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Effect of Temperature and Asphalt Binder Type on the Properties of Foamed Asphalt Mix

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Abstract: In this study, an effect of temperature on both indirect tensile strength (ITS) test and Marshall Stability Test of foam asphalt mixture using Shell #70 A asphalt is firstly investigated. A detailed investigation of the mechanical properties of foam asphalt mixture was then carried out using two different asphalt binders. The experimental work compares the mechanical properties of foam asphalt mixes including water stability test, indirect tensile strength (ITS) test, and freeze-thaw splitting test. The test results indicate that the foam asphalt mixture is temperature dependent and also temperature sensitive material. The foaming properties of asphalt have an important effect on the properties of the foam asphalt mixture for the strength and water stability of the foam asphalt mixture.

1 Introduction

With the rapid development of transport infrastructure in China [1], the use of foamed bitumen as a stabilizing agent in pavement since 1956 [2] is improving steadfastly and internationally. Foamed technology has been used by numerous road and highway stabilization and recycling projects [3-6] after its production process is modified by injecting steam to cold water into hot bitumen in 1976 and also introducing new machineries in the market in mid-1990 [7].

The use of foam bitumen stabilization is imperative because of its high field performance properties and its environmentally friendly benefits [8-11]. Many factors such as bitumen type, grade, and additives; in particular, antifoaming agents often are added to bitumen produced by solvent precipitation processes affected its foaming characteristics.

Asphalt can be foamed at high temperature by adding approximately 2% amount of water to hot bitumen resulting in the formation of liquid asphalt binders, which is called foam asphalt [12]. Foamed bitumen advantages have grown in recent years and consist of (a) improving mix strength and durability, (b) increasing spectrum of aggregates usable, (c) reducing binder content, (d) improving workability, (e) propensity of using labor-intensive methods, (f) energy savings during the mix processing and others [13-16]. Foam asphalt technology has thus been widely used in asphalt pavement structure during the last decade all over the world [17-20]. China has mainly used it to use to recycle asphalt pavement [21]. The effects of asphalt binder properties on foamed asphalt mix properties were studied and reported by in references [22] and [23] respectively. They have concluded through their investigation that asphalt binders with higher expansion ratio and longer half-life tend to produce better quality foamed asphalt mixes

Use of new aggregate in foam asphalt mixture is also a good choice for new asphalt pavement structure. However, there is a difference between foam asphalt mixtures with foam asphalt recycled mixture in terms of the strong performance, it is imperative to research the strength characteristic in the laboratory. Mechanical performance of cold foamed bitumen mixes was investigated through laboratory [24] using bitumen source, foaming additive, fiber reinforcement and cement effect. The mechanical properties included dynamic modulus and indirect direct tensile strength of dry and conditioned specimens. The results show that bitumen with low foamability provided better mechanical performance than that with the better foamability.

The objectives of this study were to first investigate the effect of temperature on both indirect tensile strength (ITS) test and Marshall Test of foam asphalt mixture using Shell #70 A asphalt and secondly to see the effect of two different asphalt binder type on the mechanical properties of foam asphalt mixture.

2 Materials and test program

Zhonghai # 90 A grade asphalt and Shell #70 A bitumen currently used in China were investigated. For each source, penetration, viscosity, and softening point were measured. They used to produce foam asphalt at 150℃. Water content is 4% of asphalt mass when producing foam asphalt. Physical properties of base asphalt for the two sources and their respective foaming characteristics are shown in Table 1. The mixture design gradation is given in Table 2. The optimal water content of foam asphalt mixture is determined by Marshall 75 times compaction test. The optimal foam asphalt content is 3.5%.

3 Test program

3.1 Water Stability

The residual Marshall stability is used as the index to evaluate the water stability according to the Chinese Technical Specification for Construction of Highway Asphalt Pavement. Standard Marshall Test and immersion Marshall Test were conducted according to Chinese specification T0709-2011, and then the residual stability can be determined from the Marshall stability and the immersion Marshall Stability according to formula (1)

$$S = \frac{s_1}{s_0} \times 100 \qquad (1)$$

where S is the residual stability, %; S_1 is the immersion Marshall stability, kN; and S_0 is the Marshall stability, kN.

3.2 Indirect tensile strength test

For the indirect tensile test, Marshall specimens were subjected to compressive loads in equipment fabricated for this purpose. The tests were conducted at 25℃, 50 mm/min loading rate. The test procedure adopted was as per Chinese specifications JTJ T0716-2011. The split strength can be obtained according to formula (2).

$$R_T = \frac{0.006287 P_T}{h} \qquad (2)$$

in which, R_T is a split strength (MPa), h: displacement (mm), and P_T is the load when specimen destroyed (N).

3.3 Comparison of freeze-thaw splitting

The tensile strength ratio is defined as the tensile strength of specimen after freeze-thaw conditioning compared to the tensile strength of specimen at ambient temperature. During the freeze-thaw conditioning, the specimen is immersed in water under vacuum state for 15 min, then froze at −18℃ in the refrigerator for 16 h, and then immersed in 60℃ water for 24 h. The splitting strength tests were carried out according to the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering, and the maximum strength values were recorded. The tensile strength ratio (TSR) can be calculated based on Eq. 2.

$$TSR = \frac{R_{T2}}{R_{T1}} \qquad (3)$$

Where TSR: freeze-thaw strength ratio, %, R_{T1}: strength without freeze and thaw, MPa, R_{T2}: Strength after freeze and thaw, MPa.

