Fuel 221 (2018) 78–88

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

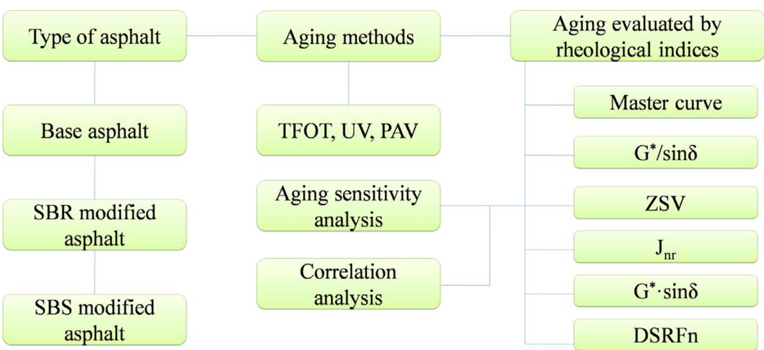
Full Length Article

Evaluation of aging behaviors of asphalt binders through different rheological indices

Henglong Zhang*, Zihao Chen, Guoqing Xu, Caijun Shi

Key Laboratory for Green & Advanced Civil Engineering Materials and Application Technology of Hunan Province, College of Civil Engineering, Hunan University, Changsha 410082, China

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Asphalt
Rheological indices
Aging resistance
Aging sensitivities
Correlation analyses

ABSTRACT

The performance of asphalt pavement is seriously affected by aging of asphalt binder, so indices are expected which can not only evaluate aging resistance of asphalt binder but also indicate asphalt mixture performance. The objective of this paper was just to investigate effects of different rheological indices which present tighter and clearer correlation with asphalt mixture performance in evaluating asphalt binder aging behaviors, these indices including complex modulus (G^*) and phase angle (δ) master curves, rutting factor ($G^*/\sin\delta$), zero shear viscosity (ZSV), non-recoverable compliance (J_{nr}), fatigue factor ($G^*\cdot\sin\delta$) and DSR function (DSRFn). Thin film oven test (TFOT), pressure aging vessel (PAV) test and ultraviolet (UV) irradiation were applied to simulate short-term, long-term thermal oxidation and photo oxidation aging, respectively. Frequency sweep tests and multiple stress creep recovery (MSCR) tests were conducted on three asphalt binders (60/80 pen grade base asphalt, styrene–butadiene-styrenecopolymer (SBS) modified asphalt and styrene butadiene rubber (SBR) modified asphalt) at different aging conditions. Meanwhile, aging sensitivities shown by different rheological indices were compared. The relationships between rheological indices were also discussed. The results showed that the ranking of aging resistances among asphalt binders evaluated by different rheological indices were nearly consistent and SBS modified asphalt exhibited the best aging resistance to three aging methods. J_{nr} and δ tended to decrease with the growth of aging severity, whereas other rheological indices were just contrary to this trend. Moreover, DSRFn proved to be the most sensitive index to aging. Based on correlation analyses, three groups of indices exhibited a strong correlation to each other, namely DSRFn versus $G^*/\sin\delta$, J_{nr} (0.1 kPa) versus J_{nr} (3.2 kPa) and J_{nr} (0.1 kPa) versus ZSV.

* Corresponding author.
E-mail address: hlzhang@hnu.edu.cn (H. Zhang).

https://doi.org/10.1016/j.fuel.2018.02.087
Received 8 November 2017; Received in revised form 14 January 2018; Accepted 12 February 2018

1. Introduction

Aging of asphalt binders is one of the principal factors causing the reduction of service life of asphalt pavement. After being intensively aged, asphalt binder becomes so stiff and brittle that pavement easily produce thermal and fatigue cracking under temperature and traffic load conditions, which in turn induces other distresses such as stripping, pothole and raveling [1–3]. Based on contributing factors, the type of aging can be categorized into thermal and photo oxidation aging, the latter mainly pointing to ultraviolet (UV) irradiation. Aging process during manufacturing, paving and compaction is included into short-term thermal oxidation aging, whereas long-term thermal oxidation aging mainly refers to service time when asphalt binder suffers heat and oxygen influences [4–6]. Ultraviolet (UV) irradiation can result in polymerization of asphalt molecules and induce more active groups, which increases the number of asphaltene components and accelerates speed of oxidation [7].

