Viscosity Reduction Mechanism and Rheological Performance Analysis of Warm Mix Rubber Modified Asphalt

Yi Tian[1,a], Wei Hong[2*], Luchun Yan[3], Zijian Liu[2]

[1]Gansu Highway Traffic Construction Group Co., Ltd., China
[2]Gansu Henglu Traffic Survey and Design Institute Co., Ltd., China
[3] Observation and Research Base of Transport Industry of Long Term Performance of Highway Infrastructure in Northwest Cold and Arid Regions, China

[a]934426167@qq.com; *hongw0238@163.com

Abstract. A surface-active agent was added to the project in order to investigate the process of viscosity reduction in rubber-modified asphalt by the warmed mixing agent and its effects on rheological characteristics of asphalt. Different periods for preservation for warm-mix asphalt treated with rubber powder were created. Using a Brookfield viscometer, the viscosity change of the warm mix asphalt was measured, and bar chromatography were utilized to study the process of viscosity reduction. Using the DSR frequency and temperature scanning tests, the rheological characteristics of the warm mix asphalt were assessed. According to the research, the warm mix is primarily made up of volatile tiny molecules that successfully lower the viscosity of the asphalt. However, this also softens the asphalt and negatively impacts its resistance to low-temperature cracking, creep recovery, and high-temperature rutting. Asphalt aging is caused by volatile components releasing from the heated mix as storage time approaches. The warm mix asphalt showed high-temperature mechanical characteristics that were comparable to the original asphalt after 48 hours of storage.

Keywords: Warm mix; Rubber-modified asphalt; Rheological properties; Viscosity reduction.

1 Introduction

Due to its high road performance and reputation as an environmentally benign pavement material that solves the problem of disposing of leftover rubber powder, rubber-modified asphalt has been increasingly popular in recent years[1-3]. However, the application of this technique is limited due to the high viscosity of rubber powder-modified asphalt, which presents issues during production and construction. These challenges include high heating temperatures, pollution from asphalt smoke, as well as construction difficulties. Road management and construction organizations are paying more and more attention to warm mix asphalt technology, which lowers asphalt viscosity through chemical or physical means. Warm mix asphalt technology has emerged as a way to

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minimize environmental pollution, optimize construction methods, and streamline characterization[4-7].

Warm mix technology and rubber powder-modified asphalt technology can be used in combination to maximize the benefits of each strategy while reducing the negatives of each. The partnership technique seeks to reduce pollutant emissions, lower the mixing and compression temperatures of asphalt modified with rubber powder, and facilitate the wider adoption of asphalt pavement applications[4, 6]. The components and production procedures used in warm mix rubber powder asphalt technology are different which means more research into its mechanism of viscosity reduction and rheological performance analysis is expected[3].

This research uses a surfactant-based warm mix modifier and focuses on composite rubber powder-modified asphalt as the subject of the study. In order to match the varied warm mix conditions, the warm mix rubber powder-modified asphalt is exposed to varying period for 0, 12, 24, 36, and 48 hours at 180°C. By employing a Brookfield viscosity meter, the warm mix asphalt treated with rubber powder viscosity variations are assessed. Additionally, rod chromatography are used to examine the viscosity reduction process of warm mix-modified asphalt, while DSR temperature scanning and frequency scanning are used to evaluate the rheological properties. The BBR low-temperature bending tester is used to examine the warm mix modified asphalt's low-temperature performance. In order to provide technical support for the use of warm mix rubber powder-modified asphalt technology, these analyses attempt to clarify the mechanism of viscosity reduction of rubber powder-modified asphalt at various mixing conditions as well as comprehend the viscoelastic properties and mechanical behavior across varying storage times.

2 Test Materials and Methods

2.1 Test Materials

Rubber modified asphalt using Gansu Changtong Highway Maintenance Technology Co., Ltd. factory production of activated rubber high viscosity and high elasticity modified asphalt, product specifications such as Table 1.

