Construction and Building Materials 29 (2012) 386–393

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Experimental evaluation of anti-stripping additives in bituminous mixtures through multiple scale laboratory test results

Yong-Rak Kim [a,1], Ingryd Pinto [b,2], Seong-Wan Park [c,*]

[a] Department of Civil Engineering, 224 Engineering Building, Kyung Hee University, Yongin-si, Gyeonggi-do 446-701, South Korea
[b] Department of Civil Engineering, W333.3 Nebraska Hall, University of Nebraska, Lincoln, NE 68588-0531, United States
[c] Department of Civil and Environmental Engineering, Dankook University, Yongin-si, Gyeonggi-do 448-701, South Korea

ARTICLE INFO

Article history:
Received 1 October 2010
Received in revised form 27 September 2011
Accepted 2 October 2011
Available online 29 November 2011

Keywords:
Hot-mix asphalt
Pavement
Moisture damage
Hydrated lime
Fly ash

ABSTRACT

This paper presents performance changes and material characteristics associated with moisture damage due to anti-stripping additives in asphalt mixtures through various laboratory tests. Two additives (hydrated lime and fly ash) are investigated by adding them into two types of mixes where different asphalt binders and aggregates are used. Two widely-used asphalt concrete mixture performance tests (the AASHTO T-283 and the asphalt pavement analyzer under water) and two mixture constituent tests (the boiling water test and the pull-off tensile strength test) are conducted to characterize the effects of anti-stripping additives on the binder–aggregate bonding potential in mixtures. Results from laboratory tests indicate that the mixes, where high-quality aggregates and polymer-modified binder are used, are fairly self-resistant to moisture damage without treating any anti-stripping additive and do not show any visible sensitivity between additives, whereas the effects of additives and their sensitivity are significant in the mixes that use the unmodified binder and low-quality aggregates. With the limited amount of test data, both hydrated lime and fly ash contribute to reducing moisture damage, which implies potential significant cost savings by the use of fly ash as an alternative additive.

1. Introduction

Moisture damage is a major problem in asphalt pavements, and shows itself in various forms with multiple mechanisms, such as adhesion failure between asphalt and aggregate; moisture-induced cohesion failure within the asphalt binder; cohesion failures within the aggregate; emulsification of the asphalt; and freezing of entrapped water. Among those, the reduction of adhesion between asphalt and aggregates in the presence of water and the deterioration of asphalt due to cohesive failure within the asphalt binder itself have been known as two primary driving mechanisms of moisture damage since the 1920s [1]. In 2002, Aschenbrener [2] conducted a survey on moisture damage of hot-mix asphalt (HMA) pavements in the United States and found that a total of 44 states have experienced severe moisture damage in their pavements. To reduce moisture damage, 82 percent of the nation's state highway agencies require some sort of anti-strip treatment. Of those agencies that treat, 56% use liquids, 15% use liquid or lime, and 29% treat with lime only.

Due to the great number of pavements under severe moisture damage, attempts have been made to identify the moisture-damage mechanisms [3–9] and to develop test procedures that can estimate the moisture susceptibility of asphalt mixtures. Recently, fundamental material properties and mechanisms to assess moisture susceptibility of asphalt mixtures have been actively pursued in order to overcome shortcomings of traditional test methods that are mostly empirical. Many studies [5,9,10–16] proposed new concepts associated with key material properties, such as fracture parameters, surface energy, diffusion coefficients, and adhesion characteristics, to better identify and understand moisture-damage characteristics of asphalt mixtures. Furthermore, many different types of additives have been applied to the asphalt mixtures to minimize moisture-related damage. Numerous studies [6,17–22] indicate that anti-stripping additives can positively affect the binder–aggregate bonding characteristics and overall mixture performance by reducing mixtures' moisture susceptibility.

One well-known anti-stripping additive is hydrated lime. Hydrated lime provides better adhesive compatibility between aggregate and asphalt mastic. Thus, the use of hydrated lime may increase bonding characteristics between aggregate and asphalt. Furthermore, it has also been demonstrated that hydrated lime significantly changes rheological properties of asphalt systems. Many experimental results have shown that adding hydrated lime to asphalt mixtures significantly improves moisture-damage resistance, especially when subjected to the wetting–drying treatment

---

* Corresponding author. Tel.: +82 31 8005 3472.
E-mail addresses: ykim3@khu.ac.kr (Y.-R. Kim), ingrydpinto@gmail.com (I. Pinto), spark@dankook.ac.kr (S.-W. Park).
[1] Tel.: +82 31 201 2545; fax: +82 31 202 8854.
[2] Tel.: +1 402 472 9696.

0950-0618/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2011.10.012

[19,21]. Therefore, many state highway agencies employ and/or require the use of hydrated lime in HMA pavements. 1.0% hydrated lime by weight of total dry aggregates in a mix is typically applied to HMA used in US pavements. Sufficient literature strongly supports the use of hydrated lime to control moisture sensitivity of asphalt mixtures and also to induce other benefits due to lime addition, such as stiffening the asphalt binder and HMA, improvements in the resistance to fracture growth at low temperatures, and favorable oxidation kinetics and interactions with products of oxidation to reduce deleterious effects by aging [20,21,23].

