Journal of Southeast University (English Edition) Vol. 23, No. 1, pp. 122 – 126 Mar. 2007 ISSN 1003—7985

Evaluation of modification effect of epoxy resin based on performance of asphalt mixtures

Yang Jun[1] Lu Haizhu[1] Yuan Dengquan[2] Wang Jianwei[1]

([1] School of Transportation, Southeast University, Nanjing 210096, China)

([2] Luwan Administration Bureau of Construction of Shanghai, Shanghai 200020, China)

Abstract: Based on the analysis of the main failures discovered in pavement on steel deck plate and the demanding service condition of the pavement on steel deck, high-temperature rutting test, low-temperature bending test and controlled stress flexural fatigue test are used to study the performance of asphalt mixtures modified by epoxy resin including high-temperature stability, low-temperature cracking-resistance, and fatigue cracking-resistance, which are served to evaluate the modification effect of epoxy resin of different contents. With the addition of epoxy resin, all the three performances are improved greatly. However, when the amount of epoxy resin added is over a certain value, the modification effect will be stable with no extra benefit detected. Finally, in terms of the properties of the three respects, 20%, 30%, 30% are given separately as the proposal adding contents.

Key words: pavement on steel deck plate; content of epoxy resin; asphalt mixtures modified by epoxy resin; performance; modification effect

In China, epoxy resin modified asphalt mixture has already been used on several long-span bridges as the deck pavement since its debut in the Second Nanjing Yangtze River Bridge in 2000, the pavement material of which was then imported from the USA. Till now, almost all these bridges have provided satisfactory performance[1–3]; therefore, it can be concluded that the epoxy resin modified asphalt mixture may be a good option as deck pavement material due to its high strength and long durability, especially realizing the fact of large traffic volume and heavy-load vehicles in China. However, some important information is still kept confidential by the USA, such as the ingredients or the components of the epoxy asphalt. In this paper, research will be conducted to investigate the properties of the epoxy resin modified asphalt mixture and come up with suggestions for the ingredients in both economical and technical perspectives.

The available literature has demonstrated that the premature failure in bridge pavement always happened in the forms of high temperature rutting, low temperature cracking, fatigue cracking and some other distresses induced by them. The service environment was certainly an important factor leading to these failures, but what should be blamed more is the pavement itself[4–5]. As a result this research put more emphasis on the study of the modification effect of epoxy resin with different contents, all of which were realized through laboratory tests. During all these tests, the ratio of epoxy resin and hardening agent is kept constant at 100/80, while the portions their mixes take in the asphalt mixtures as variables.

Received 2006-06-23.

Biography: Yang Jun (1968—), female, doctor, professor, yangjun@seu.edu.cn.

1 Materials

1.1 Bitumen and additive (epoxy resin and hardening agent)

The asphalt used in the research is Shell 60/80. The detailed information is shown in Tab. 1.

Tab. 1 Properties of bitumen

Items	Test result	Test procedure
Penetration (25 ℃, 100 g, 5 s)/(0.1 mm)	70	JTJ 052—2000 (T0604—2000)
Ductility (5 ℃, 15 ℃)/cm	14.1, >100	JTJ 052—2000 (T0605—2000)
Softening point(R&B)/℃	47.5	JTJ 052—2000 (T0606—2000)

The properties of epoxy resin, hardening agent and their mixes are shown in Tab. 2.

In the following part of this paper, the mixes of epoxy resin and hardening agent will be referred to as EP.

1.2 Aggregate and mineral filler

Basalt aggregates were introduced as both the coarse and fine aggregates in this study, the same aggregates used in the pavement of the Third Nanjing Yangtze River Bridge in 2005. They have been regarded as of high quality and grade and nearly

Tab. 2 Properties of the epoxy resin, hardening agent and their mixes

Items	Material	Specification	Test result	Test procedure
Density (25 ℃)/(g · cm^{-3})	Epoxy resin	1.00 to 1.25	1.159	JTJ T0603—1993
	Hardening agent	0.75 to 1.00	0.831	
Viscosity(25 ℃)/(Pa · s)	Epoxy resin	2 to 15	12.5	JTJ T0625—2000
	Hardening agent	30 to 80	43	
Tensile strength/MPa	Mix(EP)	≥4.9	5.8	JISK 7113[6]
Ductility/%	Mix(EP)	≥100	227	

Note: Epoxy resin : hardening agent = 100/80(by weight).

all the properties can meet the associated requirements well. In order to achieve a desirable bonding between the binder and the aggregates, a limestone filler is used, which can make up for the disadvantages of the Basalt aggregates.

