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Improving fatigue and low temperature performance of 100% RAP mixtures using a soybean-derived rejuvenator

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HIGHLIGHTS

- A virgin PG58-28 binder was modified using 6% and 12% soybean-derived material.
- An extracted RAP binder was rejuvenated using the soybean-modified PG58-28 binder.
- Rejuvenated RAP showed great reduction in the critical high and low temperatures.
- Rejuvenation led to a notable improvement in the RAP binder fatigue resistance.
- 100% RAP mixtures using soybean-modified PG58-28 showed increased fracture energy.

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ABSTRACT

One of the major obstacles towards higher mixture percentages of reclaimed asphalt pavements (RAP) is its greater susceptibility to failure under low temperatures and fatigue loading. Rejuvenators offer a very attractive solution by partially or fully restoring the aged properties of the RAP binder. In this research, a soybean-derived rejuvenator is used to modify a PG58-28 binder at 6% and 12% by weight. The soybean-modified PG58-28 and a neat PG58-28 are blended with an extracted RAP binder. Changes in the rheological properties of the different blends are assessed using performance grading (PG), temperature-frequency sweep and linear amplitude sweep (LAS) testing. RAP mixtures made of 100% RAP with the addition of neat PG58-28 or soybean-modified PG58-28 were used to prepare dynamic modulus and disk-shaped compact tension (DCT) specimens. The binder testing results clearly indicate that the soybean-derived rejuvenator has a significant impact on both the low and high temperature properties of the RAP binder. Such improvement was not attainable by using the neat PG58-28 alone. The soybean-derived rejuvenator also shows sustained durability with aging. The LAS results indicate a significant increase in the fatigue life of the soybean rejuvenated RAP binder. Results of dynamic modulus testing do not reveal significant differences between the various mixtures. The fracture energy of the mixtures prepared with the soybean rejuvenator is higher than the control mixtures as revealed by DCT test results.

1. Introduction

Over the past several years, there has been an increasing interest in reclaimed asphalt pavement (RAP) owing to the increase in virgin binder and aggregate costs and RAP being readily available. Environmental concerns over binder production as well as the declining supply of good virgin aggregates are also strong reasons in favor of more RAP usage. The current low trends in using RAP, which did not exceed 20% RAP in new mixtures during the year 2014, is attributed to the deteriorated properties of the RAP binder [1]. Aged RAP binder exhibits high stiffness and low stress relaxation ability as a result of excessive oxidation [2]. Additionally, high RAP content mixtures tend to be difficult to field compact and can lead to unexpected premature failure [3].

A number of techniques have been devised to mitigate the effect of RAP including adding a softer virgin binder, increasing the asphalt content, and utilizing warm-mix technology to lessen the effect of short-term aging and lower asphalt absorption [4]. These techniques seem to be appropriate for mixtures with low RAP content however they fail to provide satisfactory results with increasing RAP content [5]. Rejuvenators have provided the impetus for researchers to further investigate mixtures with increasing RAP content. Rejuvenators are added to aged binders to help partially or fully restore their aged properties to its original state.

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During aging, the maltenes fraction in the asphalt is converted to the more viscous asphaltenes fraction by means of oxidation. Asphaltenes, with higher molecular weight, tend to form a colloidal suspension in the lower molecular weight maltenes. Asphaltenes is largely responsible for the viscosity of asphalt materials [6]. An increase in asphaltenes due to aging result in high stiffness and low creep rate. Rejuvenators reverse the effect of aging by either providing more maltenes to balance the excess amount of asphaltenes, or by allowing better dispersion of asphaltenes [7]. Several studies have examined the low temperature properties and stiffness of aged binders upon rejuvenation [7,8]. It was shown that rejuvenators improve low temperature cracking resistance and reduce the aged binder stiffness. A number of rejuvenators have been proposed including petroleum based aromatic extracts, distilled tall oil, and organic oil [9].

The durability of rejuvenators is crucial to their proper usage. Softening agents containing volatile compounds can only provide a temporary reduction in stiffness to aid compaction. Upon volatilization of these compounds, the softening agents can no longer provide additional enhancement to the mixture. Rejuvenators need to have a prolonged effect on the asphalt mixture properties. In a recent study, the long-term aging performance of five different rejuvenators was studied [10]. It was shown that the studied rejuvenators differ greatly in terms of their durability performance. Some rejuvenators improved the aging rate compared to the virgin binders whereas others accelerated aging. The chemistry of the interaction between the rejuvenator and the binder is also very important. A recent study showed that an aromatic extract rejuvenator worked effectively for a PG58-10 and not as effectively with a PG58-28 binder [2].

