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Three-dimensional characterization of morphology and abrasion decay laws for coarse aggregates

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HIGHLIGHTS

- The specific scanning process was used obtain shape information of aggregate.
- FEI, SI and SSA are proposed to characterize the morphology of aggregate.
- The minimum bounding box algorithm was developed to calculate FEI of aggregate.
- Abrasion decay laws of the quantitative indexes were illustrated by image analysis.

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ABSTRACT

In order to quantitatively evaluate morphological characteristics and abrasion decay laws of coarse aggregate so that make an accurate performance evaluation for aggregates, flat-elongated index, sphericity index and specific surface area are proposed to characterize the shape properties of coarse aggregate. Limestone aggregate particles ranging in size scale of 4.75–9.5 mm, 9.5–13.2 mm, 19–26.5 mm were worn by the Los Angeles Abrasion tester respectively. Three-dimensional (3-D) laser scanner was used to obtain three-dimensional points cloud data of aggregate particles experienced 0, 500, 1000 and 2000 abrasion cycles. Afterwards, the data was processed by the software of reverse engineering based on morphology evaluation indexes, and the minimum bounding box algorithm was developed to calculate flat-elongated index, illustrating the morphological characteristics of coarse aggregate particles with different size and abrasion cycles. Test results show that: aggregates with small size have bigger quantity proportion of elongated particle; the greater the angularity of aggregates was, the faster the angular decay rate of the aggregates was; aggregate particles with small size has richer surface texture but easier to lost in abrasion process. Sphericity index increased, while specific surface area and flat-elongated index presented a downward trend as the particle size became bigger for different abrasion cycles. However, the flat-elongated index of aggregate particles with different size increased abnormally when abrasion cycles increased at 2000 abrasion cycles as the result of aggregate crushing. Besides, the sphericity and specific surface area of some 4.75 mm aggregate under 500 abrasion cycles showed an abnormal increasing compared to its 1000 abrasion cycles, which caused by inadequate abrasion under low abrasion cycles. Therefore, the indexes proposed in the study are able to characterize different aspects of coarse aggregates morphological property, and it is beneficial for the evaluation and selection of aggregates used in engineering construction.

1. Introduction

Aggregate is an important type of road construction materials, as well as an indispensable component of asphalt concrete and cement concrete providing supporting skeleton [1]. Coarse aggregate occupies almost 50–80%/wt. of asphalt or cement concrete, and its performance have significant influence on strength and durability of concrete [2]. In the field of performance evaluation for coarse aggregate, Los Angeles Abrasion (LAA) test is a common test method used to indicate strength characteristics of aggregate for it can be closer to the actual material breaking condition in the process of mixing, unloading and compaction, and LAA value used to evaluate the performance of aggregates [3,4]. However, LAA value is not directly related to field

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performance of aggregates [5]. Researches have reported that even if some types of aggregate have great Los Angeles Abrasion value, the strength and stability of aggregate mixture is not necessarily very good, the morphology of aggregate also plays an important role in the performance of aggregate mixture [5,6]. In general, morphological features of coarse aggregate include contour shape, angularity and surface texture [7], in which contour shape and angularity belong to macroscopic morphology, and the surface texture is a kind of mesomorphology. The morphological characteristics of coarse aggregate will affect different aspects of strength and using performance in mixture. In LAA test, the anti-abrasion behaviour of particles is finally reflected by the mass loss rate of abrasion, and the real-time morphological changes of aggregate before and after abrasion are ignored, not to mention the changes of morphology in the abrasion process. Therefore, it is necessary to accurately characterize morphological characteristics of coarse aggregates, and study the decay laws of morphology for aggregate to estimate the wear characteristics of aggregates. Thus the performance evaluation and forecast of aggregate in engineering will be more comprehensive and accurate.

