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Mitigation of moisture damage in asphalt concrete: Testing techniques and additives/modifiers effectiveness

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HIGHLIGHTS

- Liquid antistrip (LAS), hydrated lime (HL), SBS and PPA were used in this study.
- They were evaluated based on their effect on asphalt mix moisture susceptibility.
- LAS and HL enhanced the asphalt mix resistance to moisture and fracture.
- HL and SBS improved the rutting resistance.
- PPA failed to improve the asphalt mix performance.

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ABSTRACT

Moisture damage is a serious pavement distress that most transportation agencies face. It's complicated mechanisms are dependent on several factors in asphalt pavement. This phenomenon triggers several pavement distresses, thus costing the country billions of dollars in pavement maintenance and rehabilitation. The most traditional technique adopted to mitigate moisture damage is adding selected additives or modifiers to asphalt mixtures. The additives and modifiers are used during construction to improve water resistance in asphalt pavement. However, each additive or modifier performs differently. This study evaluates the effects of two additives and two modifiers on the moisture susceptibility of two asphalt mixes. The additives include a liquid anti-stripping agent and hydrated lime while the modifiers include styrene butadiene styrene (SBS) and polyphosphoric acid (PPA). The effectiveness of the additives and modifiers was evaluated by conducting three mixture tests, including the Lottman AASHTO T283-02 test with five freezing and thawing (FT) cycles, the wheel-tracking test, and a fracture test using semicircular bending (SCB) specimens. The Lottman AASHTO T283-02 showed that adding liquid anti-strip to asphalt binder produced the best moisture resistance for both mixes followed by hydrated lime. The wheel track test showed that hydrated lime and SBS modifiers resulted in the least rut depth when used in both mixes. The results of the fracture test showed that liquid anti-strip and hydrated lime produced the highest fracture resistance. On the other hand, the three above test results indicated that PPA may not control asphalt mixers' moisture susceptibility.

1. Introduction

Pavements around the world are generally exposed to moisture from different sources which may eventually make them susceptible to moisture damage. Moisture damage was first recognized in the early 1930s and has been studied and analyzed since then [1]. However, it was not until the early 1960s that moisture damage was recognized as a serious problem [2]. Moisture damage is responsible for at least $54 billion in additional annual vehicle operating costs because of its contribution to premature failure [1] and millions of dollars in maintenance and reconstruction costs [3]. Although moisture damage is not considered to be a failure mode by itself, its induced damage can, however, accelerates other failure modes and leads to severe distresses such as rutting,

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raveling, shoving, and bleeding [2,4]. Despite the developments that have increased the understanding of asphalt mixture behavior and mix design, moisture is still considered a complex problem in asphalt pavements.

Moisture damage in asphalt mixtures can be defined as the loss of strength and stiffness of the mix because of moisture [5,6]. Moisture can infiltrate the mixture through three main transport modes, including permeability (infiltration from surface), capillary rise, and vapor diffusion [7]. Moisture damage usually follows two mechanisms in asphalt pavements: loss of adhesion and loss of cohesion [3,4,8–10]. The loss of adhesion bond or the physical separation of aggregate and asphalt binder film as a result of moisture is also called stripping, while the reduction of cohesion and stiffness of the asphalt binder film, within its structure, is called softening.

Several factors control the moisture susceptibility of asphalt mixtures. These factors can be divided into two main categories: the first category is related to compatibility between asphalt binder and aggregates and the second is related to moisture and drainage conditions inside the pavement [12]. The first category includes the properties and source of the mixture components (aggregates and binder), mix design, construction process, and compaction; while the second category includes drainage characteristics, climate, environmental conditions, and traffic volume [2,6,9–12].

Hot-mix asphalt (HMA) consisting of moisture-susceptible aggregates and located in a poor drainage area would most likely lead to rapid stripping and pavement deterioration [12]. Another case that will lead to severe moisture damage is the presence of moisture at high temperatures on roads with heavy and repetitive traffic loads [12]. The field conditions that should be mitigated and accounted for in test procedures are traffic, time, and environmental conditions [14].

