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Research on Design Technology of TLA Modified Asphalt Mixture

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Abstract: Marshall Test design methods are used to design TLA modified asphalt mixture and base asphalt mixture respectively, and their pavement performance is tested. The results showed that there is a transforming coefficient of 1.15 between OAC of 40% TLA modified asphalt mixture and that of base asphalt mixture, and ultimate gradation of the TLA modified asphalt mixture is finer than previous gradation. TLA modified asphalt mixture has excellent high temperature stability, capacity of moisture-resistance damage and impermeability. So it can be applied to asphalt pavements engineering of expressway in China.

Keywords: TLA, modified asphalt mixture, mixture design, pavement performance.

1. INTRODUCTION

Trinidad Lake Asphalt (TLA) is the most famous natural asphalt in the world. Because TLA is natural material which was formed after full oxidation under the crustal pressure and high temperature in several ten million years, it has the advantage of high softening point, excellent thermostability, oxidation resistant capacity, oil resistant capacity, acid and alkali resistant capacity and so on [1-5]. As early as in 1880, TLA was used in Washington streets, and later it was mostly used in highway with heavy-traffic, airfield, bridge pavement, express way and son on. Furthermore, TLA was widely used in Britian and Germany, and it enhanced pavement's service life and reduced pavement's maintenance cost effectively [1, 4-5]. During 1970 and 1980, TLA was researched in China, and the test roads were paved in Beijing, Shanxi and Zhejiang, etc, which showed excellent pavement performance. But TLA wasn't popularized in China because it's high price and low price of chinese asphalt at that tiame. In recent years, China's economic strength has greatly increased, and prices of asphalt at home and abroad have significantly changed, and price of TLA modified asphalt is slightly lower than the price of SBS modified asphalt, furthermore, TLA modified asphalt has very good compatibility with petroleum asphalt and excellent pavement performance [6-9]. It is predicted that TLA modified asphalt will have good application prospect in China, therefore, the deep research on application technology of TLA modified asphalt mixture has important economic value and realistic significance.

2. CHNICAL CHARACTERISTICS OF RAW MATERIALS AND PREPARATION OF TLA MODIFIED ASPHALT

2.1. Base Asphalt

The base asphalt used in the research is ESSO A-70#, and its main cynical characteristics are shown in Table **1**, which meet the requirements specified specification.

Table 1. Main Chnical Characteristics of Base Asphalt

Items		Units	Test Value	Technical Requirements
Penetration (25◦C, 100g, 5s)		0.1mm	64	60-80
Softening point		◦C	48.5	≥46
Ductility	(10◦C, 5cm/min)	cm	113.4	≥15
	(15◦C, 5cm/min)		>150	≥100
Density (15◦C)		g/cm^3	1.035	-

2.2. Trinidad Lake Asphalt (TLA)

Researches showed that TLA is composed of four materials as following: (1) Petroleum asphalt (Soluble part of carbon disulfides) account for 53% ~55%, it contains 36% soft asphalting and 18%asphalting. Soluble asphalt contains 67%~70%soft asphalting and 30%~33% asphalting; (2) Mineral powders (ash), about 33% to 38%, are mainly composed of quartz and clay. Mineral particles are very fine, and 90% of them are smaller than 0.075mm, 44% of them are smaller than 0.01mm. They are coral-like, under the high temperature function, light asphalt components can be inhaled into stoma; (3) 4.3% mineral combined water ; (4) 3.2% organic material (insoluble in carbon disulfides). Chnical characteristics of TLA was tested and shown in Table **2**, which meet the requirements specified specification.

2.3. Chnical Characteristics of TLA Modified Asphalt

TLA modified asphalt is prepared in the laboratory according to the following methods : Heating base asphalt and TLA to 150◦C and 160◦C respectively, mixes up them according to 40:60 proportion, then enhances the temperature to 170◦C and stirs 30 minutes. Chnical characteristics of TLA modified asphalt was tested and shown in Table **3**, which meet TMA-30 requirements specified specification.

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Table 2. Main Chnical Characteristics of TLA

Items	Units	Test Value	Technical Requirements
Penetration (25◦C,100g,5s)	0.1mm	2.7	0~5
Softening point	◦C	99.6	≥90
Ash content	%	35.4	33~38
Density (25◦C)	g/cm^3	1.381	1.3~1.5
Penetration ratio after thin-film oven test	%	74	50

2.4. Aggregate

The coarse aggregate and fine aggregate used in the research are both granite gravel produced in Hongda quarry of Zhuhai, Guangdong providence. Their main cynical characteristics are shown in Tables **4** and **5**, which meets the requirements, specified specification.

