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Anti-cracking mechanism of diatomite asphalt and diatomite asphalt mixture at low temperature

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Abstract: A kind of neat asphalt and three kinds of diatomite asphalt are tested using differential scanning calorimetry(DSC). The anti-cracking mechanism of diatomite asphalt is analyzed by DSC and the thermal stress restrained specimen test(TSRST) of the asphalt mixtures. The results show that the low temperature performance of diatomite asphalt is better than that of neat asphalt. The glass transition temperature can reflect the low temperature performance of the diatomite asphalt better and has a good relationship with breaking temperatures. Besides, the TSRST, the bending test, the compressing test and the contraction coefficient test are used to study the low temperature performance of the diatomite asphalt mixture. The results prove that the low temperature performance of the diatomite asphalt mixture is better than that of the neat asphalt mixture. The critical bending strain energy density and the compressing strain energy density of the diatomite asphalt mixture are greater than those of the neat asphalt mixture. After adding diatomite to the asphalt mixture, the contraction coefficient is reduced. Based on the above results, the anti-cracking mechanism of the diatomite asphalt mixture is analyzed from the angle of contraction performance and breaking energy.

Key words: diatomite asphalt; low temperature performance; glass transition temperature; differential scanning calorimetry; anti-cracking mechanism

Contraction crack is one of the main failure modes of asphalt pavements at low temperature. It can lead to block crack, mud-pumping and so on, endangering the life and quality of roads seriously. Hence, it is an important task to improve the anti-cracking performance of asphalt pavements[1]. The results of the Strategic Highway Research Program (SHRP) show that the performance of asphalt has a great influence on the anti-cracking performance of asphalt pavements[2]. So it is important to improve the performance of asphalt and asphalt mixtures.

Diatomite asphalt is a new kind of asphalt that has been used in recent years. The researches about diatomite asphalt can be traced back to the eighties. Houston, Calgary, and Los Angeles in North America adopted diatomite asphalt pavements, and the results were effective[3-4]. China has started using diatomite asphalt since 1999. Some parts of Kun-E road, An-Wen road, Chu-Da road, Kun-Yu road, and Da-Bao road have used diatomite asphalt[5]. Both the Road Science and Technical Institute of Yunnan and the Highway College of Chang'an University investigated diatomite asphalt mixtures and the results showed that the diatomite asphalt mixture has better pavement performance, and it is worthy of being used widely[6].

At present, diatomite asphalt mixtures are already being used in pavements, but researches about diatomite asphalt and asphalt mixtures are still in the initial stages. Most of the low temperature indices in the standards are based on experience, and some researches show that the evaluation indices in the standards have low sensitivity in evaluating the low temperature performance of diatomite asphalt[7-8]. The rheology characteristics of asphalt at low temperatures is an important factor in the cracking at low temperatures[9-10]. So the anti-cracking performance of diatomite asphalt should also be studied from the angle of rheology characteristics. Although the good low temperature performance of diatomite asphalt pavement has been known, the suitable evaluation indices of diatomite asphalt and asphalt mixtures have not been established since their anti-cracking mechanisms are not clearly understood. In order to promote the use of diatomite asphalt and asphalt mixtures, their low temperature performances are researched and the anti-cracking mechanisms are analyzed.

1 Materials and Tests

1.1 Materials

90# neat asphalt and three kinds of diatomite (Changbai diatomite, Linjiang diatomite and white diatomite) are used. The basic performances of neat asphalt are presented in Tab. 1 and the chemical components are shown in Tab. 2. It shows that there is much SiO_2 in all the three kinds of diatomite and the amount of SiO_2 in the white diatomite is the highest. The amount of SiO_2 can reflect the amount of diatoms in the diatomite. The more SiO_2 the diatomite has, the purer it is. For DSC, the proportion of diatomite is 14%.

Tab. 1 Basic performance of neat asphalt

Penetration/(0.1 mm)			PI	Ductility/cm		Soft point/℃
30 ℃	25 ℃	15 ℃		5 ℃	15 ℃	
153	85	25	−1.72	14.6	>150	45.8

The aggregates are basalt. The gradation adopted the median of AC-16 Ⅰ with 19 mm nominal maximum sieve size. The proportion of diatomite is 14%, and the asphalt contents determined by the Marshall test are 5.2% for Changbai diatomite, 5.2% for white diatomite, 5.3% for Linjiang diatomite, and 5.0% for neat asphalt by weight.

