Aggregate Particle Size Calculation Based on Optimized Equivalent Ellipse

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Abstract. The precise calculation of the aggregate size is crucial for detecting aggregate gradation. Therefore, the aim of this study was to propose a method for calculating aggregate particle size. First, a series of image-processing methods, such as filtering, enhancement, segmentation, and morphology, were implemented to obtain a binary image. Consequently, a method for determining the particle shape and correcting the particle size was devised. The aggregate particles are divided into four categories, i.e., rectangle, ellipse, diamond, and triangle, according to three parameters: compact factor, projected contour, and distance distribution from edge point to centre of mass. The corresponding correction coefficient of each category based on the equivalent elliptical minor axis was then calculated, and the grading accuracy of the corrected particle size was analyzed. The accuracy of the particle size classification obtained by the method of aggregate particle shape determination and particle size correction proposed in this paper is 80.7%.

1. Introduction
Asphalt is dominantly used in pavement structure on highways. The main component of asphalt concrete is aggregate, which plays a key role in filling the whole road surface. Aggregate gradation directly determines the service life and performance of asphalt pavement [1]. The conventional test objects of aggregate gradation are mostly asphalt concrete pavement specimens. In this case, even if a deviation or error of gradation is found through the test, it is no longer possible to repair the pavement. Therefore, there is an urgent need for a new method for detecting aggregate gradation conveniently and quickly [2,3,4].

Moaveni et al. proposed a method to collect and process images of aggregate particles at the construction site to extract and analyse the size and shape characteristics of individual aggregate particles[5]. Guo used the digital image processing techniques of the grading method to put forward a method to obtain asphalt concrete surface[6]. Liu Yand others improved a three-dimensional high-resolution image Fourier transform interference detection system for the characterization of aggregate morphology[7]. Yang X and others proposed a three-dimensional method to quantify the aggregate angular index and surface texture index[8]. Kuang D (2017) et al. Used digital imaging techniques to study the macroscopic changes in particle surfaces before and after abrasion of limestone and granite[9].Li Qiang used MATLAB to filter and segment the cross-section image of the asphalt mixture beam specimen, and obtained the centroid, area, perimeter, minimum circumscribed rectangle, equivalent Ellipse and other parameters[10]. Su D et al. Proposed a method for detecting angularity of particles in general shapes. It performs a Fourier series analysis on a two-dimensional image of particles, reconstructs the particle morphology, and then evaluates it from a gradient-based angle index[11]. Ji Lun et al. analyzed the morphological characteristics of aggregate particles in asphalt
concrete, and used CT to scan the sections of asphalt concrete under different grades, use image processing techniques and statistical methods on the acquired images. The results show that the cumulative distribution of the aspect ratio and angularity of the aggregate particles conforms to the Weibull distribution; parameters such as the aspect ratio and area parameters of the aggregate seriously affect the changes in aggregate gradation[12].

It can be seen that digital image processing technology has been widely used in the field of aggregate particle size detection. However, there are some errors in digital image processing methods, it is inaccurate to use only the size results of image analysis as the basis for aggregate screening. In view of this, this paper proposes a method for determining the shape and size of aggregate particles based on an equivalent ellipse by processing the aggregate particle image.

2. Collection and Processing of Aggregate Particle Images

2.1. Aggregate Particle Image Acquisition

Figure 1 presents the hardware diagram of the aggregate particle image-acquisition system. The system mainly comprised a light source, camera, background plate, and custom stent. The captured image of the aggregate particles is shown in Figure 2.

![Figure 1. Schematic diagram of aggregate particle image acquisition system](image1.png)

![Figure 2. Aggregate particle image](image2.png)

A light source is a very important part of machine vision system and must be selected by considering its contrast, brightness, and robustness. BASLER aca1300-60gm was selected as the industrial camera for image acquisition. This camera can be seamlessly connected with Halcon, LabVIEW, OpenCV, and other third-party visual development software, which are easy to develop and use. The camera target size is 5.32 mm and the working distance is 400 mm. Therefore, according to the triangle similarity principle, the focal length of the camera lens can be calculated as 7.09 mm. Thus, the Lens Edmund Optics CFFL F1.3 f8.5 mm 2/3” Lens was used in this experiment.

