Construction and Building Materials 75 (2015) 488–495

Contents lists available at ScienceDirect

Construction and Building Materials

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

A mathematical model for predicting stripping potential of Hot Mix Asphalt

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HIGHLIGHTS

- Parametric studies should be directed to find any interaction terms.
- Lime content had the greatest effect on TSR increase.
- PPSS 4.75 mm had the greatest effect on TSR decrease.

ARTICLE INFO

Article history:
Received 18 January 2014
Received in revised form 19 September 2014
Accepted 17 November 2014

Keywords:
Stripping potential
Response Surface Methodology
Grading
Bitumen content
Lime content
Hot Mix Asphalt

ABSTRACT

Stripping – the most important mode of Hot Mix Asphalt (HMA) failure – is a problematic issue in the pavement performance and its maintenance. Identification and quantification of the pertinent parameters influencing on stripping process is a prerequisite for dealing with it effectively. Previous studies on stripping potential of HMA have focused on this issue based on empirical/semi-empirical models. In the present work Response Surface Methodology (RSM) was used for the study and optimization of pertinent factors, namely bitumen content employed, grading and lime content, in the stripping process of HMA. Tensile Strength Ratio (TSR) was chosen as the response for the evaluation of stripping potential of HMA using a Central Composite Design (CCD). The statistical analyses showed that second order polynomial models can successfully describe the relationship between the response and factors and the maximum Tensile Strength Ratio (TSR) is achieved at 5.73% bitumen content, 1.84% lime content and 65.30% of the materials passing sieve size 4.75 mm.

1. Introduction

1.1. Background

Hot Mix Asphalt (HMA) made from certain materials may be sensitive to the presence of water in the finished pavement. Water trapped in the pavement structure may cause a separation of bitumen from aggregate and/or failure within the bitumen itself. This phenomenon is often referred to as stripping [1]. Stripping change mechanical properties of pavement and gradually decrease the strength of the material leading to rutting, corrugation, shoving, ravelling, cracking, etc. [2]. Stripping phenomenon leads to a premature rehabilitation and higher maintenance cost [3,4].

Various kinds of test procedures have been proposed by researchers to assess moisture sensitivity of asphalt mixtures [1,2,5–9], but it appears that there is no global agreement among researchers on a single procedure for evaluating this distress mechanism [2]. Among the several common test procedures, such as boiling test, Marshall and indirect tensile tests (Modified Lottman Test), some researchers and institutions [10–14] believe that the latter is more capable of predicting stripping phenomenon. Indirect tensile test (AASHTO T283) is a test method that can be used to determine whether the material is prone to stripping and also to measure the effectiveness of additives [2,15].

There are many methods that can be used to prevent or control stripping phenomenon. One the most common is the use of anti-stripping additives such as liquid anti-stripping or hydrated lime. Researchers found that the mixes containing hydrated lime and

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http://dx.doi.org/10.1016/j.conbuildmat.2014.11.041
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liquid anti-stripping agent are stiffer, less susceptible to rutting, moisture damage and cracking and have improved fracture toughness at low temperatures [2], also, they indicated that for a single source of aggregate and bitumen, hydrated lime has the most prominent effect on increasing moisture resistance [2]. A literature review reveals that around 1–1.5% hydrated lime is an optimum value that can prevent or control stripping potential of asphalt mixtures [16–18].

The physical and mechanical properties of asphalt mixtures depend on mix design, traffic loading and environmental parameters [3,19–21]. Two of the relevant parameters, which affect the mechanical properties of HMA and consequently its moisture resistance, are the aggregate grading and bitumen content (BC) [22,23]. Khodaii et al. reported that decreasing the aggregate size and increase in mastic asphalt would increase the stripping potential of hot mixes asphalt with dense gradation [16]. Also, they found that increasing the mastic asphalt would decrease the stripping potential of stone matrix asphalt (SMA) [17].

1.2. Response Surface Methodology

Response Surface Methodology (RSM) is a statistical approach used for deriving a mathematical relation between responses and factors as well as the analysis of the problems [24,25]. Second order equations are commonly deployed to model the relationship between responses and factors. Such models, albeit approximate, can be used to predict response value for a given variable, determine the significance of the factors and to estimate the combination of the factors that can yield to a maximum or minimum value of the response over a certain region of interest [24–26].

This methodology has recently been employed by researcher in the field of pavement materials to investigate the effects of various factors such as grading and lime content on stripping potential [16,17], frequency and temperature on permanent deformation [27] and bitumen content, specimen diameter, test temperature and load duration on resilient modulus of HMA [28]. Also, Kavussi et al. evaluated the interactive effects of lime and Zycosoil, warm additive content and grading on stripping potential of warm mix asphalt (WMA) using RSM [18,29]. Hamzah et al. [30] employed this methodology to determine the optimum binder content of warm mix asphalt incorporating Rediset.

