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Effects of polyphosphoric acid modified asphalt on the low-temperature cracking of asphalt mixtures

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Abstract: In order to determine whether polyphosphoric acid (PPA) can partially or completely substitute styrene-butadiene-styrene (SBS) modifier while it does not adversely affect the resistance to thermal cracking of the asphalt mixture, the low-temperature fracture properties of the PPA modified mixtures are evaluated and compared to the SBS modified mixtures. First, laboratory compacted test samples were tested by the indirect tensile test (IDT) and the newly developed fracture testing protocol, named as disk-shaped compact tension (DCT). Then, the effects of the test temperature and air-void ratio on the low-temperature fracture properties of asphalt mixtures were analyzed. The results show that the fracture resistance of the PPA modified mixtures is worse than that of the SBS modified mixtures. However, for those modified mixtures that use the PPA substituting part of the SBS modifier, a relatively low-temperature fracture resistance can be obtained compared with the mixture only using the SBS modifier.

Key words: asphalt mixture; low temperature; polyphosphoric acid; disk-shaped compact tension
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The increasing traffic loads which asphalt pavements are subjected to have accelerated the need to explore new paving materials and technologies to improve their performance. A common method used to improve the performance of asphalt binders is increasing the high-temperature limit of the performance grade (PG), and consequently expanding the temperature range without affecting the low-temperature limit. For this reason, special polymer additives have been used to produce modified asphalt binders that can improve resistance to rutting while they do not change the thermal cracking resistance. Recent investigations have shown that the asphalt binders modified by polyphosphoric acid (PPA), alone or in combination with traditional polymers, can reduce the cost of modification[1-4]. However, due to premature failures observed in some asphalt pavements containing PPA modified binders, its application has been restricted by some highway agencies[5-7]. Kodrat et al. [8] investigated the low-temperature fracture properties of the PPA modified binders and compared them to those of plain and polymer modified (SBS, Elvaloy) binders at similar grades. Tests were performed on a large number of binder types using the extended bending beam rheometer (EBBR), the compact tension (CT), and the double edge-notched tension (DENT). The results confirmed that the addition of PPA can increase the PG span without affecting its lower-temperature limit. The effects of PPA on the fracture properties at the brittle state and on the reversible aging process were found to be insignificant. However, the PPA modified binders subjected to the DENT test at ambient temperature can significantly reduce strain tolerance, thus leading to the increase in occurrence of fatigue cracking during the service life of the pavement. In this paper, the effects of PPA modification on the low-temperature fracture properties of asphalt mixtures are investigated. The traditional indirect tensile test (IDT) and new fracture test, namely disk-shaped compact tension (DCT), are used to determine the fracture properties of a set of laboratory prepared specimens.

1 Material and Sample Preparation

Three superpave asphalt mixtures are used in this investigation (see Tab. 1). Asphalt modifiers are used to upgrade a base binder of PG 46-34 to a binder of PG 58-34. The amount of modifiers for each asphalt mixture was added in such a way to acquire the same high-temperature PG limit.

Tab. 1 Description of asphalt mixtures used

Binder grade	Asphalt modifiers
PG 46-34	
PG 58-34	0.75% PPA
PG 58-34	1.0% SBS + 0.3% PPA
PG 58-34	1.5% SBS

The mixtures have a maximum aggregate size of 13.2 mm. All the mixtures have the same mix design except for the type and amount of modifiers. The mixtures are compacted to two target air-void ratios of 4% and 6%,

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respectively. The latter is assumed to be more representative of typical asphalt pavements immediately after construction. The cylindrical SGC compacted cores were cut according to required sample geometry of both IDT and DCT. The IDT and DCT laboratory specimens obtained from SGC cylinders had air-void ratios of 4% and 6%, respectively, and were tested at temperatures of −34 and −24 ℃, respectively.

2 Test Methods

The IDT test is used to determine the creep compliance and strength of the mixtures according to AASHTO specification T322. The experimental set-up of IDT is shown in Fig. 1. The disk-shaped compact tension test is a newly developed method for obtaining the fracture energy of mixtures from cylindrical specimens, namely gyratory compacted specimens or field cores[9]. The main purpose of using disk-shaped compact tension is to overcome the specimen molding difficulties[10]. The DCT test is conducted with a constant crack mouth opening displacement (CMOD) rate of 1 mm/min. The test set-up is shown in Fig. 2 with the loading fixtures and a clip gage attached to the specimen. The DCT test is performed to determine the fracture energy of the mixtures according to the ASTM standard D7313-13.

