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A study on moisture susceptibility of stone matrix warm mix asphalt

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HIGHLIGHTS

- Zycosoil can improve moisture resistance of WSMA where the siliceous aggregates used.
- Influence of SaC is more than the influence of other factors on increasing TSR.
- Influence of grading is more than the influence of other factors on decreasing TSR.
- All first and second order plus interactive terms were statistically significant.

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ABSTRACT

Stone matrix asphalt (SMA) is known to have high resistance to permanent deformation and reflective cracking due to their stone structure but similar to other hot mixes it has a high energy intake during its production. Warm mix asphalt (WMA) has recently gained a lot of popularity worldwide due to environmental concerns. Moisture susceptibility as one of the drawbacks of warm mixes has been investigated by many researchers but the extent and interactive effects of different parameters affecting moisture susceptibility particularly for SMA has not yet been reported. The aim of the present study was to examine the effects of grading, bitumen content, Zycosoil content, Sasobit content and mixing temperature on moisture susceptibility of SMA warm mix asphalt (WSMA), as well as their interactions, using response surface methodology. The results indicated that the influence of Sasobit content and grading was more than the influence of other factors on tensile strength ratio -used as an index of moisture susceptibility- respectively. Also, interaction plots between factors affecting tensile strength ratio were generated that can help to understand the interactive relationship between investigated factors.

1. Introduction

Stone matrix asphalt (SMA) is a gap-graded mix that has gained popularity world-wide. SMA has been used successfully in Europe for over 25 years to provide better rutting resistance and to resist studded tire wear [1,2]. These mixtures contain a large amount of coarse aggregate and enough fine aggregate to help fill the voids in the coarse aggregate [3]. In a SMA mix, the passing 4.75 mm sieve must be below 30 percent to ensure proper stone-on-stone contact [1] as the main source of strength [3].

Some advantages of SMA mixtures are its high rut resistance [4], high durability, and improved resistance to reflective cracking and reduced noise pollution; however drainage of binder and higher primary costs are known as its disadvantages [5]. SMA mixture typically contains a polymer in the asphalt binder or fiber (cellulose or mineral) in the mixture to prevent drainage of the asphalt binder. This mixture has a surface appearance similar to that of an open graded friction course; however it has low in-place air voids similar to that of a dense graded hot mix asphalt (HMA) [3,6,7].

The use of warm mix asphalt (WMA) technology as a substitute for hot mix has been widely increased due to the concerns over global warming, air quality and fuel crisis. By lowering the viscosity of asphalt binder and/or increasing the workability of mixture using minimal heat, WMA technology allows the mixing, transporting, and paving process at significantly lower temperature compared to the conventional HMA [8]. The use of warm mix reduces energy consumption, lowers emissions and odors or greenhouse gases from plants, creating better working conditions at both the plants and the paving sites [9–12]. Researchers identified as many as fifteen different WMA technologies currently available. The most commonly used technologies are either using foaming or some chemical or organic additives [8]. These technologies facilitate reduced mixing and compacting temperature.

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Mixing temperatures commonly used for most of WMA production is about 30–50 °C below the temperatures used for HMA [13–16]. This lower temperature can well lead to an increase in moisture susceptibility due to adhesion failure as moisture may have remained in the aggregates. In the temperatures of 100–140 °C that WMA are produced, aggregates are not completely dry and hence many researchers recommended using aggregates from dry sources [8].

Researchers have reported using many different tests to evaluate moisture sensitivity of asphalt mixtures. These include boiling test, Marshall and indirect tensile tests; however some researchers and institutions prefer the indirect tensile test as they believe it can predict moisture susceptibility of the mixtures. [12,17,18]. Many researchers introduced various approaches for reducing moisture susceptibility in asphalt mixes [12,16–18]. One of the most widely adopted approaches is to use anti-stripping agents in order to increase the aggregate surface charges with the aim of increasing the bond between bitumen and aggregate particles. However, recent technologies have presented some other new materials, including nanomaterials such as Zycosoil [18,19].

Three common types of agents that are used to decrease the moisture sensitivity of asphalt mixes are hydrated lime, fatty amido-amines and fatty amines. It is believed that these create a temporary bond with aggregate surface and also they are not effective in all types of aggregates [20]. On the other hand, Zycosoil is claimed to be able to modify the aggregate surface as it is an organosilane compound that can react with soil particles and convert the hydrophilic silanol groups to hydrophobic siloxane groups and form a hydrophobic layer on the surfaces of aggregate [19,20]. This mechanism repels moisture and reduces water sensitivity of aggregate offering a permanent protection against moisture damage. Researchers showed that Zycosoil can be a good candidate to improve moisture resistance of asphalt mixture.

