RESEARCH ON THE PERFORMANCE OF LOCALLY DEVELOPED EPOXY ASPHALT MIXES

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ABSTRACT

In China, epoxy asphalt concrete has been widely used for paving the decks of long-span steel bridges because of its excellent performance. As a patent material, most epoxy asphalt used in China has been imported from the USA. The Southeast University Paving Team in China has been studying and developing epoxy asphalt for five years. The details of various laboratory investigations to evaluate the performance of locally developed epoxy asphalt mixes are presented in this paper. In the laboratory tests, rutting, low temperature cracking and fatigue characteristic were evaluated by the wheel track test, the beam bending test and the complex beam fatigue test respectively. Locally developed epoxy asphalt mixes, stone matrix asphalt mix (SMA) and mastic asphalt mix (MA) were tested. Compared with SMA and MA, locally developed epoxy asphalt mixes performed better on resistance to fatigue and permanent deformation. They also performed significantly better on low-temperature properties and resistance to moisture damage. The test results show that locally developed epoxy asphalt mix is an excellent material for steel deck pavement and can offer great performance and economic advantages. It is an optional material for paving long-span steel bridges in China and has good prospects for this application.

Keywords: Locally developed epoxy asphalt mix; strength performance; experimental research; pavement; flexural strain energy

1. INTRODUCTION

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 in high-temperature conditions. Asphalt pavements can also be damaged by climatic conditions such as temperature and moisture (Nan Su et al*.*, 2002; Palit et al*.*, 2004).

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. Use of epoxy asphalt in pavement construction was one of the steps taken in this direction. Since 1999, for the Nanjing 2nd Yangtze River Bridge construction, Professors Huang Wei and Qian Zhendong have been importing epoxy asphalt from the USA. Epoxy asphalt mixes have been successively used in the Runyang Yangtze River Bridge, the Nanjing 3rd Yangtze River Bridge, the Yangluo Yangtze River Bridge and others. The performance of the epoxy asphalt pavements on these bridges is good. Since 2002, the SEU Pavement Laboratory has researched and developed local epoxy asphalt because of the economic advantages.

The present investigation was initiated by the need to evaluate the engineering characteristics of paving mix containing the locally developed epoxy asphalt binder developed by Huang Wei and Qian Zhendong in the Pavement Laboratory of Southeast University, China. The main focus of the present investigation was directed towards the evaluation of locally developed epoxy asphalt mixes in terms of:

1. Moisture susceptibility
2. Relative rutting performance
3. Low-temperature performance
4. Relative fatigue performance.

2. MATERIALS

2.1 Basic information on epoxy resin, asphalt and aggregate

Since asphalt concrete made with epoxy resin is relatively new to most engineers, it is desirable to familiarise readers with some basic information on bituminous materials, epoxy resin and aggregate.

The locally developed epoxy asphalt binder, which is a thermosetting material, consists of two cement components: Component A (epoxy resin) and Component B (80/100 penetration grade asphalt). Component A was used to modify 80/100 pen bitumen. Basalt stone chips collected from Jurong in Jiangsu Province were used as aggregate. The properties of the different materials used in this investigation are given in Table 1.

Table 1. Properties of different materials

Material	Parameters measured	Value
Epoxy resin (Component A)	Epoxide equivalent weight (the weight of the material which contains 1 g epoxide) (g)	190 g
	Specific gravity	1.165
Bitumen (80/100) (Component B)	Penetration (25 ^{o}C, 5 s, 100 g)	90
	Softening point (ring and ball) (^{o}C)	45.5
	Ductility (27 ^{o}C, 50 mm/min) (cm)	≥100
	Flash point (Cleveland open cup) (^{o}C)	336
	Specific gravity (27 ^{o}C)	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

2.2 Properties of binder

The specification developed earlier was used for blending epoxy resin with asphalt (Min Zhaohui, 2004). In this procedure, both 80/100 penetration grade bitumen and epoxy resin are heated to a temperature of 100 ^{o}C before the blending. The blend is mixed at high speed for about 1 min. The mix is heated to 120 ^{o}C and the temperature is maintained between 120 ^{o}C and 125 ^{o}C. The basic properties of locally developed epoxy asphalt binder are given in Table 2.

