Construction and Building Materials 114 (2016) 172–180

Contents lists available at ScienceDirect

Construction and Building Materials

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

# Proposing a solvent-free approach to evaluate the properties of blended binders in asphalt mixes containing high quantities of reclaimed asphalt pavement and recycled asphalt shingles

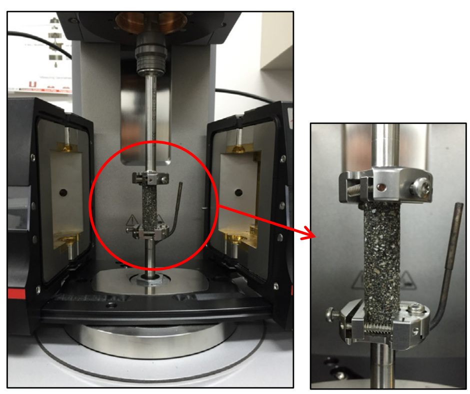
Yuan He, Mohammad Zia Alavi *, David Jones, John Harvey

*University of California Pavement Research Center, Department of Civil and Environmental Engineering, University of California, Davis, 2001 Ghausi Hall, One Shields Ave, Davis, CA 95616, United States*

## HIGHLIGHTS

- A solvent-free approach for characterizing blended has been proposed.
- FAM mix can be tested using a torsion bar fixture in a dynamic shear rheometer (DSR).
- Effects of binder source/grades, RAP/RAS, and rejuvenator can be captured by FAM testing.
- Sensitivity of FAM testing to binder aging, moisture, and additives should be further evaluated.
- Characterization of FAM mix properties at low temperature must be further evaluated.

## GRAPHICAL ABSTRACT



## ARTICLE INFO

*Article history:*
Received 17 August 2015
Received in revised form 1 March 2016
Accepted 17 March 2016
Available online 1 April 2016

*Keywords:*
Fine aggregate matrix
Dynamic shear rheometer
Reclaimed asphalt pavement
Recycled asphalt shingles
Rejuvenating agent

## ABSTRACT

Traditionally, the properties of blended binders in asphalt mixes containing reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) are evaluated through rheological testing of the binder extracted and recovered from a mix. However, this approach has long been criticized for being labor intensive, for potentially altering the chemistry of the binder and consequently changing the binder rheology, for forcing blending of binders that may not have been present in the mix, and for creating hazardous material disposal issues. The research presented in this paper proposes an alternative approach for characterizing blended binders by testing the linear viscoelastic properties of a fine aggregate matrix (FAM) asphalt mix using a torsion bar fixture in a dynamic shear rheometer (DSR). A procedure has been developed for preparation and testing of these FAM specimens. Based on the results from this preliminary study, FAM testing is considered to be an effective alternative approach to chemical binder extraction for characterizing the properties of blended binders, compatibility of virgin binders with RAP and RAS binders, and the influence of rejuvenating agents.



* Corresponding author.
*E-mail addresses:* yuhe@ucdavis.edu (Y. He), alavi@ucdavis.edu (M.Z. Alavi), djjones@ucdavis.edu (D. Jones), jtharvey@ucdavis.edu (J. Harvey).

http://dx.doi.org/10.1016/j.conbuildmat.2016.03.074
0950-0618/

## 1. Introduction

The use of reclaimed asphalt pavement (RAP) and recycled asphalt shingle (RAS) materials has been increasing in asphalt pavement construction due to environmental and cost-saving benefits. RAP and RAS materials can be used in place of an appreciable portion of virgin materials (both aggregate and asphalt binder) in new asphalt mixes, resulting in the use of less non-renewable natural resources and less dumping of materials in landfills. There are also potential reductions in life cycle greenhouse gas (GHG) emissions [1], and production time and cost savings. However, these benefits cannot be realized if the RAP or RAS negatively influences the performance properties of the mix.

To date, the majority of the studies on the characterization and design of asphalt mixes containing RAP and/or RAS have involved extraction and recovery of asphalt binder from the mix using chemical solvents [2–13]. The extraction/recovery method has long been criticized for being labor intensive, for potentially altering the chemistry of the binder and consequently changing the binder rheology, for forcing blending of binders that may not have been present in the mix, and for creating hazardous material disposal issues. The extraction process will typically fully blend aged and virgin binders resulting in a totally homogenous composite binder that may not be truly representative of the composite binder in the mix after production. Studies have demonstrated that some of the aged binder may also still remain on the aggregate after extraction, and thus the measured properties from the extracted and recovered binder may not be fully representative of the actual properties of the binder in the mix [4,14]. Asphalt binder also becomes stiffer after extraction due to the potential reactions between binder compounds and the solvent [15].

