Construction and Building Materials 150 (2017) 520–528

Contents lists available at ScienceDirect

Construction and Building Materials

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

Advanced mechanical characterization of asphalt mastics containing tourmaline modifier

Haibo Ding [a,b], Ali Rahman [a,b], Qiushi Li [c,*], Yanjun Qiu [a,b]

[a] School of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, China
[b] Highway Engineering Key Laboratory of Sichuan Province, Southwest Jiaotong University, Chengdu 610031, China
[c] School of Civil Engineering, Northeast Forestry University, Harbin 150040, Heilongjiang, China

HIGHLIGHTS

- Evaluating the fundamental mechanical properties of tourmaline modified asphalt.
- The performance discrepancies of different kinds of modifier are compared.
- Physical properties of two kinds of commercial available tourmaline modifier are investigated.
- Tourmaline ions powder is environment friendly alternative modifier.

ARTICLE INFO

Article history:
Received 13 March 2017
Received in revised form 28 April 2017
Accepted 24 May 2017

Keywords:
Tourmaline
Modifier
Mineral filler
Asphalt mastic
Mechanical properties

ABSTRACT

Tourmaline modified bitumen as an environmentally friendly pavement material has got an increasing attention in recent years in China. In this regard, previous studies mainly focused on the linear viscoelastic properties of asphalt or asphalt mastic. In this paper, multiple stress creep and recovery (MSCR) test, linear amplitude sweep (LAS) test and double edge notched tension (DENT) test were adopted as fundamental performance evaluation methods for high-temperature rutting, fatigue, and low-temperature thermal cracking of asphalt binder, respectively. Moreover, straight run asphalt and polymer modified asphalt containing various percentages of two kinds of tourmaline as asphalt modifier were also prepared to gain the knowledge of the interaction between asphalt and tourmaline. To study the feasibility of applying tourmaline as an alternative modifier and compare its performance with conventional fillers, asphalt mastic containing limestone was also prepared. The results show that small amount of modifier can enhance the mechanical properties of asphalt binder, but different modifiers do not have similar effect. In addition, market available tourmaline additive has different chemical composition and physical properties; asphalt mastic containing tourmaline ions powder showed the best performance among modifiers utilized here.

1. Introduction

At present, the development of low-carbon economy and construction of low-carbon society have become the primary focus of China and the world. With raising awareness about environmental protection among the society and rapid economic growth during the past decades in China, more requirements for sustainable road materials have begun to put forward. Note that production of road materials is not just limited to the purpose of having good performance and durability. Consequently, having multifunctional pavement materials with low-carbon and eco-friendly properties become one of the main research directions of researchers. Over the past decades, for decreasing energy consumption and reducing greenhouse gas emissions, warm mix asphalt (WMA) [1,2], low-energy asphalt [3] and cold mix asphalt [4] widely employed. The design concept of most of the eco-friendly asphalt materials developed through adding a certain amount of additives with a special performance. Accordingly, the functional properties of corresponding road materials mainly come from additives. Note that these additives not only enhance pavement performance but they should not have a detrimental effect on it in general. To reduce asphalt pavement surface temperature during severe solar radiation in summer, Hu et al. [5–9] systematically studied using ther-

* Corresponding author.
E-mail addresses: dinghaibo@my.swjtu.edu.cn (H. Ding), a.rahman@my.swjtu.edu.cn (A. Rahman), shijiannimei@126.com (Q. Li), publicqiuyj@vip.163.com (Y. Qiu).

http://dx.doi.org/10.1016/j.conbuildmat.2017.05.203
0950-0618/

mochromic materials as asphalt additive to produce a larger solar reflectivity at high temperatures. Hassan [10,11], Shafabakhsh [12] and D Osborn et al. [13] by adding titanium dioxide (TiO_2) into asphalt tried to purify the traffic emissions.

In recent years, Wang et al. [14] suggested using tourmaline inorganic powder as an additive in asphalt to make modified asphalt. Tourmaline is a kind of inorganic material, which has the characteristics of permanent spontaneous polarization, pyroelectricity, piezoelectricity, far-infrared emission, electrolysis of water, and anion releasing. Tourmaline has strong pyroelectric performance which generates electric charges on the crystal surfaces and thus can absorb some harmful gas or certain hazardous fumes. Flame retardant and smoke suppression performance [15], pavement cooling performance [16], emission reduction effect [17], and conventional mechanical properties [14,18] of tourmaline modified asphalt showed that it can be considered as a promising and ecofriendly asphalt pavement material. Furthermore, preliminary experiments also showed that tourmaline modified asphalt meet the requirements of pavement performance. Nonetheless, previous researches mainly focused on the linear viscoelastic behavior of asphalt or asphalt mastic. Apart from this, relative researches have shown that it is difficult to establish a correlation between the Superpave asphalt binder specification criterion and field asphalt pavement performance [19]. Consequently, it is imperative to employ more fundamental asphalt test methods to precisely predict the long-term performance of asphalt pavement containing tourmaline.