2.5. Filling

The filling is Xinhui 32.5 cement produced in Yunan, Guangdong province.

3. RESEARCH ON METHOD OF TLA MODIFIED ASPHALT MIXTURE DESIGN

3.1. Design of Mineral Aggregate Gradation Composition

AC-13C which “Technical Specification for Construction of Highway Asphalt Pavements”(JTG F40-2004) put forward was used as mineral aggregate gradation of the top surface layer of the First Loop Expressway of Foshan City. In order to guarantee the anti-rut capacity at high temperature of asphalt mixture, simultaneously give attention to the crack resistance at low temperature, when determine the design gradation, base on the median of AC-13 gradation, we reduce amount of 9.5~16mm coarse aggregate and below 0.6mm fine aggregate, and increase amount of the medium size aggregate, so as to form the “S” gradation curve. At the same time, considering 40% TLA modified asphalt contains 12.8% ash, so passing rate of 0.075mm is controlled less than or equal to median of gradation, which ensure the final gradation of asphalt mixture is nearby the medium of gradation. Four size particles of aggregates and one size particle of padding were sampling and screened, and mineral aggregates gradation composition was designed with the compotator methods. Aim gradation and design gradation of mineral aggregates mixture are shown in Table **6** and Fig. (**1**).

3.2. Determine of Optimum Oil-Stone Rate

In order to comparison study the mixture design technology upon TLA modifield asphalt mixture and base asphalt mixture, marshall test design methods are used to determined optimum oil-stone rate of 40% TLA modified asphalt mixture and base asphalt mixture respectively.

(1) Range of Optimum Oil-Stone Rate

According to previous construction experience, feasible range of oil-stone rate of ordinary asphalt mixture AC-13C is 4.0%~6.0%. But 40% TLA modified asphalt it contains 12.8% ash, so oil-stone rate of 40% TLA modified asphalt mixture must be increased, and there must be a transform coefficient between the optimum oil-stone rates. The transform coefficient can be got by calculation: Asphalt Content of 40% TLA modified asphalt is equal to 87.2% (1-12.8%), that is to say, a piece of base asphalt is equal to 1.15 piece of 40% TLA modified asphalt. So range of oil-stone rate of 40% TLA modified asphalt mixture AC-13C should be 4.5%~6.5%, and it was also be adapted to in base asphalt

Table 3. Cynical Characteristics of TLA Modified Asphalt

Items		Units	Test Value	TMA-30 Reference Technical Requirement
Penetration	15◦C	0.1mm	7.8	
	25◦C	0.1mm	27.8	20~40
	30◦C	0.1mm	49.2	
Correlation coefficient			0.999	
Penetration index PI			-1.84	
Softening point		℃	56.0	
Ductility 25◦C		cm	70.1	
Ash content		%	12.8	7.5~19.5
Viscosity,135◦C		Pa·s	0.95	≤4.0
Relative density (25◦C)		g/cm^3	1.133	
Thin-film oven test	Mass defect	%	-0.49	
	Penetration 25◦C	0.1mm	22.3	
	Penetration ratio	%	80.2	≥58
	Softening point increment	◦C	3.6	
	Ductility ratio	%	89.3	

mixture in order to compare their physics mechanics performance.

Table 4. Main Chnical Characteristics of Coarse Mineral Aggregate

Items	Units	Test Value	Technical Requirements
Crush value	%	15.1	≤28
Los Angeles abrasion loss	%	7.3	≤30
Apparent specific gravity density	_	2.7	≥2.5
Water-absorptivity	%	0.8	≤3.0
Ruggedness	%	1.5	≤12
Soft rock content	%	2.5	≤5
Needle flaky grain content	%	1.9	≤18
Adhesion with modified asphalt	grade	5	≥5

Table 5. Main Chnical Characteristics of Fine Aggregate

Items	Units	Test Value	Technical Requirements
Apparent specific gravity density	–	2.68	≥2.5
Ruggedness (>0.3mm part)	%	1.3	≤12
Granulated substance equivalent	%	70.3	≥60

(2) Marshall Test Results and Discussion

40% TLA modified asphalt mixture and base asphalt mixture were produced respectively at five different oil-stone rate (4.5%, 5.0%, 5.5%, 6.0% and 6.5%), and the Marshall specimens were prepared with Marshall Compaction machine. Then bulk density, Marshall Stability and flow value of the specimens were tested, and volume of air voids, voids filled with asphalt, voids in mineral aggregate of them