Recently, the use of alternative additives such as fly ash has driven significant attention to the asphalt materials/pavement community, because fly ash is much more economical and convenient to access than hydrated lime in certain states such as Nebraska, where a large amount of fly ash is produced daily, which requires landfills for disposal and related costly operations. Its application in asphalt mixtures can potentially bring benefits to the environment and reduce the amount of disposed material. A survey conducted by the American Coal Ash Association (ACAA) provides information about production and application of fly ash from 170 power plants in the United States. In 2007, approximately 72 million tons of fly ash was produced in the United States and only 32 million tons (44.4% of total) were consumed. The remaining material has been deposited in landfill sites. The cost of disposing the unused fly ash varies from $12 to $15 per ton; sometimes it can reach $34 per ton. Considering the amount of abandoned fly ash in 2007, a significant amount of cost was spent in the disposal process, not to mention the environmental issues that this by-product can cause. This situation has driven highway engineers and researchers to investigate the use of fly ash for various engineering purposes, such as the application of fly ash in asphalt pavements.

Several previous studies have shown that the addition of fly ash can improve HMA performance. Rosner et al. [24] presented that the addition of 3–6% of fly ash in asphalt mixtures had comparable results for moisture-damage resistance compared to other anti-stripping additives. The improvement of moisture-damage resistance by adding fly ash to the asphalt mixture was also found by Henning [25] and Dougan [26]. Henning also reported that fly ash works as a stiffening and void-filling agent for the mixture. Ali et al. [27] stated that fly ash added in the amount of 2% of total weight of aggregates as mineral filler improves not only the stiffness characteristics, but also mixture strength and stripping resistance. However, it is not clearly understood how fly ash contributes to moisture damage-resisting mechanisms and how much effective fly ash is compared to the widely-used additive, hydrated lime. If fly ash is sufficiently effective to mitigate moisture damage, it can bring significant cost savings to certain states such as Nebraska where hydrated lime must be transported from other states, while abundant fly ash is available. In 2010, Nebraska spent approximately $1.4 M to import around 8900 tons of hydrated lime.

2. Research objectives

The overall objective of this research is to investigate the effects of two anti-stripping additives (hydrated lime as an additive that has been popularly used in many places and fly ash as an alternative, supplemental material) on moisture-damage resistance. More specifically, this study is to:

- evaluate mechanical behavior of those two additives in different asphalt mixes, where different mixture components (binder and aggregate) are involved, by an integrated evaluation of various laboratory tests in two different testing scales: mixture scale and component scale;
- provide useful insights to understand the impact of aggregate surface modification through crushing and binder modification with polymers on moisture-induced damage characteristics such as adhesive bonding potential between aggregate and asphalt binder incorporated with anti-stripping agents in the mix; and
- identify the effect of fly ash as a potential anti-stripping agent. Compared to hydrated lime, it is not clear how much effective fly ash is to mitigating moisture damage in asphaltic mixtures. Some states such as Nebraska can be benefited by the alternative material which can bring significant cost savings.

3. Research method

Fig. 1 briefly illustrates the process of the research method employed for this study. Two Superpave mixes (i.e., SP2 and SP5) used in Nebraska were selected for this study to draw more comprehensive and general conclusions on the material-specific effects of additives based on results from diverse mixes. The SP5 mix consists of better-quality (e.g., more crushed) aggregates and polymer-modified asphalt binder PG 70-28, while the SP2 mix is usually produced with less-angular aggregates and unmodified asphalt binder PG 64-22.

As mentioned, this research pursued an integrated evaluation through two different testing scales. Laboratory tests of asphalt concrete mixtures are composed of volumetric mixture design of various SP2 and SP5 mixes treated without and with the two different anti-stripping agents (i.e., hydrated lime and fly ash), and fabrication of compacted asphalt concrete samples and mechanical testing of the asphalt concrete samples using traditional performance evaluation techniques such as AASHTO T-283 [28] and asphalt pavement analyzer (APA) test under water. Furthermore, the bonding between aggregate and binder at a local-scale (component) level was investigated following the boiling water test (ASTM D 3625) [29] and the pull-off test using a Pneumatic Adhesion Tensile Testing Instrument (PATTI) procedure (ASTM D 4541) [30]. The PATTI has gained attention in the scientific community because it contributes to a better understanding of the local-scale debonding characteristics between aggregate and binder in the presence of water, which leads to a better evaluation of material-specific moisture susceptibility. Test results between the two scales (global and local) were then compared and related so that measured characteristics of each mix component can be related to performance testing results of asphalt concrete samples.

4. Materials, mixture design, and volumetric results

This section describes materials used in this research (aggregates, asphalt binders, and two anti-stripping additives—hydrated lime and fly ash). It also illustrates mix design results of six Superpave mixes (three SP2 mixes: NF2 (without additive), HL2 (with hydrated lime), and FA2 (with fly ash); and three SP5 mixes: NF5 (without additive), HL5 (with hydrated lime), and FA5 (with fly ash)).

A total of six local aggregates (three limestone types and three gravel types) that have been widely used in Nebraska pavements were used in this study. All six mixes designed were targeted to be blended with 45% limestone type and 55% from gravel type but with different level of aggregate crushing for each mix type (SP2 and SP5) so that SP2 mixes are similar to SP5 mixes in the mineralogical characteristics, while presenting different aggregate surface characteristics: angularities. Two asphalt binders were used in this study. To fabricate SP5 mixes and samples, the Superpave performance-graded polymer-modified binder PG 70-28 was used. For the SP2 mixes and samples, the unmodified binder PG 64-22 was used. Hydrated lime evaluated in this study was a typical one with its median particle size of 2 μm, 98% of $Ca(OH)_2$, and specific gravity of 2.343. Fly ash estimated in this study was Class C with specific gravity of 2.650% and 26.9% of CaO.

Individual mixtures were designed with the same blend of aggregates to avoid variability due to physical and mineralogical characteristics of the aggregates. Variables differentiate mixtures are the mix type (SP2 or SP5) and the existence and type of additive (NF, HL, or FA). The two NF mixtures (NF2 and NF5) are reference mixtures where no additive was added. Fig. 2 presents an overall gradation of