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Evaluation of asphalt concrete mixtures for railway track

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HIGHLIGHTS

- The performance of asphalt mixtures with PG64-22 and two modified asphalt was evaluated.
- Various asphalt mixture performance tests were conducted on the three mixtures.
- The performance of modified mixtures was dominant in every aspects.
- The behaviors of the two modified mixtures were very competitive.
- The modified mixtures could performed well for in railway track.

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ABSTRACT

In this study, the performance of three asphalt concrete mixtures for railway track using three different asphalt binders which are PG64-22, crumb rubber modified (CRM) asphalt binder, and styrene–butadiene–styrene (SBS) modified asphalt binder was investigated in terms of moisture susceptibility, permanent deformation, and fatigue cracking of asphalt concrete mixture. Dynamic modulus and uniaxial creep test were conducted to characterize the material properties of asphalt mixtures. The results indicate that asphalt mixtures containing crumb rubber and SBS show better performance compare with the PG64-22 binder.

1. Introduction

There is a trend for both high-speed and heavy-axle loadings trains which requires smoother and tougher railway substructures around the world [1]. Hensley and Rose [2] noted that the open-graded unbound ballast layer is incapable of performing as an elastic layer and Hot Mix Asphalt (HMA) mat was consider as an elastic system. Rose et al. [3] found that HMA was introduced to the track structure to partly replace the conventional granular material. Nowadays, it is selectively considered as an option for new main-line tracks, yards, and terminal construction due to lower delivering and placing cost compare to conventional granular subballast. HMA is also a suitable material for railway substructure to enhance performance, improve the stress distribution, weaken dynamic loading, and lower the vibration especially at the effective depth from 0 to 2 m [4]. Visco-elastic strength and modulus of HMA can make it better suited for the requirements of high-speed railway substructures [5] and there is also no indication of any damages or cracks of the asphalt after many years of heavy traffic under widely varying conditions [6]. Fang et al. [7] proved that the usage of asphalt layer in vibration control is beneficial to long-term performance of high-speed trackbeds, it reduces vibration when locating at the lower part of railway substructure. Fang et al. [8] concluded that air voids content and permeability of asphalt mixture is strongly affected by the aggregate gradation but not correlated with normal maximum aggregate size. Rose et al. [9] suggested that the loading conditions in trackbeds are different from those in highway pavements; so the asphalt content of HMA trackbeds should be 0.5% higher than that considered optimum for highway applications with air-voids of 1–3%.

The purpose of this study is to evaluate the performance of asphalt concrete mixtures as railway substructures for asphalt concrete mixtures containing styrene–butadiene–styrene (SBS) modified asphalt, crumb rubber modified (CRM) asphalt, and PG64-22 using various asphalt mixture performance tests. The asphalt mixture performance tests used in this study are indirect tensile

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strength test, flow number test, and repeated indirect tensile test. Dynamic modulus test and uniaxial creep test were conducted to investigate material properties of three different asphalt concrete mixtures.

2. Material properties and sample preparation

2.1. Material properties

Asphalt binder and aggregate are the main components in asphalt mixture. The basic principle characteristics of asphalt binder such as penetration grade, softening point, and viscosity at 135 °C were determined.

The dynamic shear rheometer (DSR) test is used to characterize the stiffness or rut resistance of asphalt binders at medium to high temperatures measured by rutting factor, $G^*/\sin\delta$. DSR tests are conducted on original and Rolling Thin-Film Oven (RTFO) aged asphalt binder samples. RTFO procedure provides simulated short term aged asphalt binder for manufacturing and placement aging. The rutting factor must be at least 1.0 kPa for original asphalt binder and 2.2 kPa for the RTFO aged one [10]. A measure of low temperature cracking of asphalt binders is carried out by Bending Beam Rheometer (BBR) on Pressure Aging Vessel (PAV) aged asphalt binder samples. PAV provides simulated long term aged asphalt binder for in-service aging over a 7–10-year period. The creep stiffness must not exceed 300 MPa and the m-value must be at least 0.30 [11]. The rheological properties of asphalt binders are described in Table 1. It shows that the characteristics of SBS and CRM asphalt binders satisfy the grade of PG76-22. The particle size distribution used in this study is shown in Table 2.

2.2. Sample preparation

The asphalt concrete mixtures were prepared at a mixing and compaction temperatures, and optimum asphalt contents at 3% air voids for each mixture are summarized in Table 3.

For indirect tensile strength test, repeated indirect tensile strength test, and uniaxial creep test, asphalt concrete mixtures were compacted at 7 ± 0.5% air voids and the specimen dimension is approximately 100 mm in diameter and 62 mm in height. For flow number test and dynamic modulus percent, asphalt concrete mixtures compacted at 150 mm in diameter and 170 mm in height were cored and cut to 100 mm in diameter and 150 mm in height. The cored specimens were 4 ± 0.5% air voids.