1.3 Aggregate gradation and asphalt content

Ref. [3] pointed out that it was reasonable to adopt fine-graded dense gradation during the design of the epoxy asphalt mixture. In terms of gradation in this study, the gradation used in the Second Nanjing Yangtze River Bridge was referred to and the information is listed in Tab. 3.

Tab. 3 Gradation adopted in this study

Sieve size/mm	13.2	9.5	4.75	2.36	0.6	0.075
Percent passing/%	100	97.6	74.2	58.6	34.4	10.5

Based on the gradation listed above, 25 Marshall specimens have been prepared while the content of epoxy resin varied from 0% to 40% and the asphalt-aggregate ratio varied from 5.5% to 7.5%. Because the main purpose of the study is to determine the influence of the content of EP on the performance of asphalt mixtures, it is necessary to undertake further tests and investigations on the specimens of one specific asphalt-aggregate ratio. According to Ref. [1], 6.5% was selected as the asphalt-aggregate ratio, which was suggested based on the air voids to be achieved. The air voids of the Marshall specimen using different EP contents excepting all with 6.5% as the asphalt-aggregate ratio is shown in Tab. 4.

Tab. 4 Air voids of the Marshall specimen using different EP contents

EP content/%	0	10	20	30	40
Air voids/%	2.4	1.7	1.5	2.1	1.9

2 High Temperature Performance

The dynamic stability (DS) and rutting depth (RD) under 2×10^4 passes were selected to evaluate the high temperature performance and they were achieved from the tests conducted with the conventional wheel tracking test machine and the Hamburg wheel tracking test machine separately[7]. Meanwhile, the sizes of the specimens were both 30 cm × 30 cm × 5 cm. The corresponding test results are shown in Fig. 1 and Fig. 2.

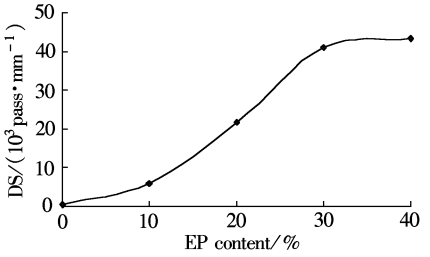

Fig. 1 Conventional wheel tracking test result

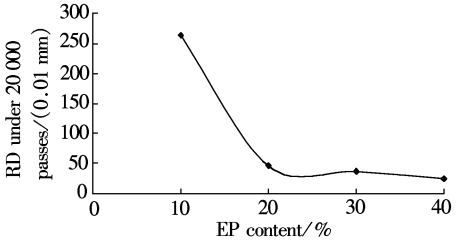

Fig. 2 Hamburg wheel tracking test result

From Fig. 1 and Fig. 2, it is concluded that, with the increase of the EP content, the capability of rutting resistance of the mixtures increases significantly. Meanwhile, the two indices, both DS and rutting depth under 2×10^4 passes of the mixtures, have a similar changing tendency with the variation of the EP content. However, the appropriate content of EP is not exactly the same concerning the two indices separately. Note that the item of the appropriate content of EP is put forward from both the economic and technical prospective, that is a higher content than the appropriate one which may do little to increase the performance of the mixture, whereas the cost may be much higher. The author thinks the appropriate content of EP based on the index of rutting depth under 2×10^4 passes is more convincing than that based on DS. That is because when the content of EP is high enough to a certain degree, the rutting depth will experience only a tiny change, which means the DS calculated by the test data will be probably influenced by the test error.

In general, it is stated that the EP has a remarkable influence on the performance of asphalt mixtures.

