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Performance evaluation and chemical property analysis of RWMA binders with 100% artificial reclaimed asphalt

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Abstract: The performance evaluation and chemical property analysis of the recycled warm mix asphalt (RWMA) binders containing 100% artificial reclaimed asphalt (RA) are presented, and the combined effects of different percentages of the rejuvenator and warm mix additive (WMA) additives on RWMA binders are analyzed through laboratory tests. Three types of WMA additives and one commercial rejuvenator named GST were selected to restore the artificial RA. The laboratory performance tests including the penetration test, softening test and rotary viscosity (RV) test were carried out. In addition, the Fourier transform infrared spectroscopy (FTIR) test was performed to explore the chemical property of RWMA binders. The results of the performance tests indicate that the rejuvenator GST has the ability to restore the artificial RA; choosing the optimum content of WMA additives and rejuvenator is the key to restoring 100% artificial RA, since the combined effects of them play an important role in determining the basic laboratory performance of RWMA binders. The FTIR tests show that the process of recycling mainly adjusts the chemical component of aged asphalt and no remarkable change is observed in the FTIR spectra of RWMA binders in terms of chemical functional groups with the introduction of WMA additives.

Key words: artificial reclaimed asphalt; recycled warm mix asphalt; WMA additives; rejuvenator; performance test; Fourier transform infrared spectroscopy

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Over the last few decades, as the construction of new roads has gradually satisfied the constant growth in traffic volume, increasing attention has been paid to the pavement maintenance and rehabilitation[1]. As a consequence, the reuse of reclaimed asphalt pavement (RAP) is widely promoted due to its environmental and economic benefits.

However, with the development of recycled technologies, the demand for utilizing a higher percentage of RAP continues to rise. Nevertheless, previous studies indicated that the RAP content has a significant influence on recycled asphalt pavement, particularly when the RAP binder percentage is high[1-2].

Therefore, there is still a significant challenge to employ a high percentage of RAP to maintain a high-quality well-performing pavement infrastructure. Currently, researchers have proved that the use of rejuvenator is one promising option for rejuvenating RAP binders and increasing RAP contents above 50 % without sacrificing the pavement quality[3-4]. In addition, warm mix asphalt (WMA) technology was also introduced to the construction of recycled asphalt pavement due to its lower mixing and compaction temperature.

In recent years, the research concerning RWMA with high percentage of RAP has been increasingly conducted utilizing a variety of WMA additives and facilities. Xiao et al. [5-6] restored 20% to 50% RAP with WMA technology to explore the rheological properties of recycled binders and the volumetric characteristics of superpave mix design, respectively. Buss et al. [7] suggested that the recycled binder has a greater influence on binder properties compared to WMA additives. Zhao et al. [8] evaluated the laboratory performance of WMA mixtures containing high percentages of RAP (from 0 up to 50%). The research suggested that the effect of RAP on WMA in improving the rutting resistance appears to be more significant than the effect on HMA and adding RAP will significantly reduce the moisture susceptibility of WMA. Barco Carrion et al. [9] used international blend design methodologies to study binder blend design for high RAP content hot and warm asphalt mixture wearing courses and the results show that using up to 90% of RAP is a feasible option.

High percentage of RAP usage with the WMA technology is becoming more and more common. However, a higher RAP content, even up to 100%, is required in the future. In terms of the advantages of the rejuvenator and WAM technology, the combined effect on the RAP must be evaluated to achieve this goal.

Therefore, the overall objective of this study is to explore the combined effect of the rejuvenator and WMA additives on the 100% artificial RA through evaluating the performance and chemical property of RWMA binders.

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1 Materials

The virgin asphalt AH-90 commonly used in Dalian, Liaoning Province was selected in this research. The artificial reclaimed asphalt (RA) was obtained by subjecting AH-90 to long-term aging by means of a rolling thin film oven (RTFO) for 85 min at 163 ℃ and then pressure aging vessel (PAV) equipment for 20 h at 100 ℃. Choosing the artificial RA rather than the RA recovered from milled materials is due to its pure source and its general validity. Moreover, the artificial RAP binder is always reproducible for further investigation or comparative purposes[1].

