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Predicting stripping and moisture induced damage of asphalt concrete prepared with polymer modified bitumen and hydrated lime

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ABSTRACT

Many highway agencies have been experiencing premature failures that decrease the performance and service life of pavements. One of the major causes of premature pavement failure is the moisture damage of the asphalt concrete layer. Many variables affect the amount of water damage in the asphalt concrete layer such as the type of aggregate, bitumen, mixture design and construction, level of traffic, environment, and the additive properties that are introduced to the bitumen, aggregate or bitumen–aggregate mixture.

This study is aimed to determine the effect of additives such as hydrated lime as well as elastomeric (SBS) and plastomeric (EVA) polymer modified bitumen (PMB) on the stripping potential and moisture susceptibility characteristics of hot mix asphalt (HMA) containing different types of aggregate (basalt–limestone aggregate mixture and limestone aggregate). The stripping properties and moisture susceptibility characteristics of the samples have been evaluated by means of captured images and the Nicholson stripping test (ASTM D 1664) as well as the modified Lottman test (AASHTO T 283), respectively.

The results indicated that hydrated lime addition and polymer modification increased the resistance of asphalt mixtures to the detrimental effect of water. Moreover, it was found out that samples prepared with SBS PMB exhibited more resistance to water damage compared to samples prepared with EVA PMB.

1. Introduction

Environmental factors such as temperature, air, and water can have a profound effect on the durability of asphalt concrete mixtures. In mild climatic conditions where good-quality aggregates and asphalt cement are available, the major contribution to the deterioration may be traffic loading, and the resultant distress manifests as fatigue cracking, rutting (permanent deformation), and raveling [1]. However, when a severe climate is in question, these stresses increase with poor materials, under inadequate control, with traffic as well as with water which are key elements in the degradation of asphalt concrete pavements. Water causes loss of adhesion at the bitumen–aggregate interface. This premature failure of adhesion is commonly referred to as stripping in asphalt concrete pavements [2–4]. The strength is impaired since the mixture ceases to act as a coherent structural unit. Loss of adhesion renders cohesive resistance of the interstitial bitumen body useless. Water may enter the interface through diffusion across bitumen films and access directly in partially coated aggregate [5]. Water can cause stripping in five different mechanisms such as detachment, displacement, spontaneous emulsification, pore pressure, and hydraulic scour [1,3,6].

Many variables affect the amount of moisture damage which occurs in an asphalt concrete mixture. Some of these variables are related to the materials forming hot mix asphalt (HMA) such as aggregate (physical characteristics, composition, dust, and clay coatings) and bitumen (chemical composition, grade, hardness, crude source, and refining process). Others are related to mixture design and construction (air void level, film thickness, permeability, and drainage), environmental factors (temperature, pavement age, freeze–thaw cycles, and presence of ions in the water), traffic conditions and type, and properties of the additives [5].

To alleviate or to control the deformations due to water damage, various researches were performed leading to the utilization of anti-stripping additives [7].

Anti-stripping additives are used to increase physico-chemical bond between the bitumen and aggregate and to improve wetting by lowering the surface tension of the bitumen [8]. The additives that are used in practice or tested in the laboratory include: (i) traditional liquid additives, (ii) metal ion surfactants, (iii) hydrated lime and quick lime, (iv) silane coupling agents, and (v) silicone [5].

Among them, hydrated lime and quicklime are the most commonly used solid type anti-stripping agents [9–11]. When lime is added to HMA, it reacts with aggregate and strengthens the bond between the bitumen and the aggregate interface. Lime reacts with

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highly polar molecules to inhibit the formation of water-soluble soaps that promote stripping. When those molecules react with lime, they form insoluble salts that no longer attract water. The ability of hydrated lime to make an asphalt mix stiffer, tougher, and resistant to rutting, is a reflection of its superior performance as active mineral filler [12].

There are five methods for introducing hydrated lime into HMA. These are: (i) lime slurry to dry or wet aggregate, (ii) dry lime to wet aggregate, (iii) dry lime to dry aggregate (iv) dry lime to bitumen, and (v) quicklime slurry to dry or wet aggregate [11,13–16].