A black cloth was used as the background so as to distinguish the aggregate particles clearly and facilitate the subsequent image processing. As the aggregate particle size obtained through image analysis needed to be compared with the mesh size, the ratio of pixels to real-world units should be calculated. A 100 mm × 20 mm rectangle was used as the standard object, which covers 346 × 66 pixels in an image. Therefore, the ratio of pixels to real-world units was 0.2959.
2.2. Image Processing of Aggregate Particles

To improve the accuracy of the subsequent calculation of aggregate size, many trials were conducted, after which the expected results could be obtained through high frequency filtering, information entropy-based binarization, and open operation of aggregate images in sequence. The aforementioned process is shown in Figure 3.

![Figure 3. aggregate image process](image)

(a) High-amplitude filtering  (b) threshold segmentation  (c) open operation

To facilitate the measurement of aggregate particle size, a convexity packet operation was performed on the aggregate particle image. A convex hull is defined as the range of the smallest polygons that surround all points in a point set. In this study, a nearly linear Graham algorithm was used to deal with the aggregate particle image, which can be obtained as shown in Figure 6. The effect of aggregate particles after convex hull edge is more smooth, and closer to the original shape the shape of the aggregate particles. The subsequent extraction of the characteristic parameters of aggregate particles is based on the aggregate particles after convex hull.

![Figure 4. Effect of convexity packet operation](image)

The aggregate particle size can be calculated using various models, such as equivalent circle, ellipse, equivalent rectangle, maximum inscribed circle, elliptic (ferre), equivalent rectangle (ferre), and ferre diameter. The equivalent elliptical model has the highest precision.

The equivalent elliptical model is an ellipse with the same area and circumference as the particle, as shown in Figure 5. The ellipse has two parameters, long axis $a$ and short axis $b$, which are used to represent the circumference $P$ and area $A$ of the ellipse as follows:

\[
A = \frac{1}{4} \pi ab
\]

\[
P = \pi \sqrt{\frac{1}{2} (a^2 + b^2)}
\]

The unique long and short axes can be obtained by solving the following equations:

\[
a = \sqrt{\frac{P^2}{2\pi} + \frac{2A}{\pi}} + \sqrt{\frac{P^2}{2\pi} - \frac{2A}{\pi}}
\]

\[
b = \sqrt{\frac{P^2}{2\pi} + \frac{2A}{\pi}} - \sqrt{\frac{P^2}{2\pi} - \frac{2A}{\pi}}
\]
3. Calculation of Aggregate Particle Size
Virtual screening refers to the screening of aggregate particles by using a machine vision system to obtain particles of one or more dimensions of information; these are used to calculate the size of the particles and determine their quantity through a mesh. Virtual screening is more efficient than manual physical screening and can objectively and accurately obtain the aggregate particle size and grading.

3.1. Calculation of Particle Size correction Coefficient of Aggregate Particles Based on Equivalent Elliptical Model
The fitting of elliptical or circular aggregate particles with an ellipse has the highest accuracy; however, some errors could occur when using an ellipse to fit aggregate particles with other basic shapes such as rectangle, diamond, and triangle. Figure 6 shows that fitting rectangular aggregate particles with an ellipse will considerably enlarge the particle size, and fitting diamond and triangular particles will decreased the particle size. After the shape of the aggregate particles is classified according to shape, the correction coefficient of the particles of each shape is calculated to correct the deviation in the particle-size estimation, as shown in Figure 7.

3.2. Particle-size Correction Factors
Fitting the rectangular aggregate particles with an ellipse will cause the resulting aggregate particles to have a length and width larger than the actual length and width dimensions, and an appropriate correction coefficient region can be used to correct the overestimation of the aggregate length and width. When calculating the correction factor, the area is considered a very important parameter but the circumference is not considered because the area is a dominant attribute of an aggregate particle,
and the circumference of the ellipse is not uniform. Besides area, the ratio of length to width is also used to calculate the correction coefficient.

