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The rutting and stripping resistance of warm and hot mix asphalt using bio-additives

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HIGHLIGHTS

- Results show positive impact of additives and polymer modification.
- Additives have little impact when used with neat binder.
- WMA with polymer outperformed HMA in stripping resistance for IDB, FP 1, and FP 2.
- Other additives for WMA with polymer increased stripping resistance.
- IDB, FP 1, and FP 1 showed similar trends for mix and binder results.

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ABSTRACT

Isosorbide distillation bottoms (IDB) are a co-product from the conversion of sorbitol to isosorbide and have been shown to improve low temperature binder performance when tested in the bending beam rheometer. With the successful inclusion of IDB into asphalt, other bio-chemical streams with similar properties to IDB are of interest. The incorporation of bio-additives that create softening of the binder require an evaluation of rutting resistance. To use bio-based chemical additives as a warm mix asphalt modifier, moisture susceptibility must also be examined. The objective of this paper is to evaluate how IDB and several new bio-derived material additives influence the rutting and stripping resistance in WMA binders and mixtures. Rutting resistance of short term age binder is evaluated using the multiple stress creep recovery (MSCR) test and hot mix asphalt (HMA) and WMA evaluation will employ the Hamburg Wheel-Tracking Device (HWTD) test. Reduced mixing and compaction temperatures were achieved with all bio-additives. MSCR and HWTD results using the bio-additives with non-polymer modified binder show no improvements but when with a polymer modified (PM) binder, all additives show statistical improvements in resistance to rutting and stripping compared to a PM control.

1. Introduction

WMA technologies are known to reduce asphalt binder viscosity, and decrease mixing and compaction temperatures. Studies show mixing and compaction temperatures can be decreased by as much as 20–55 °C [1]. The decrease in production temperatures reduce fuel consumption and costs, lower greenhouse gas (GHG) emissions improving air quality and reducing worker exposure to fumes [2,3]. WMA additives have been credited with improving mix compactability and extending the paving season in colder climates [3–6].

There are five categories of WMA technologies; foaming – water based, foaming – water bearing additive, wax modifiers, chemical additives, and organic/bio-derived additives. Interest in corn and soy-derived additives is growing due to initial promising results. Isosorbide Distillation Bottoms (IDB), derived from corn and produced during the conversion of sorbitol to isosorbide, have surfactant properties and have shown to be useful as a WMA additive [7]. Past research with IDB has showed that there was improvement in low temperature binder performance using the bending beam rheometer (BBR) [8–10]. The chemical reason isosorbide distillations bottoms was selected to be investigated as a WMA additive is because of its amphiphilic properties which

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are similar to classical ionic surfactants, having both lipophilic and hydrophilic properties. The literature on the isosorbide molecule establishes its amphiphilic character [11]. There are several other WMA chemical modifiers that are commercially available that have been successfully used as WMA technologies [12]. To further investigate the softening effect caused by the bio-additive, resistance to rutting and stripping at high temperatures were investigated for bio-modified binders and mixtures produced at WMA temperatures and also compared with a HMA control.

Six bio-derived/chemical additives with similar low temperature properties were examined in a base asphalt binder, Montana (MT) PG 58-28, and the same base binder but polymer modified with 1.5% styrene-butadiene-styrene (SBS), MT-PG 64-28. The dosage rate for all additives is 0.75% by weight of the binder. In past studies the dosage rate was optimized through full Superpave PG grading for the control binders, binders modified with 0.50% and 0.75% of the additives used in this work. The dosage rate of 0.75% was chosen as past studies showed that 1% is too high and mass loss criteria cannot be met [10]. Further research showed that all of the additives used at 0.75% do not change the binder grade at low and high temperature [9]. Similar WMA studies have shown that the WMA dosage rate is approximately 0.5% by weight of binder [13]. To investigate the performance each bio-derived material as a WMA additive, the rutting and stripping resistance at high temperatures included four groups: two control groups, each mixed and compacted at different temperatures, and two commercially available WMA additives derived from forest products; FP 1 additive, and FP 2 additive. The test used to examine stripping resistance at high temperature was the Hamburg Wheel-Tracking Device (HWTD), while binder performance at high temperatures used the multiple stress creep recovery (MSCR) with rolling thin film oven (RTFO) aged material (short-term aged).

