Construction and Building Materials 27 (2012) 15–23

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Influence of operational tolerances on HMA performance

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ARTICLE INFO

Article history:
Received 13 May 2011
Received in revised form 1 August 2011
Accepted 1 August 2011
Available online 24 September 2011

Keywords:
HMA
Hotmix
Asphalt
Operational tolerance
Variability

ABSTRACT

This study focuses on determining the effects of variability on key mix design factors, such as asphalt content, gradation, and density, on the laboratory performance of different HMA samples that were produced in the laboratory. Mixture variables were kept within specified limits as per allowable operational tolerances, and performance was monitored through the evaluation of the results obtained from volumetric properties and laboratory tests, such as flexural fatigue test, Hamburg wheel-tracking test, and overlay tester. A series of statistical analyses were conducted to develop relationships between the key mix design factors and the observed laboratory performances of each type of mixture. From the analysis, the effects of the main variables on the results of the performance tests used in this study were found.

Finally, a statistical sensitivity analysis was conducted to reveal the relationship between different tolerance levels and mixture performance. Based on the findings of this sensitivity analysis, recommendations to revise the current TxDOT operational tolerances and performance-based pay adjustment factors for contractual jobs were provided that not only commends high quality and a consistent end product but also promotes superior performing mixtures based on the analysis of laboratory data.

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1. Introduction

The production of hot-mix asphalt (HMA) includes several stages, each of which introduces variability into the final composition of the job mix formula (JMF) and, consequently, into the volumetric properties and performance of a given mixture design.

This variability in the HMA is also due to the inherent variability of the components used in the mixture. HMA can be broadly classified as a two phase composite material – the asphalt binder and aggregates. Variability associated with aggregates can be attributed to the inherent variability in stockpile gradation due to randomness of the crushing process, stockpile height and configuration. All these factors contribute to deliver an aggregate with a gradation slightly different from the one that was determined by sampling and design; thus affecting the physical properties of the mixture and its performance.

The variability can also come from the variability in the asphalt binder content, which can adversely affect the performance of the end product. An excess in asphalt binder content may result in unwanted tenderness of the mixture, while a deficit in asphalt binder content results in a mixture that may not be durable and overly prone to cracking. Deviations in the dosage equipment or intentional reduction in asphalt content (because of cost considerations), within acceptable operational tolerances permitted by specifications, may potentially lead to undesirable characteristics of the asphalt mixture.

It is therefore important to identify the variables that influence variations in HMA performance and to have a good understanding of the relative magnitude of these effects on the field performance of HMA.

2. Objectives and scope

The objective of this research study is to determine the effects that result from changes in mixture properties, such as (1) asphalt content, (2) gradation, and (3) air-voids content, on the laboratory performance of asphalt mixtures. To this effect, the following tests were considered pivotal for the evaluation of the performance characteristics of the mixture: four-point bending beam fatigue test, Hamburg wheel-tracking device and Texas overlay tester.

The study is limited to the mixture design, production, and testing of five different asphalt mixes using one binder (PG 76-22S) and two different types of aggregate sources (limestone and gravel) while changing the aggregate gradation, the specimen density, and the asphalt content in order to account for the effects on performance. These volumetric properties are varied in a systematic manner within acceptable tolerance limits as specified by the Texas Department of Transportation (TxDOT).

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0950-0618/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.conbuildmat.2011.08.003

Out of the five asphalt mixtures produced, three were produced using limestone: two conventional dense-graded mixtures, Type C and Type D, and one Stone Matrix Asphalt mixture (SMA-D); and the remaining two using gravel: conventional dense-graded, Type C and Type D. According to the classification system used by TxDOT, Type C has a maximum aggregate size of ¾ in. and Type D has a maximum aggregate size of ½ in.

3. Literature review

According to the scope of the current study, only dense-graded HMA (TxDOT Item 341) and SMA (TxDOT Item 346) were analyzed to determine the differences in terms of laboratory performance.

Several studies have investigated the influence of volumetric properties on the rut resistance of hot mix asphalt concrete. The WesTrack experiment showed that coarse-graded Superpave asphalt mixtures are relatively more sensitive to asphalt content, aggregate gradation and compaction effort in terms of their resistance to rutting and fatigue cracking than fine graded mixtures [3]. Similar observations were made while studying the effect of gradation on the resistance of the hot mix asphalt concrete to rutting. The coarse mixes were found to be more sensitive to the percent passing the #200 sieve as well as the in-place air-voids than the fine graded mixtures. It was observed that the magnitude of the in-place air voids affect the permanent deformation and fatigue life of the pavement.

The relationship between HMA mixture properties and their contribution to the resistance to permanent deformation have been studied under wheel tracking devices. Williams [4] observed that the rut depth varies proportionately with the voids in the mineral aggregates (VMA).