Table 2. Properties of locally developed epoxy asphalt binder

Parameters measured	Value	Method
Tensile strength (20 °C) (MPa)	1.9	ASTM D 638
Elongation (20 °C) (%)	210	ASTM D 638
Time of viscosity to 1 000 MPa (120 °C)(min)	53	JTJ 052-2000

2.3 Mixing and compaction temperatures

The times at which the locally developed epoxy asphalt mixes at 120 °C produce kinematic viscosities of 170 ± 20 × 10^6 and 280 ± 30 × 10^6 m^2/s are normally chosen as the mixing and compaction times respectively (Hensley, 1998). The viscosity-time curve of the locally developed epoxy asphalt binder at 120 °C is presented in Figure 1. The viscosity was measured with a Brookefield rotational dial viscometer (LV model). The LV-27 spindle was used. A rotating speed of 100 rpm was used in the measurement of the viscosity. According to the results shown in Figure 1, the viscosities achieved for the locally developed epoxy asphalt binder were 170 ± 20 × 10^6 and 280 ± 30 × 10^6 m^2/s at 20 and 30 minutes respectively. Therefore 20 and 30 minutes were selected as the mixing and compaction times respectively.

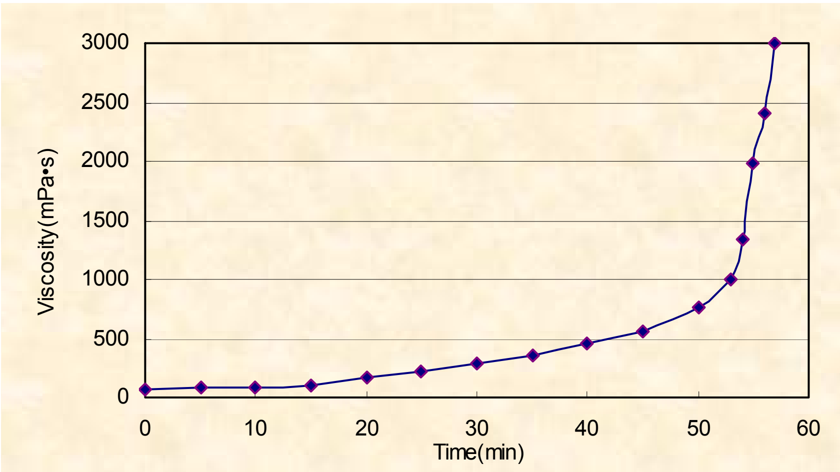

Figure 1. Viscosity-time curve of locally developed epoxy asphalt binder (120 °C)

2.3 Aggregate gradation

The aggregate gradation recommended for asphalt concrete by the Pavement Laboratory of Southeast University was adopted for the locally developed epoxy asphalt mix. The grading limit of the mix is shown in Table 3.

Table 3. Grading limit of the locally developed epoxy asphalt mix

Sieve size (mm)	16	13.2	9.5	4.75	2.36	0.6	0.075
Percentage passing (%)	100	100	95~100	65~85	50~70	28~40	7~14

2.4 Optimising the binder content

The Marshall mix design method with the 50 blows criteria was used to establish the optimum binder content. According to the test results, a 6.5% binder content was found to be optimum for the locally developed epoxy asphalt mix.

3. TESTING AND RESULTS

Major tests carried out in this programme followed the specification developed by the Ministry of Communications, P.R. China. The performance of SMA10 and mastic asphalt mix (MA) was also investigated in the following tests to compare it with that of the locally developed epoxy asphalt mix.

