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Moisture susceptibility of warm mix asphalt: A statistical analysis of the laboratory testing results

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HIGHLIGHTS

- In case of ITS_{sat} all first, second and interactive terms were significant.
- In case of ITS_{dry} and TSR the interactive term of PPSS 4.75 mm – Sasobit was not significant.
- In saturated WMA specimens, hydrated lime acts positively both as a filler and as an anti-stripping agent.
- Lime content has the greatest effect on TSR increase, compared with other parameters.

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ABSTRACT

Warm Mix Asphalt (WMA), an alternative to Hot Mix Asphalt, has gained popularity in the recent years. In this research, the effects of aggregate gradation, hydrated lime and Sasobit has been investigated in WMA mixes. Indirect Tensile Testing was performed on dry and saturated samples. Response Surface Methodology was applied to analyze the data. The results indicated that in the case of Indirect Tensile Strength at saturation condition (ITS_{sat}) all the first and second order terms of the aggregate grading, hydrated lime and Sasobit contents, as well as their interactive terms, were statistically significant at 90% confidence level. In the case of Tensile Strength Ratio (TSR) and Indirect Tensile Strength at dry condition (ITS_{dry}) parameters, the interactions between grading and Sasobit contents were rather poor.

1. Introduction

Stripping is one of the widely occurring modes of pavement failure. This phenomenon is defined as bonding failure between aggregate particles and bitumen and/or failure within bitumen structure [1]. The failure mechanisms of this phenomenon are rather complicated [2]. Stripping causes a reduction of materials strength over time, manifesting itself in terms of rutting, corrugation, shoving, raveling and cracking distresses [3–6].

Proper mix design is a prerequisite for prevention of moisture damage in pavement layers. With this regard, the use of anti-stripping agents have been successfully experienced in many projects [7]. Researchers reported that the use of hydrated lime (known as a potential anti-stripping agent), can decrease stripping, rutting and cracking potential of mixes [8–10]. Moreover, hydrated lime has been recognized to have a major role on moisture resistance of mixes, regardless of the type of aggregate and the bitumen type and grade [1,2,5,8,9].

The use of Warm Mix Asphalt (WMA), not only reduces the energy consumption, it lowers emissions, odors and greenhouse gases from asphalt plants. It also helps to create better working environment both at asphalt plants and at paving sites [11–13]. Depending on the type of additives used, WMA technologies could be classified into the following four categories [14]:

Use of organic additives.
Use of chemical additives.
Use of water-bearing additives.
Using water-based processing.

The main role of the above technologies is to facilitate decreasing mixing and compaction temperatures, from around 155 °C in

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the conventional Hot Mix Asphalt (HMA) mixes, to a range of 100–140 °C in WMA mixes [12,13,15]. However, some researchers believe that the low mixing and compaction temperatures can lead to increased stripping potential in mixes, as a result of retained moisture in aggregate particles [2].

Various testing methods have been carried out to evaluate moisture sensitivity of asphalt mixes. However, it appears that there is no global agreement between researchers on a single method for quantifying this distress mode. Among the traditional testing methods, such as boiling test, Marshall and Indirect Tensile Strength (ITS), some researchers believe that ITS can be capable of predicting stripping phenomenon [2,16]. A thorough review of the state of the art in moisture susceptibility of asphalt mixes has been performed by some researchers [17].

Although a number of researchers have investigated the stripping resistance of WMA mixes, little works have been published on the subject. This is mainly due to the fact that in the previous studies, in order to optimize and evaluate the various parameters, the commonly, one-factor-at-a-time methodology has been used. This methodology lacks the capability of recognizing interactions between the above mentioned parameters. One of the potential methodologies that is capable to identify the interactions between various involved parameters, is the factorial Design of Experiments (DOE). This methodology uses techniques such as Response Surface Methodology (RSM). The latter is able to take into consideration (which has not yet been fully understood) several factors at different levels [16,18].