In the 1990s, the US strategic highway research program (SHRP) developed Superpave asphalt binder specification system (AASHTO M320) to ensure the quality of the asphalt binder meets the requirements of road performance. AASHTO M320 specification is based on the asphalt binder rheological properties in the linear viscoelastic region, which uses $|G^*|/\sin\delta$, $G^*\sin\delta$ and, creep stiffness (S) combined with m-value as the main assessment criteria of asphalt permanent deformation, fatigue, and low-temperature thermal cracking, respectively. Although the long-term practice has shown that M320 specification can better evaluate base asphalt, but it could not differentiate the contribution of modified asphalt to pavement performance very well. Therefore, a lot of researches have been conducted on asphalt binder performance specification. Delgadillo et al. [20] developed repeat creep recovery (RCR) test aiming to separate viscous flow part which can lead to permanent deformation of asphalt from the total dissipated energy. Using irreversible loading mode during RCR test can help us to distinguish between permanent viscous strain which is one of the main reasons leading to pavement rutting and recoverable delayed elastic strain. This irreversible loading mode is a significant progress compared with reversible cycle loading mode to determine Superpave $G^*/\sin\delta$ parameter mainly because reversible cycle loading mode is very difficult to separate the viscous and delayed elastic strain energy. D'Angelo et al. [21] hold the opinion that creep and recovery under single stress are not able to accurately capture the nonlinear viscoelastic behavior of binder may exist, especially for the polymer modified asphalt. Therefore, multiple stress creep and recovery (MSCR) test was developed [22]. Given that asphalt binder fatigue is a nonlinear damage process, it has not been damaged during determination of $G^*\sin\delta$ parameter. Time sweep test was developed to better characterize the fatigue of asphalt binder [23], but this test needs a long time to finish. To remedy this deficiency, viscoelastic continuum damage (VECD) theory was introduced into asphalt binder fatigue test, using linear amplitude sweep (LAS) as a binder fatigue test method [24]. As for the asphalt binder, low temperature cracking characterization, it is believed that compared with the traditional bending beam rheometer (BBR) test, fracture mechanics based test can better recognize polymer contribution. Single-edge notch bending (SENB) test [25], compact tension test [26], fracture energy test [27], asphalt binder cracking device (ABCD) test [28], and double edge notched tension (DENT) test [29,30] were developed for asphalt binder fracture evaluation. Compared to other asphalt binder fracture tests, DENT test seems can better detect the adverse impact of some detrimental additives [31–33].

In this paper, MSCR, LAS and DENT tests were adopted as asphalt binder fundamental performance evaluation methods for high-temperature rutting, fatigue, and low-temperature thermal cracking, respectively. In addition, straight run asphalt and polymer modified asphalt containing different percentages of two kinds of tourmaline as modifier were also prepared to get the knowledge of the interaction between asphalt and tourmaline. To study the feasibility of using tourmaline as an alternative modifier and compare the performance differences between varying types of modifier, asphalt mastic containing conventional filler was also prepared. In this regard, modifiers of tourmaline, tourmaline ions powders, and limestone filler at two different volume fractions, 5 and 25% were applied.

2. Materials and methods

2.1. Materials

2.1.1. Tourmaline additive

Tourmaline can be classified as ordinary tourmaline powder (referred to tourmaline powder additive in this paper) and tourmaline ions powder (referred to tourmaline ions powder additive in this paper). Two types of market available tourmaline materials one, tourmaline powder with the fineness of 325mesh and another, tourmaline ions powder whose negative ion release quantity is 5000ions were chosen as two modifiers of asphalt binder. Limestone additive which is a common used filler in asphalt mixture also included in the test matrix to discuss the preliminary feasibility of using tourmaline as an alternative additive. Table 1 shows the basic physical properties of tourmaline and limestone additives used in this study. Table 2 shows the chemical composition analysis of tourmaline used in this study.

2.1.2. Asphalt

In this study, 60/80 penetration grade (#70) straight run Korean SK base asphalt and finished SBS modified asphalt were used to explore the effect of modifier on the performance of different kinds of asphalt. The test results for #70 straight run SK base asphalt and SBS modified asphalt are shown in Table 3.

2.1.3. Preparation of asphalt mastic

The straight run SK base asphalt binder and SBS polymer modified asphalt were mixed with tourmaline or limestone at two different volume fractions—5 and 25%—to produce mastics. First, asphalt binder was heated up to the 135 °C, and then different kinds of modifiers were added to the heated asphalt binder slowly. During this 50 minutes' procedure, the high shear mixer was set at 5000 rpm to make the additive evenly distributed in the asphalt binder.

2.2. Test methods

2.2.1. Multiple stress creep and recovery (MSCR) test

Before performing MSCR test, asphalt binder or mastic was subjected to rotating thin film oven aging (RTFO) test to simulate short-term aging. The TA discovery series hybrid rheometer (DHR-2) was used to perform MSCR test. Two stress levels of 0.1 kPa and 3.2 kPa were chosen to simulate linear and nonlinear stress state of asphalt thin film, respectively. Thirty cycles of creep and recovery were performed at each stress level which consists of 1 s creep and 9 s recovery. Owing to the unstable state at the first ten cycles of creep and recovery, only the last twenty cycles were used to obtain the parameter as per the requirements of Ontario ministry of transportation. Fig. 1 presents the typical strain versus time curve obtained from MSCR test. According to AASHTO T350 and relative researches[35,36], here we just chose non-recoverable creep compliance (J_{nr}) and percent recovery (R) under 3.2 kPa for the purpose of comparison since asphalt pavement rutting mostly occurs under nonlinear region.

2.2.2. Linear amplitude sweep (LAS) test

LAS is an accelerated fatigue test based on the theory of viscoelastic continuum damage (VECD). According to Kim's research result [37], viscoelastic continuum damage (VECD) can better describe accumulated damage occurrence during repeated loading. LAS test was performed on PAV aged sample at intermediate temperatures using 8 mm parallel plate of the dynamic shear rheometer (DSR). The test temperature is an important parameter of LAS test as reported by Hintz [38]. Flow