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Tab. 2 Chemical components of the three kinds of diatomite %

Component	Changbai diatomite	Linjiang diatomite	White diatomite
SiO_2	86. 12	82. 88	92. 90
Al_2O_3	3. 56	5. 63	
Fe_2O_3	0. 94	2. 24	
TiO_2	0. 20	0. 20	
P_2O_5	0. 08	0. 03	
MnO	0. 01	0. 02	
CaO	0. 50	2. 05	
MgO	1. 97	0. 66	
K_2O	0. 50	1. 24	
Na_2O	0. 30	0. 33	
LOS	5. 73	4. 54	

1. 2 Tests

1. 2. 1 DSC

DSC is used to study the performance of asphalt from a microcosmic perspective. It can measure the relationship between energy differences and temperature inputs to the sample. Its principle is that absorbing and distributing heat always reflect the change of the state of a substance, such as melting, crystallization, glass transition and so on, and the maximum in the DSC curve can reflect this phenomenon. The increasing ratio of temperature is 10 ℃/min, and the temperature is from −60 to 150 ℃.

1. 2. 2 TSRST

The thermal stress restrained specimen test (TSRST) is a suitable method for imitating the cracking process of asphalt pavements when the temperature is dropping. The size of the specimen is 40 mm × 40 mm × 300 mm. The starting temperature is 10 ℃, and the data are collected every second. The temperature stress curve is shown in Fig. 1. Breaking strength, breaking temperature, transition temperature and the slope can reflect the low temperature performance of an asphalt mixture.

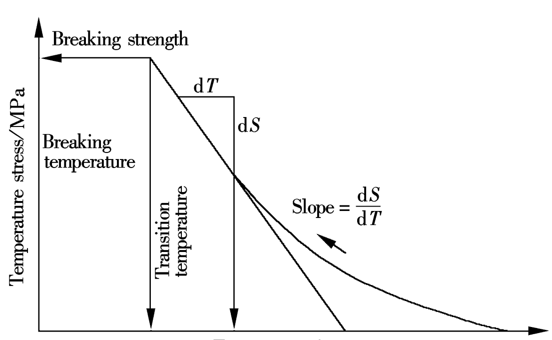

Fig. 1 Schematic of temperature stress

1. 2. 3 Bending test at low temperature

The strain energy density is a suitable method to evaluate the low temperature performance of an asphalt mixture. It is a parameter that can reflect both the strength and the distortion. The strain energy density can be calculated by Eq. (1), and the relationship between strain and stress can be obtained by analyzing the curve of strain and stress.

$$\frac{dw}{dv} = \int_0^{\varepsilon_{ij}} \sigma_{ij} d\varepsilon_{ij} \tag{1}$$

This test is based on Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTJ052—2000, T0715—1993). The size of the specimen is 250 mm × 30 mm × 35 mm. The temperature is −10 ℃ and the loading rate is 50 mm/min.

1. 2. 4 Compressing test at low temperature

The calculation theory of the strain energy density in this test is similar to that in the bending test. And the test is based on Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTJ052—2000, T0714—1993). The temperatures are 0, −10 and −20 ℃. The size of the specimen is 40 mm × 40 mm × 80 mm.

1. 2. 5 Contraction coefficient test

When the temperature drops, the contraction of asphalt pavement will be restricted by the base course and the surrounding structures, so the tension stress and strain are caused by the contraction. And it will lead to cracking in pavements. The contraction performance is one of the most basic factors for the temperature cracking in asphalt pavements. The contraction coefficient is an important parameter regarding temperature stress. The temperature contraction coefficients from 0 to −30 ℃ are obtained based on the method in Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTJ052—2000, T0720—1993).

