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Application of a bio-binder as a rejuvenator for wet processed asphalt shingles in pavement construction

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HIGHLIGHTS

- Bio-binder led to improvement of recycled asphalt shingle (RAS) properties.
- Addition of bio-binder improved low temperature properties of RAS asphalt.
- Ten percent bio-binder alleviated negative impacts of RAS on asphalt.
- Bio-modified RAS showed four degree improvements in cracking temperature.
- Rheological properties of RAS asphalt was improved after bio-modification.

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ABSTRACT

This paper investigates the merits of application of bio-binder to enhance rheological properties of asphalt binder in the presence of wet processed recycled asphalt shingles (RAS). It will further examine the performance and workability of asphalt designed with and without a specified percentage of a bio-binder produced from swine manure and RAS. Bio-binder was introduced to liquid asphalt binder modified with four different percentages of RAS; the high and low temperature properties of each RAS modified binder were then investigated. The study results showed that the addition of bio-binder led to a reduction of viscosity in the RAS modified binder to be closer to that of the virgin binder (without presence of RAS). In addition, it was found that the ductility and fracture energy of the RAS modified asphalt binder was improved significantly when bio-binder was introduced. Overall, the results show that the bio-binder improved the low temperature characteristics of RAS modified asphalt binder; the observed improvement can be attributed to the rejuvenating effect of bio-binder while also improving the blending between the RAS particles and the virgin binder.

1. Introduction

According to a survey conducted by the National Asphalt Pavement Association (NAPA), under contract to Federal Highway Administration (FHWA), about 68.3 million tons of reclaimed asphalt pavement (RAP) and 1.86 million tons of reclaimed asphalt shingles (RAS) were used in new asphalt pavement mixes in the United States in 2012. The reported amount of 1.86 million tons of RAS application reflects an almost 95 percent increase since 2009 [1]. Currently, 33 of the 50 US states reported RAS usage in 2012 [2]. This movement toward sustainability in pavement infrastructure saved the asphalt industry approximately 21.2 million barrels of liquid asphalt equivalent to nearly $2.2 billion. [2]. In spite of the fact that many road authorities and State Departments of Transportation allow usage of RAS in pavement construction, only a small percentage of shingles is diverted from landfills. This is mainly due to the technical challenges such as the difficulty in reducing variability and the moisture level in RAS as well as performance issues caused by the lack of adequate and consistent blending between the RAS binder and virgin asphalt binder. Therefore, this paper studies the effects of introducing bio-binder to enhance blending between RAS and virgin asphalt binder using wet processing.

2. Background

With increasing emphasis on pavement sustainability and promoting the use of alternative resources for asphalt binder, there

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have been many studies on the application of higher percentages of RAS [2]. It is estimated that approximately 10 million tons of Post-Consumer Tear-Off Scrap Shingles (TOSS) and one million tons of Manufactured Waste Scrap Shingles (MWSS) are being generated in the United States annually [3]. Each roofing shingle is composed of approximately 53% mineral aggregate with an average asphalt binder content of 28%; therefore, the recycling of one ton of asphalt shingles would be equivalent to avoiding the use of one barrel of oil [3,4]. However, only approximately 20% of the 11 million tons of annually produced scrap roofing shingles are reused in HMA amongst the 33 states that allow RAS in asphalt paving construction [2,5,6].

It has been reported that the inclusion of RAS in asphalt mixtures can reduce susceptibility to rutting or permanent deformation at intermediate pavement temperatures; in addition, the use of RAS in pavement construction can lead to an annual asphalt binder savings of $1.1 billion [7]. However, it is well documented that the use of oxidized/aged binder, such as recycled asphalt pavement (RAP) and recycled asphalt shingle (RAS) in new construction, can adversely affect the mixture's low temperature performance [6–11]. Therefore, the accepted percentage for the use of RAS in new pavement construction, by current means of dry blending, is less than or equal to 5% [12–15]. This limits the utilization of the vast supply of waste shingles being annually generated in the U.S, and despite the merits of using RAS in pavement construction; significant amounts of shingles end up in landfills which are compounding annually.

