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Morphological characteristics of aggregates and their influence on the performance of asphalt mixture

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HIGHLIGHTS

- Morphological characteristics of aggregates were evaluated by image technology.
- Relation between aggregate characteristics and mixture properties were studied.
- Bigger angularity, rougher texture and smaller sphericity result in better adhesion.
- Optimal angularity and sphericity were found for mechanic properties.

GRAPHICAL ABSTRACT

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ABSTRACT

With the rapid growth of traffic, asphalt pavement with well performance conditions is urgently needed. Maintenance and renovation consume large amounts of natural aggregates and generate large amounts of solid waste which are negative to environment. For improving the performance of asphalt pavement, this study identified the effect of single morphological variable on the adhesion of aggregate and the mechanical properties of asphalt mixture. In order to obtain aggregates of single morphological variable, 9.5–13.2 grade of limestone and basalt were studied and manually divided into 5 groups respectively according to aggregate angularity in the Aggregate Imaging Measurement System (AIMS) specification. AIMS was used to accurately quantify the morphological characteristics of aggregates. Aggregates adhered by asphalt and AC-13 asphalt mixture with different aggregates morphological characteristic were prepared for the measurement of road performance. Results show that there are close linear relationships between angularity or sphericity of aggregate and the asphalt-aggregate adhesive property. It was also found that the relationship between angularity or sphericity of aggregate and mechanical properties such as Marshall stability and flexural strength tends to rise first and then decrease, demonstrating that there are "optimal angularity and sphericity" for Marshall stability and flexural strength. Accurately understanding morphological characteristics of aggregates is of great significance to the initial design stage of pavement. Therefore, it is suggested that the digital aggregate morphology test could be included in the experimental specifications of aggregates for achieving better road performance.

1. Introduction

With the rapid growth of traffic flow and the combined effect of natural conditions, for instance, the global temperature increasing [1], asphalt pavement was damaged seriously. Rutting, cracks,

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potholes and other road distresses seriously affect the safety and comfort of driving. Many roads have not yet reached the designed service life and require extensive maintenance and renovation [2]. The burdensome build-up tasks consume large amounts of natural aggregates and generate much solid waste, both of which can lead to very negative environmental impacts [3,4]. Therefore, improving the performance of asphalt pavement and extending its service life are particularly important to limit the environmental impact resulted from life shortage of asphalt pavement.

The existing researches mainly focus on the properties of asphalt [5–7], anti-stripping agent [8–11] and rejuvenator [12–15] to optimize the asphalt mixture. But researches on the aggregate characteristics are being left far behind. Aggregate is account for >90% of the total mass in asphalt mixture and the study on improving the performance of asphalt mixture based on the characteristics of aggregate morphology is a significant research orientation.

The traditional testing methods of aggregate's morphological characteristics are not only time-consuming, but also depend largely on the operator's subjective judgment, making the experimental results imprecise and incomplete [16,17]. Accurate quantification of aggregate morphological characteristics has great significance to select aggregates and fully understand the relationship between morphological properties of aggregates and road performance [18,19]. Digital image processing technology has been widely used for accurately quantify the morphological characteristics of aggregate, and a variety of equipment and image testing methods based on digital image processing technology developed rapidly, such as Computer Particle Analyzer (CPA), VDG-40 Videograder, VideoImaging System(VIS), Buffalo Wire Works PSSDA, Aggregate Image Analyzer (UIAIA), Aggregate Imaging System (AIMS) and Fourier Transform Interferometry (FTI) system [20–22]. Masad and Button used erosion-dilation technique and the form factor approaches to capture aggregate morphological characteristics making use of digital image processing technology [23]. Kim et al. developed a method for segmenting a particle image acquired from laser profiling [24]. Wang et al. evaluated imaging techniques including second-generation Aggregate Imaging Measurement System, first-generation University of Illinois aggregate image analyzer, and Fourier transform interferometer system [25]. Wang et al. established a correlation between the Micro-Deval test and morphological properties of aggregate [17]. Wang et al. created an algorithm for modeling two-dimensional virtual aggregates. The virtual uniaxial compressive tests of SMA-13 and AC-16 aggregate skeleton was simulated and they found that the algorithm can not only model the mixture precisely, but also characterized its mechanical behavior well [26,27]. X Ding et al. proposed a model of coarse aggregate based on the particle morphology, and proved that modeling algorithm can capture the realistic shape of aggregates accurately [28]. Compared with other digital image processing methods, AIMS is more objective and credible, which can execute accurate analysis and calculation of sphericity, angularity, flat & elongated and texture based on digital images collected by a high resolution digital camera and a variable magnification microscope.