2 Results and Analysis

2. 1 DSC test

The DSC test can reflect the microstructure of asphalt. Neat asphalt, Changbai diatomite asphalt and Linjiang diatomite asphalt are measured by DSC. As shown in Tab. 3, after adding diatomite, the absorbing energy decreases, indicating that the temperature stability of diatomite asphalt is improved. The glass transition temperature of diatomite asphalt is lower than that of neat asphalt. It means that the low temperature performance of asphalt can be improved after adding diatomite. In addition, the glass transition temperature can reflect the microstructure of the asphalt. So the glass transition temperature is suitable for evaluating the low temperature performance of diatomite asphalt.

Tab. 3 Results of DSC test

Type	Absorbing energy/(J·(g·℃)$^{-1}$)	Glass transition temperature/℃	Scope of top value/℃
Neat	0. 535	−13. 034	−50. 800 to −34. 117
Changbai	0. 367	−18. 468	−41. 467 to −39. 540
Linjiang	0. 455	−16. 666	−50. 800 to −32. 957

2. 2 TSRST test

The results of TSRST are shown in Tab. 4. It can be seen from the breaking temperature column that after adding diatomite, the breaking temperature becomes lower. This indi-

Tab. 4 Results of TSRST test

Type	Breaking temperature/℃	Breaking strength/GPa	Transition temperature/℃	Slope/(MPa·℃$^{-1}$)
Neat	−23. 8	3. 11	−19. 3	2. 429
Changbai	−27. 4	3. 48	−23. 0	1. 667
Linjiang	−26. 3	3. 08	−19. 6	2. 048
White	−26. 5	2. 80	−22. 0	1. 789

cates that the anti-cracking performance of the diatomite asphalt mixture is better than that of the neat asphalt mixture.

The results in the breaking strength column reflect that the breaking strength of the Changbai diatomite asphalt mixture is greater than that of the neat asphalt mixture, but the breaking strength of the Linjiang and white diatomite asphalt mixture are less than that of the neat asphalt mixture. It means that the anti-cracking performance of the Changbai diatomite asphalt mixture at low temperature is better than that of the neat asphalt mixture, while the anti-cracking performance of the Linjiang and white diatomite asphalt mixture is worse than that of the neat asphalt mixture.

The results in the slope column reflect that the slopes of all the diatomite asphalt mixtures are less than that of the neat asphalt mixture. This indicates that a diatomite asphalt mixture breaks slowly after losing its relaxation ability, and its anti-cracking performance is better than that of a neat asphalt mixture.

Above all, the anti-cracking performance of a diatomite asphalt mixture is better than that of neat asphalt. Breaking strength is not suitable for evaluating the anti-cracking performance of diatomite asphalt mixtures, but breaking temperature can reflect the anti-cracking performance more intuitively.

The breaking temperature in TSRST and the glass transition temperature of diatomite asphalt are analyzed by linear regression, as shown in Fig. 2. It can be seen that the glass transition temperature of asphalt has a better linear relationship with the breaking temperature of the mixture. It also proves that the glass transition temperature has an important influence on low temperature and can explain the anti-cracking mechanism of diatomite asphalt well.

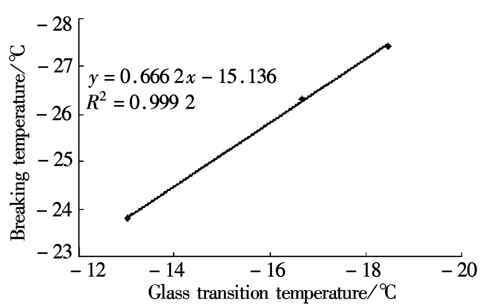

Fig. 2 Relationship between glass transition temperature and breaking temperature

2.3 Bending test

The results of the bending test are shown in Fig. 3. The critical bending strain energy densities of the diatomite asphalt mixtures are all greater than those of neat asphalt mixtures. It proves that the anti-cracking performance of a diatomite asphalt mixture is better than that of neat asphalt.