Although adding recycled materials such as RAP and RAS to pavement construction has significant economic and environmental benefits, their excessive application without pretreatment and modification could lead to undesirable pavement performance [16,17]. Previous studies indicate that one of the reasons for the lack of desirable performance and consistency in using RAS is the low-level interactions between the virgin asphalt binder and the RAS. This has been mainly attributed to the variation in chemical structure as well as the large molecular size of oxidized asphalt in RAS as reflected in the two materials' highly different softening point, morphology, and microstructure. Such variation can lead to a lack of compatibility between the two materials as well as inconsistent blending; as such, it has been shown that the utilization of wet processing can lead to a significant improvement in blending thus an improvement in pavement performance compared to that of dry processing [17–22]. Wet processing of RAS, through the process of extraction, has been previously studied [22–25]; however, this paper investigates the merits of application of a bio-binder in conjunction with wet processing to allow higher RAS percentages without compromising the overall binder performance. Bio-binder has been reported as a promising modifier for oxidized asphalt binder; it is produced from the processing of the bio-mass resources such as swine manure [26]. Swine manure based bio-binder could offer significant advantages for both the asphalt industry and agricultural industry [26,27]. The swine manure based bio-binder has shown to be highly compatible to conventional asphalt binder in terms of physical and rheological characteristics, while its production cost is approximately 35% lower than that of petroleum based asphalt binder [27,28].

It has been reported that bio-binder can improve certain asphalt properties such as temperature susceptibility and low temperature cracking resistance; this is even more evident when recycled materials such as RAP are present [29,30]. This improvement may be attributed to the rejuvenating effect of bio-binder on RAP modified asphalt. Prior studies have reported the rejuvenating effect of commercial petroleum rejuvenators as well as bio-binder on oxidized asphalt such as RAP and RAS [29,30]. It has been also shown that use of bio-binder in high RAP mixture enhances workability and reduces stiffness [31,32]. As such, this paper focuses on investigating the effects of bio-binder on rejuvenating RAS modified asphalt binder.

3. Experimental plan

In this study, the bio-modified and non-modified RAS asphalt binder samples were tested using the Rotational Viscometer (RV), Dynamic Shear Rheometer (DSR), Three Point Bending Test (TPBT) and Direct Tension Tester (DTT). The RV measurements were used to evaluate the viscosity and shear susceptibility of each specimen. It has been well established that asphalt binder with lower shear susceptibility is associated with better pavement performance [33]. Viscosity results were further used to study the effect of bio-binder on the stiffness and workability of RAS modified asphalt binder samples.

The DSR was used to characterize the viscoelastic behavior of the asphalt binder at high and intermediate service temperatures by determining dynamic shear modulus (G^*), viscous modulus (G'') also called loss modulus (non-recoverable part) and elastic modulus (G') also called the storage modulus (recoverable part), and phase angle (δ). The TPBT test results determined the limit cracking temperature (LCT) as well as the critical energy release rate ($G(t)$) of the asphalt binder while the DTT results were used to study the low temperature performance by determining ductility, fracture energy, and failure strain. Aforementioned measures were used as indicators to study rheological properties of RAS modified asphalt binder samples focusing on thermal cracking resistance.

4. Materials and methods

4.1. Asphalt roofing shingles

The neat asphalt binder used in this study was Superpave PG 64-22, which is commonly used across the United States. The asphalt roofing shingles used for this study were Tear-Off Scrap Shingles (TOSS) donated by S.T. Wooten's Quality Control lab located in Sanford, NC. The initial asphalt shingle particle size varied from 12.5 mm to 19.00 mm. However, for the wet processing, the shingles needed to be further processed in order to ensure adequate interaction between RAS particles and the virgin binder as well as to reduce particle settling. The shingles were dry grinded using a shaft driven blender for approximately 45 min to reduce the overall particle size. The final gradation of the roofing shingles is given in Table 1.

It has been reported that an average RAS particle size of 85.5 μm is ideal to ensure adequate interaction between RAS and base binder in wet processing [25]. Therefore, the same average particle size was used in this paper.

However, a batching procedure with the RAS particles was utilized to obtain the target average particle size of 85.5 μm using Eq. (1) to blend with the neat asphalt binder.

$$S_T = \frac{X_1N_1 + X_2N_2 + X_3N_3}{X_T} \quad (1)$$

where:

$N_{1,2,3}$ is the particle size based on the sieve size (μm).
$X_{1,2,3}$ are the amount of RAS on the respected sieve (g).
X_T is the total amount of RAS on the three sieves (g).
S_T is the total average size of RAS (85.5 μm).

In order to best characterize the RAS modified asphalt binder, average asphalt binder content was determined for the particles on each of the sieves used for batching. This was achieved through the use of multiple iterations of dissolving the asphalt binder by use of a solvent followed by filtering the solution using a vacuum pump. Once the asphalt binder was removed, the remaining aggregate/solvent solution was placed in an oven for 3 days at 90 °C. The percentage of asphalt binder was obtained by weighing the RAS before and after the extraction process. The results are given in Fig. 1, which shows that particles of 50 μm size had the highest percentage of asphalt binder followed by 149 μm and 74 μm particle size.