Table 1. Indicators of rubber modified asphalt

Item	Unit	Quality index	Test method
Softening point (global method)	°C	85.3	GB/T4507
Ductility (5cm/min, 5°C)	cm	40	GB/T4508
Penetration index (25°C, 5s, 100g)	0.1mm	65.8	GB/T4509
Rotational viscosity (180°C)	Pa•s	3.03	SH/T0739
Elastic recovery (25°C)	%	97	SH/T0737
Separation (softening point difference)	°C	0.2	SH/T0740

Asphalt warm mix adopts the host pavement to provide large DWMA-S-type asphalt warm mix, the product is a dark green liquid, using organic polymers and chemical surfactants and other materials prepared by the common reaction of a surface-active organic viscosity-reducing class of asphalt warm mix, and its technical indicators are shown in Table 2.

Table 2. Indicators of rubber modified asphalt

Item	Unit	Quality index
Density	g/cm^3	0.85~0.95
Active ingredient content	%	≥99
Viscosity (25°C, 5mm flow hole)	S	≥45

2.2 Sample Preparation

After being thoroughly mixed and heated to 180–190°C, the asphalt is then packed into stainless steel cups. The preparation of warm mix rubber powder-modified asphalt 0H is finished when 5% of the asphalt is added with warm mix at 180°C oil bath, utilizing a mixer at a speed of 1000 rpm for 10 minutes to guarantee total integration of the warm mix and the asphalt. In order to replicate the storage conditions of warm-mixed rubber powder-modified asphalt at different timeframes, samples of the asphalt 0H are agitated for varying lengths of time (12H, 24H, 36H, and 48H) in an oil bath at 180°C at a speed of 100 revolutions per minute.

2.3 Test Methods

2.3.1 Dynamic Shear Rheological Property Analysis

Asphalt is a viscoelastic material, and temperature and loading time are two crucial factors affecting its rheological properties. Rheological test analysis can provide rheological parameters of asphalt at different temperatures and loads, including phase angle (δ) and complex modulus (G*), allowing determination of the rutting factor G*/sinδ and fatigue factor G*sinδ based on these parameters. This study utilizes the HR20 Dynamic Shear Rheometer (DSR) from TA and follows the JTGE20-2011 specifications for sample preparation and experimentation. Frequency scanning is conducted from 30 to 80°C (temperature step of 10°C) with 6 temperature points, and an angular frequency range of 0.1-400 (rad/s) is scanned for each temperature point, with 20 points per temperature point. Temperature scanning is done at a constant frequency of 10 rad/s, covering a range from 30 to 80°C (temperature step of 10°C) with a total of 6 temperature points.

2.3.2 Bending Creep Strength Analysis

To assess the low-temperature properties of asphalt, the bending beam rheometer (BBR) test is commonly used to evaluate sample resistance to cracking. This study employs Cannon's TE-BBR according to the JTGE20-2011 specification for sample preparation and experimental operation. The experiment is conducted at -20°C with a constant stress of 875 mN continuously loaded for 240 seconds, recording the modulus of strength (S) and creep rate (m) at the 8th, 15th, 30th, 60th, 120th, and 240th seconds to evaluate the low-temperature serviceability of the asphalt. The S (t) at 60 seconds and the m value indicating the rate of stiffness change over time are examined to reflect the low-temperature properties of the asphalt samples.

2.3.3 Brookfield Viscosity Test

The Brookfield (DV- //+ Pro model) Brinell viscometer is used to determine the mixing and compaction temperatures of the asphalt mixture by measuring the Brinell viscosity of the asphalt. The compaction temperature test involves using a 27 rotor with a single standard asphalt specimen of 10.5g to determine the Brinell viscosity at 135°C and 175°C.

2.3.4 Flexural Creep Stiffness Test

The rod chromatography test, also known as the rod thin-layer chromatography-hydrogen flame ionization detector (TLC-FID) method, is utilized to analyze the four components of asphalt, namely saturated fractions, aromatic fractions, gums, and asphaltenes. The experiment involves using n-heptane for the first unfolding, followed by toluene for the second unfolding to reach an unfolding height of about 60 mm. Subsequently, a mixture of n-hexane and methanol is used for the third unfolding to reach a height of about 30 mm, followed by analysis of the different components in the FID center.

