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Evaluating fatigue performance of fine aggregate matrix of asphalt mix containing recycled asphalt shingles

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HIGHLIGHTS

- Strain sweep test was used for characterizing fatigue performance of FAM mixes.
- Strain sweep and time sweep fatigue tests provided comparable results.
- Strain sweep test required less samples and shorter time thus it is more efficient.
- Adding RAS reduced the fatigue performance of FAM mix considerably.
- Adding rejuvenating agent partially improved the fatigue performance of FAM mix.
- The long-term impact of rejuvenating agent warranted more investigation.

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ABSTRACT

The use of recycled asphalt shingles (RAS) has been increasing rapidly due to potential environmental and cost-saving benefits. RAS contains 20–30% aged asphalt binder that can replace a considerable portion of binder required in a mix. However, shingle binders are different than typical paving grade binders due to their advanced aging condition taking place during production and after years of service as roofing. This can influence mix properties upon interaction and blending with virgin binder. Asphalt mix fatigue performance is highly dominated by the properties of its fine aggregate matrix (FAM). The properties of FAM containing blends of RAS, virgin asphalt binders, from different sources and with different grades, and rejuvenating agent were evaluated in this study using the conventional time sweep test and a proposed strain sweep test. The tests were performed on small FAM cylindrical bars using a torsion bar fixture in a dynamic shear rheometer (DSR). Based on the results of the preliminary tests, it was observed that the strain sweep test and the time sweep test can similarly predict the fatigue life of the mix. The strain sweep has therefore been recommended due to its time-saving benefits. The fatigue performance of FAM mixes was found to be adversely affected by adding RAS. However, rejuvenating agent could improve the fatigue performance to some extent. The fatigue performance of FAM mixes evaluated was found to be the similar for mixes containing binders with similar grades, but from different sources.

1. Introduction

Approximately 11 million tons of recycled asphalt shingles (RAS) are disposed every year in the United States. Around 90 percent of the RAS produced consists of post-consumer (or tear-off) and the rest are the byproduct of shingle manufacture [1]. As an alternative to landfilling, one way to use this large amount of RAS is to incorporate shingles into asphalt mixes for paving. RAS is a valuable construction material containing 20% to 30% air-blown asphalt binder, fine aggregates, fillers, polymers, and cellulosic fibers [1,2]. The available asphalt binder in RAS can replace a portion of virgin binder required in a mix, thus alter chemical and rheological properties of the virgin binder to become stiffer and brittle, especially at low temperatures [2,3].

The effects of RAS on the fatigue performance of asphalt mixes are controversial. Williams et al. found that the fatigue resistance of asphalt mixes with 5% RAS is equal to or even better than control mixes without RAS when tested in strain-controlled mode using a four point bending beam test setup [3]. The improvement in fatigue performance was attributed to the presence of fibers in the RAS used.

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Conversely, Kanaan et al. [2] found that the fatigue performance of asphalt mix decreased with increasing RAS content when tested in strain-controlled mode with a push-pull fatigue test. They also performed preliminary tests on fine aggregate matrix (FAM) mixes using a dynamic mechanical analyzer (DMA), i.e., torsion bar fixture in a Dynamic Shear Rheometer (DSR), and found that the FAM stiffness increased and the fatigue life decreased with increasing RAS content.

Due to these contradictory results and the key role of fine aggregate matrix properties on the fatigue performance of a mix, there is a need for further evaluation of the influence of RAS on fatigue performance of FAM mixes.

2. Fatigue test methods

2.1. Asphalt mix fatigue tests

The most common test method for evaluating the fatigue behavior of asphalt mixes is the time sweep test that is performed either under strain- or stress-controlled mode. In a time sweep test, a repeated cyclic loading at constant stress or strain is applied to the test specimen and the response of the material is measured to calculate damage, defined as the change in stiffness of the mix, with number of loading cycles. The test can take a long time under strain-controlled mode, depending on the level of the applied constant strain and the level of damage (i.e., defined as loss of stiffness) at which the test is stopped. The repeatability of the test is also a concern, which may be attributed to the heterogeneity of the mix samples fabricated [4–6]. Therefore, researchers have attempted to develop alternative fatigue tests that are more repeatable and take less time.

