Construction and Building Materials 44 (2013) 168–174

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Influence of extended aging on the properties of asphalt composites produced using hot and warm mix methods

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HIGHLIGHTS

- We used an environmental room to simulate extended aging of asphalt composites.
- Fine aggregate mixtures (mortars) compacted after short-term and long-term aging had similar internal microstructures.
- We examined stiffness and fatigue lifer of WMA and HMA mixtures.
- We compared fatigue life rankings of short-term and long term aged mixtures.

ARTICLE INFO

Article history:
Received 30 October 2012
Received in revised form 7 February 2013
Accepted 26 February 2013
Available online 9 April 2013

Keywords:
Warm-mix asphalt
Hot-mix asphalt
Aging
Fatigue cracking

ABSTRACT

Fatigue cracking resistance of asphalt binders and composites is influenced by the presence of modifiers and aging conditions. This paper presents the findings from a study conducted to evaluate the fatigue cracking resistance of asphalt mortars or fine aggregate matrix (FAM) as influenced by two factors: (i) the presence of warm mix additives with reduced short-term aging temperatures and (ii) the influence of long-term aging of the mix. Combinations of two binders with four different warm mix additives and one aggregate type were used to evaluate the first factor. The second factor was evaluated by subjecting the loose mix to extended aging in an environmental room at high temperatures. X-ray CT analysis were conducted on a limited number of samples compacted before and after extended aging to ensure that the internal structure of the specimen did not change significantly and the differences in performance could be attributed to aging of the mix. A dynamic mechanical analyzer (DMA) was used to evaluate the fatigue cracking resistance of the FAM test specimens. The stiffness and the fatigue cracking resistance of the FAM specimens were compared before and after long-term aging. Results indicate that the specific binder–additive pair governed the influence of the warm mix additive on the fatigue cracking life of the FAM specimens. More importantly, results also indicate that the rank order of the short-term aged mixtures, in terms of their fatigue cracking resistance, did not change significantly after long-term aging. The ranking of fatigue cracking resistance of short-term aged specimens using different binders correlated well with the ranking of fatigue cracking resistance of long-term aged specimens.

1. Introduction

Warm Mix Asphalt (WMA) has gained interest in United States and other countries due to the environmental and financial benefits associated with lower production temperatures. This interest has prompted the transportation agencies in the United States to conduct several research studies in order to facilitate the implementation of this technology. Most recent studies have focused on the influence of WMA additives and production temperatures on asphalt binder and mixture performance [1–3]. In these studies, different WMA additives, foaming technologies, and a variety of unmodified and polymer modified binders were considered. A common theme throughout these studies is that binders used in WMA are likely to have reduced stiffness and increased susceptibility to permanent deformation due to the reduced temperatures associated with short-term aging. Most of the studies also show that binders with WMA additives had similar resistance to thermal cracking despite the initial reduction in the production temperature and concomitant oxidation. Several research studies have also been conducted on the moisture damage resistance of WMA mixtures and typically reported reduced performance compared to an equivalent HMA [4,5]. However, there is no reported evidence of moisture-related failure in field projects using WMA mixtures placed in the US [6]. More importantly, research studies have also investigated and reported that reduced temperature for short-term

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0950-0618/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.02.081

aging appeared to have a significant effect on the fatigue cracking resistance of binders and mixtures. This effect was also reported to be dictated by the type of WMA additive and binder [7].

Fatigue cracking, thermal cracking, rutting and moisture induced damage are the most prevalent forms of distresses in asphalt pavements. Several studies have been conducted in the past few decades to (i) better understand the mechanisms of the aforementioned distresses, (ii) accurately quantify and predict the resistance of materials to these distresses from a design stand point, and (iii) engineer material modification and production techniques that will result in an overall longer serviceable life of asphalt pavements. These studies have been conducted over several different length scales (e.g. binders, mastics, mortars and mixtures). In particular, several researchers have used the asphalt mortar or FAM to quantify the fatigue cracking, rutting and moisture damage resistance of asphalt composites with different modified binders, fillers or additives [8–10]. Although testing a FAM mixture does not provide a direct measurement of the mixture properties, it does present several advantages particularly when the objective of the study is to investigate the effect of different modifiers and/or fillers on the performance of the composite. First, it is more time and cost efficient to fabricate and test FAM specimens as compared to full asphalt mixtures. Second, the FAM specimens are designed to incorporate fine aggregate particles (typically passing #16 ASTM sieve) from the same source and in a relative proportion similar to that of the intended full asphalt mixture. This ensures that any physico-chemical interactions between the asphalt binder and the aggregate particles are accounted for while evaluating the FAM specimens. Third, due to the large surface area of the finer sized particles, distresses such as crack growth and moisture induced damage are concentrated in the mortar fraction of the full asphalt mixture. Therefore, evaluating the FAM amplifies the effect of additives and binder–aggregate interactions on these distresses. These advantages have led several researchers to use FAM mixtures to evaluate different aspects of asphalt mixture performance [8–10].