3 Test Results and Analysis

3.1 High Temperature Rheological Characterization

The master curve analysis involves assessing the dynamic shear rheometer data at various temperatures and frequencies to identify a central curve that captures the data trend. By determining the translation factor at a reference temperature, a smooth curve is derived. In this study, the reference curve was set at 50°C, and the master curve for the complex shear modulus of the asphalt used was established by translating equation[8].

Fig 1 illustrates the master curve of the complex modulus of warm mix rubber powder-modified asphalt. Throughout the frequency range, the addition of warm mix rubber powder asphalt results in a lower complex modulus, indicating asphalt softening and reduced resistance to deformation. At high frequencies, the 0H warm mix rubber powder-modified asphalt exhibits the lowest modulus, which gradually increases with heat preservation time. At 48H, the modulus is nearly equivalent to the original rubber powder asphalt. In the low-frequency range, the original rubber powder asphalt has the highest modulus, which decreases initially and then increases with storage time for the warm mix rubber powder-modified asphalt. The 24H and 36H warm mix rubber powder-modified asphalt show the lowest modulus, likely due to the decomposition of large organic components of the rubber powder asphalt mixing agent within the 0-36 hours of storage time. Beyond 36 hours, the asphalt undergoes further aging, leading to hardening and increased modulus.

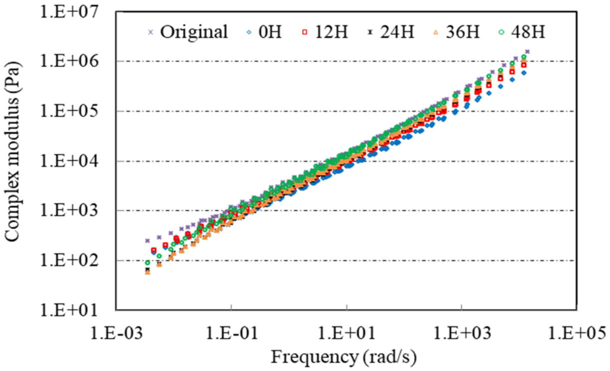

Fig. 1. Frequency scanning principal area line

The asphalt's rutting factor reaction to temperature changes is shown in Fig. 2. Increased resistance to deformation is indicated by higher rutting factors. Lower rutting factors across the temperature range are seen in the warm mix rubber powder-modified asphalt, indicating softer asphalt and decreased resistance to deformation. Rubber powder asphalt samples show the highest rutting factor between 30 and 70°C, while 0H warm mix rubber powder asphalt has the lowest rutting factor. The rutting factor of warm mix rubber powder asphalt increases with storage time but stays lower than that of the original rubber powder asphalt samples, suggesting that the addition of a warm mix ingredient reduces resistance to rutting.

The phase angle index trend with temperature, which is a crucial metric for assessing the viscoelastic qualities of asphalt, is shown in Fig. 3. Better asphalt elasticity and resistance to deformation are indicated by a smaller phase angle. Warm mix increases viscosity and decreases elasticity of rubber powder-modified asphalt, hence improving deformation resistance at low temperatures (30–55°C). On the other hand, warm mix rubber powder-modified asphalt that has been kept for more than 24 hours shows noticeably higher phase angles at high temperatures (55–80°C) than the original asphalt, which suggests a decreased ability to withstand deformation and an increased chance of rutting at high temperatures.

