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Effect of recycled engine oil bottoms on the ductile failure properties of straight and polymer-modified asphalt cements

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HIGHLIGHTS

- REOB can improve the AASHTO M320 grade span at reduced cost to producers.
- REOB decreases ductile failure properties which makes binders prone to failure.
- SB polymers improve strain tolerance and thus improve cracking performance.
- REOB addition to SB-modified binders significantly deteriorates performance.
- RAP addition to SB/REOB-modified binders further worsens cracking performance.

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ABSTRACT

This paper presents a study on the effects of recycled engine oil bottoms (REOB) on ductile failure properties of asphalt cements. Binders were tested according to regular AASHTO M320 as well as double-edge-notched tension (DENT) test protocols. The DENT test determines essential work of failure (w_e, a measure of strength and toughness) and critical crack tip opening displacement (CTOD, a measure of strain tolerance). REOB was found to increase the AASHTO M320 grade span but worsen w_e and/or CTOD. Straight and polymer-modified binders were studied, with and without REOB and reclaimed asphalt pavement (RAP) binder, and significant decreases in w_e and CTOD were found, pointing to reduced cracking performance.

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1. Introduction

The current Superpave™ bitumen specification as implemented in much of North America under AASHTO standard M320 provides inadequate control for fatigue and thermal cracking in asphalt pavements [1]. In Canada and the northern United States asphalt cements are typically produced from the best heavy crude oils in the world. These crudes from Alberta's oil sands contain mainly naphthenes and other aromatic hydrocarbons and they are largely free of paraffin. Heavy oils are used in the production of high-quality asphalt and road pavements constructed with such materials should typically last for more than 25 years without significant material-related cracking.

Unfortunately, the recent introduction of a long list of low cost additives in asphalt binders (diluents and modifiers) has decreased asphalt quality and durability and thus pavement performance [2–40]. The additive that appears to be most widely used in Canada and the northern United States—due to its low cost and the fact that it has become more widely available in recent years—is REOB [7,8,10,12,13,15–22,24–40], a waste stream obtained from the distillation of used motor oils. It has sold for a significant discount to regular asphalt cement and for that reason it is of great interest to asphalt resellers to increase their profit margins.

Currently, the most promising test methods for improving upon the Superpave specifications are Ontario's extended bending beam rheometer (EBBR, MTO Laboratory Standard 308) and double-edge-notched tension (DENT, MTO Laboratory Standard 299) test

Abbreviations: AASHTO, American Association of State Transportation and Highway Officials; CTOD, critical crack tip opening displacement; DENT, double-edge-notched tension; EBBR, extended bending beam rheometer; MTO, Ministry of Transportation of Ontario; PAV, pressure aging vessel; REOB, recycled engine oil bottoms; RAP, reclaimed asphalt pavement; RAS, recycled asphalt shingles; RTFO, rolling thin film oven; SB, styrene-butadiene diblock polymer modifier; SBS, styrene-butadiene triblock polymer modifier.

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methods [41,42]. The EBBR conditions asphalt binder samples for 1, 24 and 72 h prior to testing at pass and fail temperatures to determine continuous grades and a 72-h grade loss from the regular AASHTO M320 grade [14]. The DENT test gives an approximate CTOD which provides a measure of strain tolerance in the ductile state [42–48]. The CTOD has a lower limit that depends on the low temperature grade of the asphalt binder. The EBBR and DENT tests have shown to provide a much improved ability to separate the good from the poor performing binders. Implementing both EBBR and DENT tests for acceptance of the asphalt cement will discourage the use of low quality asphalt binders that are rheologically unstable (i.e., those containing air-blown and other oxidized residues from RAP and RAS under poor solvency conditions in the presence of paraffin oils, acid- or base-modified binders, waxy asphalt cements, etc.) [1–22,24–40,43–47].

The United States and Canada generate millions of gallons of REOB every year. This has become a very significant problem since the production of REOB is increasing and disposal methods are now limited. Governments have banned burning this material in asphalt plants or cement kilns because of pollution concerns. For that reason, asphalt resellers have started to use it at ever increasing dosage rates as an asphalt modifier and diluent [18,26,35]. Experience has shown that above certain levels of modification, the inclusion of REOB can start to negatively affect the high temperature Superpave grade. For this reason, asphalts with REOB have also been modified with polymers, acids or air-blown asphalt residues [8].

The main objective of this study was to evaluate the influence of recycled engine oil bottoms on ductile failure properties of polymer-modified asphalt binders with and without the addition of RAP-derived binder. The scope of this research is to compare asphalt binders from Cold Lake (Canada), Laguna (Venezuela), and Ural (Russia), modified with polymers, REOB and RAP.