Table 6. Mineral Aggregate Gradation Composition of AC-13C

Sieve Sizes (mm) Gradation	Passing Rate (%)										Proportion (%)
	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075	
10~15mm detritus	100	87.8	5.5	0.7	0.7	0.7	0.7	0.7	0.7	0.6	22
5~10 mm detritus	100	100	87	2.8	0.7	0.7	0.7	0.7	0.7	0.7	24
3~5 mm detritus	100	100	100	86.6	12.9	6.4	4.4	3.6	3.1	2.6	22
0~3 mm Stone chips	100	100	100	100	91.1	74.3	57.1	39.9	22.8	11.7	30
cement	100	100	100	100	100	100	100	100	99.8	97.2	2
Upper limit of gradation	100	100	85	68	50	38	28	20	15	8	
Lower limit of gradation	100	90	68	38	24	15	10	7	5	4	
Median of gradation	100	95	76.5	53	37	26.5	19	13.5	10	6	
Compound gradation	100	97.3	76.2	51.9	32.5	26.0	20.4	15.1	9.8	6.3	100

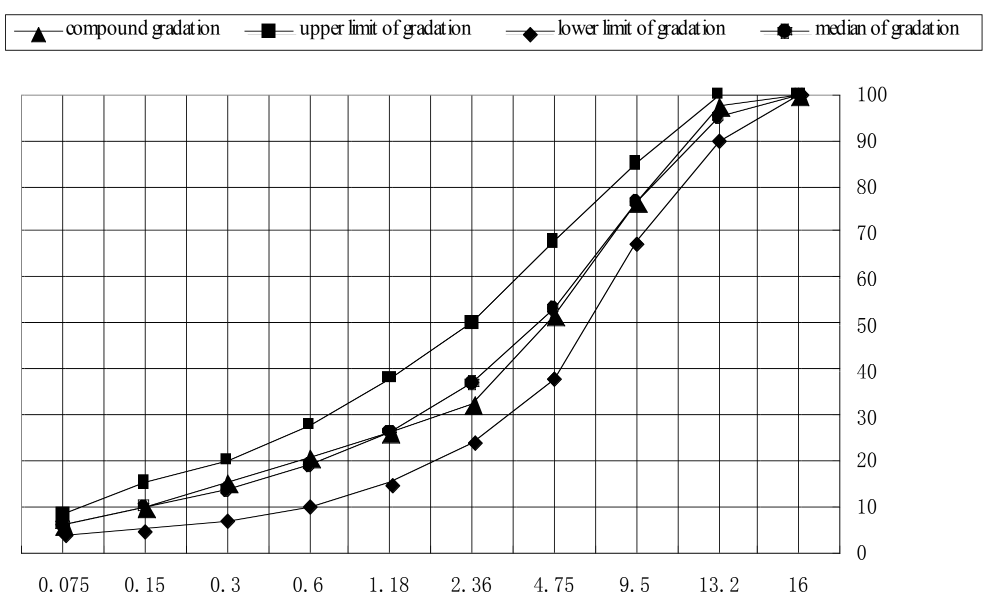

Fig. (1).

