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Study the effects of filler particle size and filler/asphalt ratio on the high and low temperature performance of asphalt mastics

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Abstract: In this study, the conventional and rheological analysis methods are employed to evaluate the effects of filler particle size and filler/bitumen (F/B) ratio on the high and low temperature performance of asphalt mastics. It is found that the addition of mineral fillers can significantly improve the high temperature rutting resistance of asphalt mastics. Meanwhile, it is detrimental to thermal cracking behavior. As the increase of particle size, the percent recovery R , creep stiffness S and m -value increase, while non recoverable creep compliance J_{nr} decrease. In addition, scanning electron microscope (SEM) imaging analysis shows that the dispersion degree and the morphology of asphalt mastics with various particle sizes have the great differences.

1. Introduction

Asphalt mixture is a superior pavement material used in road construction, which consists of filler, bitumen and aggregate[1]. In order to enhance the bond between each other, filler and bitumen are primarily found to form mastic that fills the interstices between aggregates[2, 3]. Previous researches have indicated that asphalt mixture should be regarded as a mixture comprised with mastic-coated aggregates rather than pure bitumen-coated aggregates[4, 5]. In that sense, the behavior characterization of asphalt mastics is essential to help the understanding of the asphalt pavement performance.

This study aims to evaluate the effects of particle size and F/B ratio on the performance of mastics. In order to accomplish that, conventional property, test multiple stress creep recovery (MSCR) test, bending beam rheometer (BBR) test and SEM imaging analysis are carried out.

2. Material and methodology

2.1. Materials

The limestone powder filler, one of the most commonly mineral fillers used in the construction of asphalt pavement layers, is selected to prepare asphalt-filler mastics in this paper. Three different levels of particle sizes, namely, F1 (passing the sieve of NO.200 and retained by the NO.300 sieve), F2 (passing the sieve of NO.400 and retained by the NO.500 sieve) and F3 (passing the sieve of NO.800) are used to prepared asphalt mastics.

One type of paving bitumen with 50/70 penetration grade is used as base asphalt, which is abbreviated as B in this study. The conventional performance tests such as penetration, softening point, ductility and Brookfield viscosity are presented in Table 1.



Table 1. Physical properties and chemical composition of the base asphalt.

Physical properties	Unit	Specifications	Measured values
Penetration (100g,5s,25°C)	0.1mm	ASTM D5	65
Softening point(R&B)	°C	ASTM D36	49.5
Ductility(5cm/min,15°C)	cm	ASTM D113	>100
Viscosity (135°C)	Pa s	ASTM D70	0.413

The asphalt mastics are prepared following an optimized protocol put forward in the previous studies [6-8] so as to obtain homogeneous bitumen-filler mastics. A constant F/B ratio of 0.6, 0.8, 1.0 and 1.2 are selected in accordance with Superpave specification, which recommends a ratio with the range of 0.6-1.2.

2.2. Methodology

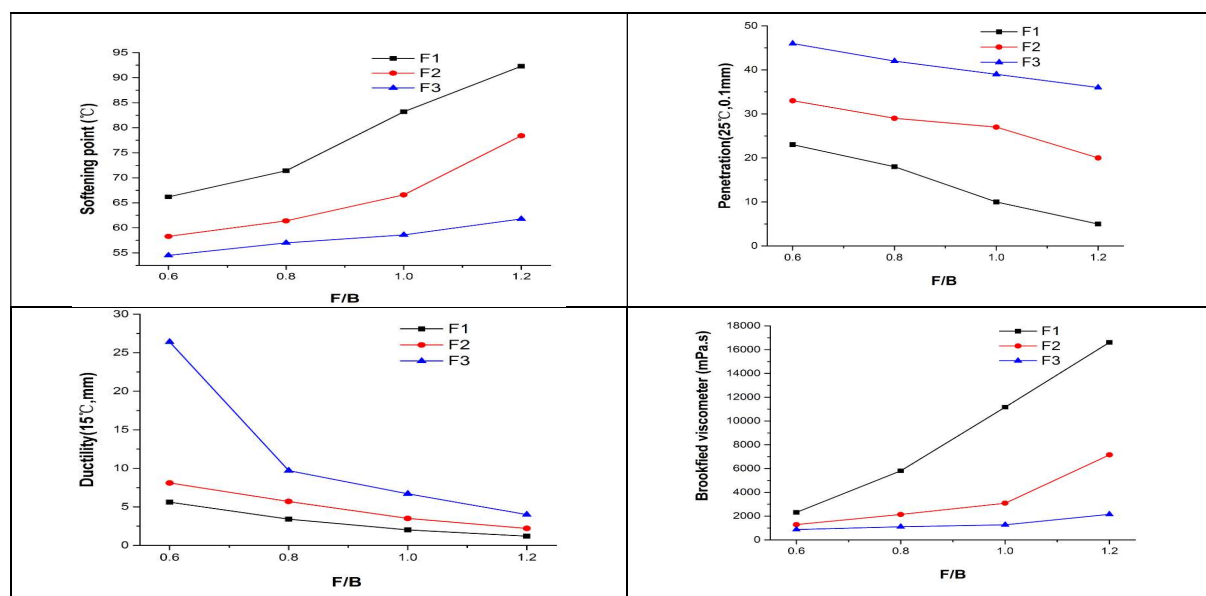
The multiple stress creep recovery (MSCR) test was conducted on short-term aged samples at specified stress levels (0.1kPa and 3.2kPa) and test temperature(60°C).During the measurements, each sample was subjected to ten consecutive cycles and every cycle undergone 1-s shear creep loading followed by 9-s recovery.