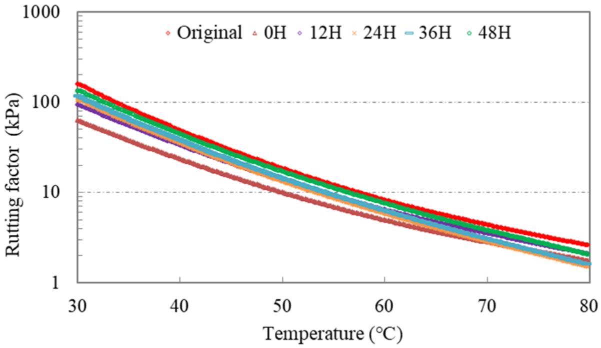

Fig. 2. Temperature scanning rutting factor curve

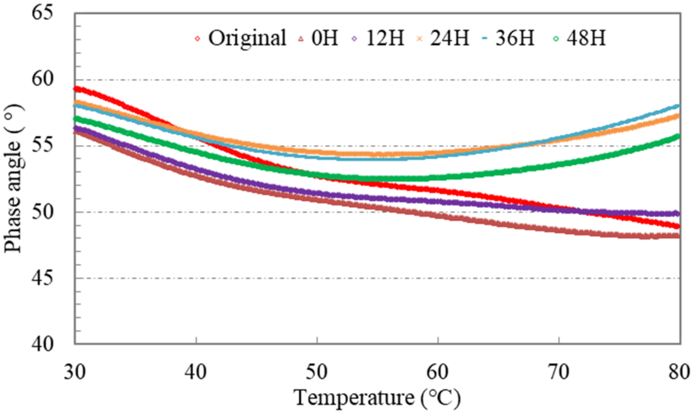

Fig. 3. Temperature scanning phase angle curve

3.2 Flexural Creep Stiffness Test

Fig. 4 displays the results of the BBR testing at -20°C, highlighting the m-values and creep stiffness of different asphalts. For the purpose of reducing the risk of thermal cracking at low temperatures, low creep stiffness and high m-values are preferred. Asphalt amended with mastic has the lowest rate of change and the maximum creep stiffness. Warm mix improves low-temperature performance by increasing creep stiffness and rate of change. Nevertheless, the rate of change m decreases with the amount of time warm mix asphalt is stored, increasing the possibility that mastic powder would break in cold weather. The integrated rheological parameter S/m offers a thorough assessment of the low-temperature performance of asphalt. This parameter rises with warm-mixed mastic asphalt storage duration and falls with the addition of warm mix, indicating a heightened risk of mastic powder cracking at low temperatures.

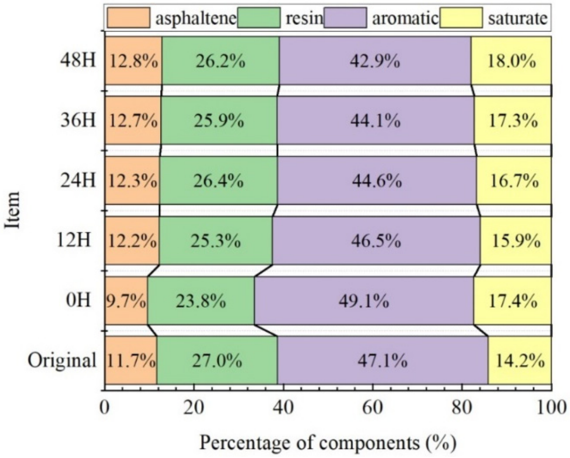

Fig. 4. Asphalt flexural creep stiffness test

3.3 Rod Chromatograph Analysis

Warm mix gum powder asphalt addition results in changes to the components of the asphalt, as seen by the rod chromatograph analysis (Fig. 5). Because the warm mix agent has a low organic content, it is likely to increase tiny molecular weight aromatic fractions and saturated phenols while decreasing bigger molecular weight asphaltenes and gums. After being stored at a high temperature for 12 hours, the aromatic percentage rapidly drops while asphaltene increases—possibly as a result of the tiny organic materials volatilizing quickly and changing the proportions of asphalt. Extended storage times result in a further decrease in aromatic fractions and an increase in asphaltene, which may be related to asphalt aging.