3.1 Stability test with oven-dried specimens

Six groups of locally developed epoxy asphalt Marshall specimens prepared in accordance with the JTJ 052-2000 standard method were placed in an oven set at a curing temperature of 60 °C for 12 h, 24 h, 36 h, 48 h, 72 h and 96 h for the first to the sixth groups respectively. The test temperature of 60 °C was adopted to simulate the roadway surface temperature on hot summer days in Nanjing, China. The measured stability values of these six groups, which increase with curing time, are shown in Figure 2. The stability values of the specimens cured at 60 °C for 96 h were close to 37.0 kN which was the stability value of the specimen cured at 120 °C for 6 h. The test data show that the curing time of locally developed epoxy asphalt mix can be decreased for construction in summer so that the pavement can be opened to the traffic within several days of paving.

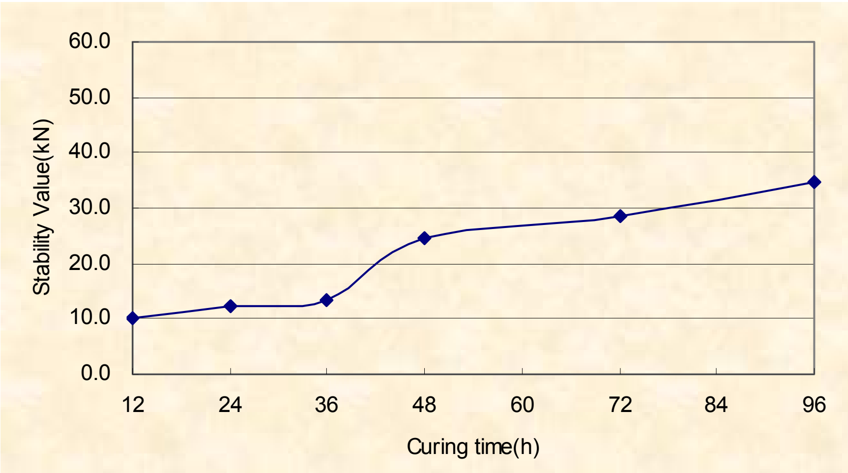

Figure 2. Marshall stability-curing time curve of locally developed epoxy asphalt mix at 60 °C

3.2 Moisture susceptibility of the mix

Moisture damage is a serious problem in asphalt concrete pavement in the field. The moisture damage was evaluated by testing the retained strength-to- tensile strength ratio. The tests were conducted on locally developed epoxy asphalt mixes cured at 120 °C for 6 h and on SMA10.

3.2.1 Retained Marshall stability

The Marshall stability of the compacted specimens was determined after conditioning in water maintained at 60 °C for 48 h prior to testing. This stability, expressed as the percentage of the stability of Marshall specimens determined under standard conditions, is the retained stability of the mix. The results are shown in Table 4. It can be seen that the locally developed epoxy asphalt mix performed significantly better than SMA10.

Table 4. Retained stability of different mixes (48 h)

Mix	Marshall stability (kN)		Retained stability (%)
	Standard condition	Conditioned at 60 °C for 48 h	
Locally developed epoxy asphalt mix	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 mixes was to determine the tensile strength ratio (Kennedy, 1978). The tensile strength ratio is the average static indirect tensile strength of the conditioned specimens expressed as a percentage of the average static indirect tensile strength of unconditioned specimens. Conditioning was done by first freezing the specimens at -18 °C for 16 h, then placing the specimens in water maintained at 60 °C for 24 h, and finally curing at 25 °C for 2 h before commencing the test. The test was conducted at 25 °C. The results are presented in Table 5. The locally developed epoxy asphalt mix was found to have better indirect tensile strength characteristics. The tensile strength ratio value of the locally developed epoxy asphalt mix is higher than that of SMA10, indicating that the locally developed epoxy asphalt mix is less susceptible to moisture damage.

