Construction and Building Materials 189 (2018) 882–889

Contents lists available at ScienceDirect

Construction and Building Materials

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

Moisture resistance study on PE-wax and EBS-wax modified warm mix asphalt using chemical and mechanical procedures

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HIGHLIGHTS

- PE-wax has positive effects at low temperatures.
- EthyleneBisStearamide (EBS) can increase TSR values of asphalt mixes by 10%.
- EBS modified mixtures are more moisture resistant than PE wax modified mixtures.

ARTICLE INFO

Article history:
Received 1 March 2018
Received in revised form 24 July 2018
Accepted 31 August 2018

Keywords:
Warm mix asphalt
Moisture susceptibility
FTIR
Rheology
Master curve
Asphalt
Lottman test
EBS
Polyethylene
PE
Wax

ABSTRACT

Global warming, environmental concerns, and energy prices have led to increased use of wax additives to produce warm mix asphalt (WMA) as an alternative to hot mix asphalt (HMA). Despite many advantages, moisture susceptibility of WMAs is a legitimate concern. Although there have been many studies about moisture susceptibility of warm mix additives, mixtures containing ethylene-bis-stearamide (EBS) and polyethylene (PE) waxes have been less studied. In this research, moisture susceptibility of asphalt mixtures containing PE and EBS were evaluated. Furthermore, rheological and chemical evaluations of EBS and PE-wax modified binders were evaluated using dynamic shear rheometry and Fourier infrared spectroscopy, respectively. Moisture susceptibility was assessed using the modified Lottman test and the effects of aggregate type and production temperature were also evaluated. Results indicate improved moisture resistance for mixtures containing EBS. Additionally, the effect of PE-wax on moisture susceptibility was observed to be temperature dependent showing adverse effects at higher compaction temperatures.

1. Introduction

Global warming and environmental concerns have led to the production of materials and alternative methods to reduce greenhouse gas emissions and energy consumption in almost every industry. In the asphalt pavement industry, warm mix asphalt (WMA) was introduced and has been used instead of hot mix asphalt (HMA) to address these issues [1–6]. Generally, WMA production yields a significant reduction of emissions and provides environmental benefits. It has been reported that the amount of various emissions, throughout the plant-production process of WMA, decreases as follows [3]:

- 30–40% for carbon dioxide (CO_2) and sulfur dioxide (SO_2)
- 50% for VOC (volatile organic compounds)
- 10–30% for carbon monoxide (CO)
- 60–70% for nitrogen oxides (NO_x)
- 25–55% for dust.

Reductions from 30% to 50% of asphalt aerosols/fumes and polycyclic aromatic hydrocarbons have also been reported [7]. These reductions help limit worker exposure to these emissions.

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https://doi.org/10.1016/j.conbuildmat.2018.08.216
0950-0618/

Warm mix asphalt can be produced in several ways, one of which is the modification of bitumen by wax additives to reduce the viscosity and subsequently reduce mixing and compaction temperatures [2]. Many studies have been conducted investigating the effects of these additives in asphalt mixtures [8]. The semi-crystalline behavior of wax-based additives usually results in increased stiffness values for WMAs at service temperatures even though they are produced at lower temperatures compared to HMA. Despite the environmental and performance-related advantages, wax modified asphalt mixtures can be susceptible to moisture damage [1].

Loss of adhesion and cohesion are the main mechanisms of asphalt concrete (AC) damage due to presence of water [9]. Evaluation of moisture distress is crucial to pavement engineers since moisture can reduce strength and stiffness of AC and cause several moisture-related distresses such as rutting, potholes, and raveling [10,11]. Although numerous studies on moisture susceptibility of asphalt mixtures containing wax additives have been performed, less attention has been paid to polyethylene wax (PE-wax) and ethylene-bis-stearamide (EBS). According to previous studies, PE-wax can be considered as WMA additive [12–14]. In this study, the potential of EBS as warm mix additive was also evaluated. EBS is an acrylonitrile-butadienestyrene additive which is used as lubricant, slip agent and mold release agent [11,15]. Fig. 1 shows the molecular structure of EBS.

There are several qualitative and quantitative laboratory experimental methods for moisture susceptibility assessment of asphalt mixtures, such as boiling water test, static-immersion test, moisture susceptibility assessment using Indirect Tensile Strength (ITS), permanent deformation index and fatigue index [16]. However, moisture susceptibility assessment using ITS which was first proposed by Lottman, is in good agreement with field results [17,18]. This method, standardized under AASHTO T283 [19], is the most common way for evaluating moisture susceptibility of AC [10,20].