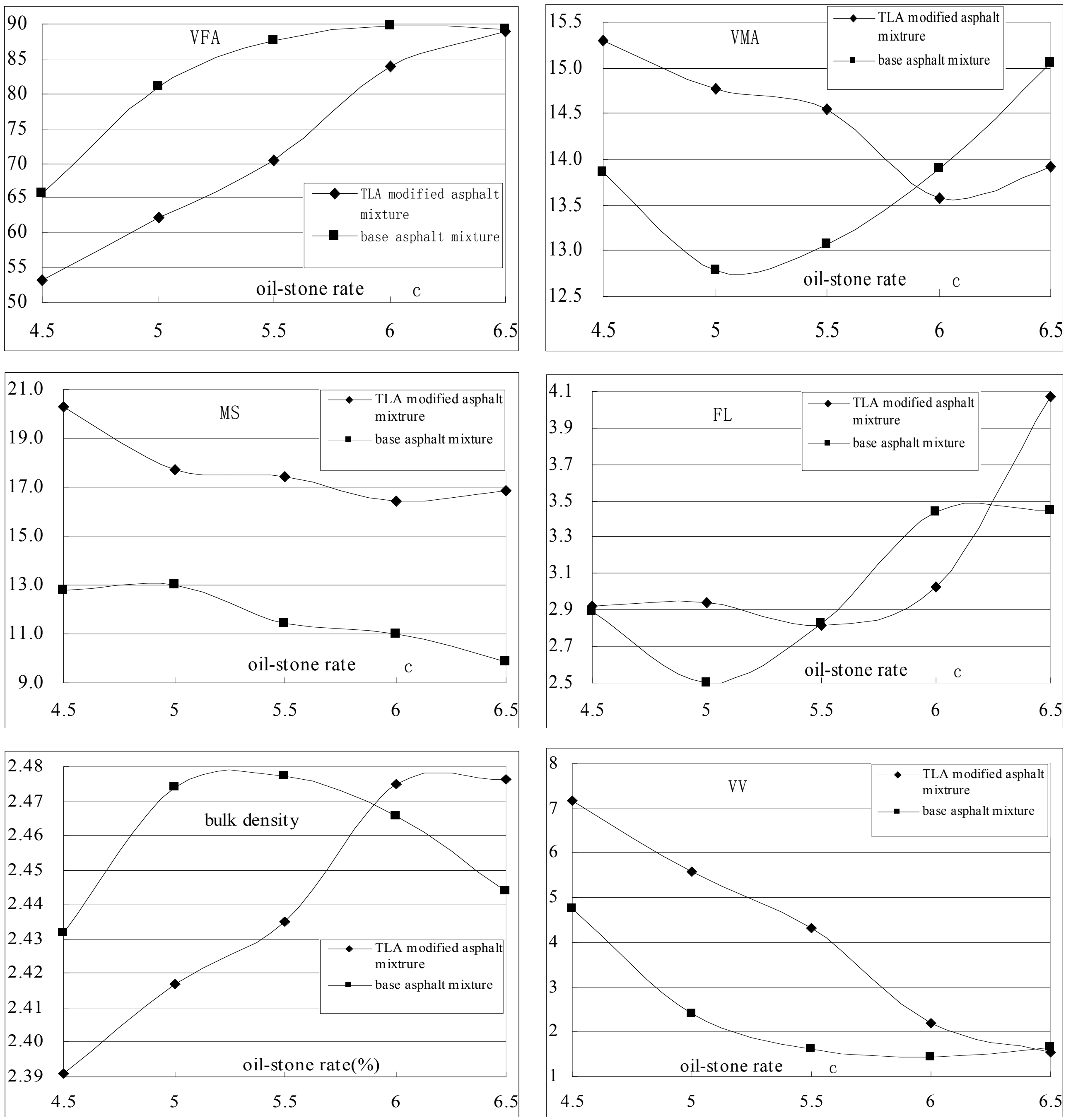

Fig. (2). The curves of physics mechanics parameter versus oil-stone rate of asphalt mixture.

were calculated. The curves of physics mechanics parameter versus oil-stone rate of two kinds of asphalt mixture are shown in Fig. (**2**).

Fig. (**2**) shows as following:

1) Marshall stability of TLA modified asphalt mixture is bigger than that of base asphalt mixture at the same oil-stone rate. Because TLA is a kind of unique natural asphalt, and it contains more gel structure than sol structure, it provides structure performance for TLA modified asphalt and reduces temperature sensitivity of TLA modified asphalt by its unique microscopic size and character of asphalting.

2) Volume of air voids of TLA modified asphalt mixture is bigger than that of base asphalt mixture, while voids filled with asphalt of TLA modified asphalt mixture is smaller than that of base asphalt mixture at the same oil-stone rate. Because TLA contains ash, asphalt content of TLA modified asphalt is less than base asphalt at the same oil-stone rate.

3) In the curves of voids in mineral aggregate versus oil-stone rate and bulk density versus oil-stone rate, minimum value of voids in mineral aggregate and maximum value of bulk density of TLA modified asphalt mixture both appear latter than that of base asphalt mixture. The reason is the same as 2.

Table 7. Marshall Test Results of AC-13C Under the Optimum Oil-Stone Rate

Technical Index	Unit	Base Asphalt Mixture	40%TLA Modified Asphalt Mixture	Technical Requirements
Bulk density	g/cm^3	2.457	2.435	_
Theoretical maximum density	g/cm^3	2.542	2.545	_
Volume of air voids	%	3.4	4.3	3~5
Voids in mineral aggregate	%	13.2	14.5	≥13;≥14
Voids filled with asphalt	%	74.9	70.4	65%~75%
Marshall stability	kN	12.89	17.44	≥8
Flow value	mm	2.66	2.82	1.5~4
Marshall modulus	kN/mm	4.85	6.18	-

4) At the same oil-stone rate, the difference of flow value between TLA modified asphalt mixture and base asphalt mixture is little.

