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# Rheological and physical properties of asphalt mixed with warm compaction modifier

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## HIGHLIGHTS

- Warm compaction modifier has significant effect on the asphalt physical properties.
- Rheological behavior of asphalt can be improved by warm compaction modifier.
- MSCR test can quantify the effect of the warm compaction modifier on asphalt binder.
- The optimum content of warm compaction modifier is recommended as 0.3% by weight.

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## ABSTRACT

This study was carried out to investigate the effect of the warm compaction modifier on the physical and rheological properties of High-viscosity High-elasticity modified asphalt and SBS modified asphalt. Three types of asphalt binder with different concentrations (at 0.3%, 0.5%, 0.8% by weight) of the warm compaction modifier were studied respectively. The influence of the warm compaction modifier on the physical and rheological properties was evaluated by penetration, softening point, and ductility and Dynamic Shear Rheometer (DSR) test. It was evident that the addition of the warm compaction modifier had a significant effect on the stiffness and elasticity behavior of the asphalt both at high and intermediate temperatures. It is indicated by DSR analysis that the warm compaction modifier could increase stiffness and fatigue behavior compared with base modified asphalt. Based on the physical and rheological tests, the concentration of warm compaction modifier was recommended to be at 0.3% by the weight of base modified asphalt.


## 1. Introduction

The warm mix asphalt (WMA) refers to technologies that allow for a significant reduction of mixing temperatures, but will not reduce the mechanical performance of asphalt mixes compared with Hot Mix Asphalt through different mechanisms [1–4]. Meanwhile, modified asphalts have been popularly used in variously rigorous environment due to its high performance, such as bearing high traffic level, suppressing the noise level, reducing reflective cracking and low-temperature cracking with other desirable effects [5]. Previous studies about mechanical properties of modified asphalt mixtures in presence of warm mix additives have been investigated [6–8].

Although the WMA represents environmental-friendly technologies with broad application prospect, it still exists a huge number of drawbacks and challenges, which deserve further research [6]. Previous studies have shown that the warm mix modifier can decrease the mixing temperature of modified asphalt mixture by using different processes [9,10], indirectly resulting in the lower compaction temperature. The lower mixing temperatures, however, may cause a number of problems, including, but not limited to, the incomplete drying of the aggregates, the poor bitumen coating, the poor moisture susceptibility as well as the rutting resistance [11–14]. In some special case (such as long distance transporting and constructing under relatively low temperatures environment), the mixing temperature is required as high as normal, whereas the compaction temperature is expected as low as possible. For solving these problems, the warm compaction modifier has been developed and its effects on the asphalt mixture performance was investigated, indicating that the warm compaction modifier can remain the same mixing temperature but reduce the compaction temperature of asphalt mixture, which have similar volume parameters and road performance compared with the traditional asphalt mixture [15].

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In this paper, warm compaction modifier with different concentrations (0.3%, 0.5%, 0.8%) was blended into High-viscosity High-elasticity (HVHE) and the SBS modified asphalt by high-shear mixer respectively. The physical and rheological properties of modified asphalt with warm compaction modifier were investigated for better understanding the effect of warm compaction modifier on the asphalt binder performance. Therefore this study can provide a further insight for warm compaction asphalt technologies and binder modifications.

## 2. Experimental program

### 2.1. Materials

In this research, two asphalt binders commonly used in the Heilongjiang Province of China were selected in this study: High-viscosity High-elasticity (HVHE) and SBS modified asphalt. HVHE modified asphalt refers to the asphalt binder with the high dynamic viscosity (higher than 30,000 Pa.s) and high elastic recovery (higher than 85%) properties, according to Chinese specification of GB/T 30516-2014. The properties of the HVHE and SBS modified asphalt are shown in Table 1.

The warm compaction modifier was developed and provided by a research institute of China. The mechanism of this modifier is reducing surface tension of asphalt to make the asphalt mixture can be compacted well under lower temperature. Modifier is dark yellow oil liquid.

### 2.2. Sample preparation

A Ross high-shear mixer (HSM-100L) was employed to mix the warm compaction modifier with HVHE and the SBS modified asphalt to obtain homogeneous asphalt binder. The processing parameters were suggested by the provider of the warm compaction modifier, which are summarized in Table 2.

### 2.3. Physical tests

Penetration test, softening point test, and ductility test were used to determine the physical properties of the asphalt blended with and without warm compaction modifier. These tests were carried out according to the ASTM D5, ASTM D36 and ASTM D113, respectively. It is should be notes that the penetration test and ductility test were conducted at 25 °C and 5 °C, respectively.