When the EP content amounts to 10%, the capability of rutting resistance of the mixtures will well meet the related specifications and standards; furthermore, if the content rises to 20%, more excellent performance will be achieved and nearly no rutting will be detected during the indoor test. However, if the EP content is higher than 20%, no further improvement of rutting resistance capability is clearly found.

3 Low Temperature Performance

As for the pattern of stress response, the beam specimen resembles much the pavement on the orthotropic deck plate of the steel bridge. Also for the ease of fabrication, a beam specimen (200 mm × 30 mm × 35 mm) was adopted as the test subject to study the influence of EP of different amounts on low-temperature performance[8-9]. In order to make a better comparison, the test results under room temperature are also listed in Fig. 3 and Fig. 4.

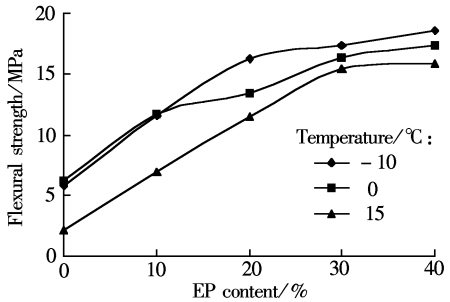

Fig. 3 Relationship between flexural strength and EP content

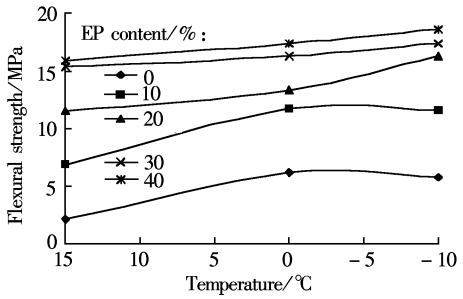

Fig. 4 Relationship between flexural strength and temperature

From Fig. 3, it is concluded that, the flexural strength of the mixtures under different temperatures increases with more EP added. Meanwhile, it is found in Fig. 4 that, the flexural strength of the mixtures with different EP contents increases when the temperature drops. In general, the flexural strength of the mixture with a higher EP content has a smaller changing rate when the temperature changes, which means the larger the EP content, the smaller the sensitivity of the flexural strength to the temperature. It can also be regarded that EP plays a dominant role in strength generating than the base asphalt.

Fig. 5 shows the influence of the EP content on the maximum flexural strain, from which it is found that under the temperature of 15 ℃, the maximum flexural strain decreases gradually with the increase of the EP content. However, when the temperature drops to 0 ℃ or even lower, the changing tendency may be nearly the opposite to that of 15 ℃. In addition, it can also be found that with the increase of the EP content, the maximum flexural strain under different temperatures has a tendency to be the same, that means the properties of base asphalt are much more likely to be influenced by the temperature than the EP. Fig. 6 shows how the maximum flexural strain changes with the temperature. It is found that with more EP added, the changing rate of the maximum flexural strain with the decrease of temperature will be smaller. That means EP plays a very important role in the flexibility of the mixture and with EP added the flexibility will be less likely influenced by the temperature, which is quite desirable in the pavement on the bridge.

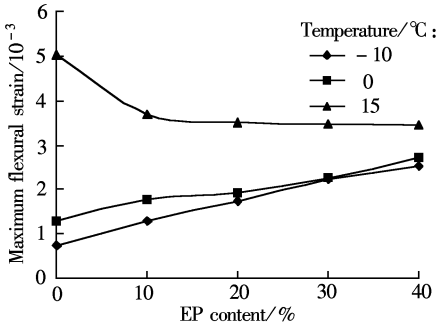

Fig. 5 Relationship between maximum flexural strain and EP content

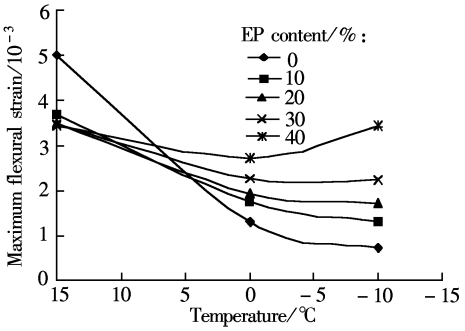

Fig. 6 Relationship between maximum flexural strain and temperature

With a comprehensive study for test results and the field requirement of the flexural strength and the maximum flexural strain, it can be considered reasonable to recommend approximately 30% as the EP content to achieve a satisfactory low temperature performance of the asphalt mixture.