Recent work has suggested that the strain sweep test may be useful to evaluate the fatigue performance of asphalt binders [5–10]. In the strain sweep test the strain amplitude is increased during the test to accelerate damage in the specimen, rather than kept at a constant level as in the time sweep test. Johnson [6] studied this test in detail and concluded that the strain sweep test could successfully indicate fatigue performance of asphalt binders. Viscoelastic Continuum Damage (VECD) theory was used by Johnson to interpret the strain sweep test results of binders. The benefit of this new method is that the results from a single test run at different strain levels can be used to predict damage of the material under a variety of strains in the field [8], while the time sweep test needs at least two tests run at different stress or strain levels to develop the relationship between stress or strain and damage. The duration of strain sweep test is also considerably short compared to the time sweep fatigue test. However, this time-saving and cost-effective test method has only been used on a limited basis for FAM so far [4].

2.2. Fine aggregate matrix

Asphalt mix consists of two distinct phases: coarse aggregate matrix and fine aggregate matrix (FAM). FAM can be defined as the blend of asphalt binder, fine aggregate less than the 4.75, 2.36 or 1.18 mm sieve (depending on the definition used), and fillers. Initiation and propagation of micro-cracks occur mostly in the FAM phase rather than through the coarse aggregates. Consequently, Kim proposed testing of the fine portion of a mix rather than full-graded mix to investigate fatigue behavior [11]. FAM is relatively homogeneous because of the smaller aggregates used and thus makes it easier to test with an acceptable level of repeatability. FAM can be tested in a torsion bar setup in a DSR (also known as DMA).

2.3. Objective

The objective of this study was to investigate the applicability of strain sweep test for characterization of fatigue behavior of FAM mix containing RAS.

Selective FAM mixes were first tested using the strain sweep test and the time sweep test to assess the effectiveness of strain sweep test method. The fatigue performance of FAM mixes containing RAS, different binder sources, and rejuvenating agent was then evaluated using strain sweep test.

3. Experimental plan

3.1. Materials

A partial factorial experimental plan, as shown in Fig. 1, was developed to evaluate the fatigue performance of FAM mixes with and without RAS at the level of 15% binder replacement, asphalt binders with different grades and sources, and rejuvenating agent (RA). All materials used in this study were sourced from local suppliers in California. Crushed granite was used as the virgin aggregates. Asphalt binders (two PG64-16 and one PG58-22) were sourced from two different refineries, which used different crude oil sources (referred to as Refinery A and B in this paper). The commercially available petroleum based rejuvenating agent was provided by one of the refineries.

3.2. FAM specimen fabrication

The FAM used in this study contained aggregates passing the 2.36 mm sieve, based on the findings from preliminary tests. FAM with finer aggregates (e.g., passing 1.18 mm sieve) was not recommended given the large volume of fine materials required for preparation of a compacted FAM specimen. In addition, the variability of test results was shown to be higher for FAM mixes containing larger aggregates (passing 4.75 mm). The aggregate gradation and binder content were the same for all FAM mixes regardless of their components. Fig. 2 shows the target FAM gradation as well as RAS gradation used in this study. FAM mixes containing RAS had slightly different gradation than the control FAM mix. However, this difference is negligible since only 5.4 percent RAS by total mass of mix (15 percent by binder replacement) was used in mixes.

Asphalt binder content and the gradation of the FAM must be representative of the binder content and gradation of the fine portion of a full-graded asphalt mix [4,12–15]. The binder content of FAM mix can be determined by either ignition oven testing (AASHTO T308) or solvent extraction testing (AASHTO T164) of the fine portion of a full-mix (i.e., passing 2.36 mm); solvent extraction was used in this study. The developed method of FAM

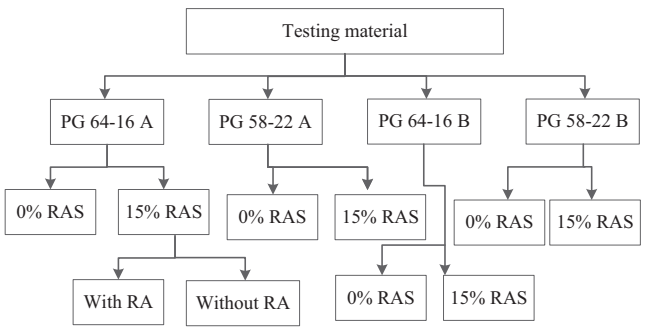

Fig. 1. Partial factorial experiment plan.