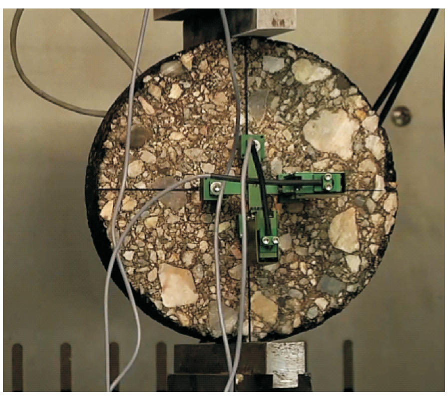

Fig. 1 Experimental set-up with measurements of IDT

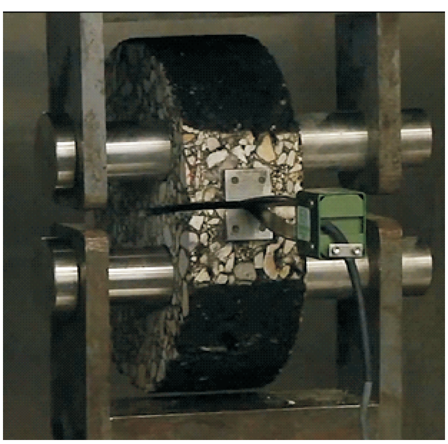

Fig. 2 Experimental set-up with measurements of DCT

3 Test Results of Laboratory Compacted Samples

3.1 IDT test result

The IDT strength results are given in Fig. 3. As can be seen, the strength of the mixtures decreases as the temperature drops. However, the SBS modified mixture with the air-void ratio of 6% appears to be less sensitive to the change in temperature. As expected, the mixtures with less void content have a higher strength than the mixture with a higher void content. With regard to the effect of modification, SBS and PPA + SBS modified mixtures have higher strength values at all air void and test temperature levels.

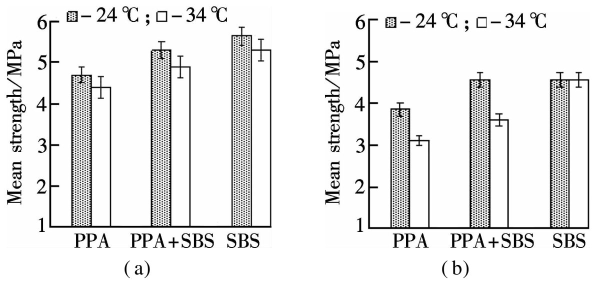

Fig. 3 IDT strength test results under different temperatures. (a) With an air-void ratio of 4%; (b) With an air-void ratio of 6%

Fig. 4 summarizes the IDT stiffness at 60 and 300 s. It can be seen that, for all the considered mixtures, stiffness increases dramatically when the temperature drops. Similarly, the stiffness is much higher in the mixtures with the air-void ratio of 4%. Moreover, the PPA modified mixture with the air-void ratio of 4% is relatively less sensitive to any change in temperature. On the contrary, with the air-void content of 6%, the PPA modified mixture has the highest increase in stiffness. Considering the effect of modification, the SBS alone and PPA + SBS modified mixtures have higher stiffness values compared

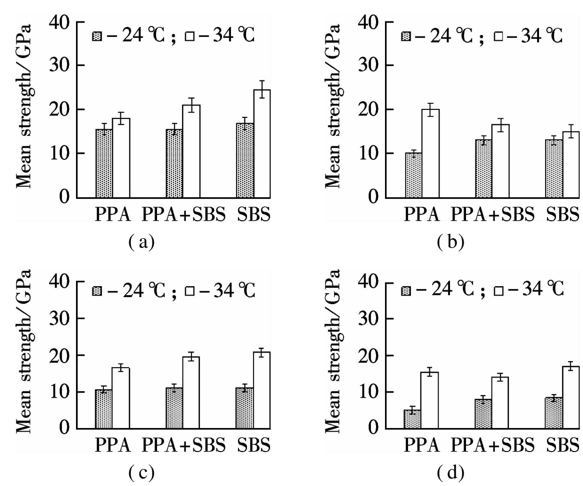

Fig. 4 IDT creep stiffness results under different temperatures. (a) With an air-void ratio of 4% and stiffness at 60 s; (b) With an air-void ratio of 6% and stiffness at 60 s; (c) With an air-void ratio of 4% and stiffness at 300 s; (d) With an air-void ratio of 6% and stiffness at 300 s

to the PPA modified mixture. It can also be seen that for all samples, the IDT stiffness at 60 s is higher than that at 300 s. This means that the longer the load time, the worse the crack resistance of the asphalt mixture.

3.2 DCT test result

The fracture energy is measured by the DCT test. The results are shown in Fig. 5. The DCT results show that the SBS and PPA + SBS modified mixtures have higher fracture energy than the PPA modified mixtures.

