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Investigation of the shape, size, angularity and surface texture properties of coarse aggregates

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ABSTRACT

The shape, size, angularity and surface texture properties of coarse aggregates were studied in this paper. Aggregates with different shapes were separated manually and the percentage by number of each shape was computed. The three sizes (length, width and thickness) of aggregates were extracted using an image analysis approach and their statistical distributions were studied. An indicator called angularity and surface texture (AT) index was developed to characterize the combined effect of the coarse aggregate angularity and surface texture based on two-dimensional aggregate images. The statistical distributions of the AT indices of different sized limestone and basalt aggregates and their composite AT indices were studied. The void contents of different sized limestone and basalt aggregates in loose condition were tested to validate the AT index.

1. Introduction

The morphology of coarse aggregates includes shape, size, angularity and surface texture. Many studies have demonstrated that the coarse aggregate morphology has a significant effect on the performances of aggregate based materials such as the field compaction of asphalt mixtures, the permanent deformation of asphalt mixtures and the shearing resistance of railway ballast [1–4]. In addition, the discrete element method (DEM) is now employed more and more to study the micromechanical behavior of asphalt mixtures. It is very important to model the three-dimensional (3D) morphology of coarse aggregates when the DEM is used to analysis the micromechanical behavior of asphalt mixtures. Laboratory investigation of the actual 3D morphology of coarse aggregates serves as a way to correlate the particles generated by DEM to real aggregates. Therefore, it is important to quantitatively characterize the aggregate shape, size, angularity and surface texture for the prediction of material performances and reconstruction of the coarse aggregates by DEM.

In the last decades, the image analysis method has been used to characterize the morphology of coarse aggregates [5–9]. The 3D sizes of aggregates can be determined by taking two images of each aggregate particle. The sizes of each particle are different even the particles are within the same sized aggregates. Studying the size distributions of coarse aggregates contributes to understanding the size properties of aggregates and to modeling the aggregates by DEM. The shape was usually characterized by the indicators such as sphericity and roundness in the image analysis method [6,9]. The shape indicators can then be correlated to the performance of the aggregate based materials. However, these shape indicators cannot be used to construct the 3D shapes by DEM. It is necessary to study the actual 3D shapes of coarse aggregates.

In the image analysis method, two dimensional aggregate images were used to evaluate the angularity and surface texture of coarse aggregates [7,8]. The angularity index (AI) was developed by Rao et al. [10] to characterize the coarse aggregate angularity by tracing the change in slope of the outline of the two-dimensional aggregate image. Also, the surface texture (ST) index was proposed by Rao and Tutumluer [11] to characterize the coarse aggregate surface texture using the image analysis technique known as “erosion and dilation”. Further study by Tutumluer et al. [12] shows that a definite relationship with a coefficient of determination R^2 of 0.79 existed between the AI and ST index of the studied aggregates. This indicates that the AI and ST index are significantly related to each other. Therefore, the angularity and surface texture of aggregates may be characterized by one index since the two properties are both related with the outline of the two-dimensional aggregate image.

The objective of this study is to investigate the shape, size, angularity and surface texture properties of coarse aggregates.

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The main work includes: (1) separate aggregates of different shapes manually and compute the percentage by number of each shape; (2) extract the length, width and thickness of aggregates using an image analysis method and study their statistical distributions; (3) develop an indicator to characterize the angularity and surface texture of coarse aggregates and analyze its statistical distributions; and (4) validate the proposed indicator.

2. Shape, size, angularity and surface texture characterization

The 3D shapes of the coarse aggregates are approximated to be hexahedron, pentahedron and tetrahedron in this study. Flat and elongated aggregates are considered as an individual type since they are undesirable in the specifications of many countries. The flat and elongated aggregate herein is determined as the particle whose ratio of the maximum to minimum size is bigger than 3:1. Schematic drawings of the 3D aggregate shapes are illustrated in Fig. 1.

The size property of coarse aggregates is characterized by length, width and thickness. Length is defined as the maximum size of the particle, width is the maximum size in the plane perpendicular to the length and thickness is the maximum size perpendicular to the length and width. The thickness is assumed to be the shortest size of the particle in this study.

The two-dimensional image analysis method is now usually used to characterize the angularity and surface texture of coarse aggregates. As shown in Fig. 2, the angularity is defined as the convex part on the outline of a coarse aggregate image and the surface texture is considered as the tiny bumps on the outline. The main difference of the two morphological properties is that the angularity is a macro-property of the outline of the coarse aggregate image while the surface texture is a micro-property. Therefore, the angularity and surface texture reflected by a two-dimensional coarse aggregate image can be characterized by one indicator. As can be observed in Fig. 3, the coarse aggregate outline with more macro- and micro-bumps has a longer perimeter. Based on this, an indicator called angularity and surface texture (AT) index is developed here to characterize the combined effect of the angularity and surface texture. The AT index is defined by the difference of the outline perimeter and the convex outline perimeter of a two-dimensional coarse aggregate image, as expressed by Eq. (1). As shown in Fig. 3, the outline perimeter is the total length of the image outline and the convex outline perimeter is the length of the image boundary lines that omit the concave part of the outline. The length of the concave lines is replaced by the length of straight lines in the computing of the convex outline perimeter.