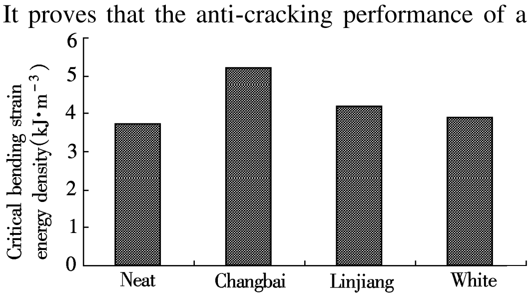

Fig. 3 Bending strain energy density of asphalt mixtures

2.4 Compressing test

Fig. 4 shows the critical compressing strain energy density of different asphalt mixtures. The compressing strain energy densities of the diatomite asphalt mixtures are all greater than those of neat asphalt. It shows that the anti-cracking performance of a diatomite asphalt mixture is better than that of a neat asphalt mixture if using compressing strain energy density as an index. The results are in accord with the results using bending strain energy density.

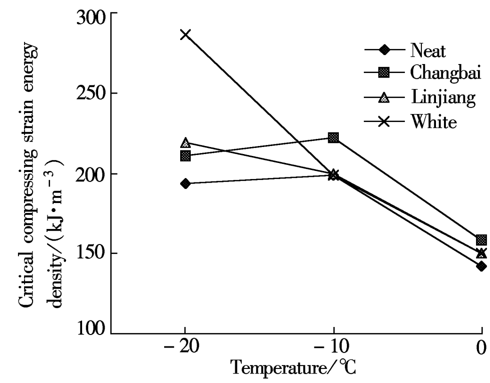

Fig. 4 Critical compressing strain energy density of asphalt mixtures

2.5 Contraction coefficient test

In Fig. 5, it is shown that under different temperature ranges, the contraction coefficients of a diatomite asphalt mixture are obviously smaller than those of a neat asphalt mixture. With decreasing temperature, the contraction coefficients of all the asphalt mixtures decrease. The low temperature performance of a diatomite asphalt mixture is better than that of a neat asphalt mixture using a contraction coefficient as an evaluation index.

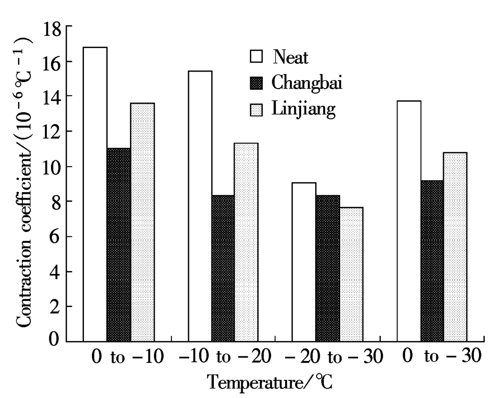

Fig. 5 Contraction coefficient of asphalt mixtures

2.6 Comparing the indices

Breaking temperature can really reflect the anti-cracking performance of an asphalt mixture, but the machine and the method are complicated. The contraction coefficient can reflect the deformation performance of asphalt mixtures under low temperatures, but it cannot reflect the performance when the mixture is restricted. It is not used as an anti-cracking evaluation index alone. The critical strain energy has a clear physical meaning and the corresponding tests are simple. So the critical strain energy is recommended as an anti-cracking evaluation index for diatomite asphalt mixtures.

The relationships between breaking temperature and bending strain energy at −10 ℃, compressing strain energy at 0, −10 and −20 ℃ are analyzed by a gray relation analysis. The original data used for the gray relation analysis are summarized in Tab. 5. The gray relation degree between the bending strain energy at −10 ℃ and the breaking temperature is 0. 638; between the compressing strain energy at 0 ℃ and the breaking temperature it is 0. 896; between the compressing strain energy at −10 ℃ and the breaking temperature it is 0. 748; between the compressing strain energy at −20 ℃ and the breaking temperature it is 0. 553. It shows that the gray relation degree between the compressing strain energy at 0 ℃ and the breaking temperature is the biggest. So it is the most suitable index to evaluate the low temperature performance of the diatomite asphalt mixtures.