2. Objectives

The objective of this paper is to evaluate how IDB and several new bio-derived material additives influence the rutting and stripping resistance in WMA binders and mixtures. The binder performance will be measured using the multiple stress creep recovery (MSCR) test. The important factors studied in the binder performance tests include polymer modification, and four experimental bio-derived WMA additives and two commercially available WMA additives. The binder study will answer two primary research questions: What impact does polymer modification have? Do any of the bio-derived material additives influence the modified asphalt binder's rutting resistance? The mixture performance will investigate the effects of WMA additives on rutting resistance and stripping resistance compared to a control and polymer modified binder. Finally, a comparison between the MSCR binder test results and the HWTD will be performed to see if similar trends are evident in both binder and mixture performance testing.

Table 1
Properties of WMA additives FP 1 and FP 2 [19].

	FP 1	FP 2
Physical form	Dark amber liquid	Dark liquid
Specific Gravity at 25 °C (77°F)	0.97	0.999
Conductivity at 25 °C (77°F) (μS/cm)	2.2	4.3
Dielectric Constant at 25 °C (77°F)	2–10	2–10
Viscosity (Pa S)		
At 27 °C (80 °F)	0.28–0.56	1.05–1.90
At 38 °C (100 °F)	0.15–0.30	0.47–0.85
At 49 °C (120 °F)	0.08–0.16	0.20–0.40

3. Experimental materials and methods

3.1. Experimental materials

Corn is the parent material for many bio-refining processes, including isosorbide. Several steps and material streams are produced during the processing of isosorbide. Since the isosorbide distillation bottoms showed promising results in initial testing [9,10], additional materials from various points in the processing are now being considered. The reactor product (RP), crude isosorbide and the isosorbide distillation bottoms will be studied. In addition, a fatty acid derived from epoxidized soy bean oil will be compared to the isosorbide-materials. Commercial bio-based WMA additives will also be included in the study (designated FP 1 and FP 2). These are water-free and derived from pine tall oil. The properties of FP 1 and FP 2 are shown in Table 1. When FP 1 and FP 2 are used to modify asphalt, a reduction of friction between the aggregate-binder interface occurs during the mixing and compaction process making it possible to use lower mixing and compaction temperatures [13,14].

A PG 58-28 and a polymer modified PG 64-28 of the same base binder were used in the study. The base asphalt binder's parent material source was a Montana crude and was supplied by a major binder supplier. The supplier performed the polymer modification by blending 1.5% styrene-butadiene-styrene (SBS) to achieve a PG 64-28 binder. Four experimental WMA additives were used – IDB, reactor product (RP), crude isosorbide (CI), epoxidized soy bean fatty acid (FA) and two commercially bio-based WMA additives included: FP 1, and FP 2. The additive dosage was 0.75% by weight of binder and blended using a Silverson shear mill with a blending speed of 3000 rpm at 140 °C ± 2 °C for one hour. A heating mantle was used with an electronic temperature probe to control the heating of the mantle. The heating mantle controlled the binder at 140 ± 2 °C.

For mixture testing, a 10 million ESAL surface mix design approved by the Iowa Department of Transportation (DOT) was used. The aggregate source information, individual aggregate gradations and the blended aggregate gradation used to produce this mix design are shown in Table 2. The gradation for each source aggregate was verified prior to mixing.

Table 2
Mix design gradation and supplier information.

Source		Martin Marietta (Ames)	Martin Marietta (Ames)	Oldcastle Materials Group (Johnston)	Hallet (Ames)	Martin Marietta (Ames)	Martin Marietta (Ames)	Blend
Aggregate		12.5 mm Limestone	9.5 mm Limestone	Quartzite	Natural Sand	Manuf. Sand	Agg Lime	
U.S. Sieve	Sieve, mm	29% % Passing	16% % Passing	15% % Passing	13% % Passing	15% % Passing	12% % Passing	100% % Passing
3/4″	19	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1/2″	12.5	79.7	100.0	100.0	100.0	100.0	100.0	94.1
3/8″	9.5	65.8	90.1	71.5	100.0	100.0	100.0	84.2
#4	4.75	37.2	20.5	5.1	96.8	95.2	99.0	53.6
#8	2.36	18.1	2.1	2.2	64.2	65.5	97.0	35.7
#16	1.18	12.5	0.7	2.0	33.7	36.3	75.0	22.9
#30	0.60	9.5	0.4	1.9	11.4	17.4	53.0	13.6
#50	0.30	7.5	0.3	1.9	0.9	6.5	38.0	8.2
#100	0.15	6.2	0.3	1.5	0.1	1.9	29.0	5.8
#200	0.075	5.2	0.3	1.2	0.0	0.8	22.3	4.5