Construction and Building Materials 177 (2018) 378–387

Contents lists available at ScienceDirect

Construction and Building Materials

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

# Investigation into the performance of asphalt mixture designed using different methods

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## HIGHLIGHTS

- A vertical vibration design method for asphalt mixture was proposed.
- Performances of asphalt mixture designed by vertical vibration method were evaluated.
- Fatigue behaviour of asphalt mixture was analysed.
- Field tests were conducted to validate the laboratory design methods.

## ARTICLE INFO

*Article history:*
Received 25 January 2018
Received in revised form 26 April 2018
Accepted 10 May 2018

*Keywords:*
Road engineering
Asphalt mixture
Vertical vibration design method
Marshall design method
Road performance
Fatigue property

## ABSTRACT

To investigate the performance of asphalt mixture designed by the vertical vibration method, the vertical vibration design method (VTM design method) and Marshall design method were used to design the AC-16 (asphalt concrete with nominal maximum aggregate size = 16 mm) asphalt mixture. The physical properties, mechanical properties, road performance and fatigue property of the asphalt mixture designed by these two methods were examined. The results show that compared with that of the Marshall method, the optimal asphalt content of the asphalt mixture designed by the VTM method is decreased by 9.0%, and the density is increased by 1.8%; the mechanical properties, anti-rut ability and anti-crack ability are increased by at least 30%, 34% and 17%, respectively; and the water stability is also improved slightly. In addition, the fatigue life can be increased by at least 59%. The results also show that the Marshall stability, compression strength, splitting strength, tensile strength and shear strength of field drill cores designed by the VTM method are increased by at least 42%, 32%, 21%, 31% and 33%, respectively, compared with those of the Marshall method. Clearly, the performance of the asphalt mixture designed by the VTM method is better than that of the Marshall method, which could offer a better choice for asphalt mixture design.


## 1. Introduction

Asphalt mixture design is the key to influencing the performance of asphalt pavement and its construction quality [1]. Currently, the Marshall, Hveem, gyratory testing machine (GTM) and Superpave design methods are the most representative design methods for asphalt mixture throughout the world [2–4]. One of the main differences in those design methods is the moulding method applied to the specimens. The Marshall method uses the hammer compaction method, the Hveem method uses a kneading compaction moulding method, and the Superpave and GTM methods use the gyratory compaction moulding method. With the rapid development of traffic, the limitation of the Marshall design method has gradually emerged. The compaction method in the Marshall design method is different from the vibratory compaction of field engineering construction and the effect of vehicle-load kneading compaction on the road surface after opening to traffic, and the compaction work has been found to be incompatible with modern traffic [5–8]. Although the specimens moulded by kneading or the gyratory compaction moulding method show better correlation with field samples, the equipment used to mould the specimens is too expensive for worldwide application [9–11].

Therefore, certain researchers have conducted a number of studies on the vibration compaction method for asphalt mixtures. The feasibility of using the vibratory compaction method to compact the asphalt mixtures was investigated in the laboratory [12]; the laboratory vibratory asphalt compactor was used to investigate the compaction characteristics of hot-mix asphalt (HMA) [13]; the density of the asphalt mixture compacted by

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https://doi.org/10.1016/j.conbuildmat.2018.05.108
0950-0618/

**Nomenclature**

| | | | |
|---|---|---|---|
| $P_a$ | Asphalt-aggregate ratio | $R_B$ | Flexural tensile strength |
| $VV$ | Volume of air voids | $\varepsilon_B$ | Flexural tensile strain |
| $VFA$ | Voids filled with asphalt | $TSR$ | Freeze-thaw splitting strength ratio |
| $VMA$ | Voids in mineral aggregate | $MS_0$ | Retained Marshall stability |
| $MS$ | Marshall stability | $P_B$ | Flexural failure strength |
| $FL$ | Flow value | $S$ | Stress level |
| $R_C$ | Compression strength | $N$ | Fatigue life |
| $R_T$ | Splitting strength | $R$ | Circulation characteristic value |
| $\sigma$ | Tensile strength | $P$ | Failure probability |
| $\tau_d$ | Shear strength | | |
| $DS$ | Dynamic stability | | |