Tab. 5 Original data of the gray relation analysis

Type	Bending strain energy/ (kJ·m^{-3})(−10 ℃)	Compressing strain energy/(kJ·m^{-3})			Breaking temperature/℃
		0 ℃	−10 ℃	−20 ℃	
Neat	3. 73	142. 17	198. 69	193. 81	−23. 8
Changbai	5. 21	158. 47	222. 20	210. 93	−27. 4
Linjiang	4. 19	150. 00	199. 27	219. 05	−26. 3
White	3. 87	149. 85	198. 95	286. 26	−26. 5

3 Anti-Cracking Mechanism of Diatomite Asphalt Mixture

Now there are many calculation modes used to research the cracking mechanism at low temperatures, such as the limited stress method, the admitted distortion method, the cracking temperature. These methods hold that cracking will occur when the accumulative temperature stress or strain exceeds the admitted stress or strain. In fact, contraction cracking is a very complex problem. The performance of asphalt, asphalt content, pavement structure and construction and so on can influence the performance of pavement. So it is not suitable to use a single influence factor to evaluate the performance. The relationships between material performance and mechanics analysis of pavement structures should be established. A calculation method of cracking ratio is brought forward based on energy; it is expressed by cracking space as follows:

$$L = \frac{hU_{\mathrm{ur}}}{\alpha} \frac{1}{\int_0^h \sigma(t_0, h') \Delta T(t_0, h') \mathrm{d}h'} \tag{2}$$

where h is the pavement thickness; U_{ur} is the cracking energy, and it is a function of asphalt performance, gradation, temperature and strain ratio; α is the contraction coefficient.

The equation shows that the cracking energy has a direct ratio with cracking space, and the contraction coefficient has an inverse ratio with cracking space. If the cracking energy is greater and the contraction coefficient is smaller, the cracking ratio will be smaller.

From the angle of contraction, Fig. 5 shows that after adding diatomite to an asphalt mixture, the contraction coefficient becomes smaller, so the cracking space will get bigger based on Eq. (2). It means that the anti-cracking performance gets better.

The critical strain energy of the three kinds of diatomite asphalt mixtures are greater than that of the neat asphalt mixture, as shown in Figs. 3 and 4. The anti-cracking mechanism of a diatomite asphalt mixture can be explained based on the figures and Eq. (2). Because the cracking energy of a diatomite asphalt mixture is greater than that of a neat asphalt mixture, the cracking space in a diatomite asphalt pavement is greater than that in a neat asphalt pavement.

4 Conclusion

A kind of neat asphalt and three kinds of diatomite asphalt are tested by DSC. And the corresponding asphalt mixtures are tested by TSRST, bending test, compressing test and contraction coefficient test. The results show that the low temperature performance of a diatomite asphalt (mixture) is better than that of a neat asphalt (mixture). The glass transition temperature can reflect the low temperature performance of diatomite asphalt better and it has good relationship with breaking temperature. The critical bending strain energy density and the compressing strain energy density are greater than those of neat asphalt. After adding diatomite to an asphalt mixture, the contraction coefficient will be reduced. The compressing strain energy at 0℃ is recommended as a suitable index to evaluate the low temperature performance of diatomite asphalt mixture. The anti-cracking mechanism of diatomite asphalt can be explained by DSC. Based on the results of asphalt mixture and the calculation equation of cracking space, it is believed that diatomite can make the contraction coefficient smaller and the cracking energy greater, so the anti-cracking performance of asphalt mixture can be improved.

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硅藻土沥青及沥青混合料低温抗裂机理

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摘要:对一种基质沥青和3种硅藻土沥青进行了差示热扫描分析,并结合相应的混合料约束试件的温度应力试验分析了硅藻土沥青的低温抗裂机理. 结果表明:硅藻土沥青有优于基质沥青的低温性能;玻璃态转化温度可以较好地反映硅藻土沥青的低温性能;玻璃态转化温度与破断温度有较高的相关性. 另外还进行了相应的4种沥青混合料的低温弯曲试验、低温压缩试验和收缩系数试验. 结果表明:硅藻土沥青混合料的低温性能优于基质沥青混合料;硅藻土沥青混合料临界弯曲应变能密度及压缩应变能密度均大于基质沥青混合料;沥青混合料加入硅藻土后收缩系数降低. 在此基础上,从混合料收缩性能和破坏能量2个角度分析了硅藻土沥青混合料的低温抗裂机理.

关键词:硅藻土沥青;低温性能;玻璃态转化温度;差示热扫描分析;抗裂机理
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