Construction and Building Materials 174 (2018) 202–209

Contents lists available at ScienceDirect

Construction and Building Materials

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

Damage characteristics of waste engine oil bottom rejuvenated asphalt binder in the non-linear range and its microstructure

Yanjun Qiu [a,b], Haibo Ding [a,b,*], Ali Rahman [a,b], Wenqi Wang [c]

[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, Architecture and Environmental Engineering, Xihua University, Chengdu 610039, China

HIGHLIGHTS

- Comparison study on the damage characteristics of two rejuvenated asphalt binders.
- Fatigue performance of WEOB is more suitable in thin asphalt pavement layers.
- DENT test is an effective method to evaluate the physical hardening of asphalt binder.
- Different performance of regenerated asphalt binder after extended conditioning time.

ARTICLE INFO

Article history:
Received 3 November 2017
Received in revised form 3 April 2018
Accepted 6 April 2018

Keywords:
Waste engine oil bottom (WEOB)
Recycling agent
Non-linear range
Damage characteristics

ABSTRACT

This paper aims to compare the damage characteristics of the waste engine oil bottom (WEOB) rejuvenated asphalt binder with aromatic extract oil rejuvenated asphalt binder in the non-linear range. To fulfil this objective, the aged asphalt binder was prepared by aging SBS modified asphalt binder in the laboratory. High temperature, fatigue and low-temperature damage characteristics in the non-linear range were evaluated by conducting multiple stress creep and recovery (MSCR) test, linear amplitude sweep (LAS) test and double edge notched tension (DENT) test, respectively. The microstructure of rejuvenated asphalt binders was characterized by environmental scanning electron microscope (ESEM). The results showed that although the performance of aged asphalt binder can be restored to some extent with two recycling agents, however after conditioning in the bath for 120 h, the two rejuvenated asphalt binders exhibited different ductile states. The microstructure of rejuvenated asphalt binders revealed that WEOB rejuvenated asphalt binder presented a more gelation transition than aromatic extract oil rejuvenated asphalt binder which could be considered as the main reason for the reduction in the ductile performance of WEOB rejuvenated asphalt binder.

1. Introduction

It is well recognized that three primary failure modes of asphalt pavement are high-temperature permanent deformation, fatigue cracking caused by repeating load and non-load related cracking at low temperature. Asphalt binder plays an essential role in asphalt pavement behavior under different circumstances such as climates and loadings. Using low-quality asphalt binder may deteriorate common distresses of asphalt pavement. Using high-quality asphalt binder, however, is an efficient way to mitigate or even eliminate these failure modes [1]. Application of reasonable test methods to evaluate the performance-based properties of the material is the traditional method of the quality control during pavement construction. Superpave binder specification system (AASHTO M320) was developed during SHRP program to verify that whether the quality of asphalt binder meets the requirement of pavement performance or not. This standard is based on the linear viscoelastic properties measured at pavement service temperature [2]. Long-term practices showed that AASHTO M320 specification could better distinguish the performance differences among unmodified asphalt binders. However, it cannot identify the effect of modifier on the pavement performance, and even well-controlled pavements with the same performance grade (PG) may perform entirely different [3–5]. Therefore, extensive modifications were made to current Superpave PG specification.

* Corresponding author at: School of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, China.

E-mail addresses: dinghaibo@my.swjtu.edu.cn (H. Ding), a.rahman@my.swjtu.edu.cn (A. Rahman), wangwenqi88@yeah.net (W. Wang).

https://doi.org/10.1016/j.conbuildmat.2018.04.056
0950-0618/

Repeated creep-recovery test (RCRT) was developed during NCHRP 9–10 to better separate viscous flow part, which can lead to permanent deformation, from total dissipated energy [6]. Compared with reversible loading mode, which is used for the determination of asphalt binder rutting parameters, irreversible loading mode is used in RCRT, which can separate non-recoverable viscous strain energy from recoverable delayed elastic strain energy [7]. D'Angelo et al. [8] proposed multiple stress creep and recovery (MSCR) test to reduce the test time for creep and recovery test and characterize the stress dependency of polymer modified asphalt binder. Linear amplitude sweep (LAS) test was recommended as a surrogate for the traditional time sweep fatigue test which is consisted of repeated cyclic loading at constant amplitude [9]. The time sweep fatigue test is considered unsuitable for asphalt binder specification ranking because of the ambiguity in the required time to induce and quantify fatigue [10]. For asphalt binder low-temperature characterization, many shortcomings of regular Superpave direct tension test (DTT) have been reported [11–13]. The most significant issue is its low repeatability. This defect can be explained using the theory of molecules orientation [11]. After cooling DTT test sample, molecules inside the sample molds may develop uniform or nonuniform orientation. Uniform orientation leads to higher strength, that is, higher failure stress of asphalt binder. Fracture mechanics-based test methods have got more attention in recent years. Three-point bending fracture test [14,15] (CEN/TS 15963:2014), double-edge notched tension (DENT) test [16,17] (LS-299 and AASHTO TP 113-15), asphalt binder cracking device (ABCD) test [18], cyclic shear cooling (CSC) failure test [19], and acoustic emission (AE) approach [20] all claimed as effective ways for evaluating the low-temperature fracture potential of asphalt binders. In order to better gain the knowledge of macroscopic damage properties of asphalt binders, some microstructure characterization methods were also employed [21,22].

