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Laboratory evaluation of epoxy resin modified asphalt mixtures

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Abstract: The pavement performance of epoxy resin modified asphalt mixtures was investigated by the Marshall test, the indirect tensile test, the rutting test, the three-pointed bending test and the composite beam fatigue test. In comparison with the performance of epoxy resin modified asphalt mixtures, the performance of stone matrix asphalt mixtures (SMA10) was also investigated. The rutting test and composite beam fatigue test results show that the epoxy resin modified asphalt mixtures can improve permanent deformation and fatigue characteristics. They also show lower temperature susceptibility and greater resistance to moisture damage compared to the SMA10. Findings from the research indicate that the epoxy resin modified asphalt mixture provides an optional material for the pavement of long-span steel bridges in China due to profound performance and economic advantages.

Key words: epoxy resin modified asphalt; epoxy resin modified asphalt mixture; pavement; strength performance

Repeated application of traffic loads causes structural damage to asphalt pavement in the form of fatigue cracking and rutting along wheel tracks. While fatigue failure is the result of flexural cracking of asphalt pavement, rutting is the manifestation of permanent deformation under high temperature conditions. Also, climatic factors such as temperature and moisture are other major causes for concern[1-2].

The development of modified asphalt materials to improve the overall performance of pavements has been the focus of several research efforts made over the past few decades. The use of epoxy asphalt in pavement construction was one of the steps taken in this direction. Since the construction of the Nanjing Second Bridge across the Yangtze River in 1999, Professors Huang Wei and Qian Zhendong at the Pavement Laboratory of Southeast University of China have imported the epoxy asphalt from America. Then, the epoxy asphalt mixtures were successively used in the Runyang Yangtze River Highway Bridge, the Third Nanjing Yangtze River Highway Bridge, the Yangluo Yangtze River Highway Bridge and so on. The epoxy asphalt pavements in these bridges display good performance. Since 2002, the Pavement Laboratory of Southeast University of China has researched and developed domestic epoxy resin modified asphalt because of its economic advantage.

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The present investigation was initiated by the need to evaluate the engineering characteristics of paving mixtures containing the epoxy resin modified binders (ERMB) developed by Huang Wei and Qian Zhendong at the Pavement Laboratory of Southeast University, China. The main focus of the present investigation was directed towards the evaluation of asphalt and epoxy modified asphalt mixtures in terms of ① Relative fatigue performance; ② Relative rutting performance; ③ Temperature and moisture susceptibility.

1 Materials

Since asphalt concrete made with epoxy resin is relatively new to most engineers, it is desirable to familiarize readers with some basic information on bituminous materials, epoxy resin (ER) and aggregates.

The epoxy resin modified asphalt consists of two kinds of cements: component A (epoxy resin) and component B (80/100 penetration grade asphalt). Component A was used to modify 80/100 asphalt. Basalt stone chips collected from Jurong in Jiangsu province were used as aggregates. The physical properties of different materials are given in Tab. 1.

The specification developed earlier was used for blending ER with asphalt[3]. In this procedure, both 80/100 penetration grade asphalt and ER are heated to 100 ℃ before the blending. The blend is mixed at a high speed for about 1 min. The mixtures are heated to 120 ℃ and the temperature of the mixtures is maintained between 120 and 125 ℃. The basic properties of the modified binders are given in Tab. 2.

Tab. 1 Physical properties of materials used

Materials	Parameters measured	Value
Epoxy resin (component A)	Epoxy equivalent/g	190
	Specific gravity	1.165
Asphalt (80/100) (component B)	Penetration (25 ℃, 5 s, 100 g)	90
	Softening point (ring and ball)/℃	45.5
	Ductility (27 ℃, 50 mm/min)/cm	≥100
	Flash point (cleveland open cup)/℃	336
	Specific gravity (27 ℃)	1.026
Coarse aggregate	Specific gravity	2.949
	Water absorption/%	1.0
	Los Angeles abrasion value/%	11.5
	Crushing value/%	9.4
Fine aggregate	Specific gravity	2.899

Tab. 2 Binder properties

Parameters measured	Value	Method
Tensile strength (20 ℃)/MPa	1.9	ASTM D 638
Elongation (20 ℃)/%	210	ASTM D 638
Time of the viscosity to 1 000 mPa·s (120 ℃)/min	53	JTJ 052—2000

