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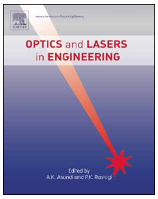

Assessment of optimum threshold and particle shape parameter for the image analysis of aggregate size distribution of concrete sections

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ABSTRACT

Aggregate gradation is one of the key design parameters affecting the workability and strength properties of concrete mixtures. Estimating aggregate gradation from hardened concrete samples can offer valuable insights into the quality of mixtures in terms of the degree of segregation and the amount of deviation from the specified gradation limits. In this study, a methodology is introduced to determine the particle size distribution of aggregates from 2D cross sectional images of concrete samples. The samples used in the study were fabricated from six mix designs by varying the aggregate gradation, aggregate source and maximum aggregate size with five replicates of each design combination. Each sample was cut into three pieces using a diamond saw and then scanned to obtain the cross sectional images using a desktop flatbed scanner. An algorithm is proposed to determine the optimum threshold for the image analysis of the cross sections. A procedure was also suggested to determine a suitable particle shape parameter to be used in the analysis of aggregate size distribution within each cross section. Results of analyses indicated that the optimum threshold hence the pixel distribution functions may be different even for the cross sections of an identical concrete sample. Besides, the maximum ferret diameter is the most suitable shape parameter to estimate the size distribution of aggregates when computed based on the diagonal sieve opening. The outcome of this study can be of practical value for the practitioners to evaluate concrete in terms of the degree of segregation and the bounds of mixture's gradation achieved during manufacturing.

1. Introduction

Aggregate is the primary component of Portland cement concrete occupying up to 80% of the mixture's volume. Because of their volumetric significance, aggregates can thus influence to a large extent both fresh and hardened properties of concrete, in particular by their size and shape characteristics. In fact, aggregate size distribution is one of the key parameters of mixture design affecting the strength and workability of concrete mixtures [1]. During the mix design, it is known that void spaces between aggregate particles determine the amount of cement paste required to gain the expected strength of concrete. The paste requirement will be higher if uniformly graded aggregates are used because of the large voids between them while it will be smaller for the aggregates of well gradation due to the densely packed particles in the aggregate structure [2]. Therefore, achieving the design aggregate gradation during manufacturing is critical to control the certain engineering properties that are related to the structural performance of concrete mixtures. Apart from the strength and workability concerns, minimizing the degree of segregation is another important quality criterion that must be monitored during the placement of concrete, which also indirectly affects its strength properties. It is believed that a practical means of identifying the existing aggregate gradation in concrete mixtures would be of great importance to satisfy these QC/QA requirements. In this study, the use of digital image analysis and processing methods are proposed to study aggregate gradation from cross section image of hardened concrete samples using typical desktop flatbed scanners. The utility of the method relies on several aspects, such as rapid image acquisition without a need for complex optical camera and acquisition systems, ability to reach high resolution levels that are sufficient for accurate particle analysis, and most importantly availability of the desktop scanners at reasonable costs for practical applications.

In recent years, digital image analysis and processing methods have been particularly used to investigate various aspects of concrete, e.g., micro-structural characteristics, particle size distribution, aggregate size and shape characteristics, air voids distribution, and so forth. Because of moderate hardware and software requirements, methods relying on the digital imaging methods attracted many researchers to perform an efficient and rapid

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analysis of aggregate characteristics, such as shape index, size distribution, surface texture, etc., controlling the structural performance of concrete. In recent years, digital image analysis and processing have also been used to study various aspects of engineering materials, such as crack length and fracture properties [3,4], strain and displacement distributions [5–7], particle tracking and pore size distribution [8–10], microstructural analysis of asphalt and concrete sections [11–13]. Using X-ray computed tomography, even three dimensional internal structure of asphalt and Portland cement concrete can be analyzed [14,15]. It is believed that as the image acquisition and analysis tools continue to enhance, while they remain cost effective, new application fields in engineering will emerge over time.

