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Impacts of aggregate geometrical features on the rheological properties of asphalt mixtures during compaction and service stage

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HIGHLIGHTS

- Sieving diameter, shape index and angularity of aggregate were characterized.
- SGC indexes were used to study the compactability of asphalt mixture.
- Creep slope and E* were used to study in-service rheological properties.
- Gray relational analysis method was applied.
- Relation between mixture properties and geometrical features were studied.

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ABSTRACT

To study the influence of aggregates geometrical features on the rheological properties of asphalt mixtures during compaction and service stage, asphalt mixtures with partially substituted aggregates were compacted by Superpave gyratory compaction (SGC), and their properties in service were measured by creep and dynamical modulus tests. The relation between rheological properties of mixtures and aggregate geometrical features was studied by gray relational analysis method. Results show that the rheological properties of mixtures during compaction and service stage are more sensitive to sieving diameter and shape index, but are less sensitive to angularity. The results indicate potential for using these parameters for quality control and quality assurance of asphalt mixture during production.

1. Introduction

Aggregates of asphalt mixtures account for more than 95% of the mix mass or 85% of the overall volume [1]. Therefore, the properties of the aggregates such as gradation and strength have direct influence on the performance of hot-mix asphalt (HMA) [2]. Many studies have been conducted to characterizing aggregates mechanical properties (toughness/abrasion resistance and durability/soundness etc.) and their relationship to the performance of asphalt pavements. Using uniaxial penetration test and triaxial compression test, Xu et al. [3] suggest that the reducing of needle and plate particle content, crushing value and abrasion value can improve shear resisting performance of asphalt mixture. Alvarado [4] noted that aggregate should possess the necessary strengths to avoid degradation during handling, construction, and trafficking. Elliott et al. [5] revealed that the fine-coarse and coarse-fine gradation variations had the greatest impact on mix properties but that none of the variations had a significant effect on resilient modulus. The data also showed that within the range normally encountered, air void content had a greater impact on split tensile strength than did gradation variation. However, besides aggregate strength and the cementing action of asphalt binders, the mixture strength depends significantly on the interlocking and friction effects among particles. Hence, geometrical features such as size, shape, angularity and texture might greatly affect the mix behavior. For example, Han et al. [6] tried to develop stress-strain relations with the parameters of physical and geometric properties of asphalt and aggregates. Results show that higher degree of aggregate angularity gives rise of stiffer response of asphalt pavement, indicating a

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better interlocking interaction for coarse aggregates. Dharamveer Singh et al. [7] developed a model that utilizes aggregate shape parameters (i.e. angularity, texture and form) in estimating the dynamic modulus of asphalt mixes. Results show that the dynamic modulus of the mix increases with an increase in the angularity and texture of aggregates and that the inclusion of shape parameters can enhance the prediction capability of a model. Therefore, it is important to relate aggregate geometrical features with the properties of mixtures during mixing, compaction and service stages.

Recently, several laboratory-measured indexes were suggested as indicators of compactability of (HMA) mixture [8,9]. Bahia et al. [10] proposed two quantitative index (1) compaction energy index (CEI), and (2) traffic densification index (TDI). The CEI is the area of the SGC compaction curve from the eighth gyration to 92% of the maximum theoretical specific gravity of the mixture (Gmm), whereas the TDI is the area under the curve from 92 to 98% of Gmm. A lower CEI value represents less power needed to compact the mixture, while high TDI represents a desirable capability of resisting densification under traffic. Zhengqi Zhang et al. [11] proposed the concepts of TDI 96 and TDI 98 on the basis of TDI. TDI 96 is determined from SGC as the area under the curve from 92 to 96% of Gmm, and the TDI 98 quantifies the area of the curve from 96 to 98% of Gmm. The compacted rate reaches its limitation, and the mixture is in the plastic zone when it is compacted to 98% of Gmm. A high TDI 98 indicates that more axial load is needed to reach the limiting mixture density. Research also shows that larger slope of the compaction curve indicates higher shear strength, smaller permanent shear strain and better rutting performance [12].