2. Materials and methods

2.1. Materials

The asphalt binders used in this study were produced from Laguna (Venezuela), Cold Lake (Alberta), and Ural (Russia) crude oils. Cold Lake asphalt was obtained from a Canadian refinery while the Laguna and Ural materials were obtained from Scandinavian and Russian sources. Straight and polymer-modified asphalt cements were blended with 6% or 8% REOB obtained from an Ontario source. Two asphalt binders from Cold Lake, modified with 3.5% and 7% SBS D1101 grade obtained from Kraton Polymers of Texas, and asphalt from Laguna, modified with 4% EE-2 grade oxidized polyethylene (OPE) and 3% SBS D1118 grade obtained from Westlake Chemicals and Kraton Polymers both from Texas, respectively, were chosen to investigate the effect of REOB on various commonly used polymer-modified binders. An additional material made from Ural crude from Russia was used to investigate the effect of simultaneous addition of REOB and 4% EE-2 grade oxidized polyethylene (OPE) wax in a lesser quality base asphalt. Two binders modified with 3% and 5% SBS D1192 grade were used to investigate the effect of the simultaneous presence of RAP-derived binder and REOB. Both the RAP and REOB were obtained from local sources. Binders were prepared according to standard procedures using high shear blending for a minimum of one hour until stable binders were obtained. Table 1 provides pertinent information about the tested binders.

Table 1
Pertinent information for investigated binders.

Binder	Source	Modification	PG XX-YY, °C
A	Cold Lake	Straight	51–34
B	Cold Lake	7% D1101	82–40
C	Cold Lake	3.5% D1101	58–34
D	Cold Lake	7% D1101 + 8% REOB	75–43
E	Cold Lake	3.5% D1101 + 8% REOB	60–43
F	Laguna	Straight	63–27
G	Laguna	Straight	56–32
H	Laguna	3% SB D1118	62–33
I	Laguna	5% SB D1118	66–34
J	Laguna	3% SB D1118 + 6% REOB	60–36
K	Laguna	4% OPE + 8% REOB	63–36
L	Ural	Straight	62–30
M	Ural	Straight	63–28
N	Ural	8% REOB	68–30
O	Ural	4% OPE + 8% REOB	62–33
P	Laguna	3% SBS D1192 + 8% REOB	60–27
Q	Laguna	5% D1192	70–23

2.2. Methods

2.2.1. Superpave grading

The asphalt binders were tested according to current grading protocols embodied in the AASHTO M320 standard [49–51]. The asphalt cements were aged in the laboratory in a RTFO for 85 min at 163 °C and in a PAV for 20 h at 100 °C, both according to standard procedures [50,51]. Residues were tested to determine their Superpave grading properties and other parameters.

Grades listed in Table 1 are continuous rather than commercial. The high temperature Superpave grades were determined with a TA Instruments AR2000ex Dynamic Shear Rheometer at 0.5–1.0 percent strain. Rheological properties such as complex modulus and phase angle were also identified. Low temperature Superpave grades were determined with a Canon Instruments Thermoelectric Bending Beam Rheometer (TE-BBR) using PAV-aged asphalt binder.

2.2.2. Double-edge-notched tension testing

The PAV residues were tested in the double-edge-notched tension test according to Ontario Ministry of Transportation Laboratory Standard 299 [42]. Samples were poured in silicone molds and were conditioned for 3 h prior to testing in a water bath. Testing was done at a constant speed of 50 mm/min. Asphalt samples were tested at 15 °C and the failure energy of the asphalt binders was determined from the force–displacement curves in order to predict fatigue cracking in service. An image of three specimens prior to a test is provided in Fig. 1.

The DENT test is best described as an *improved* ductility test since it is more mechanistic and less empirical. Ductility has long been known to provide a good correlation with pavement cracking

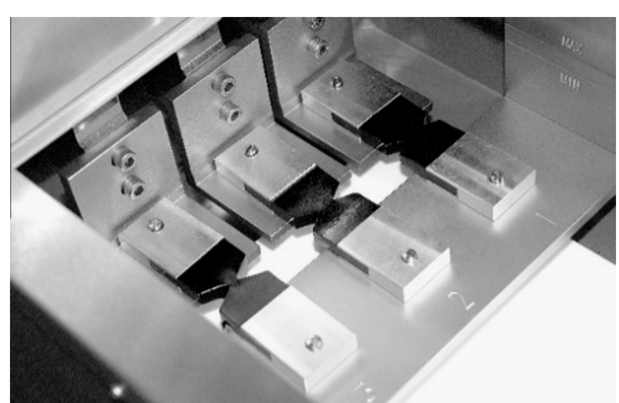

Fig. 1. DENT specimens with 5, 10 and 15 mm ligaments just prior to testing. Water was left out of the bath for image clarity. Normally specimens are tested in a water bath.

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