1.3. Center composite design

To be able to conduct a response surface, it is essential to have an appropriate choice of design of experiments. The most common design for fitting a second order model is the central composite design (CCD) which consists of 2^k runs (k is the number of factors), $2k$ axial (star) runs and some center runs (Fig. 1) [25,26]. Using fractional factorial designs (FFD) such as CCD, can show any interactions between parameters with the use of far less experiments compared to full factorial design [26].

1.4. Objective of study

The aim of the present study was to examine the effects of the percent of materials passing sieve size 4.75 mm (PPSS 4.75 mm), bitumen content (BC) and lime content (LC) on stripping potential of dense graded HMA made with siliceous aggregate and 60/70 penetration grade bitumen, as well as interactions between them, using proper methodology, namely RSM. A half fractional factorial center composite design was selected as the design matrix since it allows the identification of first order interaction between factors and provides second order polynomial models, which can be employed to predict optimum level of these parameters.

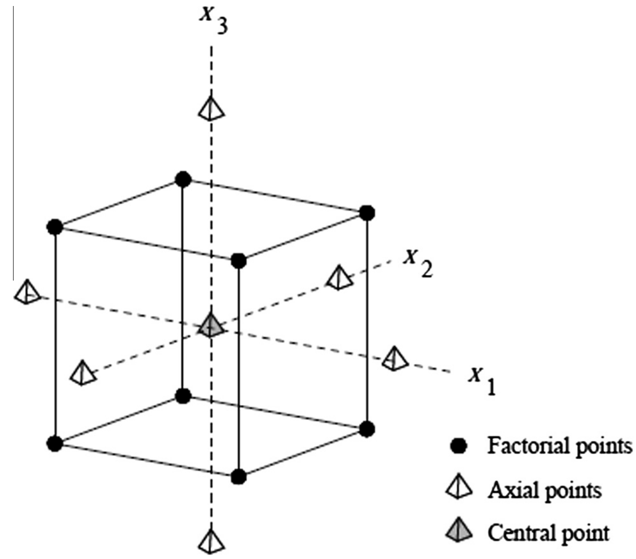

Fig. 1. Central composite design for 3 design variables at 2 levels [26].

2. Materials

Three grading levels of one aggregate type, containing 85%, 70% and 55% passing 4.75 mm sieve size were selected according to ASTM D3515 [31]. These are shown in the dense gradation curves of Fig. 2. The grading levels were named as fine, medium and coarse grading. Tables 1 and 2 show physical properties of the siliceous aggregates used in the research. The filler was siliceous and the percentages of the filler used were 10%, 6% and 2% for fine, medium and coarse grading respectively. Furthermore, different percentages of hydrated lime (i.e. 1.5% and 3%) utilized as the anti-stripping were in addition to the filler content already present in the aggregate mix.

AC 60/70 penetration grade bitumen was used to prepare all mixes. Properties of the bitumen are presented in Table 3.

3. Experimental methods

3.1. Indirect tensile strength test

The aim of the modified Lottman Test (AASHTO T283) [15] is to evaluate susceptibility characteristics of the mixture to water damage. The test is performed by compacting specimens to an air void level of six to eight percent. Three specimens were selected as control and tested without moisture conditioning, and three more specimens were selected to be conditioned by saturation with water (70–80% saturation level). The specimens were then tested for indirect tensile strength by loading the specimens at a constant rate (50 mm/min) and measuring the force

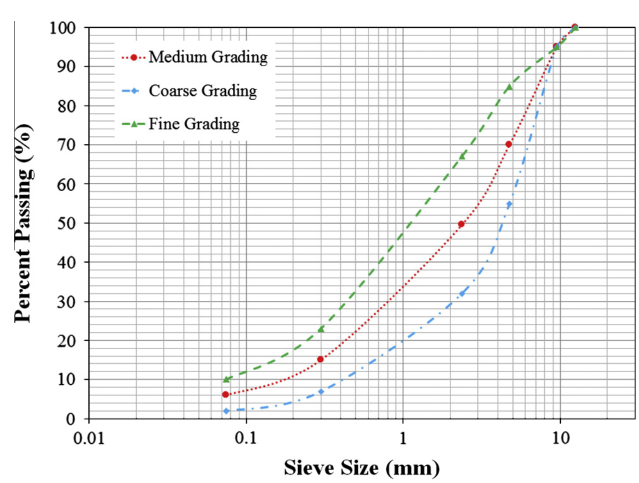

Fig. 2. Grading size distribution of the coarse, medium and fine aggregates.