Qualitative analysis of SBS modifier in asphalt pavements using field samples

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Abstract. Series of tests are implemented to analysis the related characteristics of common asphalt and unknown asphalt mainly using Fourier Transform Infrared (FT-IR) and Dynamic Shear Rheometer (DSR) for chemical compositions and rheological properties of asphalt, respectively. In addition, a series of mechanical properties were performed on asphalt mixtures, including indirect tensile strength test and three point bending test at low temperature. Experimental results indicated that compared with common asphalt, the characteristic absorption peak of the unknown asphalt are appeared at 966cm⁻¹ and 699cm⁻¹, which are accordant with the SBS modifier. The results of DSR indicated that the unknown asphalt's complex modulus is higher and the phase angle is lower. The mechanical tests indicated that some properties of the unknown mixture samples are increased by 24.7%~41.8% compared with common pavement sample, like the indirect tensile strength, the bending test at low temperature and indirect tensile resilient modulus. Comprehensive analysis indicates that SBS modifier is existed in the unknown asphalt pavement.

1. Introduction
Styrene-butadiene-styrene block copolymer (SBS) is a thermoplastic elastomer rubber that allows for greater performance than that possible with asphalt alone [1]. Due to this property, SBS can improve the asphalt in rutting resistance, thermal cracking, fatigue damage, stripping, and temperature susceptibility, which makes SBS one of the most promising and widely used polymer modifiers for asphalt. The content of SBS plays an important role on the performances of modified asphalt, so the content of SBS modifier is essential to quality control in construction.

In the last decades, several research efforts have investigated the use of SBS modifiers in asphalt. Some researches focused on the stability improvement of the SBS modified asphalt binder to ensure a good compatibility between SBS and asphalt [2] [3]. Some other researchers studied the rheological properties of SBS modified asphalt binder, performance of mixture and illustrated the mechanism of SBS modified asphalt [4] [5]. Because polymer content is an essential parameter of asphalt binder, some researchers investigated the method by quantification of polymer content in SBS modified asphalt [6] [7]. There are few studies on analysis of SBS modifier content for long service pavement.

This study is part of the research work of service pavement. The main objectives of this study are: i) to qualitatively analyze SBS modifier in asphalt pavements using field samples, and ii) to investigate the performance of asphalt mixture which was subjected to normal traffic for 8 years.
2. Experimental

2.1. Sample Preparation
Two types of samples asphalt mixture were obtained from Jinnan road in Zhejiang province for the performance tests: common asphalt mixture, which is pure asphalt cement without modifiers such as SBS, and unknown asphalt mixture, which is a need to determine whether there is SBS modifier. The core samples (100 mm in diameter) and slab samples (Long 400mm wide 400mm) were taken from the constructed wearing course. The field test section was subjected to normal traffic for 8 years. After the mechanical testing, they were further used for the extraction process to separate binder from aggregates.

2.2. FTIR
Fourier transform infrared spectroscopy (FTIR) was recorded on a TENSOR 27 spectrometer (Bruker, Germany) from 4000 to 400 cm-1 by KBr disk method, at a resolution of 4 cm-1.

2.3 Dynamic shear rheological characteristic
Dynamic shear properties were measured with MCR102 dynamic shear rheometer (MCR102, AntonPaar, Austria) in a parallel plate configuration with a gap width of 1mm. Measurements were performed at fixed frequencies 10 rad/s and temperature from 46 to 82 °C under controlled strain condition.

2.4 Indirect tensile test
The indirect tensile strength of specimens was measured at 25°C and at the loading rate 50 mm/min by using Universal Testing Machine (UTM-100). The peak load at failure is recorded and used to calculate the IDT Strength of the specimen.

Indirect tensile resilient modulus was measured at 40°C which was according to ASTM D4123. The frequency of load application was 1 Hz with the load duration of 0.1 s in order to represent field conditions and the resting period of 0.9 s. Four samples were made for each of the two kinds of evaluated mixtures and their averages represented resilient modulus for each mixture.

2.5 Three point bending test
The slabs were cut firstly on highway pavement. Then the slabs sample were cut into the beam specimens with the length of 250±2.0mm, the height of 35±2.0mm and the breadth of 30±2.0mm in lab. The tests were carried on UTM-100 at the temperatures of -10 °C with a loading rate of 50mm/min. In order to reduce discreteness of mechanics properties of samples and ensure the reliability of the test results, there were six beams in every group.

3. Results and discussion

3.1 Chemical compositions analysis by FTIR
FTIR tests were conducted on the asphalt extraction from the common asphalt mixture and unknown asphalt mixture respectively. The testing results were shown in Fig.3. Two major bands at 2924cm-1 and 1460cm-1 were identified as the stretching vibration and deformation vibration for C-H bond of hydrocarbon. However, two major bands at 966 cm-1 and 699cm-1 were just observed for the unknown asphalt compared with absent peaks of common asphalt. The 966 cm-1 band corresponds to the C=C bond in butadiene while 699cm-1 band identifies the existence of styrene. Previous study [7] [8] on SBS polymer modified found that 1375cm-1, 810cm-1 of asphalt and 966cm-1,699cm-1 of SBS could be used for quantification of SBS content. Therefore, the two major bands, 966 cm-1 and 699cm-1, can be used to detect the presence of the SBS in the asphalt binder. It means there were SBS modifiers in the unknown asphalt.
3.2 Dynamic shear rheological characteristics