The low temperature thermal cracking behavior of the PAV-aged asphalt mastics was evaluated by bending beam rheometer (BBR) at -12°C. And then the creep stiffness(S) and rate of relaxation (m-value) of samples were obtained. Moreover, in order to acquire repeatable rheological results, two replicates of samples are performed.

Surface characteristics of the fillers and mastics were evaluated by using A JSM-5610LV Scan Electronic Microscope (SEM) in accordance with ASTM E986.

3. Results and discussions

3.1. Physical properties

**Fig 1.** Physical properties of asphalt mastics with different particle sizes.

The physical properties of mastics containing different filler particle sizes and F/B ratio are measured and the results are displayed in Fig.1. As can be seen, with the increase of F/B ratio, the softening point and Brookfield viscosity of mastics increase, indicating the addition of mineral fillers can improve the rutting resistance performance. While the penetration and ductility of asphalt mastics decrease, implies that it is detrimental to thermal cracking behavior. In addition, with the increase of the filler particle size, softening point and Brookfield viscosity increase, while penetration and ductility decrease. In this regard, it can be concluded that filler particle size has significantly effect on the performance of asphalt mastics, that is, the bigger particle size can contribute to improve rutting resistance and go against the thermal cracking behavior in compared with the smaller ones.

3.2. Creep and recovery behavior

The MSCR test is performed at 60°C on TFO-aged asphalt binders and mastics in this paper. The shear stress level of 3.2kPa is selected, as it is found to demonstrate comparatively well correlated with field rutting performance of asphalt mixture[9]. In accordance with this consideration, the parameters are obtained at the stress level of 3.2kPa to provide a comprehensive understanding of permanent deformation behavior for asphalt mastics.

Fig. 2 shows the strain responses in one cycle of creep and recovery in MSCR tests for mastics with various particle sizes and F/B ratios. The date results include a one-second creep loading phase and a nine-second recovery phase. During the shear loading phase, all samples show an increase trend in actual strain value with the increasing time. Once the removal of the shear creep loading, the elastic strain starts to come into play immediately while the viscous strain is responded gradually[10, 11]. All the results reveal that various particle sizes and F/B ratios can significantly change creep-recovery behavior, to some extent, affect rutting performance.

