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Effects of alternative polymer modifications on cracking performance of asphalt binders and resultant mixtures

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HIGHLIGHTS

- Alternative polymers improved the elasticity and fracture properties of base binder.
- Alternative PMAs reduced damage accumulation rate enhanced failure limit of mixtures.
- BEF test effectively identified modifiers evaluated binder cracking performance.

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ABSTRACT

The use of styrene-butadiene-styrene (SBS) polymer-modified asphalt (PMA) binder has successfully enhanced pavement cracking performance. Meanwhile, state agencies hesitate to allow the use of alternative PMA binders that meeting existing specification requirements for PG 76-22 SBS PMA binder, due to a lack of experience and documented performance. A previous study identified four out of seven alternative PMA binders that exhibited excellent elastomeric behavior and fracture properties. This study extends these prior efforts by assessing whether binder results translate to improved cracking performance of resultant mixtures. Superpave indirect tension (IDT) tests were conducted to obtain the fracture properties of asphalt mixtures with the four alternative PMA binders, as well as a standard PG 76-22 (3% SBS) PMA binder and a PG 67-22 unmodified base binder. Results showed that these alternative PMA binders, produced with SBS plus polypropylene composite, terpolymer plus polypropylene composite, SBS plus oxidized polyethylene wax and a fourth non-SBS polymer of unknown composition, not only reduced the rate of damage accumulation but also improved the failure limit of the resultant mixtures. The energy ratio (ER) parameter which has been closely tied to field pavement cracking performance was calculated for each mixture, and the results showed that these alternative PMA binder exhibited equivalent or better cracking performance than the PG 76-22 SBS PMA binder. Finally, the binder fracture energy density (FED) results satisfactorily rank mixture cracking performance thereby supporting the use of the binder fracture energy (BFE) test as an effective tool to quantitatively evaluate the relatively cracking performance of asphalt binder.

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1. Introduction

1.1. Background

Polymer-modified asphalt (PMA) binders have been used successfully at locations with concentrated heavy traffic volume or high stress including intersections, weigh stations, race tracks, and airports [1]. Among them, styrene-butadiene-styrene (SBS) PMA binder has been increasingly popular because of its apparent achievement in mitigating rutting as well as in enhancing cracking performance of asphalt mixtures [2–4]. The Florida Department of Transportation (FDOT) has fully adopted the PG 76-22 (3–3.5% SBS) PMA binder (so called the FDOT's "gold standard binder") and specified its use in surface course for high-traffic volume facilities. In the meantime, there are PMA binders that contain polymers other than SBS only or no SBS at all (called alternative PMA binders throughout this study) available from producers and the FDOT is considering the use of these new binder sources which could bring additional economic benefits without compromising performance compared to the gold standard SBS binder.

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A previous study evaluated seven alternative PMA binders using different tests, including the Superpave PG binder tests, the multiple stress creep recovery (MSCR) test and the recently developed binder fracture energy (BFE) test [5]. Four alternative PMA binders exhibited excellent elasticity and fracture performance as indicated by the MSCR% recovery and BFE fracture energy density (FED) results, respectively. In addition, three PMA binders (plastomer-modified, non-crosslinkable polyolefin-modified, and a third one of unknown composition) were identified by as deficient by both the MSCR and the BFE tests. However, the Superpave PG binder tests were capable of distinguishing only one of the three binders as deficient based on the requirement for a maximum phase angle of 75 degree. Compared to the MSCR test, which provides a qualitative assessment (i.e., pass/fail criterion) for polymer modification, the BFE test offers the potential advantage of providing a quantitative assessment of relative binder performance based on fracture energy density (FED) values.

Asphalt mixtures with alternative polymerized binders (i.e. ethane homo-polymer with power polymer, and oxidized polyethylene was-like powder polymer, and the combinations of SBS with ethane homo-polymer) have been reported to yield comparable moisture susceptibility and rutting resistance to those of SBS mixtures [6]. It has also been indicated that base binders and polymer types could significantly affect the fatigue resistance of modified binders [7]. However, there is still a lack of experience and documented performance data showing these potential substitutes can result in equivalent or better mixture cracking performance compared to a gold standard SBS PMA binder. A previous work found that the benefit of SBS polymer to mixture cracking resistance appeared to be primarily derived by a reduced rate of micro-damage accumulation [8]. Before relaxing the strict requirement for exclusive usage of SBS polymer, there is a strong need to evaluate the effects of alternative polymers on key mixture fracture properties known to control cracking performance. Also, it is important to determine whether binder results from the BFE test extend to mixture cracking performance.