Cracking induced by fatigue is considered a primary mode of distress in asphalt pavements. The viscoelastic properties of the asphalt binder determine to a great extent the fatigue performance of asphalt mixes [11]. The fatigue resistance of binders is currently characterized using the fatigue parameter, $G^* * sin\delta$. This parameter is determined using Dynamic Shear Rheometer (DSR) measurements at 1% strain rate, as per AASHTO T315, to ensure that the binder remains within the linear viscoelastic region. Such approach has failed to capture the performance of binders under destructive loading which results in accumulated damage [11]. The Time sweep (TS) test was introduced based on the work done on NCHRP Project 9–10 [11,12]. The TS test is conducted using a DSR on RTFO +PAV aged binder with an 8-mm-diameter geometry. In this test a repeated cyclic load is applied under constant strain rate until failure. Failure is typically marked by a 50% drop in G^* [13]. The choice of the constant strain rate at which to run the test is determined to reflect the pavement structure and traffic conditions. A major drawback of the TS test is the uncertainty in testing time and the fact that it can take several hours to perform. Additionally, such elongated testing time may cause steric hardening of the binder, which could skew the results [14]. Recently, the Linear amplitude sweep test (LAS) was introduced as an efficient test to characterize fatigue in binders [15]. Similar to the TS test, the LAS test uses an 8-mm-diameter and a 2-mm gap geometry, to apply a repeated cyclic load to the binder sample. In the LAS test however, an increasing strain rate is applied to induce accumulated damage. In a recent study that investigated the use of six different recycling agents on the fatigue life of 100% RAP mixtures, LAS testing was used to evaluate the number of cycles to failure for all rejuvenated blends [8]. It was concluded that the bio-derived recycling agents were superior to the petroleum based recycling agents. The bio-derived recycling agents increased the number of cycles to failure in the RAP binder to a level comparable to that of the virgin binder. In another study, LAS testing was used to assess the fatigue performance of a RAP binder blended with both a soft and a stiff virgin binders at both 20% and 50% RAP binder content. It was shown that the fatigue life increased with higher amounts of RAP binder. It was also concluded that using a softer binder in lieu of a stiff binder led to better performance compared to increasing the stiff virgin binder content [16].

Using RAP can have a great impact on the low temperature cracking potential of asphalt mixtures. Hence, it is important to assess the low temperature properties of mixtures prepared with RAP. The disk-shaped compact tension (DCT) is one of the commonly used tests to assess low temperature cracking resistance [17]. The DCT test gives the fracture energy, in J/m^2, for a crack to propagate through a notched specimen under a displacement-controlled tensile loading. A comprehensive study that correlated fracture energy to field performance showed that a fracture energy between 350 and 400 J/m^2 marks a sufficient resistance against thermal and reflective cracking [18]. Minimal occurrence of transverse cracking was found in mixtures with fracture energies above 400 J/m^2 [18]. A recent investigation that looked into the effect of different percentages of recycled materials into asphalt mixtures was conducted at Iowa State University and the University of Illinois Urbana-Champaign [19]. This study looked at low temperature performance of eight different mixtures, containing various percentages of RAP and recycled asphalt shingles (RAS), used in the construction of Illinois Tollway (I-90). DCT testing done at -12 °C revealed that the fracture energy decreased with the addition of recycled materials, with the specimens containing 50% recycled materials failing to meet the minimum threshold of 350 J/m^2 [19]. DCT testing was also used to assess the effect of aging on the low temperature fracture behavior of asphalt mixtures [20]. It was concluded that fracture energy decreased consistently with longer hours of aging. With aging, an increase in the peak load was noted followed by a steep drop in the load resulting in an overall less area under the load-displacement curve hence less fracture energy.

Previous studies have shown that the soybean-derived additive was successfully applied to reduce the stiffness and enhance the low temperature properties of both a polymer modified PG 64-28 and a neat PG 58-28 binders [21]. Fourier transform Infrared-Attenuated total reflection (FTIR-ATR) analysis has verified the durability of the binders rejuvenated with the soybean-derived additive by examining changes in the carbonyl and sulfoxide indices with aging. In this work, the soybean-derived additive is used to modify RAP binders and to prepare 100% RAP mixtures.

2. Materials and methods

A PG58-28 and a soybean-derived rejuvenator was used for this study. The reclaimed asphalt pavement (RAP) used in this study was milled from pavements in the State of Iowa, USA. The RAP was crushed to a nominal maximum aggregate size of 12.5 mm, and dried in an oven at 110 °C. The RAP gradation is given in Table 1. The RAP binder content was determined to be 5.1% using an ignition oven. Extraction of the RAP binder was performed as per ASTM D2172-Method A- using toluene as a solvent. Subsequent recovery of the RAP binder was done by the aid of a rotary evaporator as specified in ASTM D5404. A nitrogen blanket was pumped over the binder solution continuously to eliminate any oxidation of the RAP binder

Table 1
RAP gradation.

Sieve size (in.)	Sieve size (mm)	Percent passing
3/4	19	100
1/2	12.5	91
3/8	9.5	82
#4	4.75	57
#8	2.36	42
#16	1.18	26
#30	0.6	14
#50	0.3	12
#100	0.15	10
#200	0.075	8