A number of studies have been conducted using asphalt mortar testing to characterize properties of blended binder without the need for binder extraction and recovery [16–18]. Single sized RAP or RAS materials (100 percent passing the 300 μm [#50] sieve and retained on the 150 μm [#100] sieve) are used to make the asphalt mortar samples, which may not be representative of the actual fine aggregate proportion in a full-graded mix. This approach includes testing of two asphalt mortars using a dynamic shear rheometer (DSR) and a bending beam rheometer (BBR): one mortar sample contains virgin binder plus fine RAP or RAS particles and the other contains virgin binder plus the burned aggregates obtained from processing RAP or RAS in an ignition oven. If the total binder contents and gradations are exactly the same for both samples, the differences between the rheological and performance properties of the two samples at high and low in-service temperatures can be attributed to the RAP or RAS binder [16–18]. Mortar testing is also often limited to low percentages of RAP or RAS because of difficulties in preparing workable samples containing higher quantities of the reclaimed materials.

Testing only the fine aggregate portion of a mix containing RAP or RAS is an alternative to asphalt mortar testing. Fine aggregate matrix (FAM) is a homogenous blend of asphalt binder and fine aggregates (i.e., passing a 4.75 mm, 2.36 mm, or 1.18 mm [#4, #8, or #16] sieve). Small FAM cylindrical specimens can be tested with a solid torsion bar fixture in a DSR (known as a dynamic mechanical analyzer [DMA]). The DMA has been successfully used to characterize fatigue damage, healing potential, and moisture susceptibility of asphalt mastics and FAM mixes in several studies [19–25]. However, its application for charactering blended binders in mixes with RAP or RAS is recent. Kanaan [24] evaluated the viscoelastic, strength, and fatigue cracking properties of FAM mixes with different amounts of RAS. The results showed that FAM testing detected differences of the evaluated properties between the various mixes, specifically that the stiffness and strength of mixes increases with increasing RAS content. Under strain-control mode, the fatigue life of the FAM specimens decreased with increasing RAS content, while under stress-control mode, opposite trends were observed.

The FAM testing approach is similar to the asphalt mortar testing approach explained above. If the aggregate gradations and binder contents of a FAM mix containing only virgin materials and a FAM mix containing virgin materials plus a percentage of RAP and RAS (total binder content considering reclaimed and virgin binder) are kept the same, any differences between the rheological and performance properties of the specimens can be attributed to the age-hardened RAP/RAS binder. It is worth mentioning that the properties of the mineral aggregates in the RAP and RAS, including strength and absorption level, may need to be taken into consideration when comparing performance. In most instances, these properties are similar for the small aggregate sizes used in FAM mixes and they usually have significantly less influence on the performance of the mix than the aged binder.

## 2. Objective

The objective of this study was to develop and assess a sound alternative approach for evaluating the properties of composite binders in mixes containing high quantities (i.e., ⩾25 percent by weight of the mix) of RAP and RAS without the need for extraction and recovery of the asphalt binder. To meet this objective, testing of small cylindrical specimens of FAM mixes with the DMA was examined. This FAM testing procedure is intended to be applicable to both practitioners and researchers. Additional research is currently being undertaken to assess the low temperature properties of FAM mixes and is not discussed in this paper.

### 3. Experiment details

Based on the objective of this study, a partial factorial experimental plan was developed to evaluate the sensitivity of FAM testing in capturing the influence of different RAP contents, inclusion of RAS, virgin binder source and type, and use of a rejuvenating agent (RA). Fig. 1 summarizes the scope of the experimental plan. All materials used in this study were sourced from local suppliers in California. A granitic aggregate was used as the virgin material asphalt binders (two PG 64-16 and one PG58-22) were sourced from two different refineries that use different crude oil sources (referred to as Refinery A and B in this paper). The petroleum based rejuvenating agent was provided by one of the refineries.

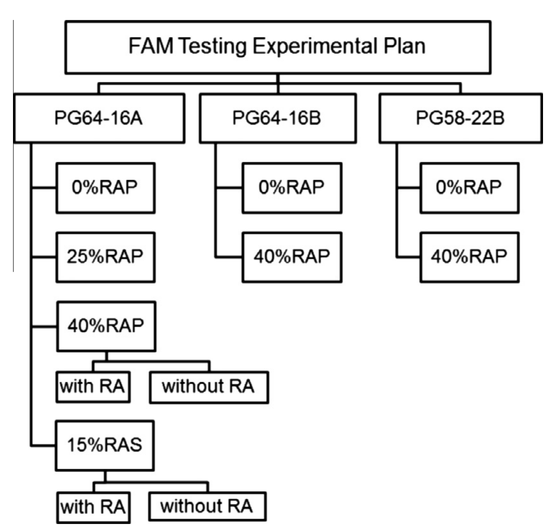



**Fig. 1.** Partial factorial experimental plan.