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Influence of volumetric property on mechanical properties of vertical vibration compacted asphalt mixture

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HIGHLIGHTS

- Influence of volumetric properties on mechanical properties of ATB-30 asphalt mixture was investigated.
- Design-suggested values of volumetric properties based on VVCM were proposed.
- Rationality of design-suggested values of volumetric property was evaluated.

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ABSTRACT

Volumetric properties, such as volume of air voids (VV), voids filled with asphalt (VFA), and voids in mineral aggregate (VMA), strongly influence the performance of asphalt mixtures. This paper analyzes the influence of volumetric properties on the mechanical properties of the ATB-30 asphalt mixture which molds using vertical vibration compaction method (VVCM). Suggested values of volumetric properties were proposed based on the optimization of mechanical properties. Additionally, the proposed design was evaluated based on its performance in practice. Results show a 92% testing accuracy of the mechanical properties of VVCM specimens. This accuracy reveals that the vibration molding is compatible with the mechanism of the roller. High consistency was observed between the mechanical properties of the ATB-30 asphalt mixture and VV, VFA. However, the correlation between mechanical properties and VMA was poor. Hence, the suggested values of VV and VFA in the ATB-30 asphalt mixture are 2.8%–4.0% and 64%–74%, respectively, and VMA is only used as a reference with a value of at least 10.5%. Compared with the Marshall Compaction method (MCM), the Marshall stability, dynamic stability, splitting strength, and tensile strength of the ATB-30 asphalt mixture increased by 54.4%, 39.1%, 54.8%, and 53.7%, respectively, when using the design-suggested values of the VVCM design. The water stability of the asphalt mixture also improved.

1. Introduction

The performance of asphalt mixtures depends on their material and structural properties. Material composition mainly includes the properties of raw materials, mineral aggregate gradation, and P_a. Material distribution and density are the two important indexes of the mixture structure. In addition, volumetric properties, such as the VV, VFA, and VMA, directly affect the structure of asphalt mixture. Volumetric properties are strongly affected by the compaction method and power. Therefore, the performance of asphalt mixtures mainly depends on the asphalt-aggregate ratio and the compaction method (compaction method and power) of the mixtures in the given raw materials and mineral aggregate gradation. Volumetric properties, such as VV, VFA, and VMA, play an important role in the mechanical properties of asphalt mixtures. Studies have suggested strong correlations between the mechanical and volumetric properties of asphalt mixtures [1–3].

VV is the most important volumetric property of asphalt mixtures that influences mechanical properties [4]. The strength, high-temperature stability, durability, and water permeability of asphalt mixtures strongly depend on their VV values being neither too high nor too low [5,6]. Excessively high VV values will reduce water stability and the fatigue life of asphalt mixtures, where as excessively low VV values will decrease the resistance of the asphalt mixture to ruts [7–9]. VMA is a controversial volumetric property in the design of asphalt mixtures. Several researchers have reported that VMA is an important design-suggested value

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Nomenclature

P_a	asphalt-aggregate ratio	R_T	splitting strength
VV	volume of air voids	σ	shear strength
VFA	voids filled with asphalt	τ_d	tensile strength
VMA	voids in mineral aggregate	*TSR*	freeze-thaw splitting strength ratio
MS	Marshall Stability	MS_0	retained Marshall Stability
R_c	compression strength	*DS*	dynamic stability

of Superpave asphalt mixtures [10]. However, other studies have shown no correlation between minimum VMA and road performance; hence, the durability of asphalt mixtures is evaluated using the thickness of the asphalt film instead of VMA [11]. VFA can be derived from VMA and VV; enhanced properties of asphalt mixture were obtained when VFA ranged from 65% to 80% [12].

Volumetric properties strongly influence the mechanical properties of asphalt mixtures. It thus plays an important role in the design of asphalt mixtures. Different laboratory compaction methods produce asphalt mixtures with different volumetric properties [13–16]. The Marshall Compaction method (MCM) has been used since the 1970s as a guide in designing asphalt mixtures in China. The method was originally proposed by Bruce Marshall of the Mississippi Highway Department [1]. As the most common volume design method for asphalt mixtures, MCM is highly appropriate for low-grade highways; however, studies have shown poor correlations between MCM specimens prepared laboratories and asphalt mixture specimens obtained from actual pavement [17–19].