4 Test results and discussion

4.1 Comparison of test indexes under different temperature

The effect of temperature on both indirect tensile strength (ITS) test and Marshall Test of foam asphalt mixture using Shell #70 A asphalt is investigated. The test results of dry and wet indirect tensile strength test at 25℃ are shown in Table 3. Table 4 shows the results of dry wet indirect tensile strength test under different temperatures. The Marshall test results at 40℃ and 60℃ are shown in Table 5.

Table 1. Physical property of the two asphalt binders

Test items	Unit	Shell #70 A	Zhonghai # 90 A
Penetration (25℃)	0.1 mm	65	84
Ductility (10℃)	cm	34	135
Softening point	℃	47.5	48
Dynamic viscosity (135℃)	Pa.s	1..71	1.73
Density (15℃)	g/cm^3	1.02	1.03
Expansion ratio		6	14
Half-life	s	5	8

Table 2. Foam asphalt mixture gradation

Passing percentage (%) of each mesh sieve (mm)											
26.5	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
100	96.4	92.6	82.5	76.6	53.5	37.7	28.8	22	15.8	13.4	11

Table 3. 25℃ dry and wet indirect tensile strength test

Test item	25℃ dry ITS	24h 25℃ soaking wet ITS
Average value	0.417	0.353
Dry ITS/wet ITS	84.7%	

Table 4. 15℃ and 25℃ dry wet t indirect tensile strength test

Test item	15℃ dry ITS	15℃ soaking wet ITS	25℃ dry ITS	25℃ soaking wet ITS

Average value	0.4853	0.4669	0.417	0.353
Dry ITS/wet ITS	96.8%		84.7%	

Table 5. 60℃ and 40℃ Marshall test

Test item	60℃ standard Marshall stability (35min)	40℃ immersion Marshall stability (35min)
Average value	5.96	9.1

Note: ITS stands for indirect tensile strength.

Table 6. Water stability test results

Asphalt binder type	40℃ standard Marshall stability (kN,35min)	40℃ Immersion stability (kN,48h)	Residual stability (%)
Shell #70 A	9.1	8.89	97.7
Zhonghai # 90 A	9.23	9.21	99.8

Table 7. 25℃ Indirect tensile test results

Shell #70 A asphalt			Zhonghai # 90 A asphalt		
Dry ITS (MPa)	Wet ITS (MPa)	Dry/Wet ratio	Dry ITS (MPa)	Wet ITS (MPa)	Dry/Wet ratio
0.417	0.353	84.6%	0.485	0.415	85.5%

Table 8. Comparison of freeze-thaw splitting test results

Test item	Shell #70 A asphalt		Zhonghai # 90 A asphalt	
	Before freeze-thaw	After freezing and thawing	Before freeze-thaw	After freezing and thawing
	0.3924	0.303	0.3819	0.3648
Wet and dry splitting ratio	77.2%		95.5%	

Through Tables 3 to 5, it can be seen that the properties of the foam asphalt mixture are temperature dependent and are also temperature sensitive materials. The dry-wet ITS ratio of foam asphalt mixture at 15℃ increased obviously than that of25℃, and the dry ITS increased 40.4% while that of wet ITS increased by 60.6%

4.2 Mechanical properties of foam asphalt mixture.

The compared performance properties of foam asphalt mixture from two kinds of asphalt binder including water stability, indirect tensile strength, and freeze-thaw splitting was carried. The results of water stability tests were shown in Table 6.

It can be seen from Table 6 that the water stability of these two foam asphalt mixtures meets the specification requirement. And the residual stability of Zhonghai # 90 A asphalt mixture is greater than that of Shell #70 A, which means that the water stability of Zhonghai # 90 A asphalt mixture is better than that of Shell #70 A asphalt mixture. There is no much difference from Shell #70 A asphalt and Zhonghai # 90 A asphalt, after 48 hours of immersion Marshall Attenuation. The above test data demonstrate that the Marshall stability is not sensitive to the performance of the foamed asphalt and that the Marshall stability can meet the specified requirements when the foaming performance is poor. Table 7 presents the results of the indirect tensile test.

From the Table 7, it can be seen that the dry splitting strength of Zhonghai # 90 A asphalt is 16.3% higher than shell asphalt while its wet splitting strength is 17.5% higher. Whether it is dry or wet splitting, the Zhonghai # 90 A asphalt has a better strength ability compare to Shell #70 A asphalt. The results of the freeze-thaw splitting test for the two sources of asphalt are shown in Table 8.

It can be seen that after a freeze-thaw cycle, the wet splitting strength of both Shell #70 A and Zhonghai # 90 A foam asphalt mixtures decreased in varying degrees. After the freeze-thaw cycle, the water stability of Zhonghai # 90 A foam asphalt mixture is better than that of Shell #70 A foam asphalt mixture, and after a freezing-thawing cycle the water stability of Shell #70 A foamed asphalt mixture was significantly decreased

5 Conclusion

The aim of this study is to first investigate the effect of temperature on both indirect tensile strength (ITS) test and Marshall Test of foam asphalt mixture using Shell #70 A asphalt and secondly to see the effect of two different asphalt binder type on the mechanical properties of foam asphalt mixture. The main conclusions drawn from the current research work are presented as follows:

- Foam asphalt mixture is temperature dependent and are also temperature sensitive materials

- The water stability of Zhonghai # 90 A asphalt mixture is better than that of Shell #70 A asphalt mixture.
- Foam asphalt mixture with Zhonghai # 90 A asphalt has a better indirect tensile strength compared to that of the Shell #70 A asphalt.
- The water stability of Zhonghai # 90 A foam asphalt mixture is better than that of Shell #70 A foam asphalt mixture after the freeze-thaw cycle.

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