### 2.4. Dynamic Shear Rheometer tests

DHR-2 Rheometer manufactured by TA Instruments was employed to carry out DSR tests. The complex shear modulus ($G^*$) and phase angle ($\delta$) of the modified asphalt with warm compaction modifier were measured by DSR tests. In this study, rutting and fatigue parameters were determined according to the Superpave specification. Frequency sweeps were conducted with the frequencies from 0.1 to 30 Hz. At low and intermediate temperatures (12, 24, 36, and 48 °C), the diameter plate and the gap were 8 mm and 2000 μm gap, respectively. At high temperatures (60,70,80 °C), the diameter plate and the gap were 25 mm and 1000 μm gap, respectively. The results of the complex shear modulus ($G^*$) and phase angle ($\delta$) were used to plot the master curves at a reference temperature (36 °C) based on Time Temperature Superposition Principle and WLF equation [16,17]. Temperature sweeps test were conducted from 12 to 72 °C with 1.59 Hz shear frequency and 3 °C/min heating rate.

**Table 1**
Physical properties of HVHE and SBS modified asphalt.

| Test Methods | HVHE modified asphalt | SBS modified asphalt | Specification |
|---|---|---|---|
| Penetration @ 25 °C (0.1 mm) | 71.1 | 70.2 | ASTM D5 |
| Ductility @ 5 °C with 5 cm/min (cm) | 55.6 | 39.6 | ASTM D113 |
| Softening point (°C) | 102.10 | 94.85 | ASTM D36 |

**Table 2**
Blending binder protocol.

| Asphalt Type | Mixing time (min) | Mixing speed (rpm) | Mixing temp (°C) |
|---|---|---|---|
| HVHE modified asphalt | 15 | 2000 | 190 |
| SBS modified asphalt | 15 | 2000 | 180 |

### 2.5. Multiple stress creep and recovery test

MSCR test was used to evaluate the rutting performance of binders. According to AASHTO T 350-14, the non-recoverable creep compliance ($J_{nr}$) was calculated as a measure of the binder's contribution to mixture permanent deformation behavior and percent recovery (R%) reflects the elasticity of asphalt binder. While results of the MSCR test were promising, based on the results of recent studies, the MSCR test procedure was slightly modified by increasing the number of cycles at each stress level from 10 to 30 cycles to minimize the effect of non-steady state response in each stress step. Also, a third stress level of 10 kPa, believed to be more representative of binder stress state in the mixture, was added to the standard 0.1, 3.2 kPa stress levels used in the test [18–20].

The expressions of $J_{nr}$ and R% in 0.1 kPa stress level are shown as follow.

$$J_{nr}(0.1,N) = \frac{\varepsilon_{10}}{0.1} \quad (1)$$

$$J_{nr0.1} = \frac{SUM[J_{nr}(0.1,N)]}{30}, N = 1 \text{ to } 30 \quad (2)$$

$$\mathrm{R}\%(0.1,\mathrm{N}) = \frac{(\varepsilon_1 - \varepsilon_{10})}{\varepsilon_1}, N = 1 \text{ to } 30 \quad (3)$$

where $\varepsilon_{10} = \varepsilon_r - \varepsilon_0$
$\varepsilon_0$ : initial strain in the creep stage,
$\varepsilon_r$ : final strain in the recovery stage.

The calculation method in 3.2 kPa and 10 kPa stress level is similar to that in 0.1 kPa.

The test was carried out at 70 °C, which is the highest work temperature of the bridge deck asphalt pavement in Heilongjiang Province of China. For each type of binder, three samples were prepared for MSCR test.

## 3. Results and discussions

### 3.1. Results of the physical tests

#### 3.1.1. Penetration test

As shown in Fig. 1, the penetration value shows a pronounced increase with increasing warm compaction modifier concentration, which can be attributed to a softening effect of the warm compaction modifier introduced into the base asphalt (SBS modified asphalt and HVHE modified asphalt). It is determined that the addition of warm compaction modifier softens the base asphalt. The penetration value of original HVHE modified asphalt is slightly higher than that of SBS modified asphalt. The addition of 0.8% warm compaction modifier increases the penetration value of the HVHE modified asphalt binders by about 1.5 mm and 2.42 mm for the SBS modified asphalt, which implies that the effect of warm

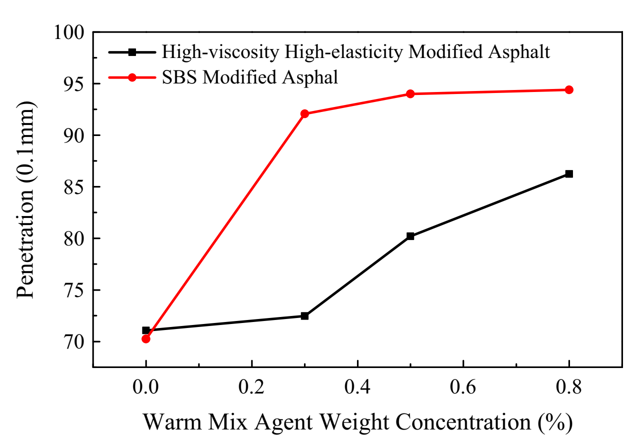


**Fig. 1.** Effect of warm compaction modifier on penetration of asphalt binder.