Although some studies have shown that the morphological characteristics of aggregates can seriously affect the performance of pavement [29–33], the morphological variables of the aggregates did not be controlled by the most of researchers in the experiment. For instance, Aragão et al. used AIMS to tested aggregates from different sources blended with each other to obtain aggregates with different angularities and textures [22]. Although road performance of the corresponding mixture is obtained, it is not clear which kind of morphological characteristics influencing it, since the angularity and texture are both variables. Wang et al. used Los Angeles Abrasion tests to obtain aggregates with different angularity and calculated fractal dimension [34], but it also changes aggregates' size and surface texture. The angularity and texture of different aggregates types are various, which can-not effectively explain the correlation between the single variable and the result.

This study evaluated the effect of single morphological variable on the adhesion of asphalt-aggregate and the mechanical properties of asphalt mixture. AIMS was used to quantify morphological characteristics of aggregates. Aggregates covered by asphalt and asphalt mixtures were prepared for the measurement of mechanical properties. Through the combination of aggregate image analysis technology, UTM (Universal Testing Machine) mechanical testing equipment and image analysis methods, the relationship between single morphological variable of aggregate and behavior of asphalt mixture was evaluated.

2. Materials

2.1. Aggregates

Basalt, limestone and steel slag were selected in this study. Basalt is a kind of basic volcanic rock, with a large compressive strength, low water absorption, and good wear resistance. Limestone has outstanding physical properties such as excellent sturdiness and cementation. However, it is generally not used on the surface of asphalt concrete pavement due to its lower strength than volcanic rocks such as basalt. Most limestone is used in the middle or lower level or base course, or directly as a mineral powder. Steel slag as an industrial waste, has been more and more widely used in road engineering in recent years. The 9.5–13.2 grade of aggregates used in this study were of 11 types totally: five types of basalt and five types of limestone via manual distinction, with the addition of one type of steel slag. The basic performance indicators of the three aggregates are shown in Table 1.

2.2. Asphalt binder

Asphalt binder plays a role of cementing throughout the concrete system, making the loose particles connected into a whole, and directly affects the road performance of asphalt mixture. AH-70 base asphalt was used in this study. Characteristics of AH-70 base asphalt binder are presented in Table 2.

2.3. Asphalt mixture

In order to determine the correlation between coarse aggregate morphology and the behavior of asphalt mixtures, dense-graded asphalt concrete (AC-13) was prepared, whose gradation was shown in Fig. 1. The asphalt-aggregate ratio was optimum ratio for each kind of mixture in this study and there are 11 types of asphalt mixtures corresponding with 11 kinds of aggregates belonging to grade of 9.5–13.2. In order to avoid interference from other factors, the 4.75–9.5 grade of coarse aggregate and fine aggregate used in all mixtures were basalt which is from same source.

Table 1
Aggregate basic performance indicators.

Properties	Unit	Technical requirements	Tested value			Specification used
			basalt	limestone	Steel slag	
Crushing value	%	≤26	8.9	15.6	18.5	T0316-2005 [35]
Abrasion value	%	≤28	15.7	15.1	11.6	T0317-2005 [35]
Apparent relative gravity	–	≥2.6	2.978	2.708	2.872	T0304-2005 [35]
Water absorption	%	≤2.0	0.2	0.3	0.2	
Flat-elongated particles (5:1)	%	≤12	6.8	8.4	7.2	T0312-2005 [35]