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Long term effectiveness of anti-stripping agents

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HIGHLIGHTS

- Zycosoil improves long term performance compared with the hydrated lime.
- The most significant factor affecting the TSR is the bitumen content.
- The proposed model can be employed to find the proper time for rehabilitation.

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ABSTRACT

Numerous factors affect long term resistance of asphalt mixtures against stripping, therefore, proposing a mathematical model between the stripping failure and these factors is essential. The rehabilitation time of pavements, a very pivotal issue, can be predicted if the developed model comprises time as an independent factor. Apart from the capability of such model for prediction of rehabilitation time, the proposed model reveals the effect of each individual factor on the stripping process and it discloses the interrelationship between the pertinent factors. In this study, Response Surface Methodology (RSM) was successfully employed to establish the time dependent models between Tensile Strength Ratio (TSR) as the response parameter and independent factors such as time and anti-stripping additives (namely hydrated lime and Zycosoil). The results obtained through the modeling showed that both the short and long term performance of the Zycosoil is superior to the hydrated lime. The proposed models can be solved to find the time that asphalt mixtures take to reach certain terminal TSR; e.g. for TSR = 80. A mathematical model is developed that can predict the proper time of rehabilitation of pavement before stripping failure.

1. Introduction

Stripping of asphalt mixtures is defined as the detachment of the aggregate and bitumen typically accompanied by the failure in bitumen structure. This distress can result in rutting, cracking, shoving, raveling of the asphalt pavement layer. This mode of failure imposes a large waste of energy and financial expenses on highway authorities [1].

There is extensive literature on the factors significantly influencing the stripping of the asphalt mixtures such as chemical composition and gradation of the aggregates [2–7], the type/amount of the bitumen and the bitumen modifier [8–11], the void content of the mixtures [12] and the type/amount of the anti-stripping agents [2,13–15].

For instance, a comparison between the lime stone and siliceous material aggregates indicated that lime stone improves the resistance of asphalt mixtures against the freeze–thaw cycles [2]. Also, it was reported that the aggregates with alkali metals content, such as lime stone, has a higher moisture resistivity compared to the basalt aggregates [6,7]. Moreover, hydrated lime improves the fatigue and cracking resistance of the mixtures [16,17].

Another important point regarding the factors influencing the stripping of asphalt mixtures is the gradation of aggregates. Khodaii and coworkers have found that the moisture sensitivity of the coarse graded mixtures is lower than that of the fine graded mixtures and the stripping resistivity of the asphalt mixtures with dense grading aggregates drops by an increase in the mastic asphalt content [3,18]. In addition, higher mastic asphalt content of the mixtures enhances the stripping resistivity of stone matrix asphalt (SMA) [4].

Optimum bitumen content has significant effect on stripping resistance; it has been shown that a bitumen (60/70 penetration

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grade) content of 5.5% enhances the moisture susceptibility of the hot mix asphalt with the dense grading siliceous aggregate [8]. In addition, polymer type has shown considerable effect on moisture resistance of the polymer modified bitumen. According to Gorkem and Sengoz styrene–butadiene–styrene (SBS) is a more effective polymer compared to ethylene–vinyl acetate (EVA) regarding the moisture resistance of asphalt mixtures [11].

Recently, it has been shown that Zycosoil, an organosilane compound, improves the moisture resistance of asphalt mixtures [14,19], regardless of the source of aggregate [2,20].

To the authors' best knowledge, most of the investigations have only focused on the short term moisture susceptibility of the asphalt mixtures; for instance, a period of 24 h is considered for the moisture susceptibility of the asphalt mixtures in the modified Lottman Test (AASHTO T283) [21]. It should be noted that the obtained moisture susceptibility did not show the actual resistivity of the asphalt mixture in a real pavement system. In a previous study conducted by Lu and Harvey, it was observed that most of the detrimental effects of moisture occur in the first four months [22]. By conditioning of different asphalt mixtures in water for certain period (maximum 7 days), Gandhi et al. also showed that the hydrated lime is the most effective anti-stripping agent. However, they found hydrated lime and liquid anti-stripping have similar effect on actual resistivity of the asphalt mixture after 90 days of conditioning [5].

Systematic evaluation of the effect of the above mentioned factors is necessary for proposing a feasible procedure for proper asphalt mixture preparation. Besides, this systematic approach can results in collective identification and quantification of the effective factors and their probable interrelationships [3,4,8,13,14,23,24]. The factorial design of experiment (DOE) is a powerful tool for conducting such strategy. A suitable mathematical relationship between the factors and the response is achievable by employing an appropriate DOE that provides the opportunity to predict optimum value of these factors [3,4,8,13,14].

An appropriate choice of design of experiments is essential to be able to determine a response surface. One of the conventional designs to derive a second order model is to deploy the central composite design (CCD) with 2^k runs (k is the number of factors), $2k$ axial (star) runs and a few center runs [8,25]. Instead of carrying out a full factorial of experiment design, fractional factorial designs (FFD) such as CCD, can be used with less number of experiments and derive any interactions between parameters [8,23,25].

In the present work, authors attempt to present second order polynomial relationships between TSR and bitumen content, grading, anti-stripping content (hydrated lime and Zycosoil) and time. A CCD is considered as the design matrix since it allows identification of first order interaction between factors and gives second order polynomial model which can optimize these factors. The effect of time – as the pertinent factor – is also varied in the CCD, to acquire a time dependent model. This model can be employed to find the proper time for rehabilitation of the pavement before the occurrence of the stripping failure. Also, the long term performance of each anti-stripping additive can be examined.

2. Materials and mix design

2.1. Materials

Three grading levels corresponding to the aggregate type according to (ASTM D3515-01) [26], with different size distribution (85%, 70% and 55% passing through 4.75 mm sieve size) were selected as shown in Fig. 1. The grading levels were named as the fine, medium and coarse grading. In Tables 1 and 2, the physical properties of the siliceous aggregates are listed.

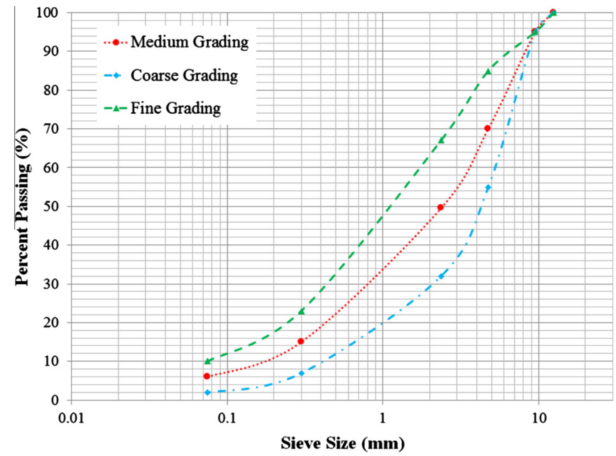

Fig. 1. Grading size distribution of the coarse, medium and fine aggregates.

Table 1
Properties of the siliceous aggregate used.

Test	Standard	Values (%)	MS – 2 specifications (%)
LA abrasion loss	AASHTO T96	19	<30
Fractured in one face	ASTM D5821	100	–
Fractured two faces and more	ASTM D5821	93	90<
Coating of aggregate	AASHTO T182	97	95<
Flakiness	BS – 812	20	<25
Sand equivalent	AASHTO T176	75	50<
Sodium sulfate soundness	AASHTO T104	2.90	<12
		0.40	<8

Table 2
Engineering properties of aggregate used.

Fraction	Standard	Specific gravity (g/cm^3)		Absorption
		Apparent	Bulk	
Retained on 2.36 mm (No. 8)	AASHTO T85	2.62	2.52	1.58
Passed from 2.36 mm and retained on 0.075 mm	AASHTO T84	2.62	2.51	2.2
Passed from 0.075 mm (No. 200)		–	2.68	–
Bulk specific gravity on blended aggregate		–	2.53	–

The AC 60/70 penetration grade bitumen was used to prepare all the mixtures. The properties of the bitumen, hydrated lime and Zycosoil are given in Tables 3–5, respectively.

2.2. Mixture design

Asphalt mixes used in this investigation were mixed and compacted according to Marshall mix design method according to ASTM D1559-89 [27]. The flow, stability and air voids in the total mix, air void content in the mineral aggregates, as well as the percentage of voids filled with binder are examined at various binder contents to determine the 'optimum' value for stability.

The optimum bitumen contents were determined as 6%, 5.5% and 5.1% for mixtures with fine, medium and coarse aggregate grades, respectively.

3. Experimental methods

3.1. Test procedure

The modified Lottman Test (AASHTO T283) was used to evaluate the moisture susceptibility of the asphalt mixtures. The test is conducted by compacting specimens to an air void content of 6.0–8.0% percent. Three specimens were selected