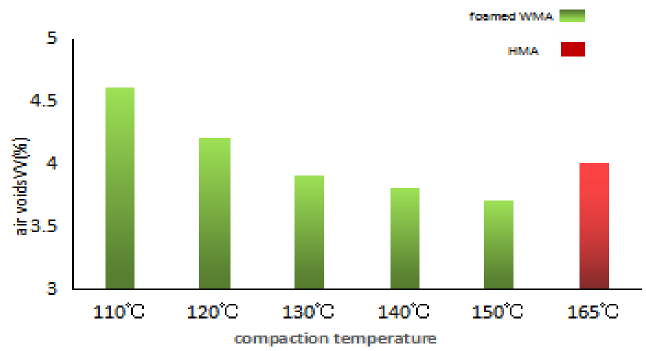

Fig 3 Comparison between Foamed WMA and HMA air voids under different molding temperatures

From the Table 7 and Figure 3, we found that the foamed warm mix bulk density increases with the increasing of compaction temperature, while the air voids gradually increases with decrease to compaction temperature.

For foamed WMA, when the compaction temperature reaches 125□ ~130□, the specimens air voids and density equals with the conventional hot mix when temperature is 165□,by Comparing with hot mix compaction temperature the foamed WMA cooling temperature is about 35□,therefor,from a comparative analysis of the volume indicators of foamed warm mix asphalt mixture and conventional hot-mix asphalt, the optimum molding temperature of foamed warm mix is about 130 □and the mixing temperature is between 140 ~ 145, reached to this temperature means it achieved a good cooling effect, saving a lot of Energy, and reduced environmental pollution.

V. FOAMED WARM MIX ASPHALT PERFORMANCE VERIFICATION

the purpose of Foamed warm mix asphalt mixture is not only to reduce the construction temperature of the mixture, but also the performance of the mixture should be able to reach (or close) even more than conventional hot mix asphalt. This section through the laboratory test and comparison with conventional HMA method for the designed asphalt mixture, the performance of foamed WMA at high temperature, low temperature, and water damage resistance were evaluated.

A. Foamed warm mix asphalt at high temperature performance evaluation

The high temperature stability indicator of asphalt mixture is the main standard parameter used to evaluate the mixture at high temperature for season resistance to the vehicle loads will not occur without compaction or shear flow. High temperature rutting test was used to evaluate the high temperature performance indicator of foamed warm mix.test average results are shown in Table 7.

TABLE VII. HIGH TEMPERATURE RUT TEST RESULTS

Mixture type	dynamic stability (times /mm)				
	1	2	3	average	Requirements
Foamed WMA	4328	4874	5276	4826	≥2800
Hot mix	6329	5681	5834	5948	

Compared with conventional hot mix,Foamed warm mix asphalt dynamic stability was slightly lower, may be due to the low mixing temperature which decreased the asphalt aging, and mixture deformation slightly greater, In general, the foamed warm mix asphalt mixture reached a higher dynamic stability, its high temperature stability performance is excellent, and meets the standard requirements.

B. Foamed warm mix asphalt at low temperature performance evaluation

Low temperature stability indicator of asphalt mixture is the main standard parameters used to evaluate the resistance to vehicle load will not occurs cracks in low temperature season, bending-beam rheometer (BBR) test is a test method for evaluating the stability of asphalt mixture at low temperature.Test average results are shown in Table 8.

TABLE VIII. BENDING BEAM TEST RESULTS

Mixture type	Specimen No	Maximum load (KN)	Span deflection （mm）	Flexure - tension strength（MPa）	Failure strain （με）	Stiffness modulus （MPa）	Requirement （MPa）
Foamed warm	1	1.091	0.573	8.91	0.00301	2960.6	≥2500
	2	0.995	0.565	8.12	0.00297	2738.3	
	average	1.043	0.569	8.52	0.00299	2849.5	
Hot mix	3	0.932	0.498	7.61	0.00261	2910.0	
	4	0.979	0.512	7.99	0.00269	2973.2	
	average	0.956	0.505	7.80	0.00265	2941.6	

Table 8 shows that: the foamed warm mix asphalt stiffness modulus is equal to the conventional hot mix asphalt, and both are greater than the value of the standard requirements. this indicates that the foamed warm mix asphalt meets the specification requirements of low temperature performance, from the failure strain result it showed that the Foamed warm mix asphalt failure strain was significantly greater than the conventional hot mix. that means the foamed warm mix

asphalt has a strong low temperature performance,From the above analysis, the foamed Warm Mix Asphalt has an excellent low temperature performance, compared to conventional hot mix asphalt the foamed WMA resistance to lower temperature cracking was enhanced.

C. foamed warm mix resistance to moisture damage performance evaluation

The quality of foamed warm mix moisture stability can reflects the resistance to moisture damage and durability of foamed warm mix asphalt mixture pavement especially for its ability to the resistance to moisture damage of foamed warm mix at low temperature compaction. therefore, this paper used the freeze-thaw splitting test to make a comprehensive evaluation of the foamed warm asphalt mixture moisture stability [14]. Test methods and standard requirements according to (AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing). Test average results are shown in Table 9.

TABLE IX. FREEZE-THAW SPLITTING TEST RESULTS

Mixture type	Unconditioned		conditioned		TSR （%）	Requirements（%）
	Specimen No	Splitting strength（MPa）	Specimen No	Splitting strength（MPa）)		
Foamed warm	1	0.8655	4	0.7274	82.2	≥80
	2	0.8742	5	0.7022		
	average	0.8699	average	0.7148		
Hot mix	1	0.9133	4	0.7902	85.6	
	2	0.9451	5	0.8011		
	average	0.9292	average	0.7957		

From the Table 9, we found that the foamed warm mix asphalt’s TSR meets the standard requirement , this indicates that the foamed asphalt mixture resistance to moisture damage meets the specification of pavement requirement,in comparison to the conventional hot mix asphalt , the foamed warm mix asphalt’s TSR slightly decreased, because of the reduction in foamed WMA mixing temperature, the aggregates and asphalt additives became weak. lastly, the foamed warm mix asphalt resistance to moisture damage performance met the pavement standard requirements.

VI. CONCLUSION

Based on literature review and indoor experiments, this paper analyzed the optimum molding method determination, optimum molding temperature and performance verification of foamed warm mix asphalt mixture. The main conclusions are summarized as follows.

1. Through the comparison with marshall compaction method ,superpave gyratory compaction method (SGC) is more efficient for controlling the temperature and the gradation during the compaction process, as well the method is more sensitive to the changing compaction temperature which is good for determining the construction temperature of foamed WMA. Therefor ,it is recommended that to use the superpave gyratory compaction molding method (SGC) to mold the foamed WMA mixture specimens.
2. From the comparative analysis of the volume indicators of foamed warm mix asphalt mixture and conventional hot-mix asphalt , the optimum molding temperature of foamed warm mix is about 130 □ and the mixing temperature is between 140 ~ 145□. By reaching to this temperature it means achieved a good cooling effect, saving a lot of Energy, and reduced environmental pollution.
3. The indoor performance experiments showed that the high temperature, low temperature and resistance to moisture damage of foamed warm mix asphalt met the standard design requirements and the resistance to low temperature cracking performance is better than that of the conventional hot mix asphalt, while the resistance to moisture damage performance is slightly lower than that of conventional hot mix asphalt.

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