3. Results and analysis

3.1. Dynamic modulus test

Dynamic modulus testing was conducted according to the AASHTO TP 62-07 [12] at temperatures of 4, 21 and 37 °C and frequencies of 0.1, 0.5, 1.0, 5, 10 and 25 Hz. The significance of this test is to determine the complex modulus, $|E^*|$, a viscoelastic material properties of asphalt mixtures that reflects its stiffness at wide range of temperatures and/or frequencies. The complex modulus is defined as the ratio of the amplitude of the sinusoidal stress and the amplitude of the sinusoidal strain at the same time/frequency.

Table 1
Rheological properties of PG64-22, CRM, and SBS asphalt binders.

Asphalt properties	PG64-22	CRM	SBS
Penetration at 25 °C	61	38	43
Softening point (°C)	50.5	83.3	64.6
Viscosity at 135 °C (cPs)	368.8	2025	1231
Original $G^*/\sin\delta \geqslant 1$ kPa			
70	0.534	2.536	2.62
76	0.267	1.479	1.39
82	–	0.902	0.77
RTFO $G^*/\sin\delta \geqslant 2.2$ kPa			
70	1.113	7.28	4.661
76	0.529	3.84	2.202
82	–	2.06	0.939
PAV creep stiffness at 60 s $\leqslant$ 300 MPa			
−6	84.3	69.54	81.467
−12	220	156.33	176.37
−18	359.1	303.54	307.23
PAV m-value at 60 s $\geqslant$ 0.3			
−6	0.3965	0.50	0.37
−12	0.338	0.42	0.30
−18	0.2805	0.28	0.23
PG grade	PG64-22	PG76-22	PG76-22

The dynamic modulus testing is normally conducted using a uniaxially applied sinusoidal stress pattern on the specimen. According to the Mechanistic-Empirical Pavement Design Guide [13], the modulus of asphalt mixtures at all levels of temperature and time rate of load is determined using a master curve constructed at a reference temperature. Master curves are constructed using the principle of time-temperature super-position. The dynamic modulus master curve was established according to a method presented by Christensen et al. [14] at reference temperature of 21 °C as shown in Fig. 1. The following equation was used to form the master curve:

$$\log(E^*) = \delta + \frac{\alpha}{1 + e^{\beta+\gamma\left[\log(f) - c\left(\log(\eta) - \log(\eta_{fr})\right)\right]}} \tag{1}$$

where E^* = dynamic modulus (MPa), f = loading frequency (Hz), η = viscosity at temperature of interest (cPs), η_{fr} = viscosity at reference temperature (cPs), and δ, α, β, γ and c = fitting parameters from experimental data.

The modulus of each curve represents the average of two specimens. The coefficient of variation is 10%, 13% and 8% for asphalt mixture with PG64-22, SBS, and CRM, respectively which is considered generally acceptable for asphalt mixtures. The three asphalt mixtures are showing a plateau glassy modulus at high frequency; around 25,000 MPa and a distinct change in the high temperature (low frequency) modulus. At low frequency (equivalent to high temperature) shown in Fig. 1, predicted results suggested that asphalt mixtures with SBS asphalt has the highest stiffness while asphalt mixture with PG64-22 asphalt has the least stiffness at 54 °C among all asphalt mixtures.

Rutting and fatigue cracking can be characterized using the dynamic modulus $|E^*|$ and phase angle (φ) [15]. The dynamic modulus values were obtained at 21 °C and 37 °C, respectively because rutting usually occurs during summer at high temperature condition and fatigue cracking is a common phenomenon at intermediate pavement service temperature. The frequency of 10 Hz and 25 Hz was selected for both parameters because it most closely corresponds to vehicle speeds of about 64 km/h and over 160 km/h, respectively [16]. Figs. 2 and 3 illustrate the rutting factor and fatigue factor of different mixes. Lower fatigue factor ($|E^*|\sin\varphi$) is an indication of better performance against fatigue while higher rutting factor ($|E^*|/\sin\varphi$) shows greater rut resistance [16]. As seen in Figs. 2 and 3, asphalt mixture with PG64-22 asphalt has worst performance compared to the two other asphalt mixtures with CRM and SBS additives due to its low rutting factor and high fatigue factor. Asphalt mixtures with CRM and SBS have almost similar fatigue factor at 21 °C, but with respect to rutting, asphalt mixture with CRM shows better resistance to rutting with the higher rutting factor at 37 °C.

3.2. Uniaxial creep test

The rational for performing the uniaxial creep test is to investigate the linear viscoelastic properties of asphalt concrete mixture. Testing was performed in an environmental chamber set at 20 °C. A uniaxial static creep stress of 130 kPa was applied for 1000 s followed by 1000 s unloading under contact load of 13 kPa. The control stress was chosen to maintain an ultimate creep strain under 1500 microstrain. This is in line with the maximum strain allowed in dynamic modulus samples after completing a full range frequency testing. This maximum range ensures that the samples response remains in the linear-viscoelastic range. The asphalt mixtures experienced instantaneous strain upon loading and instantaneous rebound upon unloading reflecting the elastic behavior. The