For aging effect on performance of asphalt pavement is essentially concerned, it is significant to adopt indices which can closely connect pavement performance with asphalt binder property to evaluate aging behaviors of asphalt binder. This will help to deduce age-induced change in pavement performance from aged asphalt binder. Currently, methodology for assessing aging degree of asphalt binder is primarily through measurement of changing amplitude of certain parameter before and after aging, these parameters often belonging to physical, chemical and rheological properties. The greater amplitude of these parameters means more serious aging degree of asphalt binder. As conventional physical aging indices calculated by softening point, penetration and ductility, these indices have been used to evaluate aging resistance of different asphalt binders by many of researches [8–11]. However, these physical indices are empirical indices to some extent that cannot effectively describe viscoelastic characteristics of asphalt binder and fails to correlate quite well with asphalt mixture performance. Moreover, these physical indices are insufficient to characterize property of modified asphalt binder as well [12]. Many researches have also suggested that using differing physical aging indices to evaluate, aging resistance sequence in asphalt binders is inconsistent [13,14]. As for chemical aging indices, content of oxygen functional groups in asphalt, like carbonyl and sulfoxide groups, and generic fractions (saturates, aromatics, resins and asphaltenes) are usually utilized to quantitatively monitor aging extent in asphalt binder [15–17]. However, there is no sufficient evidence to indicate strong direct correlation between pavement performance and chemical indices. Additionally, the preparation or isolation procedure of testing sample also has the large effect on the determination result. Compared with physical and chemical indices, the most obvious advantage of rheological indices is that some of them have been proved to be more associated with pavement performance by so many researches. As known, rutting factor ($G^*/\sin\delta$) and fatigue factor ($G^*\cdot\sin\delta$), developed by The Strategic Highway Research Program (SHRP) in the 1990's, prove to be efficient indicators for pavement rutting and fatigue behaviors respectively and are commonly used to classify asphalt binder grade in SHRP specification [18–20]. However, considering the limit of $G^*/\sin\delta$ which underestimates the performance of some modified asphalt binders [21], researchers have further developed zero shear viscosity (ZSV) and non-recoverable compliance (J_{nr}) in an attempt to replace $G^*/\sin\delta$ to assess rutting performance of asphalt binder. At almost zero shear rates, asphalt with purely viscous response behaves like Newtonian liquids where the flow resistance reaches a constant value. At this point the viscosity is called ZSV [22–24]. J_{nr} obtained from multiple stress creep recovery (MSCR) tests, is equal to the average non-recovered strain for the 10 creep and recovery cycles divided by the applied stress for those cycles. Many researches have proved that both ZSV and J_{nr} have a better correlation with rutting performance of mixtures prepared with different asphalt binders, including polymer modified asphalt binders (PMAs) [25–30]. The concept of DSR function (DSRFn) has been proved to be a good predicator of low-temperature cracking of asphalt pavement. Many research reports have demonstrated that DSRFn not only has a specific correlation with asphalt ductility (conducted at an intermediate temperature) but also has a extremely high correlation with the degree of m-value measured using a bending beam rheometer (BBR) near the lowest pavement temperature [31–33]. Although rheological indices mentioned above have been verified to be pavement performance-related indices, most of researches are only limited to adoption of complex modulus (G^*) and phase angle (δ) to evaluate aging behaviors of asphalt binder. Indeed, these two parameters can roughly reflect stiffness or viscoelastic balance of asphalt binder but they still lack tight and clear correlation with asphalt mixture performance.

Based on above analyses, rheological indices selected in this paper to evaluate aging behaviors of asphalt binder consisted of rutting factor ($G^*/\sin\delta$), zero shear viscosity (ZSV), non-recoverable compliance (J_{nr}), fatigue factor ($G^*\cdot\sin\delta$) and DSR function (DSRFn), which presents a clearer and tighter correlation with asphalt mixture performance than usual physical and chemical indices. Further, these rheological indices selected can characterize asphalt mixture performance in the entire range of temperature a pavement may experience: rutting factor ($G^*/\sin\delta$), zero shear viscosity (ZSV) and non-recoverable compliance (J_{nr}) correspond to high-temperature performance, fatigue factor ($G^*\cdot\sin\delta$) to intermediate-temperature performance and DSR function (DSRFn) to low-temperature performance. Moreover, complex modulus and phase angle master curves of asphalt binders at different aging conditions were also constructed by using the time-temperature superposition principle (TTSP), because it not only allowed for description of rheological characteristics over a larger scale of temperature or frequencies but also was a base on which to calculate some other rheological indices. Three asphalt binders, including one base asphalt and two commonly used PMAs, were selected as research objects. Thin film oven test (TFOT), pressure aging vessel (PAV) test and ultraviolet (UV) irradiation were adopted to simulate short-term, long-term thermal oxidation and photo oxidation aging respectively. Meanwhile, sensitivities to aging shown by different rheological indices were compared to each other. The relationships between rheological indices were also discussed.

2. Experimental and testing methodology

2.1. Materials

Three types of asphalt binders selected in this paper were 60/80 pen grade base asphalt, styrene–butadiene-styrene copolymer (SBS) modified asphalt and styrene butadiene rubber (SBR) modified asphalt. SBR modified asphalt with 3% content of SBR was prepared using high speed shearing method and detailed procedures were presented in our previous paper [13]. Other two asphalt binders were directly obtained from manufacturers. The main physical properties of three asphalt binders are shown in Table 1.

2.2. Aging procedures

TFOT and PAV were performed according to ASTM D1754 and

Table 1
Physical properties of three asphalt binders.

Asphalt	Penetration (25 °C, dmm)	Softening point (°C)	Viscosity (135 °C, mPa·s)	Ductility (5 °C, cm)
Base asphalt	63	47.9	437.5	12.7
SBR modified asphalt	59	50.8	665.6	47.6
SBS modified asphalt	54	89.2	2678.0	35.4