An important factor in the context of fatigue cracking resistance of asphalt mixtures is the aging of the asphalt binder. Oxidative aging of asphalt binders is known to increase the stiffness of the binder, reduce its ductility, and possibly affect its resistance to fatigue induced cracking [11]. The oxidation of the binder creates carbonyl compounds, mainly by oxidizing aromatic compounds in the naphthene aromatic, polar aromatic, and asphaltene fractions. An increase in the polar fractions in turn leads to stiffening of the binder seen as increase in the elastic modulus and viscosity [11]. In practice however, test specimens used to evaluate the fatigue cracking resistance of asphalt mixtures or mortars are typically only short-term aged prior to compaction. This is because of the extensive time required to simulate long-term aging in asphalt mixtures in a laboratory. For example, the AASHTO R30 recommends long-term aging of compacted asphalt mixtures at 85 °C for 120 h. The extent and uniformity of aging in compacted specimens when subjected to such limited aging times can be questioned. For example, in order to evaluate the effect of long-term aging on asphalt mixtures, Morian et al. [12] aged test specimens for 3, 6, and 9 months at 60 °C. Therefore, a relevant question that arises is whether the relative fatigue cracking resistance of different mixtures (as determined only after short-term aging) changes significantly after long-term aging?

This paper presents the findings from a study conducted to evaluate the influence of mixture production temperatures and additives on the fatigue cracking resistance of asphalt mortars or FAM mixtures. An important objective of this study was not only to evaluate the fatigue cracking resistance of different FAM mixtures modified using the warm mix additives, but also to compare the stiffness and fatigue cracking resistance of asphalt mortars before and after long-term aging.

2. Materials and tests

In order to achieve the aforementioned objectives, the experimental plan shown in Table 1 was developed to conduct tests on FAM specimens. Two binders and four WMA technologies were used. The binders used were a PG76-28 and a PG64-22 obtained from local refineries within the state of Texas, USA. The WMA technologies used were an organic wax based additive (Sasobit®), a moisture based additive that is intended to improve workability by micro-foaming (Advera®), and two chemical technologies (Evotherm® 3G and Rediset® WMX). In addition to the four WMA technologies, a control mix and dry Advera were also used. The dry Advera was used as a control for the mixture produced using the Advera WMA technology in order to isolate the effect of water trapped in the zeolite particles from the effect of the particles itself. Dry Advera was obtained by spreading 40 g of the additive on a PAV pan and placing it in an oven at 150 °C for 24 h immediately prior to adding it to the asphalt binder. The temperature and duration used to remove the moisture from Advera was based on preliminary tests using Thermogravimetric Analysis (TGA). The preliminary tests using the TGA demonstrated that this duration of heating was more than adequate to remove all the moisture that can escape from the zeolite particles at this temperature. The binders modified with dry Advera were mixed with aggregates using the HMA production temperatures. A qualitative observation was that the mixture had similar workability compared to the control-HMA mixture produced at the same temperature. Note that although only two different binders were used in this study, the combination of the binders with the different WMA additives resulted in modified binders with significantly different rheological properties as well as resistance to permanent deformation and fatigue cracking. The detailed properties of these binders and the significant differences are documented in other literature [3].

The additives were blended with the asphalt binder using a low shear mixer. Dosage and mixing time of the additives were in accordance with the recommendations provided by their respective producers. The additives were added manually and slowly into the asphalt binder to achieve a homogenous distribution of the additive. The additives were blended into the asphalt binder using a digital overhead mixer equipped with a four blade propeller, and stirred for 30 min. Additives were not added directly into the asphalt concrete mixing bucket to avoid the variability that may be incurred due the inconsistency between asphalt binder and mixture blending procedures, especially for such small quantities. Quantities of the additives used to mix with the binders are presented in Table 2. The modified binders were later mixed with the aggregates to produce the FAM mixtures.

A limestone aggregate was used for this study. The aggregate was obtained from a quarry located in Buda, Texas. A Type C mixture following a typical dense gradation was designed in accordance with the specifications followed by the TxDOT (Texas Department of Transportation) [13]. The aggregate gradation for the asphalt mortar or FAM essentially follows the same relative proportions of different sizes as the full asphalt mixture with the only difference being that aggregates passing #16 are used to produce the FAM mixtures. Table 3 presents the final gradation of the FAM mixture. The optimum binder content for the Type C dense graded asphalt mixture using the PG64-22 binder was determined to be 5.5%. This binder content was then used to estimate the binder content for the mortar (the mixture passing #16 sieve size) using the following procedure. Approximately 7000 g of the Type C mixture was prepared with 5.5% of the PG64-22 binder. The loose mix was then carefully spread out over a large surface area and the particles were separated by hand to the extent possible while the mix was still hot. After the loose mix cooled down, a rubber mallet was used again to separate the particles in the loose mix. The separated loose mix was then sieved using ASTM sieve #16 and the fine aggregate mixture passing sieve #16 was ignited in the ignition oven in accordance with AASHTO T308. The binder content for the material passing the number #16 sieve was found to be 7.6%. This was the binder content that was used to produce FAM mixes using the two binders (PG64-22 and PG76-28) with/without WMA additives. This method to determine the binder content in the FAM mixtures was similar to that proposed by Sousa et al. [14].

Fine aggregates passing sieve #16 and following the gradation shown in Table 3 were mixed with the different binders (with and without WMA additives) to produce the FAM mixtures. For the PG76-28 binder, the control mixtures (including dry Advera) were mixed at 163 °C and compacted at 143 °C, and the mixtures with the warm mix additives were mixed at 143 °C and compacted at 123 °C. For the PG64-22, the control mixtures were mixed at 143 °C and compacted at 123 °C, whereas the mixtures with the warm mix additives were mixed at 123 °C and compacted at 103 °C. Note that in each case, the mixing temperature denotes the temperature of the aggregate. The binder temperature for the control and modified binders was the same prior to adding it to the aggregates.

2.1. Short and long-term aging of asphalt binders and mortars

The mixing and compaction temperatures for the WMA mixtures represent a 20 °C temperature reduction from the mixing and compaction temperatures used for the control mixtures. This corresponds well with the typical drop in mixing