2 Preparation of Mixtures

2.1 Mixing and compaction time at 120 ℃

The time at which the mixtures of ER modified binder at 120 ℃ produces kinematic viscosities of (170 ±20) and (280 ±30) mm^2/s is normally chosen as the mixing and compaction temperatures, respectively[4]. The viscosity of the ER modified binder changing with time is shown in Fig. 1. The viscosity was measured using the Brookefield rotational dial viscometer (LV model) with the LV-27 spindle, and the rotational speed of 100 r/min was used in the measurement of the viscosity. Fig. 1 indicates that a mixing time of 20 min and a compaction time of 30 min are selected.

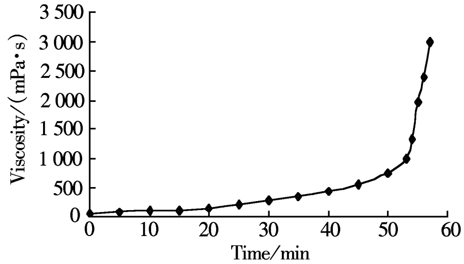

Fig. 1 Viscosity-time curve for ERMB

2.2 Aggregate gradation

The aggregate gradation recommended for asphalt concrete by the Pavement Laboratory of Southeast University was adopted for the preparation of Marshall specimens with ER modified binders. The gradation curve is shown in Fig. 2. The aggregate gradation in the investigation can improve the strength and fatigue performance of mixtures.

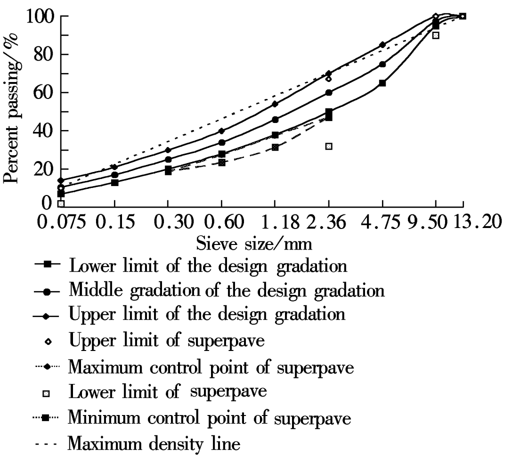

Fig. 2 Comparison of gradation types

3 Test Programs

Major tests carried out in this program followed the specifications developed by the Ministry of Communications, China. Three specimens were tested in each test. The following sections describe tests conducted in the laboratory.

3.1 Marshall test

The basic material properties of the asphalt mixtures are prerequisite to the Marshall mix and stability value tests.

3.1.1 Marshall mix design

Prior to the Marshall tests the aggregates were dried in an oven regulated at a temperature of 120 ℃ for a minimum of 6 h until they reached an absolute dry condition. Then asphalt mix design was performed by the Marshall method as specified in JTJ 052—2000. Fifteen samples with ER modified binders were prepared by heating and compressing, which were mixed with various binder contents in 0.5% increments from 5.0% to 7.0%. The samples were compressed by 50 blows per face with a standard Marshall hammer. All of the samples were placed in an oven regulated at 120 ℃ for 6 h. The 120 ℃ for 6 h was adopted to make the ER modified asphalt mixtures cure absolutely and rapidly. The Marshall stability and flow were measured by the Marshall apparatus. The results are shown in Tab. 3. The 6.5% binder yielded the highest Marshall stability and bulk density. Flow values increased marginally with the binder content. Air voids content showed a decreasing trend with the increasing ER modified binder concentration. The 6.5% binder content was selected as the optimum asphalt content in accordance with JTG F40—2004 of China.