4 Fatigue Performance

Nowadays the traffic volume of the bridge is becoming increasingly greater; that can cause the premature failure of the pavement due to its poor fatigue resistance and this performance is also predictable through some controlled tests[10]. As a result, it is quite necessary to study the performance of fatigue resistance and investigate the effect of different EP contents in this respect. In this study, the beam specimens (200 mm × 30 mm × 35 mm) were subjected to the flexural fatigue test under the stress-controlled mode and the test temperature was set at 15 ℃. The fatigue properties of asphalt mixtures are usually analyzed based on Eq. (1).

$$N_f = k\left(\frac{1}{\sigma_0}\right)^n \quad (1)$$

where N_f is the fatigue life, and σ_0 is the stress in the mixture (MPa).

Through the tests on the specimens of different EP contents and the fitting curve of the test results under the coordinates on lg-lg scale, the parameters of k and n were obtained. The parameters of the fatigue formula with different EP contents are listed in Tab. 5. Fig. 7 shows the fatigue life of the specimens of different EP contents under different stresses.

Tab. 5 Parameters of the fatigue formula with different EP contents

Parameters	EP content/%				
	0	10	20	30	40
k	2.86×10^7	1.18×10^8	2.78×10^9	5.71×10^{11}	8.08×10^{11}
n	1.388 2	2.049 0	3.068 1	5.058 4	5.179 3

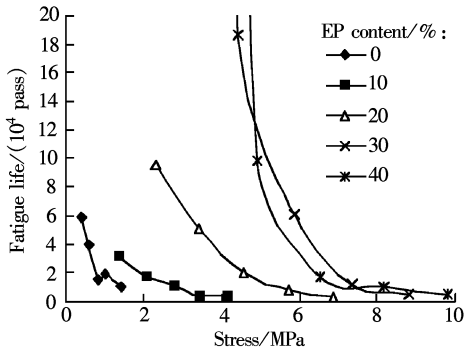

Fig. 7 Fatigue life of the specimens of different EP contents

Also, this paper predicts the fatigue life of the Second Nanjing Yangtze River Bridge with the formula achieved by the flexural fatigue test. How the mixtures with different EP contents may perform is listed in Tab. 6. $N_{f(n)}/N_{f(n-1)}$ in Tab. 6 means how the fatigue life changes with the increase of the EP content, through which the difference of modification effects can be found out readily. It is concluded that EP greatly helps to improve the fatigue life, which will well overcome the tough conditions on deck pavement and reduce the possibility of premature cracking occurrences effectively. Meanwhile, it is also found that when the EP content is 30%, the fatigue life is 304.5 times that of adding 20% EP. However, if the EP content is 40%, there is no significant improvement in the fatigue life.

Tab. 6 Fatigue life of the Second Nanjing Yangtze River Bridge

EP content/%	Maximum stress σ/MPa[1]	Predicted fatigue life N_f/pass	$N_{f(n)}/N_{f(n-1)}$
0		3.76×10^7	
10		1.77×10^8	4.7
20	0.821	5.09×10^9	28.8
30		1.55×10^{12}	304.5
40		2.25×10^{12}	1.4

Similar to the low and high temperature performance, there is also an appropriate content of EP in terms of performance of fatigue resistance. It is found that with the increase of the EP content, the fatigue resistance performance of the mixture experiences a significant improvement. However, when the content rises over 30%, the improvement becomes quite small.

5 Conclusions

1) The indices of dynamic stability and rutting depth under 2×10^4 passes are used to quantitatively evaluate the influence of the EP of different content on the high temperature performance of mixtures. The results show that EP can improve the high temperature performance of mixtures significantly.

