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An experimental investigation of optimal asphalt–aggregate ratio for different compaction methods

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HIGHLIGHTS

- Mechanical behavior of asphalt mixture was investigated.
- Effects of compaction methods on mechanical behavior were evaluated.
- Effects of compaction methods on optimal asphalt–aggregate ratio were evaluated.
- Laboratory tests were carried out to validate the results.

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ABSTRACT

This paper presents an experimental investigation of the optimal asphalt–aggregate (A–A) ratio determination of asphalt mixture. The asphalt mixtures are from a practical construction in Yulin-Suide highway, Shaanxi province of China, which are compacted by the Marshal compaction method (MCM) and the vertical vibration compaction method (VVCM), respectively. The density, percent voids in mineral aggregated (PVMA), Marshall stability, compressive strength, splitting strength and shear strength of asphalt mixtures are respectively studied by series of laboratorial tests. The effects of compaction method on the optimal A–A ratio determination are discussed. The results show that the optimal A–A ratio of vertical vibration compacted asphalt mixture is smaller than the optimal A–A ratio of Marshall compacted asphalt mixture, which should be noticed in the highway construction.

1. Introduction

The asphalt mixture is widely used in the highway construction in China. For such material, a critical challenge is to explore the optimal asphalt–aggregate (A–A) ratio (bitumen content), which significantly influences its mechanical performance. It is of significant importance to determine the optimal A–A ratio for the highway design and construction [1–4].

The optimal A–A ratio is generally determined based on the combination of density, air voids and mechanical behaviors, e.g. Marshall stability, compressive strength, shear strength etc. [5–7]. The optimal A–A ratio is regarded as a density design criterion, which is evaluated by the air void of whole mixture in the volumetric design of super-pave [7,8]. Besides the density, the maximum compaction is utilized to determine the optimal A–A ratio either, which is effected by the gradation and geometrical shape of aggregates [9].

The density, air void and mechanical behavior of asphalt mixture are significantly affected by the compaction method [10–12]. Therefore, the optimal A–A ratios are different for different compaction methods. Two compaction methods are commonly used in the road construction. The Marshall compaction method has been widely used as the asphalt mix design guide in China since 1970s. The method was originally proposed by Bruce Marshall of the Mississippi Highway Department [13,14]. Recently, another compaction method called vertical vibration compaction method (VVCM) was proposed to satisfy the rapid growth of traffic volume in China [15–18]. The VVCM was originally proposed for the cement-stabilized crushed rock material, which was compacted by a vibration loading [19]. Therefore, such compaction methods can simulate the practical dynamical loading better than the quasi-static compaction methods [19–21]. By now, the investigation of optimal A–A ratio determination for these two compaction methods has not been explored yet.

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This paper reported an experimental investigation of the optimal A–A ratio determination for asphalt mixture compacted by the MCM and the VVCM, respectively. The effects of compaction method on the density, percent voids in mineral aggregate (PVMA), Marshall stability, compressive strength, splitting strength and shear strength were evaluated. The optimal A–A ratios of asphalt mixture compacted by the MCM and the VVCM were suggested, respectively.

2. Laboratory testing

The present study is based on the practical field construction of Yulin-Suide highway, Shaanxi province of China. The asphalt and rock used in the present study are the same as those used in the practical Yulin-Suide highway engineering [19]. The VVCM used for the cement-stabilized crushed rock material was modified to satisfy the experimental requirements of asphalt mixture [20,21]. Since the engineers are more concerned about the macroscopic mechanical behavior, the average and effective mechanical properties of asphalt mixture was used [22,23]. Similar laboratory tests for the cement-stabilized crushed rock material were used in the present study [24,25].

Table 1 shows the general specifications of asphalt, which is obtained from Karamay, Xinjiang province of China [26]. The aggregate used in the asphalt mixture is limestone obtained from a quarry in Liuling city, Shanxi province of China, with a crushing value of 20.4%.

Fig. 1 shows the particle size distribution of aggregate by a sieve analysis. It is observed that 99.9% aggregates by weight are with diameters smaller than 31.5 mm, while all of the aggregates are with diameters smaller than 37.5 mm [27]. The characteristic particle size distribution of aggregates is shown in the Table 2. d_{10}, d_{30}, d_{50}, d_{60} and d_{90} are the values of particle diameter at 10%, 30%, 50%, 60% and 90% of the cumulative particle size distribution, respectively (see Fig. 1). E.g., d_{60} = 15.08 mm reveals that 60% of the particles in the sample are smaller than 15.08 mm, and 40% larger than 15.08 mm.