It has been suggested that WMA is more prone to moisture damage compared to HMA [1,21]. However, the cause of decrease in moisture resistance for WMA is not clear. Production temperature decreases, the intrinsic properties of the additives, or both of these factors may contribute to the reduction of moisture resistance. It is questionable whether the use of wax-based additives in asphalt mixture compensates the decrease in moisture resistance (which may be due to temperature drop) or worsens it. Also, less attention has been paid to the moisture evaluation of PE-wax and EBS modified asphalt mixtures.

Given the key questions and needs described above, the major objectives of this study were to:

1. Further identify the behavior of WMAs with different content of PE-wax and EBS additives through their viscosities, rheological properties, and chemical properties.
2. Evaluate moisture susceptibility of WMAs produced with PE-wax and EBS additives, and study changes in moisture resistance considering different parameters.
3. Investigate the effect of additive content, aggregate type, and compaction temperature on moisture susceptibility of WMAs, separately and together.

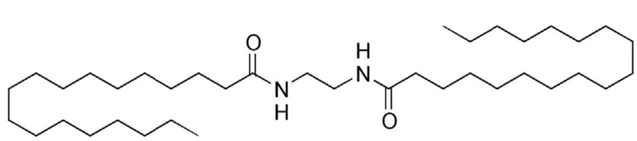

Fig. 1. Structure of ethylene-bis-stearamide (EBS).

To accomplish these objectives, rheological and chemical properties of the wax modified binders were evaluated using rotational viscometry, dynamic shear rheometry, and Fourier Transform Infrared (FTIR) spectroscopy. Also, the Modified Lottman test was used to assess the resistance of WMAs to moisture. Finally, statistical analysis and discussion on the results were performed.

2. Materials and methods

2.1. Bitumen and aggregates

For the laboratory experiment, a PG 64-22 asphalt cement was selected as the base bitumen because it is commonly used in most parts of Iran. Softening point, penetration, and ductility of this bitumen are 52 (°C), 61 (0.1 mm), and over 100 (cm) according to ASTM D36 [22], ASTM D5 [23], and ASTM D113 [24], respectively. Since aggregate type is one the most important factors affecting moisture susceptibility of asphalt mixtures, two aggregate types (limestone and siliceous) were selected for mixture fabrication. For both aggregate types, the percent passing 19 mm, 12.5 mm, 9.5 mm, 2.36 mm, and 0.075 mm sieves were selected 100, 95, 81, 43, and 6, respectively. The gradations of limestone and siliceous aggregates used in this study were selected so that they fall between the lower and upper limits according to the current specification of the surface course layer for nominal maximum aggregate size of 12.5 mm according to AASHTO M 323 [25].

2.2. Additives

2.2.1. EBS (ethylene-bis-stearamide)

EBS is a synthetic wax and an organic compound, based on fatty unsaturated straight chain monocarboxylic acids derived from naturally occurring vegetable oils [26]. It can be used as a dispersing agent or lubricant for plastic applications to facilitate and stabilize the dispersion of solid compounding materials [27,28]. It also enhances processability, decreases friction of the polymer surface, and prevents polymer degradation [29]. The polarity of its two central amide group and the non-polarity of the two fatty chains [29,30] make this product an excellent surface-active agent. EBS as plasticizer, playing the role of internal lubricant, can reduce the interaction between the macromolecular polymer chains [29].

Based on results regarding the plasticizer's role in EBS [30], 2% and 3% of EBS by the weight of asphalt were used in this study. To pre-evaluate the effect of EBS on the viscosity of bitumen, the dynamic viscosity of the base bitumen as well as EBS modified binders was measured by a rotational viscometer (RV) in accordance to AASHTO T316 [31] for temperatures higher than 110 °C. For temperatures below 110 °C, shear viscosity of the bitumen was determined using vacuum capillary viscometer according to ASTM D2171 [32]. The results are illustrated in Fig. 2(a) which shows that with increasing temperature, the viscosity of the resulting modified binder is slightly decreased due to the addition of EBS. It should be also noted that in temperatures lower than 110 °C, modification with EBS will results in stiffer binder. The main reason for this behavior can be attributed to crystallization effect of EBS wax. At temperatures lower than 110 °C, it forms crystals leading to higher viscosity. However, temperatures more than 110 °C breaks the crystal network and causes the reduction in binder viscosity. However, temperatures more than 110 °C breaks the crystal network and causes the reduction in binder viscosity [33].

2.2.2. PE-wax (polyethylene-wax)

PE-wax has been less commonly used as modifier in AC, although it has been used in plastic and polishes as thickener and as paraffin wax improver [4,13]. Some physical properties of