Bailey [13] presented parameters that defined the grading curve as a method of quantifying compaction. The parameters include (1) CA (2) FA_c (3) FA_f. An increasing CA ratio increased the difficulty in compacting process, and a decrease FA_c ratio increased the compactability of the mixture. Anderson et al. [14] studied the affecting factors of the Superpave gyratory compaction (SGC) compaction curve, and found that the properties of aggregates (gradation, shape, texture) were the predominant factor rather than the properties of binders (hardness and volume). Leiva et al. [15] confirmed that the grading, lithology and size of aggregates have a significant influence on the compactability of SGC specimens. The densification characteristic of asphalt mixture was also associated with fine aggregate angularity (FAA). It is indicated that the increase in FAA values resulted in higher resistance to compaction.

Additionally, lots of attempts have been made to relate aggregate geometric features to the performance of asphalt mixture in service [16–18]. The influence of aggregate parameters such as shape, angularity and texture on creep deformation and dynamic modulus of asphalt mixture have been studied [19,20]. Link et al. [21] developed the University of Illinois Aggregate Image Analyzer (UI-AIA), an aggregate image analysis system, which can accurately obtain the content of needle and plate particles and the gradation curve, and several experiments were conducted to study the relation of the shape index of the coarse aggregate to the modulus of elasticity and the permanent deformation of asphalt mixture. Aggregate texture and shape can also affect the internal pore structure of asphalt mixture, and then affect the rut depth [22–24].

Despite extensive researches for relating aggregate geometric features to the performance of asphalt mixture have been reported, many challenges remain regarding the relationship between individual aggregate morphological features and asphalt mixture performance parameters. Most previous researches were conducted by using the traditional laboratory testing methods, which depends significantly on the testing equipment, conditions, and operators, etc. The research findings were results of the combination of many influencing factors (aggregate features, asphalt, air voids, and etc.) The objectives of this study are to relate the individual geometrical features of aggregate to the rheological property of mixture during compaction and service stage.

2. Materials and experiments

2.1. Raw materials and mixture design

Karamay 70# asphalt binder and AC-20 aggregate gradation were selected to prepare mixture specimens. The properties of Karamay 70# asphalt binder are shown in Table 1. The gradations of the mixs are shown in Table 2, and the optimum asphalt content of 4.1% was obtained with the Marshall procedure.

Keeping the gradation, asphalt, and air voids of all the mixs identical, for the study of the influence of aggregate morphological features, the coarse aggregates of those having sieve sizes of 16–19 mm was replaced. The natural aggregates selected were limestone, gneiss and basalt, supplied by a local quarry. The second type of aggregate was selected to represent the extreme case of the surface roughness since their shapes and angularity could be easily controlled, and the density is close to natural aggregates. Therefore, the glass aggregates were selected to study the effects of shape and angularity of aggregates, as shown in Fig. 1.

2.2. Morphological features of aggregates

The sieving diameter d_A is defined as the smallest size that the particles can pass through [25,26], as shown in Eq. (1).

$$d_A = \sqrt{2}(D_i + D_S)/2 \quad (1)$$

where D_i is the intermediate dimension of the smallest aggregate; D_S is the shortest dimension; $d_A = D_i$, when $D_i/D_S \leq \sqrt{2} + 1$.

Two morphological parameters, namely shape index and angularity, are expressed in Eqs. (2) and (3) [27,28].

$$F = \frac{L \times L}{4\pi S} \quad (2)$$

Table 1
Properties of Karamay 70# asphalt binder.

Indicator	Softening point (R&B)/°C	Penetration (25 °C, 5 s, 100 g)/0.1 mm	Ductility (5 °C)/cm	Rotary viscosity (60 °C)/Pa·s
Tested value	51.4	69	7.8	182

Table 2
Asphalt mixture gradation of AC-20.

Sieve size (mm)	0.075	0.15	0.3	0.6	1.18	2.36	4.75	9.5	13.2	16	19	26.5
Passing rate (%)	5.0	9.0	13.0	16.5	22.0	32.0	45.0	57.0	67.0	80.0	96.5	100