One type of commercial rejuvenator named GST, which mainly consists of aromatic components, was used to restore the performance of the RA and its content was 7% of the weight of the RA.

Furthermore, three types of warm mix additives, denoted as A, B and C, were added into the recycled asphalt, respectively. A was a type of white powder which was a polyethylene wax. Additive B was a deep brown sticky liquid surfactant and C was a type of white fine powder which was a manufactured synthetic zeolite that had been hydrothermally crystallized. Their photos are shown in Fig. 1.

(a)

(b)

(c)

Fig. 1 The picture of WMA additives A, B and C. (a) WMA additive A; (b) WMA additive B; (c) WMA additive C

Additives A, B and C were provided by their suppliers to be added into the binder at 3%, 0.5% and 2% by weight of RA, respectively. However, considering the combined effect of WMA additives and GST on the RA, the actual content of all the additives will be adjusted on the basis of the performance test results of RWMA. The basic properties of the AH-90 and warm mix binders with recommended content are shown in Tab. 1.

Tab. 1 Properties of different binders

Binder type	Penetration (25 ℃)/0.1mm	Softening point/℃	RTFO(163 ℃, 85 min)	
			Residual penetration/0.1 mm	Softening point increment/℃
AH-90	83.7	48.34	56.7	3.03
3% A-WMA	116.0	42.60	62.0	7.03
0.5% B-WMA	84.3	45.51	59.3	4.04
2% C-WMA	90.3	49.42	47.7	7.86

2 Experimental Design

2.1 Performance tests

In this study, the penetration and softening point tests were performed to investigate the effects of different contents of the additives on the RA.

Rotary viscosity (RV) tests of various asphalt binders were employed at 135 ℃. The viscosity of the asphalt binder at a high temperature is considered to be one of the important properties since it represents the ability of binders to thoroughly coat the aggregate in asphalt mixture, and to be mixed and compacted[2].

2.2 FTIR test

The Fourier transform infrared spectroscopy (FTIR) test was chosen to study the chemical property of RWMA binders. Through the FTIR test, the covalent bonds in molecules can be determined by interpreting the infrared absorption spectrum. It is commonly used to study the molecular structure of asphalt binder and its additives[10-11]. In accordance with the principle, the covalent bonds in molecules absorbing the infrared spectra at specific frequencies are distinctive. Therefore, the functional groups of the material can be determined[12]. The asphalt materials can use the FTIR because the FTIR spectra of pure compounds are generally different from the others[13]. Thus, through the FTIR test, the chemical property of the RWMA can be obtained by observing the change in functional groups.

3 Results and Discussion

3.1 Performance test results

First of all, to explore whether the WMA additives themselves had the ability to restore the artificial RA, three types of WMA additives without GST were added into the RA to conduct the penetration test. The results are shown in Tab. 2.

Tab. 2 Penetration of RA with WMA additives

Asphalt type	RA	RA + 3% A	RA + 0.5% B	RA + 2% C
Penetration	37	49.3	31.5	35.7

From Tab. 2, it can be observed that the penetration value of RA is significantly reduced. Moreover, with the introduction of WMA additives, only the incorporation of A into RA binder increases the penetration value slightly, while the addition of B and C even reduces the value. It shows that the three WMA additives do not have recycling ability. Thus, the rejuvenator GST is required to restore the RA binder.

There should be some RWMA binders containing different contents of additives according to the effect on the virgin asphalt as shown in Tab. 1. First, the binders were blended following the recommended content. Then, the content of WMA additives or GST was adjusted on the basis of the ability of AH-90 to achieve the recycling aim. The binder types and their properties are shown in Tab. 3.

Tab. 3 Properties of recycled binders

No.	Binder type	Penetration (25 ℃)/0.1 mm	Softening point/℃	RV(135 ℃)/(mPa · s)
1	RA	37.00	55.59	545.80
2	AH-90	83.67	45.97	252.80
3	7% G + RA	84.00	47.84	292.00
4	3% A + 7% G + RA	131.67	44.71	215.60
5	3% A + 4% G + RA	103.00	46.01	268.80
6	0.5% B + 7% G + RA	92.33	48.00	322.20
7	2% C + 7% G + RA	78.00	52.24	290.50
8	3% C + 7% G + RA	84.50	55.56	310.90
9	4% C + 7% G + RA	71.67	60.90	328.60
10	2% C + 8% G + RA	91.00	47.89	254.60

Note: G represents GST.