On the other hand, with the lack of natural mineral resources and continuous rising price of crude oil around the world, the demand for using high percentage of reclaimed asphalt pavement (RAP) materials in asphalt pavement or other infrastructures has been continued to rise. Increasing proportion of RAP materials in asphalt binder mixture has also gradually become a topical subject in the field of road engineering [23–25]. One of the different approaches to increase RAP proportion in asphalt mixture is the application of recycling agent [26–30]. Recycling agent should restore the fatigue and low-temperature fracture resistance properties of aged asphalt binder while should have no detrimental effect on the high-temperature rutting resistance properties of regenerated asphalt binder. Owing to the carcinogenic effect of traditional rejuvenators, application of bio-derived rejuvenators such as those produced from soybean oil and vegetable oil are increasing. [31–33]. In recent years, the application of waste engine oil bottom (WEOB) in asphalt binder has been received considerable attention [34–37]. The main reason lies in the fact that it can decrease the regular AASHTO M320 low-temperature PG while it would not significantly reduce the high-temperature PG of asphalt binder used in regions where straight-run asphalt binder cannot be found easily [38]. Furthermore, waste engine oil is a waste material which may pollute the environment in case of improper treatment. Its utilization in asphalt pavement not only can decrease the construction costs but also can diminish its negative environmental effects. Nevertheless, previous publications mainly focused on using WEOB as an asphalt binder modifier rather than a recycling agent, and consequently, most of the existing evaluations just measured the viscoelastic properties within the linear range. There is a distinct lack of in-depth research regarding damage properties of regenerated asphalt binder within non-linear range. In addition, very few studies performed a comprehensive analysis of combining damage properties within non-linear range and the microstructure of regenerated asphalt binder to evaluate reasonably the regenerative effect of various kinds of recycling agents. All things considered, this paper aims to assess the high temperature, fatigue and low-temperature damage characteristics of WEOB rejuvenated asphalt binder in the non-linear range by performing multiple stress creep, and recovery (MSCR) test, linear amplitude sweep (LAS) test, and double-edge notched tension (DENT) test, respectively. Meanwhile, the changing trends of critical crack tip opening displacement (CTOD) of two kinds of rejuvenated asphalt binders at different conditioning times were compared. The microstructure of rejuvenated asphalt binders was characterized by environmental scanning electron microscope (ESEM).

2. Materials and methods

2.1. Materials

2.1.1. Asphalt binders

Original asphalt binder used in this study is a styrene-butadienestyrene (SBS) three-block polymer modified asphalt binder which is widely used in Sichuan, China. Original asphalt binder was aged in rolling thin film oven (RTFO) according to the method adopted by Cong et al. [39]. Note that the primary failure mode of regenerated asphalt binder mixture is low-temperature cracking caused by embrittlement of oxidized asphalt binder while the high-temperature rutting is not predominant distress due to the high stiffness of aged asphalt binder. Consequently, the dosage of recycling agent applied in this study was based on achieving similar low-temperature PG of original asphalt binder. The dosage of aromatic extract oil (AO) and WEOB recycling agents determined as 7.3% and 8% (mass of aged asphalt binder), respectively. The fundamental properties of original, aged and regenerated asphalt binder are shown in Table 1.

2.1.2. Recycling agent

In this study, AO was also used along with WEOB as a recycling agent to compare regeneration effects. Table 2 shows the basic properties of recycling agent used in this study. It should be noted that unlike reported natural organic recycling agents such as waste cooking oil [40] and sunflower seed oil [41], the recycling agent used in this study is the product of petroleum refinery.

2.2. Test methods

2.2.1. Multiple stress creep and recovery (MSCR) test

According to AASHTO M332-14 (2014), the MSCR test should be conducted on RTFO-conditioned asphalt binder using AASHTO T315(DSR). The procedure of this test follows the AASHTO T350-14(2014) or ASTM D 7405-15(2015) standards. The 25-mm parallel plate geometry was used with a 1-mm gap setting. The sample was tested in the creep mode at two stress levels followed by recovery at each stress level. The stress levels used are 0.1 kPa and 3.2 kPa. The creep portion of the test lasts for 1 s, followed by a 9 s recovery. Ten creep and recovery cycles were tested at each stress level. For highly polymer modified asphalt binder, the higher stress level was needed to characterize the nonlinear behavior of asphalt binder sample realistically. MSCR is designed to identify the presence of an elastic response in a binder and changing of elastic response at two different stress levels while being subjected to ten cycles of creep stress and recovery. Two performance parameters have been suggested, namely the non-recoverable compliance (J_{nr}) and the percent recovery (R) to evaluate rutting resistance of asphalt binders.