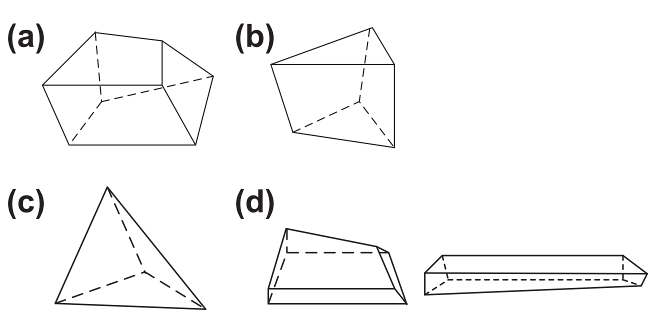

Fig. 1. Schematic drawings of the 3D aggregate shapes: (a) hexahedron; (b) pentahedron; (c) tetrahedron; and (d) flat and elongated particles.

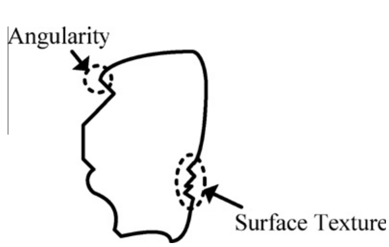

Fig. 2. Schematic drawing of a two-dimensional aggregate image.

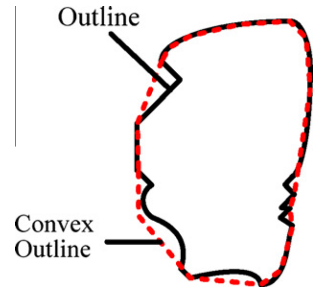

Fig. 3. Schematic drawing of the outline and convex outline.

$$\mathrm{AT} = \frac{\text{Outline Perimeter—Convex Outline Perimeter}}{\text{Convex Outline Perimeter}} \quad (1)$$

The AT index of an aggregate particle is established by averaging the AT index values of its two-dimensional images weighted by their areas, as shown in following equation:

$$\mathrm{AT} = \frac{\sum_1^n A_i \cdot \mathrm{AT}_i}{\sum_1^n A_i} \quad (2)$$

where n is the number of images used in the calculation, A_i is the area of the ith image of the particle and AT_i is the AT index of the ith image of the particle. The AT index of the whole aggregate sample (composite AT index) is determined by averaging the AT index values of aggregate particles weighted by their areas used in computing their own AT index. The composite AT index of the aggregates mixed by different aggregate samples can be determined by averaging the composite AT index values of different aggregate samples weighted by their weights.

3. Materials and experimental methods

3.1. Materials

The 4.75–9.5 mm, 9.5–13.2 mm, 13.2–16 mm, 16–19 mm and 19–26.5 mm limestone aggregates and the 4.75–9.5 mm, 9.5–13.2 mm and 13.2–16 mm basalt aggregates were used in this study. The 4.75–9.5 mm aggregates are the particles that pass the 9.5 mm sieve but retain on the 4.75 mm sieve. Other sized aggregates have a similar meaning. The 4.75–9.5 mm aggregates are simply called 4.75 mm aggregates in the following discussion and so are other sized aggregates.

3.2. Experimental methods

Different shaped aggregates in an aggregate sample were separated first manually and then the percentages by number of hexahedron, pentahedron, tetrahedron and the flat and elongated aggregates were computed. In determining the aggregate shape, the face with a relatively small area was not counted and Fig. 1 was used as a reference. Fig. 4 shows the manually separated aggregates in which they are tetrahedron, pentahedron and hexahedron aggregates from the left to right. Fig. 5 shows the typical 3D aggregate shapes in which they are hexahedron, pentahedron and tetrahedron aggregates from up to down. The sample sizes (by number) of different sized aggregates used in the shape statistical analysis are shown in Table 1.

Three sizes (length, width and thickness) of the aggregates were extracted using an image analysis approach. Two sizes of each aggregate particle can be extracted from an image of the aggregates. In order to obtain the third size of each aggregate particle, all particles were set upright and the other picture was taken. The outline perimeter and the convex outline perimeter of each coarse aggregate image were also extracted using these images. The sample sizes (by number) of different sized aggregates used in the size, angularity and surface texture analysis are shown in Table 2. Detailed procedures are described as follows: