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Analysis of parameters affecting asphalt mixture performance and new perspectives on the design parameters

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HIGHLIGHTS

- Factors affecting asphalt mixture performance can be divided into four categories.
- Compaction effort should be a variable design parameter during mixture design process.
- The interaction of parameters affecting mixture performances can't be overlooked.

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ABSTRACT

In this paper, various factors affecting asphalt mixture performance were discussed. First, various factors were divided into four categories: material factors (MF), design factors (DF), compaction factors (CF) and volumetric factors (VF), based on how they influence the performance of the asphalt mixtures. MF referred to the properties of the aggregate, filler and binder. DF were those parameters needed to adjust in order to meet some design specifications. CF were related to the specimen compaction approach and compaction effort when molding asphalt mixture specimen. VF characterized the properties of asphalt mixtures through indices such as air voids (AV), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA). The second section of the paper explored the distinctive effects from these four categories of parameters defined above, based on the study and critical review of historical literatures. Based on the discussions and analyses, the limitation of using VF in controlling asphalt mixture design results, as well as the irrationality of setting compaction effort as constant in the design process were revealed. Finally, suggestion was made that it was necessary to introduce compaction effort as DF in mixture design process, and asphalt mixtures should meet performance-based criterion and specific volumetric requirements by adjusting the MF and DF.

1. Introduction

Volumetric properties of asphalt mixtures have significant impact on asphalt mixture performance so that they are often parts of asphalt mix designs. Asphalt mixtures must meet certain volumetric requirements in order to pass the mix designs. Generally, asphalt mixture designs have three steps: (a) selection of aggregates and associated gradation, (b) selection of asphalt type and grade, and (c) determination of asphalt content [1]. In the process of asphalt mix designs, compaction effort for making samples is often kept constant as long as traffic level is fixed. For instance, asphalt mixture specimen, regardless of mix types, is fabricated with 75 below on each face for heavy traffic and 50 below for light traffic in the Marshall mix design method. Similarly, Superpave method utilizes 50, 75, 100, and 125 gyrations to fabricate specimens for light, middle, heavy, and very heavy traffic, respectively. Since the compaction effort is fixed during the mix design process, people turn to other parameters to achieve asphalt mixture performance, such as coarse aggregate shape [2], fine aggregate angularity (FAA) [3], asphalt grade [4], asphalt content [5], aggregate gradation [6], volumetric parameters [7]. For instance, Superpave method emphasized the use of coarse gradation for better stability [8], as shown by Gao [9]. However, both WesTrack and NCAT track results indicated that the stability of the mixes with the fine gradation was equal to, even better than, those with the coarse gradation [10,4]. Additionally, some researchers found that asphalt mixtures would be unstable when air voids (AV) was lower than approximately 3% [11,12]. However, Oliver [13] showed that when asphalt mixture was compacted to a AV lower than 3%, it exhibited higher stability rather than unstable. This conclusion was also confirmed by Gao [9].

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Three observations are made from reviewing the literature: (a) researchers have different focuses and draw different, even contradictory conclusions, indicating that asphalt mixture performance is affected by many factors; (b) interactions between different factors are often neglected; and (c) compaction effort may be varied for different types of mixes under the same traffic level. Therefore, it is important to critically review the literature and then enhance existing asphalt mix design methods.

The objective of this study is to review and discuss the effect of various factors on asphalt mixtures performance in terms of stability and to reconsider the compaction effort in the mix design process with an ultimate goal of establishing a performance-based asphalt mix design method. It must be noted that asphalt mix design should balance rutting, cracking, and moisture damage. And mixture stability is discussed only as a case in this paper. This by no means implies that other properties of asphalt mix are unimportant.

This paper first divided various factors affecting asphalt mixture performance into four categories, that was MF, DF, CF and VF. Then the four categories factors was discussed one by one. Finally, this paper concluded that compaction effort should be incorporated into the DF, and asphalt mixtures should meet performance-based criterion and specific volumetric requirements by adjusting the MF and DF.