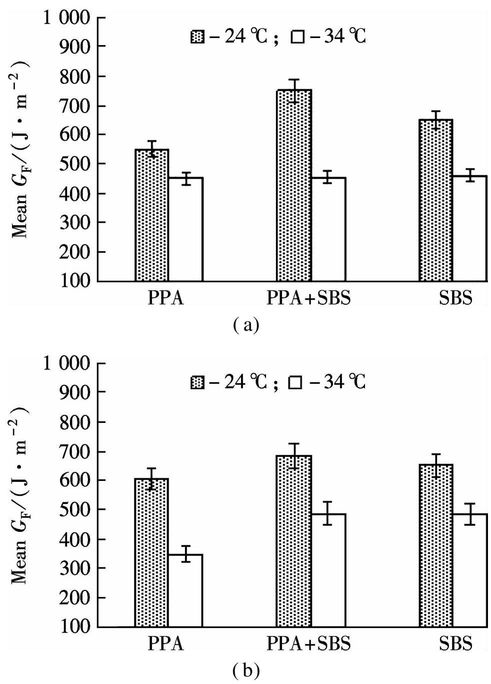

Fig. 5 DCT fracture test results under different temperatures. (a) With an air-void ratio of 4%; (b) With an air-void ratio of 6%

3.3 Statistical analysis of results from laboratory compacted samples

A summary of the ANOVA results for all the test parameters is shown in Tab. 2.

Tab. 2 Summary of ANOVA analysis

Factor	G_F	Strength	Stiffness at 60 s	Stiffness at 300 s
Type of asphalt modification	☆	☆	—	—
Void content	☆	☆	☆	☆
Test temperature	☆	☆	☆	☆

Note: ☆ highly significant; — not significant.

The significant treatment effects are indicated in Tab. 2. According to the statistical analysis, the effects of temperature and air void content observed for all the test parameters are statistically significant. The effect of modifiers, which is the subject of this research work, is found to be statistically significant in DCT fracture energy G_F and IDT strength. The change in stiffness due to the effect of modifiers is found to be not significant. This means that the change in mixture stiffness attributed to the three different types of modification is comparable. In addition, multiple comparisons at 5% level of significance were performed to rank the tested mixtures according to different test methods. The outcomes are reported in Tab. 3.

Tab. 3 Statistical grouping and ranking of modified mixtures

Modifier	Strength		G_F	
	Group mean/MPa	Rank	Group mean/(J · m^{-2})	Rank
SBS	5.08	A	560.7	A/B
PPA + SBS	4.38	B	583.8	A
PPA	4.06	C	491.3	B

In Tab. 3, the letter A indicates the best mixtures in terms of fracture resistance. The letter B refers to the second best mixtures in terms of fracture resistance. Mixtures which are difficult to distinguish are shown by two or three group letters. Accordingly, the SBS and PPA + SBS modified mixtures generally have higher strength and fracture resistance than PPA. The difference of IDT strength between PPA + SBS and SBS is also considered to be statistically significant; SBS alone provides higher material strength.

4 Conclusions

1) The differences in IDT stiffness due to the type of modification are not statistically significant. Therefore, the three types of modifications considered in this paper have a similar effect on mixture stiffness.

2) For IDT strength, the PPA + SBS and SBS modified mixtures are significantly stronger than the PPA modified mixtures.

3) The comparison of the mixtures with regard to the DCT fracture parameter confirms that PPA + SBS and SBS modified mixtures have better resistance to cracking than the PPA modified mixtures.

4) It can be concluded that the low-temperature fracture properties of mixtures modified with 0.75% PPA are reasonably good. The SBS and PPA + SBS modified mixtures have a generally higher strength and higher fracture resistance than those containing PPA. The results suggest that using PPA + SBS modified mixtures, in which the amount of SBS is half of the amount used in typical SBS modified mixtures, may provide a cost-effective alternative for improving the cracking resistance of asphalt pavements. Furthermore, it is necessary to do more tests to check the performance of asphalt modified by PPA.

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多聚磷酸改性沥青对沥青混合料低温抗裂性能的影响

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摘要:为确定多聚磷酸(PPA)是否能部分或完全替代苯乙烯-丁二烯-苯乙烯(SBS)改性剂而不会对沥青混合料的低温性能产生不利的影响,对PPA改性沥青混合料的低温断裂特性进行了评估,且与SBS改性沥青混合料进行了比较.首先,采用间接拉伸试验及新开发的断裂测试方法,即盘状紧凑拉伸试验对室内成型试件进行了测试.然后,分析了测试温度及空隙率对沥青混合料低温断裂特性的影响.结果表明,PPA改性沥青混合料的低温抗裂性能劣于SBS改性沥青混合料,而PPA部分替代SBS改性剂制得的改性沥青混合料的低温断裂性能与仅采用SBS改性剂的混合料断裂性能相当.

关键词:沥青混合料;低温;多聚磷酸;盘状紧凑拉伸

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