vibratory hammer was higher than that achieved by the conventional Marshall, Hveem or gyratory methods [14]; the influence of the roller, Marshall, vibrating hammer and gyratory compaction methods on the mechanical behaviour of the asphalt mixture was investigated in the laboratory [15]; the effect of the vibration parameters on the density of HMA were studied using test sections [16]; the mechanical properties of gyratory, vibratory and slab compacted specimens were studied in laboratory tests, and the arrangements of the aggregate particles in the specimens were examined using image analysis techniques [17–19]; the specimen size had an influence on the aggregate orientation and mechanical properties of asphalt mixture specimens moulded by the vibratory compaction method [20]; and the applied load and vibration energy of the vibratory rollers aided in the reorientation and interlocking of aggregates in the mixtures and also increased the density of the mixtures [21]. In conclusion, the current research on vibration compaction methods for asphalt mixtures is still in the exploration stage, and most of the previous studies on the vibration compaction method for asphalt mixtures are confined to the influence of the compaction method on the density, mechanical properties, aggregate orientation and compaction characteristics, etc., without consideration of whether the indoor vibration compaction effect is consistent with that in the field. In addition, no worldwide uniform design standard for vibration compaction method exists. To this end, Jiang et al. proposed the vertical vibration compaction method (VVCM) to better simulate practical dynamic loading, and a large number of surveys showed that the correlation between VVCM specimens and field pavement cores reached 93% [22,23]. Subsequently, the VTM design method, which is particularly appropriate for heavy traffic, was proposed by analysing the effect of volumetric properties such as void ratio (VV), voids filled with asphalt (VFA) and voids in mineral aggregate (VMA) on the mechanical properties of asphalt mixtures compacted by VVCM [22,23]. Until now, the performance of asphalt mixtures designed by the VTM method has not been explored.

This paper reported an experimental investigation of the performance of asphalt mixtures designed by the VTM and Marshall methods. The physical properties, mechanical properties, road performance and fatigue property of the AC-16 asphalt mixture were evaluated in laboratory tests. Subsequently, field tests were conducted to validate the superiority of the VTM design method.

## 2. Materials and test methods

### 2.1. Raw materials

#### 2.1.1. Materials

The coarse aggregate used in this test was amphibolite sourced from Shangluo, Shaanxi, China. The fine aggregate and mineral powder used in this test was crushed limestone produced by Shangluo, Shaanxi, China. All of the materials meet the technical requirements of Technical Specification for Construction of Highway Asphalt Pavements (JTG F40-2004) [24].

#### 2.1.2. Asphalt

The SBS (I-C) modified asphalt of this test was sourced from Xianyang, Shaanxi, China, and its technical properties are listed in Table 1.

### 2.2. Mineral aggregate gradation

The mineral aggregate gradation composition of the AC-16 asphalt mixture in this test is shown in Table 2.

### 2.3. Test methods

The performance evaluation indicators in this study include mechanical properties, road performance and durability. Mechanical performance indicators include the following: the Marshall stability ($MS$), the indicator used to evaluate high temperature stability of mixtures; the compressive strength ($R_C$), the ability of mixtures to resist failure under the condition of one-way compression; the splitting strength ($R_T$), one of the mechanical parameters for asphalt pavement structure design used to evaluate the tensile strength of mixtures; and the shear strength ($\tau_d$), the ability of mixtures to resist shear failure under high temperature. In addition, considering that the semi-circular bending (SCB) test better reflects the true tensile strength when the specimens are fractured and that the relationship between splitting strength ($R_T$) and tensile strength ($\sigma$) will be examined in future studies, tensile strength ($\sigma$), which is the indicator used to evaluate the crack resistance of mixtures, was also measured in this study.

Road performance measures include dynamic stability ($DS$), which is the indicator used to evaluate the high temperature rutting resistance of mixtures. Flexural tensile strength ($R_B$) and flexural tensile strain ($\varepsilon_B$) were used to evaluate the low temperature performance of asphalt mixture. The freeze-thaw splitting strength ratio ($TSR$) and retained Marshall stability ($MS_0$) were used to evaluate the water stability of asphalt mixtures.

In this work, the durability of asphalt mixtures was evaluated by the trabecular bending fatigue test.

The $MS$, $R_C$, $R_T$, $DS$, $R_B$, $\varepsilon_B$, $TSR$ and $MS_0$ of asphalt mixture were all measured according to the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011) [25]. In addition, the $\tau_d$, $\sigma$ and durability of the asphalt mixture were measured by the following test methods.

#### 2.3.1. Shear strength test

The shear strength ($\tau_d$) of the asphalt mixture was measured by the uniaxial penetration test [26,27]. In this test, the electronic universal testing machine was used to control the loading rate and obtain the test data. The test parameters are listed as follows: the pressure head diameter = 28.5 mm, the test temperature = 60 °C and the loading rate = 1 mm/min. The test model and process of the uniaxial penetration test are shown in Fig. 1.

The shear strength of asphalt mixture is calculated according to Eq. (1) and Eq. (2).

$$R_g = \frac{4P}{\pi d^2} \tag{1}$$

$$\tau_d = 0.339 \times R_g \tag{2}$$

where $\tau_d$ is the shear strength of the asphalt mixture, $R_g$ is the vertical compressive stress of the asphalt mixture, $P$ is the maximum load of the specimen failure and $d$ is the diameter of the penetration rod.

#### 2.3.2. SCB test

The tensile strength ($\sigma$) of the asphalt mixture was measured by the SCB test [28,29], and the electronic universal testing machine was used to control the loading rate and obtain the test data. The test parameters are listed as follows: diameter