2. Analysis of factors affecting asphalt mixture performance

2.1. Classification of factors affecting mixture properties

As mentioned above, many factors can affect the engineering properties of asphalt mixtures. It is necessary to classify them and clarify their relationships with the engineering properties of asphalt mixtures. In this context, all factors are divided into four categories in this study:

(1) Material Factors (MF): They are related to properties of the asphalt mixture components, such as coarse aggregate shape, surface texture, fine aggregate angularity, filler fineness, asphalt performance grade, etc. Note that MF is the basic parameters affecting engineering properties of asphalt mixtures.
(2) Design Factors (DF): They are adjustable factors during the mix design process, i.e. aggregate gradation and asphalt content. Adjustments to these factors are often needed to make asphalt mixtures meet certain specification.
(3) Compaction Factors (CF): They are related to compaction method and associated effort for making specimens. For example, 75 below on each side and some certain gyratory numbers are used to make specimens in the Marshall and Superpave methods, respectively. For a certain asphalt mixture method, CF actually refers to compaction effort.
(4) Volumetric Factors (VF): They are volumetric characteristics of asphalt mixtures, such as AV, VMA, and VFA. Any mix design method has some specific VF requirements.

All the above four categories of parameters affect asphalt mixture performance to some degree. However, when designing a specific asphalt mixture, its properties are simply affected by MF, DF and VF as the CF is constant.

2.2. MF and their effects on the performance of mixtures

It is a well-known fact that the properties of the asphalt mixture components have influence on mixture performance. A brief discussion is provided below. In the early stage of asphalt mix designs, people noticed the MF having effect on the asphalt mixture performance. Two major factors: aggregate properties and binder properties, are discussed below.

2.2.1. Aggregate properties

Many aggregate properties impact asphalt mixture performance. The focus of the discussions here is on the effects of coarse aggregate shape and FAA on the performance of different asphalt mixtures.

Yeggoni [14] evaluated the properties of asphalt mixtures made with different percentages of crushed coarse aggregates. It was observed that an increase in the percentage of crushed coarse aggregates results in larger Hveem and Marshall stabilities and better resistance to creep and permanent deformation of asphalt concrete. In addition, a significant correlation was found between the shape characteristics of aggregate particles, and the engineering properties of asphalt mixtures. Yeggoni's findings were verified by Masad's research [2], where an Aggregate Imaging System (AIMS) was used to measure the shape characteristics of coarse aggregates. Masad confirmed that aggregate shape characteristics had a strong correlation with measured mechanical properties. However, Masad's data was not enough to establish a quantitative relationship between the mechanical properties from aggregate characteristics. However, Westrack results showed different results: the mixtures with partially crushed gravel outperformed mixtures containing 100% crushed stone [15].

Another aggregate-related factor that influences asphalt mixture properties is FAA. In general, fine aggregate with lower FAA values has lower shear strength and then lower resistance to rutting, which is why natural sand with lower FAA values is often restricted for the use in asphalt mixtures [16]. However, the field performance of the Westrack mixes showed that the asphalt mixtures containing 25% natural sand had better rutting and fatigue performance than the mixtures without natural sand [10]. Stiady also showed that the rutting resistance of asphalt mixtures was not always consistent with the FAA values [3].

The information presented above indicates that asphalt mixture performance is not affected by the aggregate properties only, and other factors (these factors would be discussed in the following sections) also have influence, which, to some extent, explains why the different researchers reported different observations.

2.2.2. Binder properties

Binder properties always play a significant role in the performance of asphalt mixtures. The asphalt binder grade and source, with or without modification, modifier type and amount all affect binder properties. Some of these influential factors are discussed as follows.

A variety of modified asphalt binders are routinely used to improve the engineering properties, especially stability, of asphalt mixtures. One of the findings from the first NCAT test track was that modified asphalt binder (PG 76-22) had much better rutting resistance than unmodified asphalt binder (PG 67-22). After 9 million ESALs, the sections with the modified binder had an average rutting of 2.7 mm, while the sections with unmodified binder had an average rut depth of 6 mm [4]. Bissada compared studied the stiffness of asphalt mixtures with converntial asphalt binder to that of sulfur modified asphalt binder [17]. It was found that that the effectiveness of asphalt modifier depended on aggregate gradation type. For unmodified asphalt mixtures, fine gradation mixture had larger stiffness, while the coarse gradation mixture exhibited greater stiffness for those with sulfur modified binder.

All above discussion indicates that higher performance grade asphalt binder could not guarantee asphalt mixtures with a better performance when other factors are changed, which is also confirmed by other researchers. Gao [9] studied the effects of