Construction and Building Materials 149 (2017) 826–836

Contents lists available at ScienceDirect

Construction and Building Materials

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

Preliminary examination of soybean oil derived material as a potential rejuvenator through Superpave criteria and asphalt bitumen rheology

Mohamed Elkashef [a,*], Joseph Podolsky [a], R. Christopher Williams [a], Eric Cochran [b]

[a] Iowa State University, Department of Civil, Construction, and Environmental Engineering, Ames, IA 50011-3232, United States
[b] Iowa State University, Chemical and Biological Engineering Department, Ames, IA 50011-3232, United States

HIGHLIGHTS

- A soybean derived material was added at 0.75% to a PG64-28 and a PG58-28 binders.
- Rheology of the blends was studied by DSR, BBR, and rotational viscometer.
- A significant drop in the binder's critical high and low temperatures was noted.
- Results indicated a notable improvement in fatigue performance upon modification.
- The soybean derived material showed sustained performance with RTFO and PAV aging.

ARTICLE INFO

Article history:
Received 7 December 2016
Received in revised form 12 April 2017
Accepted 23 May 2017

Keywords:
Rejuvenator
Complex shear modulus
Bitumen modification
RAP

ABSTRACT

The increased use of recycled asphalt materials in bituminous mixtures has led to increasing interest in rejuvenators. Rejuvenators are primarily used to restore the rheological properties of aged bitumens to their unaged state. In this work, the effect of adding a soybean-derived biomaterial at a 0.75% by mass of bitumen to a polymer modified PG64-28 and a neat PG58-28 is studied. Dynamic Shear Rheometer, Bending Beam Rheometer, and Rotational Viscometer are used to characterize the bitumens rheology. The effect of aging on the longevity of the soybean additive is examined. It was revealed that this material is a viable candidate as a rejuvenator. At such low dosage, it had a remarkable effect on the fatigue and low temperature properties of both bitumens. It also led to a notable decrease in the complex shear modulus accompanied by an increase in the phase angle, which is essentially reversing the effect of aging.

1. Introduction

In the past years, the interest in using reclaimed asphalt pavement (RAP) has been growing rapidly. This rise in interest is motivated by a number of reasons including a desire to reduce cost, preserve the environment, and conserve energy. With the increasing bitumen prices and dwindling supply of higher quality virgin aggregate, there is a compelling need to use larger amount of less expensive RAP to replace the more expensive virgin bitumen and aggregates. Despite the need to use higher proportions of RAP, a recent survey, conducted on the use of recycled materials in asphalt pavements, revealed that the average percentage of RAP in the US has only increased from 15% in 2009 to 20% in 2014 [1]. Such reluctance to use more RAP in asphalt pavements stem from the fact that the aged RAP bitumen has undesirable high stiffness and low creep rate, which makes it susceptible to low temperature thermal cracking [2]. Accordingly, using higher percentages of RAP produces very stiff mixes which are difficult to field compact, and can result in unexpected premature failure [3].

Several techniques are being implemented to allow for the use of RAP in asphalt mixes, including mixing with a softer virgin bitumen, using higher asphalt content mixtures, and using warm-mix technology to minimize the short-term aging effect and to lower asphalt absorption [4]. These techniques are suitable for lower RAP content mixtures, however they failed to allow for the use of higher RAP content. For instance, the use of softer virgin bitumen would compensate the aging of the RAP bitumen for low RAP content mixes but its effect on high RAP content mixes would be insignificant [5]. In this regard, rejuvenators have shown to be a very attractive alternative in that they can lead to higher RAP content. Rejuvenators have proven to be very efficient in restoring the aged bitumens to their original state. With the increase in popularity of hot-in-place pavement recycling (HIR), rejuvenators are becoming even more important. In HIR, old pavements are heated

* Corresponding author.
E-mail address: mkashef@iastate.edu (M. Elkashef).

http://dx.doi.org/10.1016/j.conbuildmat.2017.05.195
0950-0618/

and milled in place before being mixed with virgin aggregates, virgin bitumen, and a rejuvenator.

Asphalt is composed of four distinct chemical fractions, namely asphaltenes, resins, aromatics, and saturates. Resins, aromatics, and saturates are collectively referred to as maltenes. The high molecular weight asphaltenes forms a colloidal suspension in low molecular weight maltenes. The asphaltene content has a great influence on asphalt viscosity. In a recent study, increasing the asphaltene content by addition of propane deasphaltene tar (PDA) resulted in a noticeable increase in the penetration index, a similar effect was also noted with aging [6]. Apart from the asphaltene content, the resins also play an important role since they act as dispersing agents to the asphaltenes. The ratio of resins to asphaltenes is an important parameter that controls the degree of dispersion of asphaltenes and accordingly the asphalt viscosity [7].

Rejuvenators are chemical or bio-derived additives which typically contain a high proportion of maltenes, which serves to replenish the maltene content in the aged bitumen that has been lost as a result of oxidation [8]. The addition of maltenes helps rebalance the chemical composition of the aged bitumen, which contain high percentage of asphaltenes. Rejuvenators are added during mixing and are believed to diffuse within the aged bitumen imparting softening characteristics. The rejuvenator initially coat the outside of the RAP aggregates before they gradually seep into the aged bitumen layer until they diffuse through the film thickness [9].