Heavy traffic is a significant issue in today's growing economies. The technical standards suited for light traffic fail to satisfy conditions of heavy traffic; thus, a new compaction method for the design of asphalt mixture is required. Researchers have suggested the vertical vibration compaction method (VVCM) subjected to indoor molding to match pavement compaction [18,20–22]. This compaction method can simulate the practical dynamical loading more effectively than the MCM. The influence of volumetric properties on mechanical properties of asphalt mixtures, which molding by VVCM, has yet to be explored. Hence, the relationships between asphalt-aggregate ratio, volumetric properties, and road performance were studied based on the VVCM and the compaction standard of heavy traffic. In addition, the volumetric design-suggested values of the ATB-30 asphalt mixture were proposed.

2. Materials and test method

2.1. Materials

Table 1 shows the general specifications of asphalt obtained from Karamay, Xinjiang, China. Five different sizes of limestone mineral mixture obtained from Liulin city Shanxi province of China. The mineral mixtures had continuous grain sizes of 19 mm–37.5 mm, 9.5 mm–19 mm, and 4.75 mm–9.5 mm. We used machine-made sand and mineral powder. According to the technical requirements of Technical Specification for Construction of Highway Asphalt Pavements (JTG F40-2004) [23], the crushed aggregate value was 20.4%. The mineral gradation of the ATB-30 mixture is listed in Table 2.

2.2. Test methods and VVCM evaluation

2.2.1. Test methods

The specimens were cylinders with a diameter of approximately 152.0 mm at the cross-section and a height of approximately 95.3 mm. A beat number of 112 was used for the specimen compacted by MCM [24]. For the VVCM, the specimens were compacted with vertical vibratory testing equipment (VVTE). VVTE used only the vertical force during the compaction procedure. The working parameters of the VVTE had a working frequency of 38 Hz, an upper equipment weight of 120 kg, a nether equipment weight of 180 kg, a static eccentricity of 0.109 kg·m, and a vibrating compaction time of 100 s [18]. The set-up of the VVTE used in the VVCM is shown in Fig. 1.

The tested mechanical properties of the asphalt mixture include Marshall Stability (*MS*), compression strength (R_c), splitting strength (R_T), shear strength (σ), tensile strength (τ_d), freeze-thaw splitting strength ratio (*TSR*), and retained Marshall stability (MS_0). *MS*, R_c, R_T, *TSR*, and MS_0 were measured according to the testing methods of Ministry of Transport of the People's Republic of China for bitumen and bituminous mixtures for highway engineering [24]. In addition, σ and τ_d were measured according to the uniaxial penetration test [25–27] and semi-circular bending test [28,29].

Table 2
General index of asphalt.

Item		Tested results	Specified value
Penetration (25 °C, 100 g, 5 s) (0.1 mm)		72	60–80
Ductility (5 cm/min, 15 °C) (cm)		151	⩾100
Softening point (°C)		51	⩾46
Flashpoint (°C)		306	⩾260
Solubility in trichloroethylene (%)		99.93	⩾99.5
Thin-film heating test (163 °C)	Mass loss (%)	−0.2	−0.8–+0.8
	Residual penetration ratio (%)	67.1	⩾61
	Ductility (10 °C) (cm)	13	⩾6
Penetration index (PI)		0.3	−1.0–+1.0

Table 1
Comparison of mechanical properties of drill cores, laboratory produced ATB-30 mixture by MCM and VVCM.

Mechanical index	Mashall Stability (60 °C) (kN)	Shear strength (60 °C) (MPa)	Compression strength (20 °C) (MPa)	Splitting strength (15 °C) (MPa)	Tensile strength (−20 °C) (MPa)	Mean value
R_X	29.2	4.7	7.2	1.9	9.1	–
R_M	20.5	3.2	5.0	1.3	2.7	–
R_V	28.8	4.6	6.7	1.7	3.7	–
R_M/R_X(%)	70.2	66.7	69.2	68.9	58.0	66.6
R_V/R_X(%)	98.7	96.6	92.8	91.6	78.1	91.6