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Aggregate shape characterization in frequency domain

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ABSTRACT

The shape of an aggregate is described in terms of its form, angularity and texture. In the present work the aggregate shape is studied in spatial frequency domain, where two-dimensional profile of aggregates are decomposed into a number of sine waves of different frequencies by using Fast Fourier Transformation. The low, medium and high frequency waves contribute to the form, angularity and texture respectively of the aggregate. In the present work, the demarcation of the frequency boundaries are identified by performing sensitivity analysis on some proposed shape parameters. Subsequently, a unified scheme is developed for quantification of the three shape parameters in the frequency domain.

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1. Introduction

Aggregates constitute a major part of the pavement structure. Shape of aggregates has a significant influence on the mechanical property and the performance of asphalt mix [1–10]. Shape of an aggregate can be described in terms of its form, angularity and texture. Form can be viewed as the description of the overall shape of an aggregate, for example, spherical, elliptical, rod-like, plate-like, etc. [11]. Angularity can be defined as the measure of sharpness of aggregate corners, for example, angular, sub-angular, round, etc. [12,13]. Aggregate texture is the measure of the smoothness of the aggregate surface.

It may be argued that these shape parameters (that is, form, angularity and texture) are description of aggregate irregularities at different scales. Since human vision has a fixed level of resolution, these may appear to be different. And, if viewed with suitable magnification levels, various shape patterns may appear to be similar. Thus, it is felt that form, angularity and texture are not necessarily discrete description of aggregate shape, rather, there may exist a continuity in scale. That is, the same definition of shape at different scales may be used to identify different shape parameters. This forms the motivation of the present work – that is, to study the aggregate shape parameters in a continuous domain. Thus, a frequency domain analysis scheme has been adopted where the two-dimensional (2-D) profiles of aggregates are transformed into continuous frequency–amplitude diagram. The objective of the study is to identify the frequency ranges that contribute to aggregate form, angularity and texture, and subsequently quantify the aggregate shape.

2. Background

Various indices are proposed by the past researchers and guidelines for estimating the form (for example, shape factor [14], form index [8], sphericity [15,16], elongation and flatness index [17–19], Fourier descriptor [20], aspect ratio, form factor, etc.), angularity (for example, angularity index [8,21], angularity parameter [22], surface parameter [13,23], etc.) and texture (for example, texture index [24], indices by intensity histogram method [8], or by wavelet analysis [25], etc.) of aggregates. These methods/definitions are different from each other, and so also the values of shape parameters obtained by these methods/definitions.

Measurement of shape parameters are done either manually [17,26–28] or by using digital image processing (DIP) technique [29–33]. Aggregate shape is also measured indirectly by determining bulk property of the aggregates, for example, angularity number [34], particle index [35], rugosity [34], void ratio, etc. In the indirect methods, generally, combined information about the shape parameters is obtained.

Limited studies are available in terms of characterization of aggregate shape in frequency domain [14,20,24]. Bowman et al. [20] used Fourier descriptor to identify the overall shape (i.e. form) of aggregates. Wettimuny and Penumadu [14] used frequency analysis to compare the reconstructed image of the aggregate with the original one to estimate the overall shape and ruggedness of aggregates. Wang et al. [24] considered frequency domain to characterize

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aggregate shape parameters, and the frequency cut-off values are considered to be given. Further, the shape parameters are taken as the sum of the amplitudes (i.e. modulus values of the Fourier coefficients) within these frequency ranges. In such an approach, there is a possibility that two aggregates having different shapes may result in same numerical value of a shape parameter; this is discussed further in a later section of this paper. Thus, the objective of the present research can be identified as follows:

(i) To develop a systematic approach for identification of frequency boundaries between form, angularity and texture.
(ii) To develop a unified quantification scheme for estimation of the individual shape parameters in the frequency domain.

3. Identification of frequency demarcation of shape indices

Shape characterization of aggregates using DIP technique generally assumes that two dimensional (2-D) projection of an aggregate sufficiently represent the shape of the aggregate and can, therefore, differentiate aggregates of different shapes. The three dimensional (3-D) shape characterization of an aggregate can be considered as statistically equivalent to repetitive 2-D measurements across various orientations of the same aggregate. It is considered that the same assumption also holds good for the current work.

The 2-D profile of an aggregate (refer Fig. 1a) can be represented as a distance (R) versus angle (θ) function as shown in Fig. 1b. This representation is invariant to translation but variant to rotation and scaling. In order to normalize with respect to rotation, a fixed point is selected on the aggregate profile as the starting point; in the present case, this point is taken as the farthest point from the centroid. It may be noted that one can, however, adopt any other suitable scheme to represent 2-D profile of an aggregate as a R–θ plot. In order to maintain a constant resolution, the height of the camera from the base on which aggregate is placed is taken as 162 mm in the present study. One pixel represents an area of 0.04 mm × 0.04 mm in the present work. These values are fixed in the present study for the purpose of uniformity only.

