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Original Research Article

Evaluation of the impact of extended aging duration on visco-elastic properties of asphalt binders

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ABSTRACT

There are variations in the haulage distance between an asphalt mixing plant and the road construction site (field) and this may cause variations in the levels of aging of the asphalt mixture produced. This study evaluates the effects of extended aging durations during mixture transport from the plant to field. The rheological properties of different binders were characterized from the complex modulus, phase angle and Superpave^{TM} rutting parameter. In addition, binder rheological properties changes were calculated using an Arrhenius activation energy equation. A prolonged aging characterization method (PACM) and its gradient (▽PACM) were also proposed to characterize the binder rheology subjected to different aging conditions. The test results showed that the trends in aging differ and depend on binder type, test temperature and aging conditions. The smoothing spline algorithm can be a suitable parameter that can predict the effects of aging on ▽PACM trend.

1. Introduction

Asphalt mixture has been used largely for road construction. Asphalt binder aging is one of the major causes of shorter pavement service life. The binder rheological properties change over time during mixing, transportation and construction. Prolonging any of these processes will result in increases in the binder viscosity, leading to stiffer and more brittle mixtures [1–3]. The actual short-term aging duration in the field varies and may depend on the haul distance. Excessive aging duration may affect pavement durability. Aging is sensitive to variations in binder type, duration between mix production and placement, aggregate type and temperature, which significantly affects mix performance and properties [4]. Therefore, characterization of aging parameters enables asphalt technologists to evaluate the long-term performance of asphalt mixture and ensure its durability. There are different methods to predict asphalt binder and mixture aging. Mirza and Witczak employed a simple performance tester and developed the Global Aging System (GAS), which predicted asphalt viscosity as a function of time and pavement depth [5]. Lee et al. and Kim et al. used High-Pressure Gel Permeation Chromatography (HP-GPC) to evaluate the effects of short-term

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aging on changes in the molecular size distribution of an asphalt binder under various conditions and found that aging increased the binder large molecular size (LMS) that caused an increase in its viscosity and stiffness [6,7]. Yao et al. used the Fourier transform infrared spectroscopy (FTIR) to evaluate the effects of aging on the changes in the ratio of chemical bonds of asphalt binder [8]. Glover et al. developed a model to predict the oxidation rate with the input of binder kinetics data, temperature profile of the pavement, and mixture characteristics [9]. Although aging has been investigated extensively by many researchers, the lack of a specific approach to characterize the observed variations in visco-elastic properties of asphalt binder due to aging still remains unknown. This study proposes an approach to evaluate the effects of extended short-term aging durations on the visco-elastic properties ($G^*/\sin\delta$) of asphalt binders at intermediate temperatures.

2. Materials and methods

2.1. Materials

Two types of binders from two sources were used in this study. For ease of reference, binders are designated according to their source and type. Thus, binders A1 and A2 refer to the 80/100 and 60/70 penetration grade binders from source A, respectively. Binders B1 and B2 refer to the 80/100 and 60/70 penetration grade binders from source B, respectively. The penetration test was carried out according to the procedures outlined in ASTM D5 [10]. The basic properties of the binders are summarized in Table 1.

2.2. Methods

The effects of aging on a binder were evaluated from the differences between their un-aged and aged rheological properties. The Rolling Thin Film Oven (RTFO) was used to produce a homogenous artificially short-term age asphalt binder in accordance with the procedures outlined in ASTM D2872 [11] except the duration were varied between 85 and 185 min at 20 min intervals. The effects of aging on the rheological properties of the un-aged and aged binder samples at intermediate temperatures were investigated in terms of complex modulus, phase angle and Superpave^{TM} rutting factor ($G^*/\sin\delta$), obtained from the results of the Dynamic Shear Rheometer (DSR) test. The tests were conducted using a 25 mm diameter spindle rotating at the rate of 1.59 Hz frequency of loading and shear stress fluctuate between 0.02 and 17 kPa, based on the materials condition. Consequently, temperature sweeps were applied from 46 °C to 82 °C at 6 °C increments for the un-aged and short-term aged samples in accordance with Superpave^{TM} recommendations [12]. The test was run four times (four replications) for each conditioned samples and the average of the results is presented in this manuscript except for statistical analyses that included all the results.

The minimum energy required to overcome intermolecular forces and starting a chemical reaction, is defined as activation energy [13]. Lower activation energy indicates that less energy is required to cause reaction. Therefore, less energy is necessary to make the asphalt binder as a chemically organic material to react with oxygen present in the environment. The Arrhenius equation gives the quantitative basis of the relationship between the activation energy and the rate at which a reaction proceeds. The Arrhenius activation energy term from the Arrhenius equation experimentally calculated the parameter that shows the sensitivity of the reaction rate to temperature. Accordingly, the effects of aging or/and oxidation on different binders' activation energies were calculated and plotted based on Arrhenius equation as shown in Eq. (1) [14]. When the experimental data are plotted, the slope of the line is equal to $-E_a/R$. Hence, the activation energy can be determined from Eq. (2).

$$\ln(k) = \frac{-E_a}{R}\frac{1}{T} + \ln(A) \tag{1}$$

$$E_a = -R\left[\frac{\partial \ln(k)}{\partial(1/T)}\right] \tag{2}$$

where k is the reaction rate coefficient of G^*, E_a is the activation energy (J/mol), R is a universal gas constant (J/mol K), T is temperature (K) and A is frequency factor for the reaction.

To compare the effects of short-term aging on $G^*/\sin\delta$ trends, the prolonged aging characterization method (PACM), as defined in Eq. (3), is used. The PACM is a unitless parameter which can be used to characterize the increase in Superpave^{TM} rutting parameter due to short-term aging duration compared with a control sample or an initial condition. This value is independent of other effects such as temperature. In addition, Eq. (4) is presented to characterize the trend of PACM to a unit aging duration (20 min) for each binder type. The results are

Table 1 – Conventional binder properties.

Binder type	State	Specific gravity (g/cm^3)	Penetration at 25 °C (dmm)	Softening point (°C)	Ductility at 25 °C (cm)	$G^*/\sin\delta$ at 64 °C	$G^*/\sin\delta$ at 70 °C	Viscosity at 135 °C (Cp)
80/100 (A1)	Un-aged	1.020	80	46	>100	1342	–	300
	85 min aged		–	–	–	3099	–	475
60/70 (A2)	Un-aged	1.030	63	49	>100	–	1938	500
	85 min aged		–	–	–	–	3239	720
80/100 (B1)	Un-aged	1.020	81	47	>100	2127	–	390
	85 min aged		–	–	–	3493	–	500
60/70 (B2)	Un-aged	1.030	62	50	>100	–	1735	510
	85 min aged		–	–	–	–	3087	690