1.2. Objectives

The overall objective of this study was to evaluate the relative cracking performance of asphalt mixtures with alternative PMA binders using the energy ratio (ER) parameter that has been closely related to field pavement cracking performance. More specific objectives of this study included:

- Evaluate effects of alternative PMA binders relative to SBS binder on:
  - o Binder and resultant mixture fracture properties
  - o Resultant mixture cracking performance
- Determine whether quantitative BFE test results are consistent with mixture cracking performance, thereby supporting its use for assessing cracking performance of asphalt binders.

1.3. Scope

This study focused primarily on the effects of various polymer modifications on the intermediate temperature cracking performance of asphalt binders and resultant mixtures. Six asphalt binder types were used including four alternative PMA binders (all graded as PG 76-22), a standard PG 76-22 PMA binder and a PG 67-22 unmodified binder. Also, six resultant mixtures with same Superpave volumetric parameters but different binder types were prepared and evaluated. The MSCR and BFE tests were employed for binder evaluation and Superpave IDT tests were conducted to obtain mixture fracture properties for ER determinations.

2. Materials and mixture design

Four alternative PMA binders tagged in a previous study as potential substitutes for SBS binder were utilized in this study. Information regarding the formulations of the alternative PMA binders was provided by the supplier as shown in Table 1. Two reference binders typically used in the State of Florida were also evaluated including a standard PG 76-22 3% SBS binder and an unmodified PG 67-22 binder which was the base binder for the former. The PG 67-22 unmodified binder is the commonly used one for structural course mixes in the State of Florida with a special high temperature designation of PG 67 [9].

Six asphalt mixtures with the same asphalt binders used for binder tests were employed to evaluate mixture fracture properties. All mixtures were designed with a 12.5 mm nominal maximum aggregate size (NMAS) fine-graded Superpave mixture using the same gradation, granite aggregate, and 6.6% asphalt binder content. The asphalt content was kept constant such that observed differences in mixture performance were in fact associated with the differences in binder properties. It has been reported that alternative polymer binders generally yield similar asphalt content compared to the SBS mixture in Superpave mix design [6]. A traffic level C, which corresponds to 3–10 million equivalent single axle loads (ESALs) over 20 years, was employed based on Superpave requirements. Fig. 1 shows mixture gradation used and Table 2 summarizes Superpave volumetric properties of the mixtures evaluated.

3. Testing program

A laboratory testing program was developed for both asphalt binder and mixture evaluations including the MSCR, BFE, and Superpave IDT tests. The following section provides detailed descriptions for each test conducted and methodologies used for analyses.

3.1. MSCR test

Research studies have found that Superpave PG binder parameters (e.g. $G^*{\cdot}\sin\delta$ and $G^*/\sin\delta$) could not fully account for the performance characteristics of modified binders [10,11]. The MSCR test has been adopted by many state agencies, including the FDOT, to more accurately evaluate rutting performance and identify the presence of polymer modifiers in asphalt binder. This test is conducted by applying a constant shear stress (0.1 kPa or 3.2 kPa) for 1 s, followed by a zero-stress recovery period of 9 s.

In general, the non-recovery creep compliance measured at a shear stress of 3.2 kPa ($J_{nr,3.2}$) is used to address high temperature rutting for both neat and modified binders. The MSCR strain recovery measurement (% recovery) is used to validate the presence of elastomeric polymers in asphalt binders. Fig. 2 shows the determination of $J_{nr,3.2}$ and % recovery in the MSCR test. The polymer modification curve adopted in AASHTO MP19, which was developed based on available PMA binders for researchers at that time. It is an exponential function of non-recoverable creep compliance $(29.37 \times J_{nr,3.2}^{-0.263})$. Asphalt binders with % recovery above the curve would be expected to have good elastomeric behavior.

Table 1
Asphalt binder and the constituents/formulations.

Binder types		Modification components
Alternative PMA Binders	Binder A	Unknown polymer (but none SBS)
	Binder B	SBS + polypropylene composite
	Binder C	Terpolymer + polypropylene composite
	Binder D	SBS + oxidized polyethylene wax
PG 67-22 Unmodified		None
PG 76-22 SBS		3% SBS