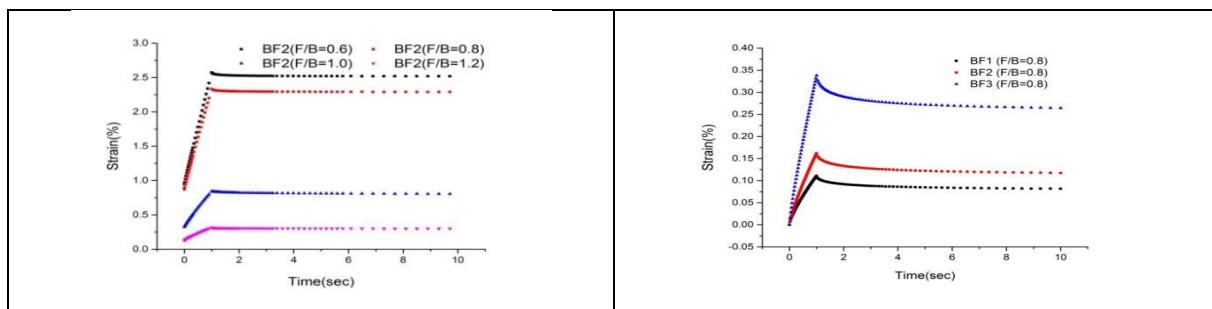


Fig 2. MSCR strain curve in one cycle of creep and recovery for various mastics

Two major parameters such as percent recovery (R) and non-recoverable creep compliance (J_{nr}) are calculated to quantitatively evaluation the effects of particle sizes and F/B ratios on the high temperature performance of asphalt mastics. Percent recovery is an indicator of binder's elastic response, the increased value of R indicates improved elastic component. Non-recoverable creep compliance J_{nr} is well accepted as a performance parameter which correlates well with the asphalt mixture rutting performance. Fig.3 presents the results for all samples. As expected, the base binder blended with various F/B ratios or filler particle sizes outperform the asphalt according to higher R and lower J_{nr} value. Moreover, it is worth noting that the values of R and J_{nr} increase with the increase of F/B ratio, this evidences that the increasing F/B ratio can produce a great improvement in the elasticity and is beneficent to resist rutting in actual pavement. The results are consistent with the change tendency of the increasing filler particle size.

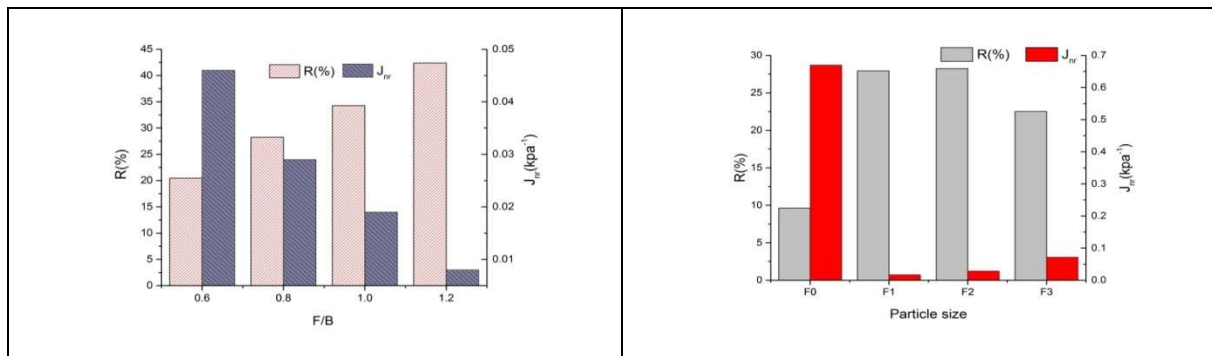


Fig.3 R and J_{nr} for the asphalt and asphalt mastics with different F/B ratios and particle sizes.

3.3. Low temperature cracking behavior

Fig.4 presents the creep stiffness module (S) and the rate of relaxation for all asphalt mastics measured at -12°C. As is well known, the decreased value of creep stiffness and increased m-value contributes to enhance performance against the low-temperature cracking resistance for road pavement.

As can be seen, the creep stiffness of samples significantly increase with the introduction of mineral fillers and then that of the m-value corresponding decrease, indicates that adding fillers to asphalt can failure the structural system of bituminous matrix. Asphalt mastics with the higher F/B ratio or larger particle size result in the higher creep stiffness value and the lower m-value, which is detrimental to the low temperature thermal cracking performance. On the contrary, the asphalt mastics containing the lower F/B ratio or smaller particle size have the decreased creep stiffness value and the increased m-value, which indicates that suitable F/B ratio and particle size can perform well on the low temperature cracking behavior.

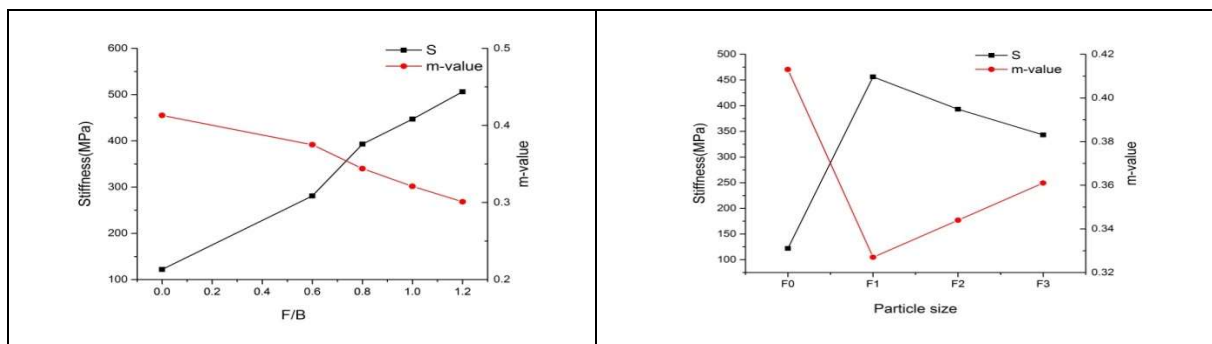


Fig 4. Stiffness and m-value for asphalt mastics with different F/B ratios and particle sizes.