A statistic model can be used to establish relationship between the various involved factors and responses [16,18,19]. In this research, RSM has been used to investigate the combining effects of anti-stripping agent (in this case hydrated lime), warm mix additive content (in this study Sasobit) and the grading of aggregates.

The effects of the above three parameters were investigated by applying Indirect Tensile Testing at dry (ITS_{dry}) and saturated (ITS_{sat}) conditions. Tensile Strength Ratio (TSR) of the samples, which provides data regarding potentiality of mixes against stripping, were determined too.

2. Materials and experimental methods

2.1. Materials

Three grading levels of one aggregate type, containing 85%, 70% and 55% passing 4.75 mm sieve size were selected. These are shown in the dense gradation curves of Fig. 1. The gradings were named as fine, medium and coarse gradation. Tables 1 and 2 show physical testing results of the aggregates used in the research.

A 60/70 penetration grade bitumen, from the Refinery of Tehran, was used to prepare all mixes. Properties of the bitumen are reported in Table 3. Furthermore, hydrated lime was utilized as the anti-stripping agent and Sasobit was used as the warm mix additive. Their properties are reported in Tables 4 and 5 respectively.

2.2. Mix design

The optimum binder content of the mixture was determined using ASTM D1559 standard method [20]. The optimum bitumen contents were 5.6%, 6.1% and 6.5% for the coarse, medium and fine aggregate gradings respectively. All the warm mix asphalt samples were manufactured at 125 °C.

2.3. Indirect tensile testing

The modified Lottman test (AASHTO T283) [21] aims at evaluating water damage susceptibility of mixes. For this testing properties, all the specimens were compacted at 7% ± 0.5% air void contents based on T283. The Marshal Compactor

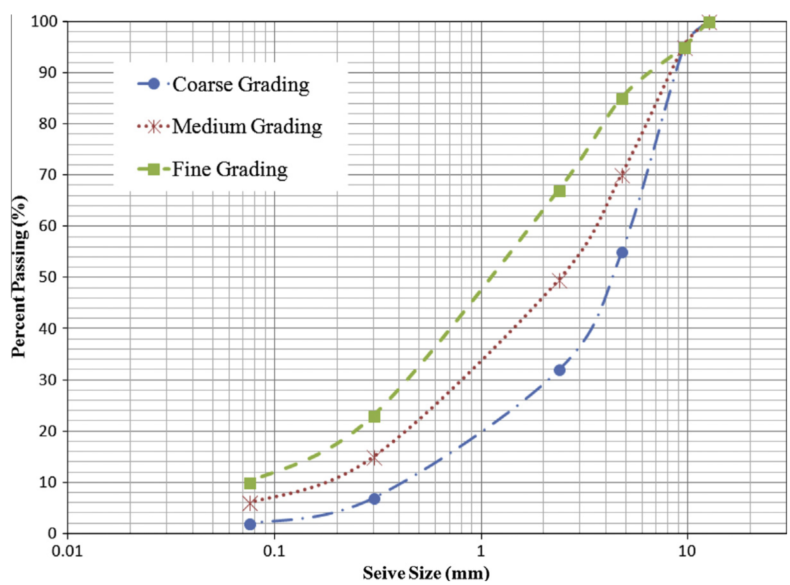

Fig. 1. Grading size distribution of the coarse, medium and fine aggregates.

Table 1
Mechanical properties of the selected aggregates.

Test	Standard method	Values (%)	Specification limit (%)
LA abrasion loss	AASHTO T96	19	<30
Fractured particles in one face	ASTM D5821	100	–
Fractured particles in two faces and more	ASTM D5821	93	90<
Coating of aggregate particles	AASHTO T182	97	95<
Flakiness index	BS–812	20	<25
Sand equivalent	AASHTO T176	75	50<
Sodium sulphate soundness	AASHTO T104	2.90	<12
		0.40	<8