Dry hydrated lime to wet aggregate is one of the most commonly used addition methods. In this method, dry hydrated lime is either added to wet aggregate (containing 3–5 percent water) or added to dry aggregate and then sprayed with water. The addition of lime to wet aggregate is generally the better method and enables good mixing, coating and treatment especially with poor aggregates. Moreover, it is the most suitable method for application in laboratory conditions [5,17,18].

Methods of treatment to reduce moisture damage also include the utilization of polymer modified bitumen (PMB) [19]. Polymer is a derived word meaning many parts. Polymers are made up of many smaller chemicals (monomers) joint together end-on-end. The physical and chemical properties of a polymer depend on the nature of the individual molecular units, the number of them in each polymer chain and their combination with other molecular types.

Two basic types of polymers are used in modified bitumen of road applications: (i) elastomers and (ii) plastomers.

SBS block copolymers are classified as elastomers that increase the elasticity of bitumen and they are probably the most appropriate polymers for bitumen modification. Although low temperature flexibility is increased, some authors claim that a decrease in strength and resistance to penetration is observed at higher temperatures [20].

SBS copolymers derive their strength and elasticity from physical and cross linking of the molecules into a three-dimensional network. The polystyrene end blocks impart the strength to the polymer while the polybutadiene rubbery matrix blocks give the material its exceptional viscosity [21].

EVA based polymers are classified as plastomer that modify bitumen by forming a tough, rigid, three-dimensional network to resist deformation. Their characteristics lie between those of low density polyethylene, semi rigid, translucent product and those of a transparent and rubbery material similar to plasticized PVC and certain types of rubbers [22].

Both SBS and EVA type polymers are usually provided in the form of pellets or powder which can be subsequently diluted to the required polymer content by blending with base bitumen by means of low to high shear mixer. Blending pellets of with base bitumen results in a special polymer concentration suitable for different applications [23].

Although, the utilization of PMBs for controlling the moisture damage is limited, there is evidence that some polymers can act as anti-stripping agents [17].

Kim et al. reported that, polymer modified systems could accommodate more damage prior to failure that of unmodified systems. They indicated that mixtures containing PMB strongly exhibited less moisture damage [24].

Kumar et al. set out to examine the strength characteristics of polymer modified mixes. In their studies they concluded that there was an improvement in the moisture susceptibility characteristics of the polymer modified mixes [25].

Stuart et al. reported that, mixtures with PMBs exhibited greater resistance to moisture damage than the mixtures with unmodified bitumen by providing increased adhesion to the aggregate and by creating a network within the bitumen [26].

The objective of this study is to evaluate the effect of hydrated lime as well as SBS and EVA based PMB on the stripping properties

Table 1
Properties of the base bitumen.

Test	Specification	Results	Specification limits
Penetration (25 °C; 0.1 mm)	ASTM D5 EN 1426	63	50–70
Softening point (°C)	ASTM D36 EN 1427	49	46–54
Viscosity at (135 °C)-Pa.s	ASTM D4402	0.51	–
Thin film oven test (TFOT) (163 °C; 5 h)	ASTM D1754 EN 12607-1		
Change of mass (%)		0.07	0.5 (max)
Retained penetration (%)	ASTM D5 EN 1426	51	50 (min)
Softening point after TFOT (°C)	ASTM D36 EN 1427	51	48 (min)
Ductility (25 °C)-cm	ASTM D113	100	–
Specific gravity	ASTM D70	1.030	–
Flash point (°C)	ASTM D92 EN 22592	+260	230 (min)

Table 2
The properties of limestone and basalt aggregate.

Test	Specification	Result		Specification limit
		Limestone	Basalt	
Specific gravity (coarse agg.)	ASTM C 127			–
Bulk		2.686	2.666	–
SSD		2.701	2.810	–
Apparent		2.727	2.706	–
Specific gravity (fine agg.)	ASTM C 128			–
Bulk		2.687	2.652	–
SSD		2.703	2.770	–
Apparent		2.732	2.688	–
Specific gravity (filler)		2.725	2.731	–
Los angeles abrasion (%)	ASTM C 131	24.4	14.2	Max 45
Flat and elongated particles (%)	ASTM D 4791	7.5	5.5	Max 10
Sodium sulfate soundness (%)	ASTM C 88	1.47	2.6	Max 10–20
Fine aggregate angularity	ASTM C 1252	47.85	58.1	Min 40