In recent years, response surface methodology (RSM) has attracted attentions of many quality engineers in different industries. RSM is one of the designs of experiments (DOE) methods used to approximate an unknown function for which only a few values are computed [21]. RSM consists of a group of techniques used in the empirical study of the relationship between response and a number of input variables. Typically, an experimenter attempts to find the optimal setting for the input variables that maximizes (or minimizes) the predicted response. RSM is a useful method for studying the effect of several variables influencing the responses by varying them simultaneously [19,22–29].

The most extensive applications of RSM are in the particular situations where several input variables potentially influence some performance measure or quality characteristic of the process [30]. Thus performance measure or quality characteristic is called the response. The input variables are sometimes called independent variables, and they are subject of the scientist or engineer to control [31].

1.1. Objectives of the study

A review of the few literatures on the influential parameters affecting moisture susceptibility of SMA that are produced using WMA technologies (WSMA) provides no clues to the existence of any interactions between important parameters. This is because in previous studies one-factor-at-a-time methodology has been used to optimize and evaluate the parameters. This methodology is very inefficient and furthermore gives absolutely no information about interactions between parameters.

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), Zycosoil content (ZyC), Sasobit content (SaC) and mixing Temperature (T) on moisture susceptibility of WSMA, as well as interactions between them, using proper methodology, namely RSM. A half fractional factorial center composite design (CCD) 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.

2. Materials and mix design

2.1. Materials

According to AASHTO M325-08 three grading levels of one aggregate type (i.e. siliceous), containing 20, 27.5 and 35% passing 4.75 mm sieve size were selected. These are shown in the gradation curves of Fig 1. The grading levels were named as fine, medium and coarse grading. Tables 1 and 2 show physical properties of the siliceous aggregates used in this research.

Zycosoil was used as an anti- stripping agent in the mix. As the aggregate was siliceous and creates an unstable bond with bitumen against moisture attack. It is expected that high percentage of hydroxyls on the aggregate surface makes it a good candidate for Zycosoil that can permanently changes the ions on the aggregate surface creating a stronger bond between aggregate and the binder [19].

The binder used was polymer modified asphalt (PMA) with a Polymer purchased from a German supplier. The modified asphalt was prepared at 160 °C. Polymer was mixed with asphalt in a stirrer equipped with a mechanical agitator (350 rpm) for 15 min in a polymer to asphalt volume ratio of 6.5%. The physical properties of the asphalt and polymer are presented in Tables 3 and 4 respectively. Zycosoil was used as an anti-stripping agent and Sasobit as the warm additive and to stabilize the SMA, cellulose fiber was also added to the mix. The properties of Zycosoil and Sasobit were reported in Tables 5 and 6 respectively.

2.2. Mix design

In SMA mix design, the optimum asphalt content is determined only based on the air voids of mixture [3,4]. In other words, in accordance with AASHTO MP8, the value of asphalt content which results in a final mixture's air void of between 3 to 4% is considered as the optimum asphalt content. Three optimum asphalt contents of 7.1, 6.4 and 5.9 were obtained for the mixture with aggregate grades of fine grading (PPSS 4.75 mm = 35%), medium grading (PPSS 4.75 mm = 27.5%) and coarse grading (PPSS 4.75 mm = 20%), respectively. It should also be pointed out that the air voids of final mixtures are around 4% using these vales of

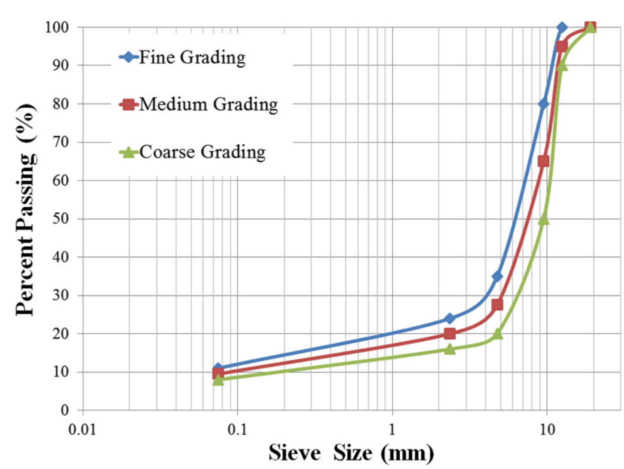

Fig. 1. Grading size distribution of the coarse, medium and fine aggregates.