Tab. 3 shows that when the GST is incorporated into the RA binder, the penetration values increase, while the softening point and RV decrease. Moreover, the test results are close to that of the AH-90. This demonstrates that the introduction of GST effectively restores the RA. However, it can be found that with the incorporation of the WMA additives into the restored binder containing GST, the properties all change correspondingly and the influence of WMA additives on the recycled binders is consistent with the results in Tab. 1. Additionally, it is noticeable that when the content of WMA additives or GST varies, the properties change. In this context, this indicates that the WMA additives and GST had a common effect on the RA. Thus, choosing an optimum content of WMA additives and rejuvenator is the key to restoring the 100% RA binder.

The penetration test is a good indicator for the initial selection of optimum content since the results provide an indication of rut resistance as well as the fatigue performance of mixture[5]. Thus, the content of WMA additive and GST corresponding to the penetration value close to AH-90 is the optimum content. As shown in Fig. 2, the penetration value of recycled asphalt with 7% GST only is approximately close to that of AH-90. The penetration values have almost no change with the incorporation of B, meanwhile, the values increase with A which are opposite to C. The softening point exhibits an opposite trend compared to the penetration.

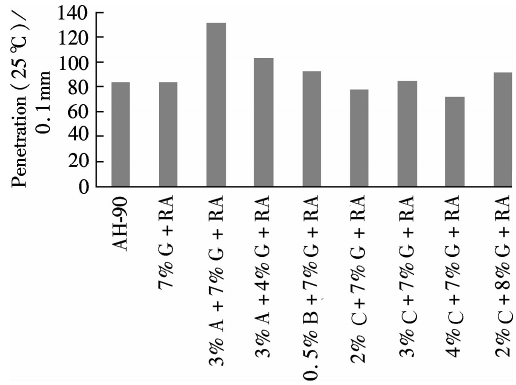

Fig. 2 Penetration of recycled binders

Additionally, Tab. 3 shows that the viscosity value of the recycled binder with GST is higher than that of AH-90 due to the RA binder. This indicates that the RA binder plays an important role in increasing viscosity. In terms of WMA additives, A and GST have the ability to decrease viscosity, while B and C do not change the viscosity remarkably.

Consequently, the influence of different WMA additives on the binders, regardless of AH-90 or RA, is the same. Furthermore, it is necessary to identify the optimum content of WMA additives and GST due to their common effect on the RA binder. Thus, through the analysis of properties concerning different contents of the RWMA binders, No. 5, 6 and 10 in Tab. 3 were selected to conduct the following FTIR test to analyze the chemical properties of RWMA binders.

3.2 FTIR test results

Fig. 3 presents the FTIR spectra of AH-90 and virgin WMA binders. It can be found that the FTIR spectra of the three types of WMA binders are approximately the same as those of AH-90 at some obvious absorbed peaks ranging from 2 923 to 1 376 cm^{-1}, except for the peak at 1 711 cm^{-1} newly produced on the A-WMA FR-IR spectra.

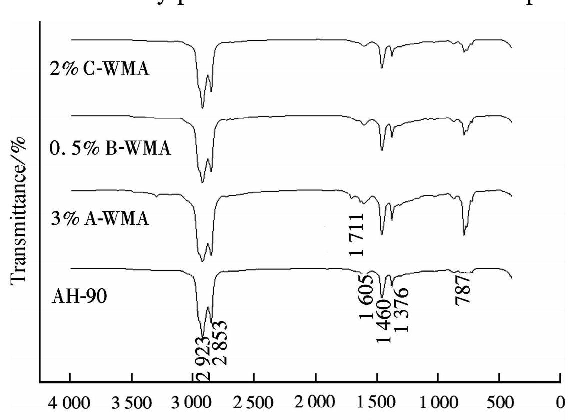

Fig. 3 FTIR spectra for virgin binders

This indicates that a new chemical functional group was produced by the interaction between the WMA additive A and AH-90. In addition, the transmittance of all the three WMA binders around 787 cm^{-1} is different from that of AH-90, which can be explained by the introduction of WMA additives changing the content of the chemical component. Perhaps, this is a reason for reducing the mix and compaction temperatures.