Oil-stone rates which correspond to maximum of density, maximum of Marshall Stability, target volume of air voids (or median) and median of voids filled with asphalt range is calculated according to Fig. (**2**), and the average of them was regarded as OAC_1. The median of oil-stone rate range OAC_{min}~OAC_{max} which each index meet technical standard (except VMA) is regarded as OAC_2. Lastly the average of OAC_1 and OAC_2 was regarded as optimum oil-stone rate OAC. The results show that OAC of TLA modified asphalt mixture is 5.5% and OAC of base asphalt mixture is 4.8%.

OAC of TLA modified asphalt mixture divided by that of base asphalt mixture is 1.15, which proves that there is a transforming coefficient of 1.15 between optimum oil-stone rates of TLA modified asphalt mixture and that of base asphalt mixture. Marshall Test results of two kinds of asphalt mixture under the optimum oil-stone rate are shown in Table **7**, which meet the requirements specified specification.

3.3. Calculation of Ultimate Compound Gradation

40% TLA modified asphalt mixture contains 12.8% ash, and its optimum oil-stone rate is 5.5%, so ash-aggregate rate of mineral aggregate is 5.5%×12.8×=0.7%, and composition proportion of mineral aggregate change into:10~15mm crushed stone:5~10 mm crushed stone:3~5 mm crushed stone:0~3mm stone chips:cement:ash=22/100.7:24/100.7:22/100.7:30/100.7:30/100.7:0.7/100.7. Gradation of ash can be regarded approximately as that 0.15mm passing rate is 100%, 0.075mm passing rate is 90%, so the ultimate compound gradation of 40% TLA modified asphalt mixture is got according to Table **8**.

As we can see from Table **8**, because TLA modified asphalt contains ash, the ultimate compound gradation of TLA modified asphalt mixture becomes finer than previous gradation, and especially has a large influence on passing rate of the sieve sizes which are less than 2.36mm.

4. EXPERIMENTAL RESEARCH ON PAVEMENT PERFORMANCE OF TLA MODIFIED ASPHALT MIXTURE

Specimens were prepared respectively with TLA modified asphalt mixture and base asphalt mixture under the optimum oil-stone rate, and them were used to pavement performance test.

4.1. High Temperature Stability Test

Rutting test was used to evaluate high temperature stability of asphalt mixture, and the results are shown in Table **9**. According to climate subarea of asphalt pavement in China, Foshan city of Guangdong province belongs to area of hot summer and warm winter (area 1-4), so the construction specification specifies that dynamic stability of ordinary asphalt mixture can not be smaller than 1000 times/mm, and dynamic stability of modified asphalt mixture can not be smaller than 2800 times/mm. Test results show that dynamic stability of two kinds of asphalt mixture both meet specification requirements. Compared with base asphalt mixture, dynamic stability of TLA modified asphalt mixture increase 285%, which shows that high temperature stability of TLA modified asphalt mixture, is more excellent than that of base asphalt mixture.

4.2. Capacity of Moisture-Resistance Damage Test

Retained Marshall Stability test and freeze-thaw split test were used to evaluate capacity of moisture-resistance damage of asphalt mixture. Test results are shown in Tables **10** and **11** respectively.

According to climate sub area of asphalt pavement in China, Foshan city of Guangdong province belong to moist area, so the construction specification specifies that retained Marshall Stability of ordinary asphalt mixture can not be smaller than 80%, and retained Marshall Stability of modified asphalt mixture can not be smaller than 85%. The test results show that retained Marshall Stability of two kinds of asphalt mixture both meets the requirements specified specification. Retained Marshall stability of TLA modified asphalt mixture are bigger than that of base asphalt mixture, which shows that capacity of moisture-resistance damage of TLA modified asphalt mixture is better than that of base asphalt mixture.