Tab. 3 Marshall characteristics of different binder contents

Binder content/%	Marshall stability/kN	Flow value/(0.1 mm)	Bulk density/($g\cdot cm^{-3}$)	Air voids/%
5.0	29.9	33.0	2.525	6.2
5.5	32.2	36.1	2.537	5.1
6.0	33.3	39.9	2.556	3.7
6.5	34.3	45.5	2.582	2.0
7.0	32.3	53.5	2.577	1.5
Specification	≥30	20 to 60		≤3

3.1.2 Stability test with oven dried specimens

Six groups of specimens made according to JTJ 052—2000 standard were placed in an oven regulated at 60 ℃ for 12, 24, 36, 48, 72 and 96 h for the six groups from the first to the sixth, respectively[5]. The 60 ℃ was adopted to simulate the roadway surface temperature during hot summer days in Nanjing, China. The measured stability values of these six groups are shown in Fig. 3. The stability values increase with curing time. The stability values of specimens cured at 60 ℃ for 96 h are similar to those cured at 120 ℃ for 6 h. Test data reveal that construction in summer can shorten the curing time of ER modified asphalt mixtures, so the pavement can be opened to the traffic within several days after paving.

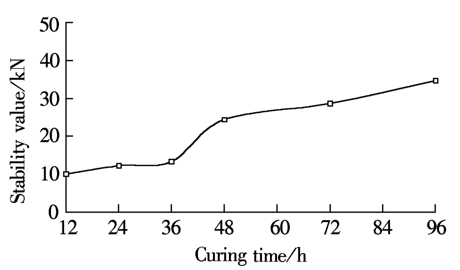

Fig. 3 Curve of Marshall stability vs. curing time at 60 ℃

3.2 Moisture susceptibility of mixtures

Moisture damage is one of the most serious problems to the asphalt concrete pavement in the field. Moisture damage is evaluated by testing the retained-strength and tensile-strength ratios. These tests were conducted on ER modified asphalt mixtures cured at 120 ℃ for 6 h and SMA10.

3.2.1 Retained Marshall stability

Marshall stability of compacted specimens was determined after conditioning them by keeping them in water maintained at 60 ℃ for 48 h before testing. This stability, expressed as the percentage of the stability of Marshall specimens determined under standard conditions, is the retained stability of the mixtures. The results are shown in Tab. 4. It can be seen that ER modified asphalt mixtures performed much better than SMA10 mixtures.

Tab. 4 Retained stability of EPMB and SMA (48 h)

Mixtures	Marshall stability/kN		Retained stability/%
	Standard condition	Conditioned at 60 ℃ for 48 h	
Epoxy resin modified asphalt mixture	36.1	35.7	98.9
SMA10	5.6	4.4	78.6

3.2.2 Indirect tensile-strength ratio

Another method adopted in the present study to evaluate the moisture susceptibility of the mixtures was to determine the tensile-strength ratio[6]. The tensile-strength ratio is the average static indirect tensile strength of the conditioned specimens expressed as the percentage of the average static indirect tensile strength of unconditioned specimens. Conditioning was done by freezing the specimens at −18 ℃ for 16 h first, then keeping the specimens in water maintained at 60 ℃ for 24 h and curing at 25 ℃ for 2 h before commencing the test. The test was conducted at 25 ℃. The results are shown in Tab. 5. It indicates that ER modified mixtures have better indirect tensile strength characteristics than SMA10. The tensile-strength ratio values of ER modified mixtures are greater than those of SMA10 mixtures indicating that the ER modified mixtures are less susceptible to moisture damage.

Tab. 5 Indirect tensile test results of EPMB and SMA

Mixtures	Indirect tensile strength at 25 ℃/MPa		Retained stability/%
	Unconditioned	Conditioned at −18 ℃ for 16 h, then at 60 ℃ for 24 h	
Epoxy resin modified asphalt mixture	31.9	25.8	80.9
SMA10	7.4	5.6	75.7

3.3 Permanent deformation test

Several attempts were made in the past to model the load-associated rutting phenomenon in asphalt mixtures[7]. The rutting test was performed employing the wheel-tracking device specified in JTJ 052—2000 of China for evaluation of pavement performance. Specimens, which were mixed with optimum asphalt contents from Marshall mix design and fabricated by the rolling machine, were 300 mm × 300 mm in cross-sectional area and 50 mm in height. Normally, the rutting tests were performed using a 0.7 MPa wheel load which was adopted to simulate the standard wheel load in the field at 60 ℃ under dry conditions. The rutting tests were conducted on ER modified asphalt mixtures cured at 120 ℃ for 6 h and SMA10 in this investigation. The rut depth was measured after 2 520 cycles in 60 min. The results are presented in Tab. 6. The ER modified asphalt mixtures yielded the smallest rutting depth. ER modified asphalt mixtures show the lower potential for permanent deformation.