The evaluation of HMA for moisture susceptibility is challenging to transportation agencies [3]. Therefore, several laboratory tests have been developed for evaluating HMA for moisture susceptibility and have been continually improved over the last 70 years. Moisture susceptibility was first evaluated using the boil test in the 1930s before further scientific advancements have led to the testing of water pressure-pore size effect in 1950s and surface reaction in 1970s. The Lottman test, wheel track test, and several other tests are currently implemented to evaluate moisture susceptibility [13]. However, these laboratory tests have several drawbacks because (1) they cannot simulate HMA field conditions, (2) they use empirical procedures, and (3) their results depend on the moisture conditioning process applied. Therefore, 87% of U.S. transportation agencies are still trying to resolve this issue through more moisture susceptibility tests and developed standards [1]. Nevertheless, the existing tests can provide useful information about the moisture sensitivity of mixes. In general, the most important two aspects assessed by laboratory tests are stripping, which occurs between asphalt films and aggregate, and the loss of strength in compacted HMA specimens [3].

Because of the complexity of the moisture damage phenomenon, it is difficult to find a unique test or analytical method that accurately simulates the field behavior and quantifies and predicts moisture damage [7]. Several approaches have been attempted to accelerate the moisture effect in the laboratory such as freezing HMA specimens, placing HMA specimens in hot water, vacuum saturating HMA specimens, and boiling loose mixtures [15].

Using proper additives and modifiers is considered the most cost-effective technique for mitigating moisture damage. If a particular HMA is determined to be moisture susceptible or sensitive, most U.S. transportation agencies add additives or modifiers to binder or aggregate to make the mix more resistant to moisture damage. The ability of numerous additives and modifiers to reduce stripping potential has been evaluated. Liquid anti-strip and polymers are added to asphalt binder while Portland cement, hydrated lime, and fly ash are added to the aggregates [5,9,10,18]. These additives and modifiers are expected to improve the resistance of HMA to moisture damage by improving the adhesion bond between asphalt binder and aggregate surface [11]. Additives and modifiers follow several mechanisms for improving the adhesion bond such as modifying the aggregate surface, promoting the spread of binder around aggregate particles by reducing binder surface tension, or improving the chemical properties of the binder and aggregate surface at the same time.

The effectiveness of an additive or modifier depends primarily on the type of aggregate and on the test method used to evaluate HMA [9]. However, the selection of an additive and modifier is usually based on three main factors: economy, the effect on adhesion and other mixture properties, and the dosage required. The short-term and long-term performances of many mixes with additives and modifiers are always questioned. For some additives and modifiers, the long-term performance of the mix could be worse than the control mix [17,19].

2. Objective and scope

The primary objective of this study is to evaluate the impact of using two additives and two modifiers on moisture-susceptible mixes to control moisture damage. The two additives are liquid anti-strip and hydrated lime, and the two modifiers are styrene butadiene styrene (SBS) and polyphosphoric acid (PPA). Two typical moisture-susceptible mixes from Illinois District 5 region – east central Illinois – were utilized in this study. The additives and modifiers were evaluated by conducting three mixture tests including modified Lottman AASHTO T283-02 test with five freezing and thawing (FT) cycles conditioning, wheel track test, and fracture test using semicircular bending (SCB) specimens.

3. Materials

3.1. Aggregate

The two mixes used in this study comprise four aggregate stockpiles; two course (CM11 and CM16) and two fine (FM20 and FM02). CM11, CM16 and FM20 are dolomitic limestone imported from a quarry in Kankakee, IL while FM02 is a type of natural sand imported from Mahomet, IL. In addition to the aggregate stockpiles, mineral filler, imported from Thornton, IL, was also used. Table 1a and b displays the aggregate gradations and some physical properties of the aggregates, respectively.

3.2. Binder

The base binder used in this study is unmodified PG 64-22. In the case of SBS and PPA, this grade was bumped to PG70-22. The binder was imported from Heritage Laboratories, Inc.

3.3. Asphalt mixes

Mixes N70 and N90 were selected from Illinois District 5 regions to be used in this study. These mixes are known to be moisture susceptible. The numerical values represent the design number of gyrations. N70 uses CM11, CM16, FM20, FM02 and MF, while N90 uses CM11, CM16, FM20 and MF. Both mixes are 19 mm NMAS and are primarily used as a binder HMA layer. The authors used a Superpave mix design procedure along with the Bailey method, a tool to understand packing of the aggregate structure, to find the appropriate aggregate blend percentages along with the optimum asphalt content for the mix design.

Bailey method is in use since 1980's and approved in different states including Illinois. It is a convenient tool that helps the user better understand the packing of the aggregate structure in the asphalt mixture and therefore achieve volumetrics required by Superpave mix design or any other mix design method such as Marshall. Therefore, Bailey method is not a mix design method. The verification of Bailey method is not included as an objective in this study. However, more details about Bailey method is found in the report by Pine [20].