2) EP can improve the flexural strength and flexibility of the mixtures under low temperature to a great degree and the more EP added, the better performance achieved. Meanwhile, it is also found that the more EP is added, the less the flexural strength and flexibility are influenced by the variations in temperature.

3) The results of the fatigue test show that the addition of EP is an effective solution to improve the performance of fatigue resistance of the mixtures. Thus, the pavement on the deck plate is more likely to overcome the demanding situation of great traffic volume and over-loaded trucks.

4) With the addition of EP, all the three performances are improved. However, if the amount of EP added is over a certain amount, there is no further improvement detected. Tab. 7 lists the proposed appropriate contents of EP that should be added to improve

the three kinds of performance separately.

Finally, it should be stressed that all the study above is based on the laboratory tests and if any trial pavement is operated in the field, the conclusion will be more convincing and valid.

Tab. 7 Proposed appropriate contents of EP

Performance	High temperature	Low temperature	Fatigue
EP content/%	20	30	30

References

[1] Yuan Dengquan. The study on the performance of the asphalt and mixtures modified by epoxy resin[D]. Nanjing: School of Transportation of Southeast University, 2006. (in Chinese)

[2] Chen Xianhua. Structure research on steel deck plate with asphalt pavement for Runyang Bridge [D]. Nanjing: School of Transportation of Southeast University, 2003. (in Chinese)

[3] The Guiding Bureau for the Construction of the Second Nanjing Yangtze River Bridge of Southeast University. The technology of epoxy asphalt used in the pavement of the Second Nanjing Yangtze River Bridge [R]. 2003. (in Chinese)

[4] Walter J L, Hicks R, Wilson J E. Impact of variations in material properties on asphalt pavement life-evaluation of warren-scappoose project, FHWA-OR-81-7[R]. Oregon: Oregon State University, 1981.

[5] Bild S. Contribution to the improvement of the durability of asphalt pavement on orthotropic steel bridge decks [D]. Aachen: RWTH Aachen, 1985.

[6] Nakanishi Hiromitsu, Okochi Takara, Goto Koji. The structural evaluation for an asphalt pavement on a steel plate deck[C]//*Proc of the* 1*st Int Conf on World of Asphalt Pavements, Session* 2*B*. Sydney, 2000: 112 - 123.

[7] Wu Guofu, Zou Hongde. Experimental investigation on evaluation indexes of megathermal stability of asphalt mixture[J]. *Municipal Engineering Technology*, 2005, **23**(6): 345 - 348. (in Chinese)

[8] Li Jing. Cracking resistance of asphalt mixtures under low temperature [J]. *Technology of Road and Transportation*, 2005, **22**(4): 9 - 12. (in Chinese)

[9] Deng Xuejun, Huang Xiaoming. *Principle and method of road design* [M]. Beijing: China Communications Press, 2001. (in Chinese)

[10] Van Dijk W, Moreand H, Quedeville. The fatigue of bitumen and bituminous mixes[C]//*Proc of the* 3*rd Int Conf on Structure Design of Asphalt Pavement*. London, 1972, **1**: 354 - 366.

基于沥青混合料性能的环氧树脂改性效果评价

杨 军[1] 陆海珠[1] 袁登全[2] 王建伟[1]

([1] 东南大学交通学院,南京 210096)

([2] 上海市卢湾区建设委员会,上海 200020)

摘要: 在分析钢桥面铺装层主要病害和特殊工作环境的前提下,分别采用高温车辙试验、低温小梁弯曲试验和控制应力小梁弯拉疲劳试验,研究了不同环氧树脂掺量下的环氧树脂改性沥青混合料的高温稳定性、低温抗裂性和抗疲劳性能. 试验结果表明:环氧树脂对这 3 个方面都有很大的改进效果,但改性效果和树脂的添加量并不是一个无限递增的关系,当添加量超过一定数值以后,改性的效果将趋于平稳. 最后就高温、低温、疲劳 3 个方面分别提出环氧树脂添加量为 20%,30%,30% 的建议值.

关键词: 钢桥面铺装;环氧树脂用量;环氧树脂改性沥青混合料;性能;改性效果

中图分类号: U416. 217