Table 5. Indirect tensile test results of different mixes

Mix	Indirect tensile strength at 25 °C (MPa)		Retained stability (%)
	Unconditioned	Conditioned at -18 °C for 16 h, then at 60 °C for 24 h	
Locally developed epoxy asphalt mix	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 load-associated rutting in asphalt mixes (Shen Derhsien et al., 2005). The rutting test was performed using the wheel track device specified in JTJ 052-2000 of China for the evaluation of pavement performance. The dimensions of the specimens, which were mixed with optimum binder content according to the Marshall mix design and prepared by the rolling machine, were 300 mm x 300 mm in cross-sectional area and 50 mm in height. Normally, rutting tests are performed using a 0.7 MPa wheel load adapted to simulate the standard wheel load in the field at 60 °C under dry conditions. The rutting tests in this investigation were conducted on the locally developed epoxy asphalt mix cured at 120 °C for 6 h, and on SMA10 and MA. The rut depth was measured after 2 520 cycles over 60 min. The results are presented in Table 6. The locally developed mix yielded the smallest rutting depth and showed the lowest potential for permanent deformation.

Table 6. Rutting test results of different mixes (60 ^{o}C, 0.7 MPa)

Mix	Dynamic stability value (cycles/mm)	Rutting depth in 60 min (mm)
Locally developed epoxy asphalt mix	>6 000	0.9
SMA10	5 465	1.4
MA	1 215	4.7

3.4 Low-temperature properties

The JTJ 052-2000 procedure of China using MTS810 equipment was applied to measure the maximum load and the maximum deflection. The flexural tensile strength and the flexural stiffness moduli were then calculated from the maximum load and the maximum deflection. The dimensions of the specimens, which were mixed with optimum binder content according to the Marshall mix design, were 30 mm x 35 mm in cross-sectional area and 250 mm in length with a span length 200 mm. All the beams were loaded using a static three-point bending test set-up. A vertical static load was applied to the specimens at a rate of 50 mm·min^{-1}. Beam bending tests were conducted at temperatures of -15 ^{o}C and -20 ^{o}C on locally developed asphalt mix cured at 120 ^{o}C for 6 h. SMA10 and MA were also tested at a temperature of -15 ^{o}C. The test results are presented in Table 7. As expected, the flexural stiffness modulus of locally developed epoxy asphalt mix decreased with an increase in temperature. At the same test temperature of -15 ^{o}C, locally developed epoxy asphalt mix yielded the highest flexural tensile strength and flexural stiffness modulus value. The maximal flexural tensile strain values obtained for the locally developed epoxy asphalt mix are almost to the same as those observed for SMA10 and MA. It can be seen that the locally developed epoxy asphalt mix performed significantly in strength at low temperature, while its deformation characteristic was similar to that of other mixes.

Table 7. Bending test results of different mixes

Mix	Temperature (^{o}C)	Flexural tensile strength (MPa)	Maximal flexural tensile strain	Flexural stiffness modulus (MPa)
Locally developed epoxy asphalt mix	-20	20.54	2.26×10^{-3}	10 172
	-15	20.29	2.60×10^{-3}	7 808
SMA10	-15	7.51	2.16×10^{-3}	3 477
MA	-15	13.56	3.63×10^{-3}	3 736

The flexural strain energy (Cai Siwei et al., 1999; Ge Zhesheng et al., 2002; Zhou Xiaohua et al., 2006) was used to assess the low-temperature performance of the asphalt mix in this study. The flexural strain energy is an index that can be used to evaluate both the strength and the deformation characteristic of mixes by applying the following equation:

$$J = \int_0^{\varepsilon_b} \sigma d\varepsilon \qquad 1$$

where

J = flexural strain energy (kPa); σ = flexural stress; ε_b = limited flexural strain.

Geometrically speaking, the flexural strain energy is the area between the stress-strain graph and the horizontal axis obtained from the beam bending test results. The relationships between load and deformation obtained from the beam bending test for the locally developed epoxy asphalt mix are shown in Figure 3.