In a typical image analysis and processing application, the acquisition of image is achieved using an analog or digital CCD camera, which convert image scene into a digitized form and send it to computer for recording. Recently, flatbed desktop scanners providing appreciable level of spatial and color resolutions are used by researchers to study aggregate shape and size distribution, and air voids distribution of concrete sections based on planar images. The desktop scanners allow for easy image acquisition from the cut sections of either laboratory samples or field cores by placing the cut surface on the scanner platform and simply performing the scanning operation. In the analysis of planar images, particles are determined through segmentation analysis in which clustering of pixels sharing similar brightness level or color information is achieved. The process involves transforming the sectional image into a binary one by a selected “thresholding” procedure, through which the objects of interest are distinguished from their background by assigning the brightness of pixels that are larger than the selected threshold to “1”, and those lower than the threshold to “0” [16]. The accuracy of information that is extracted from the digital image after segmentation depends, however, on the success in selecting an appropriate threshold value. Various factors can degrade the success of thresholding, such as non-uniform illumination, moving or vibrating targets, inherent noise from electronics, poor contrast, etc. It is possible that these challenges can be tackled to some extent by selecting an optimum threshold that is exploiting various aspects of pixel's distribution and the object characteristics to be extracted from the digital image. In the literature, thresholding methods rely generally on three different approaches: histogram shape, pixel clustering and entropy analysis [17]. In the histogram shape methods, peaks and valleys are detected, so that a possible threshold could be located between the two peaks [18,19]. In the clustering methods, pixels are classified based on a statistical criterion to define objects and background regions [20,21]. In the entropy analysis, on the other hand, the entropy is calculated within the object or background pixels, which must be maximized to capture enough information inherent to the objects [22–24]. Each approach has certain limitations and depending on the pixel intensity distribution, a suitable thresholding method should be utilized to increase the accuracy of image analysis.

Studying aggregate characteristics from cross sectional images using flatbed scanners is, however, limited because of low image contrast produced, and the difficulty in transforming two dimensional digital particles into their three dimensional equivalents to simulate the mechanical sieving. Image of 2D concrete sections can have significantly low contrast when acquired using flatbed scanners due to similar pixel intensities as produced by the cement paste and the grayish aggregate particles, in particular, limestone or of similar geological origin. In this case, finding an optimal threshold and subsequently achieving successful image segmentation becomes a challenge as the accuracy of the measured particle size and shape parameters depends highly on the output of particle analysis. On the other hand, a successful processing of sectional image by itself may not guarantee finding the actual aggregate gradation in the concrete mixture. It also requires identifying the relevant size and shape parameters together with a suitable method for transforming these parameters into the square sieve sizes.

In most of the studies reported so far, image analysis has been used for finding particle size distribution from loose aggregate samples, before utilized in concrete mixtures, instead of directly measuring from the image of cross sections. However, the main problem in these methods is to extract a relevant particle shape parameter from the digital image and then compare with the sieve opening sizes, so that the estimated particle size distribution can represent the actual aggregate gradation. The other challenge is whether to use a single view or multiple views of particles to extract information that suffices for the analysis of desired properties. In some of the past studies, the use of size correction factor was proposed to convert digital aggregate size into an equivalent sieve opening, which allows for calculating the various aggregate shape parameters [25–27]. Other researchers worked on constructing three dimensional particle models to quantify aggregate shape, size and surface texture using multi-camera systems, triangulation methods or multi-point image acquisitions [28–30]. In a recent study by Barbosa et al. [31], aggregate gradation was determined for lightweight concrete using a coefficient that is calculated from a number of synthetic images to estimate the aggregate gradation. Aggregate size distribution for asphalt concrete was also studied in another recent work using cross sectional images through combined analysis of optimum threshold and edge detection, in which sieve size was assumed to be equivalent to the minor axis of an equivalent-area ellipse [32]. Fernlund et al. [33] showed that it is indeed not necessary to calculate particle volume or mass to estimate the particle size distribution; rather one of the principal axes together with a shape parameter, i.e., minimum bounding square, may be sufficient to approximate the actual gradation curve.

In this study, an algorithm is introduced to determine an optimum threshold for the 2D cross sectional images of concrete sections in an automated sense. The optimum threshold is calculated by an iterative process by which the pixel distribution is characterized by common statistical distribution functions based on the statistical goodness of fit tests. A methodology is also presented to calculate an optimal shape parameter for aggregate particles that can be used for estimating the actual size distribution of aggregates, as determined from the mechanical sieving. Selection of the optimal shape parameter is achieved by comparing the size distribution from the image analysis of cross sections with the actual gradation curve in the least-squares sense. It is believed that the methodologies introduced herein can be successfully used for practical purposes to analyze aggregate gradation of concrete mixtures from cross sectional images, which can help justify mixture quality in terms of segregation and specifications requirements for gradation.

2. Image acquisition from concrete cross sections

2.1. Sample preparation for image analysis

The study was conducted using six different concrete mix designs by varying the maximum aggregate size and gradation. Mixtures were prepared using limestone, natural and natural crushed aggregates with $D_{max}=13$, 20 and 25 mm, respectively, and slight variations of well and gap gradations, as denoted by W1, W2, G1 and G2 in Fig. 1. The maximum aggregate sizes and the selected gradations can also be observed from Tables 1 and 2. Mixtures having the same maximum aggregate size were prepared