At present, morphological representation of coarse aggregate based on two-dimension photo-taking technique has been widely researched. Rao et al. [8,9] proposed angularity index (AI) and which traced the change in slope of the outline of the two-dimensional aggregate image to characterize the coarse aggregate angularity and surface texture (ST) index which used an image analysis technique called "erosion and dilation" to characterize the coarse aggregate surface texture. Zhang [10] proposed an indicator called angularity and surface texture (AT) index which combined AI and ST to characterize the combined effect of the coarse aggregate angularity and surface texture based on two-dimensional aggregate images and validated the AT index via test the void contents of different sized limestone and basalt aggregates in loose condition. In order to evaluate angularity of recycled coarse aggregate, Tang [11] computed roughness and sphericity based on two-dimensional image parameters and established a correlation between angularity of the recycled coarse aggregate and high temperature performance of asphalt mixture. Wang [12] used fractal dimension index to quantified morphological properties (shape, angularity, texture) of coarse aggregates based on MASCA system which is self-developed and obtained a good linear correlation between the fractal dimension and high temperature performance of asphalt mixture. Most of the above methods used two-dimension index only, or two-dimension index and three-dimensional index which calculated by two-dimension image parameters together to characterize morphological characteristics of coarse aggregate. It is not effective to describe morphological properties of coarse aggregate which have complex shape and irregular form so it is hard to establish accurate evaluation indexes of morphological characteristics and quantitative indexes related to gradation and strength characteristics of mixture.

In the field of three-dimensional morphological characterization of coarse aggregate, CT technique is an accurate method to evaluate three-dimensional shape characteristics of aggregate particles. Wang [13] and Masad [14] used two-dimensional tomography images to characterize three-dimensional surface characteristics of irregular-shaped aggregate particles. However, there is often a huge computational workload in three-dimensional reconstruction with high accuracy in the process of X-ray tomography (Xray-CT) owing to the existing technical limitation. Moreover, CT equipment is expensive, and has strict safety and radiation control requirements. In contrast, three-dimensional (3-D) laser scanning technology has become a new research hotspot recently for its superiority of safety and convenience. Researchers in the Council for Scientific and Industrial Research (CSIR) in South African have found that 3-D laser scanning technology can accurately determine shape and surface properties of rocks [15]. Anochie-boateng [16] obtained the surface area and volume of aggregate particles directly using 3-D laser scanning method. In the subsequent studies [17], 3-D laser scanning data of different quarry aggregates was utilized to substitute volume ratio to determine the content of flat and elongated aggregates, validating a new flatness equation. In addition, Pan [18] and Tutumluer [19] used 3-D laser scanning technology to evaluate surface characteristics of broken and unbroken aggregates in asphalt mixtures, which have a good correlation with their test results. It can be analysed from the aforementioned research that three-dimensional scanning technique is able to accurately and quantitatively characterize shape properties of aggregates with much less cost and time consumption compared with CT technology. Nevertheless, previous researches utilizing the 3D scanning technique are mainly focus on the shape, volume and surface properties of aggregates from one or different quarries, the morphology decay law of aggregates during the application process is not well studied.

In summary, Los Angeles Abrasion test is not enough to evaluate the performance of aggregate, and morphology and its decay properties in the wear process have a significant impact on the strength and stability of the aggregate mixture which is essential for the evaluation of the aggregate quality.

The current study selects limestone coarse aggregate with three kinds of diameter range, three-dimensional morphological data of these particles with different sizes and abrasion cycles are obtained by 3-D laser scanning and points cloud data analysis. Then, quantitative evaluation indexes representing morphological characteristics of coarse aggregates are proposed from different scales based on the morphological features of coarse aggregate. The morphological characteristics and abrasion decay laws of coarse aggregate are further analysed to provide guidance for the performance evaluation and optimization of aggregates in engineering practice.

2. Test design and methods

2.1. Materials

The 4.75–9.5 mm, 9.5–13.2 mm, and 19–26.5 mm limestone aggregates (three-size-aggregates) were used in this study. The 4.75–9.5 mm aggregates are the particles that pass 9.5 mm sieve but retain on 4.75 mm sieve. Aggregates in the range of 9.5–13.2 mm, and 19–26.5 mm have the similar definition. Furthermore, the 4.75–9.5 mm, 9.5–13.2 mm, and 19–26.5 aggregates were represented by 4.75 mm, 9.5 mm, and 19 mm in the following parts for convenient purpose.

2.2. Los Angeles Abrasion test

The Los Angeles and Abrasion test is a measure of degradation of mineral aggregates of standard gradings resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres. The LAA test is widely used as an indicator of the relative quality or competence of mineral aggregates. In order to analyse abrasion decay laws of morphological features of coarse aggregate, abrasion tests of 4.75 mm, 9.5 mm and 19 mm aggregates were carried out respectively by using Los Angeles Abrasion tester. The morphological characteristics of these particles were changed during the test. According to some researches [20,21], aggregates will be damaged heavily when the abrasion cycles exceed 2000, it would lead to a lot of dust. Therefore, the max abrasion cycles were set to 2000 in the LAA test for aggregate with different size. According to ASTM C 131 specification, the rotation speed is