This R–θ representation needs to be further processed in frequency domain to extract shape features. Thus, the R–θ representation is decomposed into its constituent sine waves of various frequencies and amplitudes using Fast Fourier Transformation (FFT). In other words, these sine waves, when added, would again return the original R–θ plot.

Ten different aggregates are taken in the present work [36] and their frequency analyses are performed using FFT. Locally available aggregates obtained from nearby quarries are used in the study. The average dimension of the aggregates is about 20 mm. It may be noted that the term frequency indicates here as the spatial frequency, that is, the number of sine waves per unit distance.

In order to normalize the size effect of various aggregates, all the amplitudes at different frequencies are divided by the respective first amplitude values. The normalized amplitude versus frequency values for these aggregates is plotted in Fig. 2. Fig. 2 reveals certain characteristic features of aggregate shape, for instance, (i) large amplitude values are observed for low frequencies and small amplitude values are observed for large frequencies, (ii) there cannot be very high amplitudes at higher frequencies and vice versa and (iii) the points of the amplitude–frequency curve lie within a band. An average value of the amplitude corresponding to each frequency is taken in the present study; a curve joining these points can be considered as the *characteristic curve* of the aggregates.

Having obtained the *characteristic curve*, the next objective is to differentiate the lower, medium and higher frequency sine waves that contribute to the different aspects of aggregate shape. This is done in the following manner [36]:

- An ellipse is considered as the basic shape of an aggregate on which there are natural undulations and irregularities defining its shape.
- As a first step, a single frequency sinusoidal wave is superimposed on the ellipse. The corresponding amplitude is taken from the *characteristic curve*. It may be recalled that due to nature of the characteristic curve, if the frequency value is chosen as small, the amplitude value will be large and vice versa. Since larger undulations indicate form, medium undulations indicate angularity and smaller undulations indicate texture of an aggregate, it can be suggested [24] that the form, angularity and texture are contributed by the low, medium and high spatial frequency of the aggregate profile.
- A shape parameter is estimated for this ellipse superimposed with the sinusoidal wave. For this purpose, suitable definitions of the shape parameters (form, angularity and texture) are proposed. The development of the shape parameters are discussed in detail in the later sections. Attempts have been made to use normalized shape parameters, so that the size of an aggregate does not influence its shape (form, angularity and texture) being evaluated.

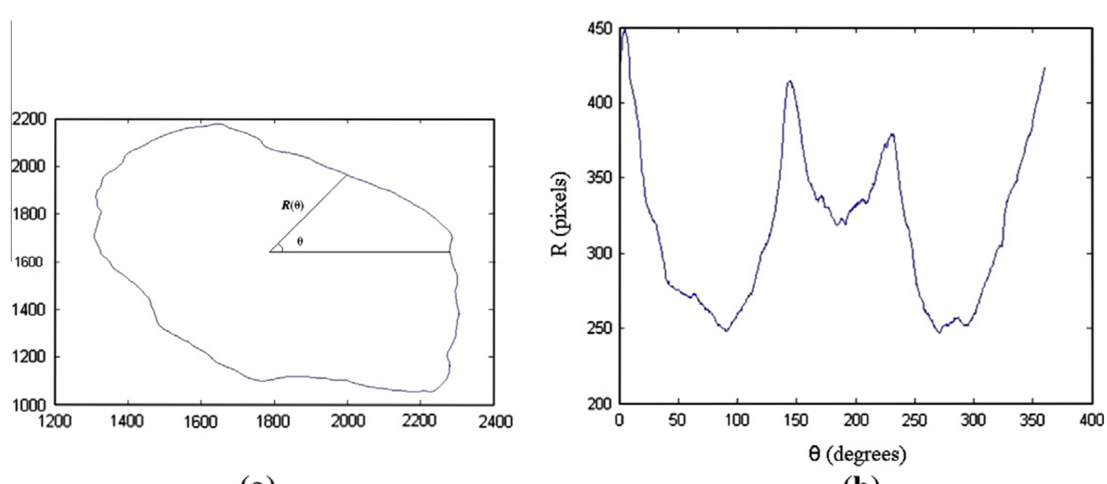

Fig. 1. 2-D profile of an aggregate and its R–θ representation. (a) The 2-D profile of an aggregate. (b) R–θ representation of the 2-D aggregate profile.

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