Kandhal et al. [5] proposed that the minimum VMA requirements should be based on the minimum film thickness requirements rather than the minimum asphalt content for the particular mix. The rationale behind the argument was that the minimum asphalt content will vary depending on the gradation for the particular mix. The study also proposed a direct and appropriate method of ensuring asphalt mix durability that encompasses various mix gradations.

Anderson and Bentsen [6] studied the effect of VMA on the performance-related properties of hot mix asphalt concrete. Laboratory tests conducted at intermediate temperatures did not show statistically significant differences in terms of the fatigue life or the mixture stiffness between mixes with 13% VMA and 15% VMA. However, shear test data suggested that an increase from 13% to 15% VMA improves the shear fatigue characteristics of a fine mixture by 50%, while reducing the high temperature stiffness and rut resistance up to 30%. On the contrary, increasing the VMA from 13% to 15% for coarse mixtures had a detrimental effect on their performance-related properties.

Based on wheel tracking tests conducted using the Asphalt Pavement Analyzer (APA) at 140°F, Sebaaly and Bazi [7] report that the rut resistance of asphalt mixes is compromised when the in-place air voids or the binder content is increased. The authors also conclude that the use of polymer modified binders has the advantage of masking the demerits of a particular asphalt mix which may have been introduced due to shifts in the gradation or certain other volumetric properties from their targeted values. Tarefder et al. [8] also reports that the APA rutting potential of an asphalt mix is compromised for asphalt mixes with higher binder content.

Mogawer et al. [9] evaluated the relationship between HMA density and performance in terms of fatigue cracking and permanent deformation based on a battery of tests that included beam fatigue, the Texas overlay tester, APA, flow number and measuring the dynamic modulus. The authors report that the complex dynamic modulus has a direct relationship with the density. On the contrary, beam fatigue test results were inconclusive. Test data and endurance limit analysis on the fine mixture indicated that density had little to no impact on the fatigue performance of the mixture. This finding was similar to previous research by Pilar and Haddock [10]. For coarse mixes, the authors found that the fatigue life of the mixture diminished with increasing density. However, results from the Texas overlay tester indicated that the number of ESALs to reach the fatigue cracking failure criteria increased as the mixture density increased. Results from the APA rut tests and flow number test indicated that the rutting potential decreased as the mixture density increased.

In a separate study, the researchers looked into the effect of aggregate angularity on the rutting resistance of the asphalt mix [11]. The authors report that the APA rutting potential definitely had an inverse relationship with the binder grade; however, they failed to observe any clear trends for mixes where the aggregate angularity was the only variable. In fact, it was reported that the APA rut depth were sometimes higher for asphalt mixtures with lower aggregate angularity than those with higher values as one would expect. The authors also looked into the possibility of using the flow number test for evaluating the effect of aggregate angularity and texture on the rutting potential of different asphalt mixtures. Unfortunately, the flow number test results also did not correlate with the AIMS Angularity and Texture Indices. The observations made in this study underscore the masking effect of the binder grade that was already reported by Sebaaly and Bazi [7].

Roque et al. [12] points out that larger aggregate size should dominantly provide the skeleton of the mixture for superior performance. The authors adopted a porosity based approach towards determining the interlock between the different size fractions. A mixture with a relatively low porosity index will imply tight packing and good interlock between aggregates. Based on this assumption, the authors determined the relative proportions of the contiguous aggregate sizes (coarse and fine sieve sizes) that will satisfy the minimum porosity requirement. The range of particle sizes that were determined was referred to as the dominant aggregate size range (DASR). The study recommends that the DASR porosity of the asphalt mixture should be less than 50% in order to have good aggregate interlock. The authors also propose that the relative proportion of the contiguous aggregate sizes within the DASR should be no greater than 70/30 (large/small aggregate proportion). However, the study also recommends that mixes with very low DASR porosity should also be avoided as they might prove to be very brittle.

Coree and Hislop [13] have recommended that the minimum VMA requirements which have been in practice needs to be revalidated to accommodate for variables like aggregate shape, texture and gradation should be given consideration. The concept of minimum VMA was proposed in order to achieve maximum stability which has recently been questioned by researchers like Kandhal et al. [14] on grounds of inadequate durability of the asphalt mix. The authors have also recommended that strict enforcement of minimum VMA should be discouraged due to the low level of precision that is involved with determination of VMA. The authors proposed that the surface area and shape factors that were determined in the 1940s also needs re-evaluation and therefore parameters like the minimum film thickness needs to be modified in the light of the latest findings.

In a separate study, Chowdhury et al. [15] observed that there is no relationship between the observed rut depth and asphalt mixes having gradation passing through the restricted zone. However, they reported mixes that are above the restricted zone are more resistant to rutting than those below. It was also observed that mixes with partially crushed river gravel were prone to permanent deformation than similar mixes which were prepared with