As a viscoelastic material, asphalt exhibits either elastic or viscous behavior. Dynamic shear test can be used to characterize the viscous and elastic behavior of the asphalt using complex modulus ($G^*$) and the phase angle ($\delta$) at different temperature. Fig. 2 shows the temperature dependency of complex modulus $G^*$ and phase angle $\delta$ for two asphalts at range of temperature 46-76°C. The results also showed that the unknown asphalt binder has a lower phase angle and higher complex modulus at range of temperature 46-76°C compared to the common asphalt, especially at relatively high temperatures. This indicates that the common asphalt mixtures is more susceptible to rutting. The complex modulus of unknown asphalt at 46°C is 155.99kPa, which is comparable with common asphalt’s 82.39kPa. The results above indicate that the deformation resistance of unknown asphalt is superior. Phase angle of
unknown asphalt are increased from 61.7° to 73.1° at range of temperature 46-76°C, which is comparable with common asphalt’s 64.5° to 79.5°. This means that the common asphalt binder has the higher phase angle significantly over temperature region. The increment of complex modulus and reduction of phase angle will contribute the resistance to the high temperature stability for asphalt binders and mixtures.

Measurements of δ are generally considered to be more sensitive to chemical structure than complex modulus [9]. The phase angle of unknown asphalt at 64°C is 68.4°. These data are in good agreement with other published results. Ma’s study [10] indicated the phase angle of asphalt modified by SBS after pressure aging vessel test at 64°C was about 70.3°. The complex modulus and phase angle of unknown asphalt in Figure 2 are consistent with the rheological properties of SBS modified asphalt.

![Figure 3. Rutting parameter of asphalt](image)

A rheological parameter, G*/sinδ has been regarded as the rutting parameter of asphalt binder in the American Strategic Highway Research Program (SHRP). High G*/sinδ value was found to correlate with high rutting resistance. Figure 3 illustrates G*/sinδ measured at range of temperature 46-76°C. As has been indicated in this study, the modulus of unknown asphalt was higher and the phase angle was lower. The G*/sinδ values of the unknown asphalt binders were increased. The unknown asphalt results in the increase of rutting parameter (G*/sin δ) at high temperatures, indicated a higher rutting resistance of the binder.

3.3 Mechanical property

| Property                              | Unknown asphalt mixture(a) | Common asphalt mixture (b) | (a-b)/b*100% |
|---------------------------------------|---------------------------|---------------------------|--------------|
| Indirect tensile strength at 25°C, MPa| 1.97                      | 1.58                      | 24.7%        |
| Bending strain at -10°C, με            | 1486.5                    | 1109.4                    | 34.0%        |
| Indirect tensile resilient modulus at 40°C, MPa | 5741                      | 4050                      | 41.8%        |
Tensile strength testing is used for evaluating the asphalt mixture’s fatigue potential and moisture susceptibility. Previous studies have indicated that the tensile strength of asphalt mixture is related to cracking performance [11] [12]. Higher tensile strength means that asphalt pavement can tolerate higher strains before failing. As shown in Table 1, the average indirect tensile strength of the unknown asphalt mixture is about 24.7% higher than the common mixture. Here the unknown asphalt mixture shows 1.97 MPa and the common mixture shows 1.58 MPa. The unknown asphalt mixture exhibits a relatively higher indirect tensile strength, which indicates better cracking resistance compared to the common asphalt mixture.

Three point bending tests were performed to evaluate the low temperature cracking of the asphalt concretes. As shown in Table 1, the failure strain of the unknown asphalt mixture is about 34.0% higher than the common mixture. In general, asphalt mixtures that exhibit greater strain at failure in the low temperature range have better flexibility which leads to superior resistance to cracking.

Resilient modulus is a measure of materials responses to load and deformation. Generally, higher modulus indicates greater resistance to deformation. The results also show that the unknown asphalt mixture yields a higher resilient modulus value compared to the common mixture at 40°C. The resilient modulus is 5741 MPa for the unknown asphalt mix and 4050 MPa for the common mixture, which indicates greater resistance to deformation compared to the common asphalt mixture.

For comparing the mechanical properties obtained from different tests, the data from indirect tensile strength, bending strain, and resilient modulus for common and unknown asphalt mixtures, respectively, were ranked, as summarized in Table 1. Test results clearly identified that the unknown asphalt mixtures was better than common asphalt mixtures. These properties of unknown asphalt mixtures are consistent with the effects of SBS modified asphalt mixture.

4. Conclusion
The following results can be concluded:

(1) The chemical compositions analysis of the unknown asphalt Shows Two major bands at 966 cm⁻¹ and 699 cm⁻¹ in FT-IR spectra compared to the common asphalt, indicated the unknown asphalt containing SBS modifier.

(2) The rheological behaviors of unknown asphalt investigated using Dynamic Shear Rheometer show significant high complex modulus and low phase angle compared to common asphalt resulting in increasing resistance to the high temperature stability.

(3) The mixture test results demonstrated up to 24.7% higher indirect tensile strength at 25°C, up to 34.0% higher bending strain, and 41.8% higher indirect tensile resilient modulus at 40°C than the common asphalt. These properties of unknown asphalt mixtures are consistent with the effects of SBS modified asphalt mixture.

(4) Based on the analysis of the chemical composition of asphalt materials and the confirmation of rheological properties and mechanical properties, it is found that the asphalt used in unknown asphalt mixture section contains SBS modifier.

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