The construction specification specifies that retained split strength ratio of ordinary asphalt mixture can not be less than 75%, and retained split strength ratio of TLA modified asphalt mixture can not be less than 80% in moist area. The test results show that retained split strength ratio of two kinds of asphalt mixture both meets the requirements specified specification. Split strength ratio of TLA modified

Table 8. Ultimate Compound Gradation of 40% TLA Modified Asphalt Mixture AC-13C

Gradation \ Sieve Sizes (mm)	Passing Rate (%)										Proportion (%)
	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075	
10~15mm stone chips	100	87.8	5.5	0.7	0.7	0.7	0.7	0.7	0.7	0.6	22/100.7
5~10 mm crushed stone	100	100	87	2.8	0.7	0.7	0.7	0.7	0.7	0.7	24/100.7
3~5 mm crushed stone	100	100	100	86.6	12.9	6.4	4.4	3.6	3.1	2.6	22/100.7
0~3 mm stone chips	100	100	100	100	91.1	74.3	57.1	39.9	22.8	11.7	30/100.7
Cement	100	100	100	100	100	100	100	100	99.8	97.2	2/100.7
Ash	100	100	100	100	100	100	100	100	100	90	0.7/100.7
Median of gradation	100	95	76.5	53	37	26.5	19	13.5	10	6	
Compound gradation	100	97.3	76.2	51.9	32.5	26.0	20.4	15.1	9.8	6.3	100
Ultimate compound gradation	100	97.4	76.3	52.2	33.0	26.6	21.0	15.7	10.5	6.9	100

Table 9. Rutting Test Results

Kinds of Asphalt Mixture	Dynamic Stability (Times/mm)	Coefficient of Variation (%)	Technical Requirements (Times/mm)
Base asphalt mixture	1215	36.2	1000
TLA modified asphalt mixture	4678	14.4	2800

Table 10. Retained Marshall Stability Test Results

Kinds of Asphalt Mixture	Marshall Stability MS (kN)	Marshall stability After being Immersed 48h MS_1(kN)	Retained Marshall Stability MS_0 (%)	Technical Requirements MS_0 (%)
Base asphalt mixture	13.2	11.5	87.0	≥80
TLA modified asphalt mixture	16.2	15.2	93.8	≥85

asphalt mixture is bigger than that of base asphalt mixture, which shows that capacity of moisture-resistance damage of TLA modified asphalt mixture is better than that of base asphalt mixture, and TLA modified asphalt mixture has more excellent capacity of moisture-resistance damage, too.

4.3. Permeability Test

Permeability test were used to evaluate impermeability of asphalt mixture. Test results are shown in Table **12**. The construction specification specifies that permeability coefficient can not be bigger than 120 ml/min. The test results show that permeability coefficient of two kinds of asphalt mixture both meet the requirements specified specification. Permeability coefficient of TLA modified asphalt mixture is smaller than that of base asphalt mixture, which shows that impermeability of TLA modified asphalt mixture is better than that of base asphalt mixture.

Table 11. Freeze-Thaw Split Test Results

Kinds of Asphalt Mixture	Split Strength Before Freezing-Thawing Cycle (MPa)	Split Strength After Freezing-Thawing Cycle (MPa)	Retained Split Strength Ratio TSR (%)	Technical Requirements TSR (%)
Base asphalt mixture	0.94	0.81	85.6	≥75
TLA modified asphalt mixture	1.87	1.70	91.0	≥80

Table 12. Permeability Test Results

Kinds of Asphalt Mixture	Permeability Coefficient (ml/min)	Technical Requirements (ml/min)
Base asphalt mixture	56.7	≤ 120
TLA modified asphalt mixture	48.3	

5. CONCLUSIONS

(1) Marshall stability and volume of air voids of TLA modified asphalt mixture is bigger than that of base asphalt mixture, while voids filled with asphalt of TLA modified asphalt mixture is smaller than that of base asphalt mixture at the same oil-stone rate.

(2) In the curves of voids in mineral aggregate versus oil-stone rate and bulk density versus oil-stone rate, minimum value of voids in mineral aggregate and maximum value of bulk density of TLA modified asphalt mixture both appear latter than that of base asphalt mixture.

(3) There is a transforming coefficient of 1.15 between optimum oil-stone rate of 40% TLA modified asphalt mixture and that of base asphalt mixture.

(4) Because TLA modified asphalt contains ash, the ultimate compound gradation of TLA modified asphalt mixture becomes finer than previous gradation, and especially has a large influence on passing rate of the sieve sizes which are less than 2.36mm.

(5) TLA modified asphalt mixture has excellent high temperature stability, capacity of moisture-resistance damage and impermeability. So it can be applied to asphalt pavements engineering of expressway in China.

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