The ellipse area is formulated as follows:

$$A_0 = \frac{\pi}{4}ab$$  \hspace{1cm} (3)

where \(a\) is the long axis length of the equivalent ellipse, \(b\) is the short axis length of the equivalent ellipse, and \(a \geq b\). The area of the rectangular aggregate particle is calculated as

$$A_\| = LW$$  \hspace{1cm} (4)

where \(L\) is the length of the rectangular aggregate particles, \(W\) is width the rectangular aggregate particles, and \(L \geq W\). The equivalent ellipse is defined as

$$A_0 = A_\|$$  \hspace{1cm} (5)

That is,

$$\frac{\pi}{4}ab = LW$$  \hspace{1cm} (6)

The length ratio of the equivalent ellipse is assumed to be equal to the length ratio of the rectangular aggregate particle, i.e.,

$$\frac{a}{b} = \frac{L}{W}$$  \hspace{1cm} (7)

By simultaneously solving equations (6) and (7), \(W\) can be eliminated:

$$L = \frac{\sqrt{\pi}}{2}a$$  \hspace{1cm} (8)

Similarly, \(L\) can be eliminated:

$$W = \frac{\sqrt{\pi}}{2}b$$  \hspace{1cm} (9)

In this way, a correction coefficient of \(\frac{\sqrt{\pi}}{2} = 0.886227\) was obtained for fitting rectangular aggregate particles with an ellipse. Moreover, depending on whether the coefficient must be applied to the long or short axis, the overestimation can be corrected. This correction factor can also be applied to square aggregate particles simultaneously as squares are the only special case in which the length and width are equal.

Similarly, correction coefficient of diamond and Triangular can be obtained as 1.253314 and 1.157875 respectively.

4. Result Analysis
After classifying the aggregate particles according to the shape, each particle size is multiplied by its corresponding correction coefficient, and the particle is virtually sieved with the corrected particle size to calculate the bin accuracy and correction. The previous virtual screening results were compared. Table 1 shows the binning situation after each particle size is corrected. As shown, the accuracy of the
corrected particle size is improved, and the correct aggregate particles of 9.5, 13.2, and 16 grades were increased by 3, 10, and 27, respectively.

| Aggregate grade | Before and after correction | >standard | In the standard | >standard | accuracy |
|-----------------|-----------------------------|-----------|-----------------|-----------|-----------|
| 9.5 Before(a)   | 5                           | 156       | 39              | 0.78      |           |
| 9.5 After(a)    | 4                           | 159       | 37              | 0.795     |           |
| 13.2 Before(a)  | 18                          | 162       | 20              | 0.81      |           |
| 13.2 After(a)   | 10                          | 172       | 18              | 0.86      |           |
| 16 Before(a)    | 39                          | 126       | 35              | 0.63      |           |
| 16 After(a)     | 23                          | 153       | 24              | 0.765     |           |
| 16 Before(a)    |                            |           |                 |           |           |
| Average         |                            |           |                 |           | 0.807     |

5. Conclusion
In this study, a physical sieving test was first conducted on aggregate particles. A total of 600 aggregate particles were selected from the 9.5, 13.2, and 16 aggregate grades as test samples. Then, according to the actual situation, the images of aggregate particles were collected. A series of processing, including image noise reduction, image enhancement, image segmentation, and image morphology processing, were used to finally obtain a better binary image of the aggregate particles. According to this, a large number of characteristic parameters of aggregate particles can be calculated, such as area, perimeter, particle size, shape parameters. After analyzing the reasons for the error in binning using the equivalent ellipse short axis, it is proposed to use the compact factor, the projection profile, and the distribution of the distance from the edge point to the centroid point to divide the aggregate particles into rectangles/ellipses/diamonds and triangles, each class has its own correction coefficient based on the equivalent ellipse short axis, the corrected particle size was obtained, and its binning accuracy was 80.7%, which was better than the equivalent ellipse short axis.

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