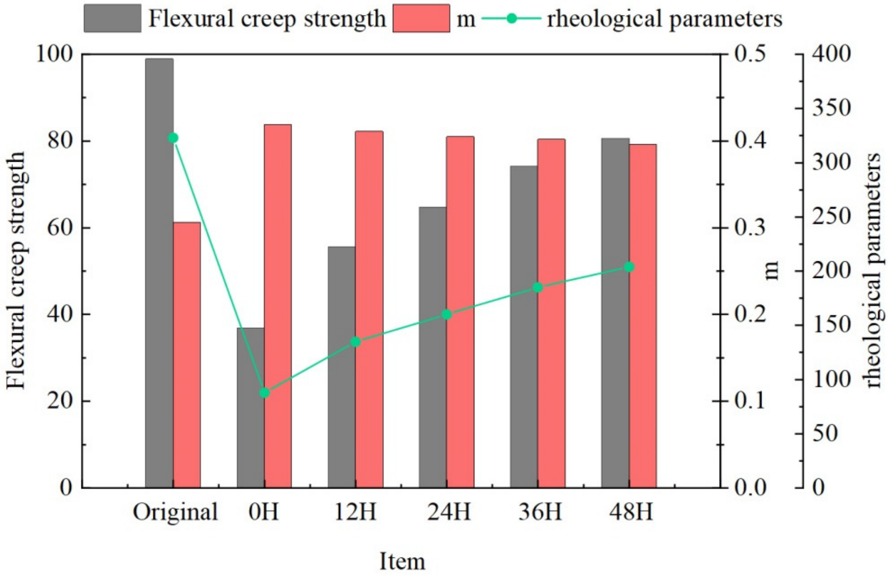

Fig. 5. Four-component analysis of asphalt

3.4 Brookfield Viscosity Test

The asphalt Brookfield viscosity curves at 135°C and 175°C are shown in Fig. 6. Warm mix effectively reduces the excessive viscosity of the original gummy asphalt at each temperature point. Warm mix sticky asphalt storage time causes a further reduction in viscosity. With longer storage times, the slope and intercept diminish, which reduces warm mix mastic asphalt's capacity to alter viscosity and operate well at high temperatures.

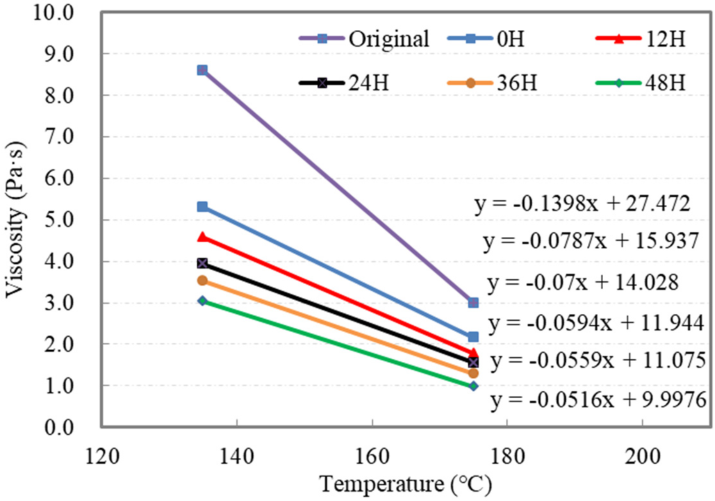

Fig. 6. Brookfield viscosity fitting curve

4 Summary

This study investigated viscosity reduction processes and rheological property impacts using warm-mixed gum powder modified asphalt and surface-active agent asphalt with different storage durations. The results show that:

(1) The warm mix is mostly made up of volatile small molecule oil, which successfully lowers viscosity but softens the asphalt, making it more susceptible to low-temperature cracking resistance, creep recovery, and high-temperature rutting.

(2) With increased storage time, volatile components dissipate, leading to partial aging. Mechanical properties of warm mix rubber powder-modified asphalt stored for 48 hours approach those of the original asphalt.

(3) Overall, warm mix effectively reduces gum powder asphalt viscosity but may heighten the risk of high-temperature rutting.

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