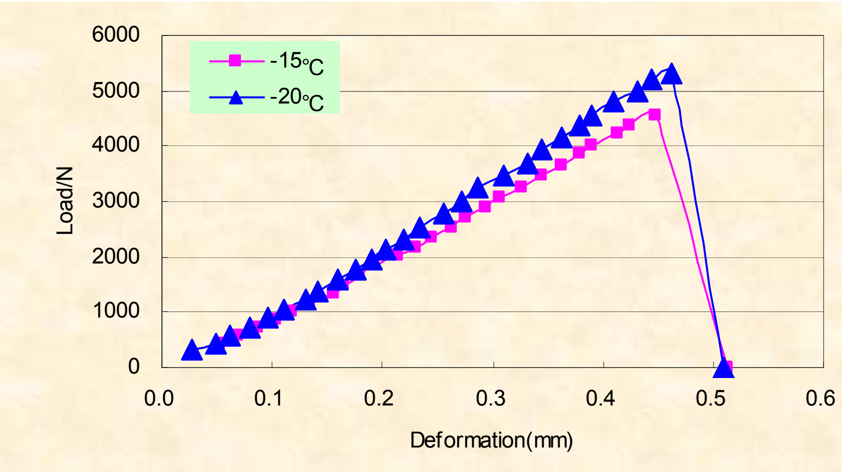

Figure 3. Load-deformation curve of locally developed epoxy asphalt mix at low temperature

Figure 3 indicates that at low temperature the stress for the locally developed epoxy asphalt mix increased in a linear fashion,, while the stress-strain curve of the common asphalt mix obtained from the beam bending test regressed in the form of a cubic parabola (Wu Tao et al., 2006). Therefore it can be inferred that the locally developed epoxy asphalt mix was similar to the elastic material at low temperature. The flexural strain energy results of the locally developed epoxy asphalt mix are presented in Table 8.

Table 8. Flexural strain energy of locally developed epoxy asphalt mix*

Mix	**Test temperature (°C)**	**Flexural strain energy (kPa)**
Locally developed epoxy asphalt mix	-15	43.25
	-20	45.31
AC-13*	-20	2.397

*The test data were obtained from the literature (Wu Tao et al., 2006)

Compared with the values of the common AC-13 material (Wu Tao et al., 2006), it can be seen that the locally developed epoxy asphalt mix performed significantly better than the normal mix due to the noticeable improvement of its flexural strain energy value.

3.5 Fatigue characteristics

The fatigue characteristic of the asphalt mix in this investigation was evaluated by conducting the complex beam fatigue test using MTS810 equipment (Huang Wei et al., 2003). This test method was selected because it simulated the actual state of the steel deck and the pavement.

In the complex beam fatigue test, the maximal load force was 5 kN, the beam loading wave was a sine wave, and the loading frequency was 10 Hz (Walter et al., 1981; Huang Wei et al., 2003). Room temperature (20 °C) was selected as the test temperature. Both the locally developed epoxy asphalt mix and SMA10 were tested. The complex beam fatigue test results are shown in Table 9. It can be seen that the fatigue life of the locally developed epoxy asphalt mix is more than three times greater than that of SMA10.

Table 9. Complex beam fatigue test results of different mixes

Mix	Load cycles(times)	Condition of the samples
Locally developed epoxy asphalt mix	12 000 000	No damage
SMA10	3 200 000	Cracking in the middle of the span

4. CONCLUSIONS

Based on the results of the experimental tests conducted on locally developed epoxy asphalt mix, SMA10 and MA, the following conclusions were drawn:

1. Marshall stability values of the locally developed epoxy asphalt mix tend to increase with the curing time. The Marshall stability value of the cured specimen was as high as 37.0 kN.
2. The locally developed epoxy asphalt mix was found to be less susceptible to moisture damage compared to SMA10 due to the higher retained Marshall stability and higher tensile strength ratio.
3. The locally developed epoxy asphalt mix displayed lower potential for permanent deformation compared to SMA10 and MA.
4. The locally developed epoxy asphalt mix performed excellently at low temperature due to its great flexural strain energy value.
5. Significantly improved fatigue behaviour of the locally developed epoxy asphalt mix was found. The fatigue life of the locally developed epoxy asphalt mix, as observed from the laboratory fatigue test results, is greater than the fatigue life of SMA10.
6. The locally developed epoxy asphalt mix is a viable paving material with many performance and economic advantages.

5. ACKNOWLEDGMENTS

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