3.4. SEM analysis

In this study, SEM imaging analysis is carried to evaluate the interaction between bitumen and filler particles inside asphalt mastics for a better interpretation of the tests results. This approach allows the identification of mastic morphology and filler particle distribution inside the bituminous matrix, which can help to better understand the differences in high/low temperature behavior between bitumen and mastics.

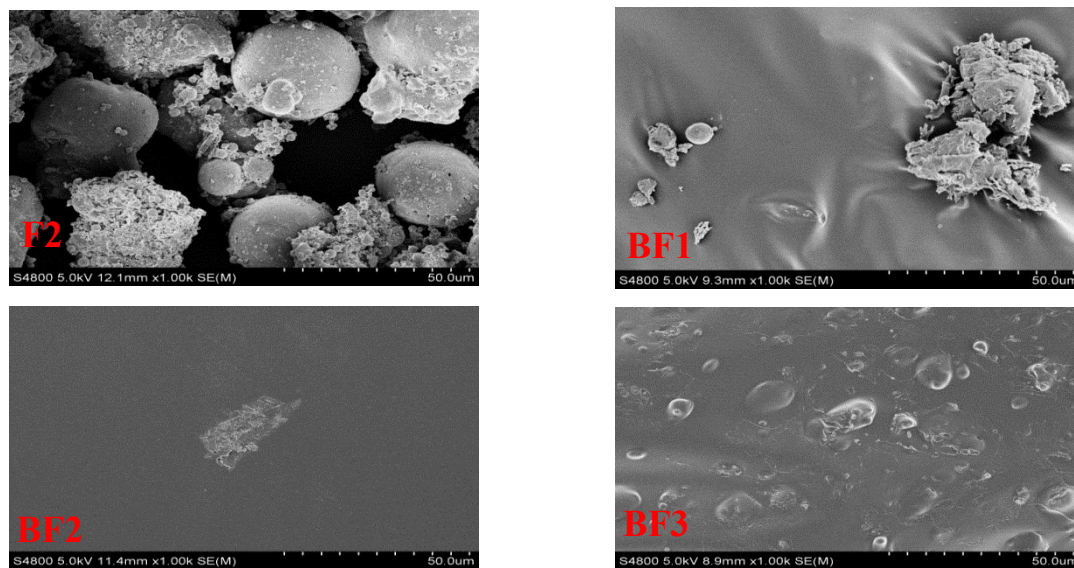


Fig 5. SEM imaging for filler particle and asphalt mastics (F/B=0.8)

Fig.5 shows SEM imaging for filler particle F2 and three kinds of asphalt mastics, captured at one resolution levels. As observed, the limestone filler particles are identified as angular type particles with smooth to mildly rough surface texture, with low propensity to agglomerate[8, 12].

As for mastics, the presence of filler particle F1 inside the bituminous matrix can be easily identified in the form of the wrinkles at the interface between bitumen and fillers. In the case of mastic BF3, it is worth noting that SEM imaging shows a discontinuous globules which can be characterized by a clear distinction between bitumen and filler. Due to fillers' scale, a difference morphological behavior can be related to the interaction between asphalt binder and filler particles. Larger filler particles such as F1 are less likely to accumulate, which can be easy to form a more identical structure, since the filler particles are better enclosed in the bituminous phase, creating a more effective cooperative morphological structure between bitumen and filler particles. Whereas, in the case of the smaller filler particles such as F3, filler particles are less linked to asphalt binder due to its clusters and form an internal discontinuous network structure which is not able to adequately englobe the filler particles. This finding further supports the results obtained in terms of the high/low temperature performance of asphalt mastics.

4. Conclusion

Adding mineral filler to bituminous matrix can help to significantly improving the high temperature rutting resistance, but it is also detrimental to its low temperature thermal cracking behavior. The larger the particle size of mineral filler particles is, the better the high temperature rutting resistance has, but the poorer the low temperature cracking behavior is.

The results of SEM imaging analysis shows that Larger filler particles (i.e. F1 and F2) are less likely to accumulate, which can be easy to form a more identical structure, since the filler particles are better enclosed in the bituminous phase, creating a more effective cooperative morphological structure between bitumen and filler particles. Whereas, in the case of the smaller filler particles such as F3, filler particles are less linked to asphalt binder due to its clusters and stand out from the bituminous matrix, forming an internal discontinuous network structure which is not able to adequately englobe the filler particles. This finding further supports the results obtained in terms of the high/low temperature performance of asphalt mastics.

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