A number of studies have investigated the performance of rejuvenated bitumens and resulting asphalt mixtures. The main focus of these studies was to investigate the effect of rejuvenators on the stiffness of the aged bitumen and the low temperature cracking resistance of the produced asphalt mixtures [10–12]. It has been concluded that rejuvenators successfully reduce the aged bitumen stiffness and notably improve the low temperature cracking resistance of the resulting mixture [13,14]. The selection of the rejuvenator dosage was found to have a great influence on the effectiveness of the treatment [15]. It was suggested that blending charts could be used to obtain an optimum dosage that meets the requirements of the bitumen specifications. Determining the proper dose is crucial since a higher dosage may cause undesirable excessive softening of the bitumen, which may lead to performance problems such as rutting. The rejuvenated bitumen properties can be determined through extraction of the aged bitumen, blending with the rejuvenator, and subsequent testing. Such technique, however, assumes perfect blending between the rejuvenator and the aged bitumen, which does not necessarily reflect actual conditions. During actual mixing, the rejuvenator might not diffuse fully through the aged asphalt film thickness.

The performance of mixes which involve RAP is controlled to a large extent by the degree of blending between the RAP bitumen and the virgin bitumen in addition to the effective percentage of RAP bitumen which contribute towards the total asphalt content [16]. Through the use of rejuvenators, the RAP bitumen becomes less stiff and can thus blend more easily with the virgin bitumen.

Aged RAP bitumens are characterized as having a high relative viscosity. The high viscosity can lead to poor mixing and compaction, hence the study of the rejuvenator's effect in reducing the viscosity is very important. Achieving low viscosity ensures that the bitumen has sufficient flow to properly blend with the virgin bitumen and to uniformly coat both virgin and RAP aggregates. It is equally important for the rejuvenator to be able to lower the RAP bitumen viscosity to acceptable levels without the need for high dosages. High dosages of rejuvenators could lead to potential rutting, stripping and mix instability problems [11]. The study of the temperature-viscosity dependence of the rejuvenated aged bitumen is also important because high mixing temperatures could damage the bitumen so it is advantageous to have an effective rejuvenator which would promote low mixing temperatures at a low dosage.

Rejuvenators vary greatly according to their chemical composition and origin. Numerous research efforts have been directed to assessing the performance of commercially available rejuvenators, as well as proposing new materials to act as rejuvenators. Materials derived from distilled tall oil, petroleum based aromatic extract, and organic oil have been successfully applied as rejuvenators [17]. Organic oil bio-derived rejuvenators have been presented as a more safe alternative to the carcinogenic polar aromatic oil rejuvenators [12]. Organic oils have been successfully used by the Florida Department of Transportation (FDOT) for mixes that contain 40% RAP. Two trial sections were constructed on I-95 using 0.75% of the organic oil by weight of RAP in 2009. Other DOTs have reported using organic oil at varying RAP contents such as the Texas DOT with 35% RAP and 5% RAS, and the New York City DOT with 20% RAP [12]. A study conducted by Zaumanis et al. [17] investigated the performance of six different rejuvenators including waste engine oil, distilled tall oil, waste vegetable oil, waste vegetable grease, organic oil, and aromatic extract. The study was performed on mixes using 100% RAP, with a 12% rejuvenator dosage by mass of RAP bitumen. It was shown that organic-based rejuvenators were more efficient in lowering the low temperature performance grade (PG) of the rejuvenated bitumen compared to petroleum-based rejuvenators. It was also shown that none of the rejuvenators significantly reduced the high temperature PG, which indicates that with the use of an appropriate rejuvenator dosage, rutting should not be a concern. All of the six rejuvenators seemed to work efficiently at this dosage except for waste engine oil which did not meet the low temperature grade and resulted in high mass loss, which indicates volatility and increased aging susceptibility.

A number of studies have addressed the issue of durability of rejuvenated asphalt. In the work done by Shen et al. [18], mixtures containing 48% RAP and 12.5% rejuvenator, by mass of RAP bitumen, were evaluated for rutting in an asphalt pavement analyzer (APA) and for moisture sensitivity using indirect tensile strength (ITS) tests. It was shown that the performance of the rejuvenated mixes was better than the control RAP mixes prepared with a softer virgin bitumen. A recent study investigated the long-term aging behavior of rejuvenated bitumen prepared using five different rejuvenators [19]. It was revealed that the long-term aging effect differed greatly among rejuvenators. Two of the rejuvenators, namely aromatic extract and a water-based emulsion from naphthenic crude, caused slowing down of the aging rate compared to virgin bitumens while the other three, namely petroleum neutral distillate, oil-based bio-rejuvenator and a polyol ester pine, accelerated aging. Study of long-term cracking and fatigue resistance of rejuvenated mixes was performed on full-depth asphalt pavement specimens [19]. The long-term aging was simulated using an Accelerated Pavement Weathering System (APWS). APWS simulates real weather conditions including rain, sunshine and temperature fluctuations. The Texas Overlay Test, as described in TEX-248-F [20], was performed to assess fatigue and cracking resistance for specimens subjected to 0, 1000, and 3000 h of APWS aging. The results indicated that the rejuvenated mixes showed better fatigue and reflective cracking resistance compared to the virgin mixes. It was shown that rejuvenated asphalt mixtures showed better performance in terms of fatigue and reflective cracking compared to virgin asphalt mixtures, even after 3000 h of APWS aging [19].

The effectiveness of the rejuvenator is also related to the bitumen's chemical composition. A specific rejuvenator could work effectively for one bitumen but not another. Two bitumens from different crude sources, namely AAD (PG 58–28) and ABD (PG 58–10) from the Federal Highway Administration's Material Refer-