Moreover, with respect to the combined effect of WMA additives and GST on the RA, the FTIR spectra of all recycled binders including the RA binder and AH-90 are shown in Fig. 4. It can be observed from the FTIR spectra of the RA binder that there are two obvious peaks around 1 699 and 1 031 cm^{-1}, representing the stretch absorption of carbonyl group (C=O) and stretch vibration of sulfoxide group (S=O), respectively[14]. The C=O is produced due to the absorption of oxygen in the unsaturated carbon chain and so is the S=O in the sulfur element. The two functional groups are used to characterize the aged asphalt binder[15].

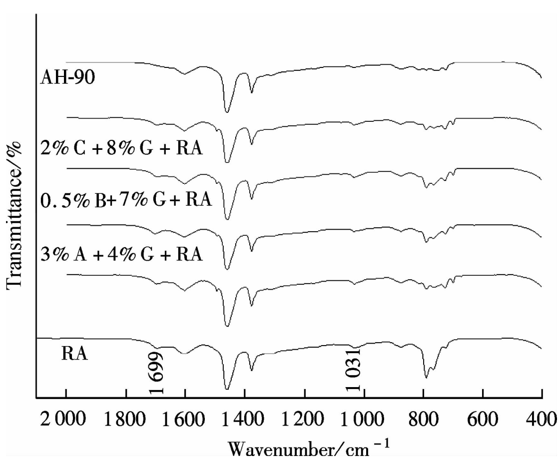

Fig. 4 FTIR spectra for RA and recycled binders

However, with the incorporation of GST and WMA additives, there is only a slight difference in the transmittance of recycled binders. Additionally, the presence of the two aged characteristic peaks indicates that the process of recycling mainly adjusted the chemical components without obvious chemical bonds cracking and recombining, regardless of any type of additives in this study. Furthermore, it is notable that when A is blended with RA and GST, there is no new peak produced at 1 711 cm^{-1} compared with Fig. 3. This suggests that only WMA additive A blended with virgin asphalt can produce the new peak at 1 711 cm^{-1}. Through the analysis of FT-IR tests, the chemical property of RWMA binders was studied, but it was necessary to conduct other test methods for further research on RWMA binders.

4 Conclusions

1) The rejuvenator GST has the ability to restore the RA. Compared with B and C, the interaction of A and GST decreases the viscosity more noticeably. Furthermore, the combination of rejuvenator and WMA additives plays an important role in determining the basic laboratory performance of 100% RA. Choosing the optimum content of WMA additives and rejuvenator is the key to restoring 100% RA.

2) The FTIR test results suggest that the process of recycling mainly adjusts chemical components that the RA loses. Moreover, only when blended with virgin asphalt, WMA additive A can produce the new peak at 1 711 cm^{-1}, but it has no influence on the physical properties of A.

3) The chemical property of RWMA binders was analyzed through the FTIR test in the view of functional groups and chemical bonds. Due to the limitations of the method, it is necessary to carry out additional tests to explore the chemical properties of RWMA binders.

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100%人工老化沥青的温拌再生结合料性能评价与化学特性分析

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摘要:通过试验分析不同比例的再生剂和温拌剂对于温拌再生沥青的共同作用, 对含有100%人工老化沥青的温拌再生沥青的性能与化学特性进行了分析评价. 选用3种温拌添加剂与1种商业再生剂GST来再生人工的老化沥青. 再生结合料的性能试验包括针入度、软化点以及旋转黏度试验,傅里叶红外光谱试验则用来探讨再生结合料的化学特性. 性能试验结果表明,再生剂GST具有再生人工老化沥青的能力;由于再生剂与温拌添加剂的共同作用对于100%老化沥青的再生性能有很大的影响,因此选择两者的合适用量是再生100%老化沥青的关键. 红外光谱试验结果表明,再生主要是一种调节化学组分的过程,而且随着温拌添加剂的加入,温拌再生沥青的红外谱图在化学官能图方面并没有发生明显的变化.

关键词:人工老化沥青;温拌再生沥青;温拌添加剂;再生剂;性能试验;傅里叶转换红外光谱

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