Tab. 6 Rutting test results of EPMB and SMA (60 ℃, 0. 7 MPa)

Mixtures	Dynamic stability value/(cycle · mm^{-1})	Rutting depth in 60 min/mm
Epoxy resin modified asphalt mixture	>6000	0. 9
SMA10	5 465	1. 4

3. 4 Beam bending test

The JTJ 052—2000 procedure of China using the MTS810 equipment was applied to measure the maximum load and deflection, then the flexural tensile strength and the flexural stiffness modulus were calculated by the maximum load and deflection. Specimens, which were mixed with optimum asphalt contents from Marshall mix design and obtained from the rutting specimens, were 30 mm × 35 mm in cross-sectional area and 250 mm in length with a span length 200 mm. All of the beams were loaded using the static three-point bending test setup. A vertical static load was applied to specimens at the rate of 50 mm/min. The beam bending tests were conducted on ER modified asphalt mixtures cured at 120 ℃ for 6 h and SMA10 at a temperature of −15 ℃. The test results are presented in Tab. 7. It can be seen that the ER modified asphalt mixtures performed significantly better than SMA10 in strength at low temperature, while the deformation characteristics of the ER modified asphalt mixtures were similar to SMA10[8-9].

Tab. 7 Bending test results of EPMB and SMA (−15 ℃)

Mixtures	Flexural tensile strength/MPa	Maximum flexural tensile strain	Flexural stiffness modulus/GPa
Epoxy resin modified asphalt mixture	20. 29	2.602×10^{-3}	7. 808
SMA10	7. 5	7.417×10^{-4}	10. 172

3. 5 Fatigue characteristics

Fatigue characteristics of the ER modified asphalt mixtures developed in this present investigation were evaluated by composite beam fatigue tests using the MTS810 equipment. This test method was selected because it simulated the practical state of the steel deck and the pavement. The sine wave load from 0. 5 to 5 kN was applied to the specimens with the frequency 10 Hz at a temperature of 20 ℃[10-11]. The dynamic deformations were measured at intervals of several cycles, while the static deformations were measured at intervals of 2×10^5 cycles with a rest period. The test results show that the dynamic and static deformations kept stability on the whole. The composite beam specimens had no macroscopic crack after 12×10^6 cycles. Test results reveal that the ER modified asphalt mixtures have excellent performance in fatigue characteristics.

4 Conclusions

1) Marshall stability value of epoxy resin modified asphalt mixtures has an increasing trend with the curing time. The Marshall stability value of the cured specimens is as high as 37. 0 kN.

2) Epoxy resin modified asphalt mixtures were found to be less susceptible to moisture damage compared to SMA10 as indicated by higher retained Marshall stability and a higher tensile-strength ratio.

3) Epoxy resin modified asphalt mixtures displayed lower potential for permanent deformation compared to SMA10.

4) Fatigue behavior of epoxy resin modified asphalt mixtures was found to be significantly improved. The fatigue life, as observed from laboratory fatigue test results, is 12×10^6 cycles.

5) Epoxy resin modified asphalt mixtures are a viable material for use in pavements, and they have good performance and economic advantages.

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环氧树脂改性沥青混合料性能试验研究

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摘要:为了解我国自主研制的环氧树脂改性沥青混合料的路用性能,采用马歇尔、劈裂、车辙、小梁弯曲和复合梁疲劳等试验,对其材料特性和路用性能进行了全面的试验研究,并与 SMA10 混合料的性能进行了对比研究. 车辙和复合梁疲劳试验结果表明,环氧树脂改性沥青混合料具有良好的高温稳定及疲劳性能;与 SMA10 混合料相比,环氧树脂改性沥青混合料具有良好的抗水损害及低温抗开裂性能. 研究表明,新型国产环氧树脂改性沥青混合料以其优异的性能和良好的经济优势为我国大跨径钢桥桥面铺装提供了一种新的铺装材料.

关键词:环氧树脂改性沥青;环氧树脂改性沥青混合料;铺装;强度性能

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