The coefficients of uniformity and curvature are used to evaluate the quality of aggregate. The coefficient of uniformity, C_u is a crude shape parameter and is calculated as

$$C_u = \frac{d_{60}}{d_{10}} \quad (1)$$

The coefficient of curvature, C_c is a shape parameter and is calculated as

$$C_c = \frac{(d_{30})^2}{d_{60} \times d_{10}} \quad (2)$$

where d_{10}, d_{30} and d_{60} are obtained by a sieve analysis as shown in the Table 2.

It is obtained from Eq. (1) that as the uniformity coefficient increases, the size differentiation becomes greater.

The C_u = 25.133 and C_c = 2.77 for the present study. Therefore, the aggregate can be regarded as well graded, which is suitable for the road construction [1,2].

Asphalt mixture specimens with five asphalt–aggregate ratios, 2.8%, 3.1%, 3.4%, 3.7% and 4.0%, were compacted according to the technical specification of construction of highway asphalt pavements in China [26].

Table 1
General specifications of asphalt.

Penetration index	Softening point (°C)	Flash point (°C)	Density (15 °C) (g/cm^3)	Solubility in trichloroethylene (%)
0.3	51	306	0.998	99.93

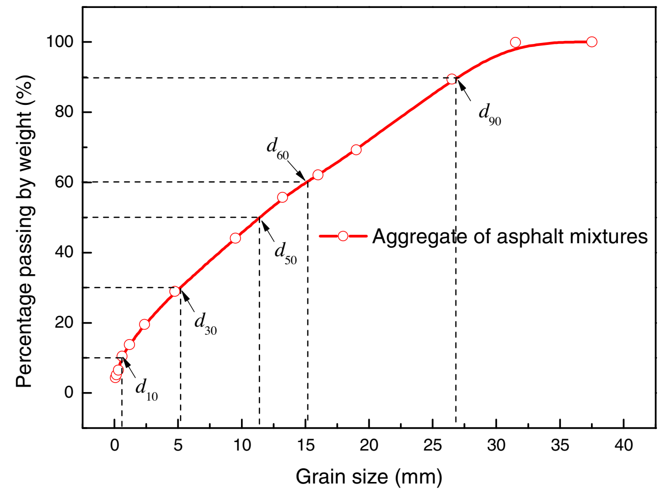

Fig. 1. Particle size distribution of aggregate in asphalt mixture.

Table 2
Characteristic particle size of aggregate.

Particle size	d_{10}	d_{30}	d_{50}	d_{60}	d_{90}
Value (mm)	0.60	5.01	11.35	15.08	26.80

The standard method of Ministry of Transport of the People's Republic of China-Standard test methods of bitumen and bituminous mixtures for highway engineering were followed for the present tests [28]. The specimens were cylinder with a diameter of around 152.0 mm in the cross section and a height of around 95.0 mm. The specimens were double-side compacted by 112 times for the MCM [28]. While for the VVCM, the specimens were compacted by a vibrate compression machine. A vertical sinusoidal force with a frequency of 37 Hz and an amplitude of 7.6 kN was applied for 100 s as previous studies [19–21].

3. Experimental results and discussion

3.1. Density

Fig. 2 shows the density of asphalt mixtures compacted by the MCM and the VVCM with five asphalt–aggregate ratios of 2.8%, 3.1%, 3.4%, 3.7% and 4.0%, respectively. The density is defined as the dry weight of compacted asphalt mixture per unit volume. Therefore, the density of specimens highly depends on the A–A ratio and the compaction method.

It is observed from Fig. 2 that the asphalt mixture by the MCM are with a smaller density than the asphalt mixture by the VVCM, which reveals that the VVCM has larger compaction energy than the MCM during the construction. It is also observed from Fig. 2 that the density of asphalt mixture increases as the asphalt–aggregate ratio increases to a maximum, then decreases as the asphalt–aggregate ratio further increases with a smaller tendency. The optimal asphalt–aggregate ratio to obtain the largest density of asphalt mixture by two compaction methods are different, which is around 3.4% for the MCM and 3.1% for the VVCM, respectively.

3.2. Percent voids in mineral aggregate

The voids in mineral aggregate (VMA) is defined as the volume of inter granular void space between the aggregate particles of a compacted asphalt mixture. Therefore, it includes the air voids and the volume of asphalt which has not been absorbed by the aggregates [29]. The term "PVMA" is used to express the ratio of the VMA to the total volume of asphalt mixture. The PVMA has significant influences on the structural stability of asphalt mixture. Higher structural stability can be obtained for the asphalt mixture with a smaller PVMA.

Fig. 3 shows the effects of A–A ratio on the PVMA of asphalt mixture compacted by the MCM and the VVCM, respectively. It is observed from Fig. 3 that the asphalt mixture compacted by the VVCM has a smaller PVMA than the asphalt mixture by the MCM. The average PVMA of asphalt mixture compacted by the MCM is 12.15%,