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Optimization in producing warm mix asphalt with polymer modified binder and surfactant-wax additive

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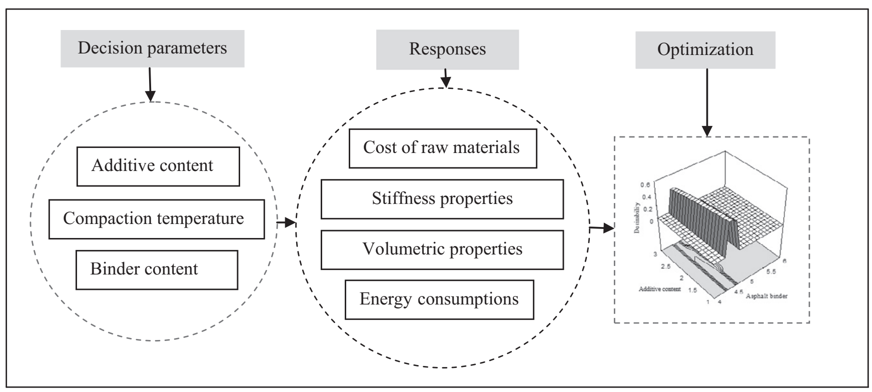
HIGHLIGHTS

- RSM can be used for optimization in production process of WMAs.
- Optimization process simultaneously determines optimum values of all production parameters.
- Recommended dosage for WMAs by manufactures may differ from laboratory results.

GRAPHICAL ABSTRACT



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ABSTRACT

Recently, numerous warm mix additives were developed and their influences on the properties of asphalt binders and mixtures were investigated in the field and laboratory. Although, most of the technical requirements for these materials have been accepted for individual conditions, some important questions still remain unfolds. For instance, which combinations of production parameters are referred to fabrication of an optimum product? This study presents a new potential approach to answer this question via a numerical optimization for all test responses using desirability functions. For this purpose, a surfactant-wax warm additive was used for modification of binders. A series of warm mix asphalts (WMA) specimens were fabricated using a polymer modified binder, in different compaction temperatures, additive contents and binder contents. Experiment design was planned and analysis was conducted by a statistical approach named response surface method (RSM). The price of raw materials, mechanical properties of mixtures and energy consumption for production of WMA were involved in the analysis of data. This method presented an optimum combination of decision factors including binder contents, additive contents and compaction temperatures to produce one ton WMA in different production scenarios. Although, there are different recommendations for use of additive contents, optimization process proposed 1% of additive for modification of binder for various scenarios. Possibility for simultaneous determination of binder content in combination with other factors could discard the process of traditional Marshall method to ascertain the optimum binder content.

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1. Introduction

Optimization process has been widely used in engineering decision making. According to Roy et al., engineering design of optimization can be categorized into three groups: expert based optimization, design of experiment based optimization and algorithmic optimization [1]. In pavement engineering, most of the optimization processes have been concentrated on the selection of optimum maintenance activities and designing optimum structural layers. For instance, Yu et al. used a multi-objective optimization method for selection of asphalt pavement maintenance plans based on the performance, cost and environmental parameters for project level studies [2]. Sanchez-Silva et al. presented a reliability based design optimization method for design of flexible pavement layers [3]. Conversely, optimization approach has not been extensively used in asphalt laboratory studies.

In laboratory, asphalt mixtures are designed and fabricated to assure selected technical requirements. Laboratory efforts are based on the selection of suitable parameters that can confirm our targets for asphalt mixtures quality. For this procedure, mathematical optimization process can present a systematic method for determining a combination of laboratory parameters to fabrication of asphalt mixtures. This study tries to find an optimum combination of binder content, additive content and compaction temperatures to produce WMA using a numerical optimization in response surface method (RSM).

RSM has been widely applied in optimization process in other disciplines as well as other civil engineering fields. For example, Sonebi et al. used RSM for Optimization of rheological and mechanical properties of super plasticised cement grouts incorporating metakaolin and viscosity modifiers [4]. Chacchouk et al. determined optimum value of three variables including calcination time, calcination temperature and% of calcined clay in the blended cement based on RSM [5]. RSM was used by Bayramov et al. for optimizing the fracture parameters of steel fiber reinforced concretes in terms of aspect ratio and volume fraction of steel fiber [6].

In asphalt mixture studies, Haghshenas et al. used RSM for determining a combination of binder content, grading type and lime content to achieve maximum tensile strength ratio (TSR) [7]. They used one objective to determine their solution and it was the maximum value of TSR. Normally, in production of asphalt mixtures depends on different objectives and constraints. Baghaee Moghaddam et al. determined optimum value of polyethylene terephthalate and binder content in fabrication of stone mastic asphalt via RSM based on marshal and volumetric properties of mixtures [8]. They used only two independent variables without considering the cost of the raw materials.

In WMA studies, most researchers investigated the effects of compaction or mixing temperatures of WMA in respect of other test parameters like binder type, aggregate source, and aggregate gradation using one-factor-at-a-time procedure [9–12]. In this approach, the interaction effects of these parameters cannot be simultaneously analyzed. Consequently, determining the optimum mixing and compaction temperatures and even binder and additive contents are difficult. Therefore, it is necessary to reach a procedure to optimize production process of warm mix asphalt in terms of mixing or compaction temperature, additive content and binder content, simultaneously. To meet this objective, using regional standard technical specifications for volumetric properties and performance of mixtures, minimization of the cost of raw materials in production of WMA, and minimization of energy consumption are necessary and important. This study considers these parameters to reach an optimum WMA product via RSM.

2. Materials

A surfactant-wax based warm additive was chosen for fabrication of WMA. It is brown in solid form with amine like odor and it is insoluble in the water (see Fig. 1). The tail of this surfactant is a long chain aliphatic hydrocarbon, while its head is $-NH_3^+$. Surfactant part acts at the microscopic interface of the binder and aggregate, while the wax part changes some binder viscosity. Surfactants reduce surface or interfacial tension between a liquid and a solid or between two liquids [13]. This warm additive easily dissolves in a hot binder without the need for a high shear stirrer device. Warm additives can reduce the compaction and mixing temperatures of asphalt mixtures [14].

A PG 76 styrene-butadiene–styrene (SBS) polymer modified binder and crushed type granite aggregate based on the median aggregate gradation of Malaysian Public Works Department (PWD) or Jabatan Kerja Raya (JKR) gradation for mix type AC14 [15] were used for fabrication of asphalt mixture samples. Upper and lower limit of this gradation is shown in Fig. 2. Technical properties of asphalt binder and aggregate are presented in Tables 1 and 2, respectively.

3. Research methodology

3.1. Definition of decision parameters

Three parameters were selected for decision making in production process of WMA. Binder content was selected as a first parameter because this is the first unknown parameter in mix designs. Compaction temperature was then decided based on the inherent characteristic of WMA. Based on previous studies, various amounts of warm additives have been selected for fabricating WMA. Therefore, additive content was chosen as the third parameter. With these in mind, experiment design was developed base on central composite method (CCD) using these three parameters including binder contents (4–6%), compaction temperatures (165–135 °C) and additive contents (1–3%) as shown in Table 3. Fig. 3 shows an alternative form for design of experiment. These parameters were used as control (independent) variables for predicting their effects on dependent parameters.

3.2. Definition of dependent parameters

In this study, four dependent variables were selected as listed below:

Fig. 1. The form of warm additive used.