A revisit to aggregate shape parameters

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Introduction

Aggregates constitute major part of the pavement structure. The engineering properties of the aggregates, as well as its shape (*i.e.* form and angularity) and texture, substantially affect the overall performance of the pavement (Kuo and Freeman 1998, Maerz 2004). A number of researchers reported that form and surface texture of aggregates have significant effect on the mechanical property of the bituminous mixes, for example, shear resistance, durability, stiffness, fatigue resistance, rutting resistance, workability, bitumen demand etc. (Herrin and Goetz 1954, Benson 1970, Ishai and Gelber 1982, Kalcheff and Tunnicliff 1982, Janoo 1998, Oduroh *et al*. 2000, Masad *et al*. 2001). The present article briefly discusses the issues related to aggregate shape characterization.

Various shape parameters

As per Indian standard IS-2386(I) (1999) flakiness and elongation index and angularity number are used as a measure of aggregate shape. ASTM D3398 (2000) proposes a parameter called *particle index* to characterize shape and texture of aggregates. By this method, voids in aggregates placed inside a mould of specified size, at two different compaction levels, are measured, and with these values the particle index is estimated. As per ASTM D4791 (2005) flat and/or elongated particles are estimated using specified caliper. Another test procedure suggested by ASTM D5821 (2001) suggests measurement of number of crushed surfaces of aggregates.

For angularity measurement, use of a subjective scale is sometimes suggested as, angular, sub-angular, sub-rounded, rounded, well-rounded (ASTM D2488 2000, BS812 1975). Packing of aggregates is also an indirect estimate of angularity. Rounded aggregates achieve a solid ratio of about 67%. The more angular are the aggregates, the less is the solid ratio (BS812 1975, IS2386(I) 1999). This may not however hold good when the aggregates tend to take cubic shape.

In most of these tests, one needs to estimate the parameters by handling the aggregates one by one, hence these are time taking process. Also, due to subjectivity involved the test results may vary person to person (Janoo 1998).

Automated aggregate shape analysis

With the advent of digital image processing (DIP) technique researchers are trying to employ automated aggregate shape characterization approach. A number of DIP

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techqniues, such as X-ray tomography, laser profiling and photogrammetry have been tried (Kim *et al.* 1992, Kuo *et al.* 1996, Kuo and Freeman 1998, Yue *et al.* 1995, Yue and Morin 1996). This approach has the following advantages:

- The method is fast and therefore can be applied as real-time quality control (Maerz 2004) and, accordingly, adjustments can be applied on to crusher or sieves.
- Since this method is automated, it is free from subjectivity associated with human judgment.
- Since a large number of samples can be tested, and the statistical reliability is expected to be enhanced.
- With the application this technique, various other geometrical features of aggregates, viz., area, cross-section, perimeter, orientation, the size distribution and even the mix volumetric parameters can be measured.

Interestingly, following fresh issues evolve with the DIP technique with reference to the conventional shape parameters (Kwan *et al.* 1999, Mora and Kwan 2000):

- Most of the time, DIP technique captures a two dimensional (2-D) image (or shadow) of the aggregates, and it is difficult to perform 3-D imaging to obtain the third dimension. Though, some researchers have successfully measured the volume of the aggregates, by taking orthogonal views (Rao and Tutumluer 2000), most of the time DIP parameters are obtained as area fraction and not as volume fraction. Thus, by using DIP technique, it is difficult to measure the shape parameters in terms of weight or volume, as is generally followed in conventional shape parameters.
- The conventional shape parameters like, flakiness index and elongation index are characterized with reference to the slot sizes. This size is neither the length, or, width or, height of the aggregates measured by the DIP technique, which uses a ‘box principle’ to circumscribe the aggregates (Maerz 2004). It is, therefore, difficult to obtain the conventional flakiness or elongation values of aggregates by using DIP technique.

Thus, while attempting to characterize aggregate shape, the researchers were prompted to use various shape parameters, other than the conventional ones. Table-1 compiles a partial list of various such shape parameters.

Table-1 Definitions of various DIP based shape parameters

Parameter	**Definition**	**References**
Elongation	$length/width$	Kuo *et al.* 1998
Flatness	$width/thickness$	Kuo *et al.* 1998
Flakiness	$thickness/breadth$	Barksdale *et al.* 1991
Sphericity	$\sqrt[3]{thickness \times width/length^2}$	Barksdale *et al.* 1991

Shape factor	$thickness \Big/ \sqrt{length \times width}$	Barksdale *et al.* 1991, Yue *et al.* 1995, Kuo *et al.* 1996
Form factor	$4p \times area \Big/ perimeter^2$	Kuo *et al.* 1998
Roughness	$perimeter \Big/ p \times average\ diameter$	Kuo *et al.* 1998
Convexity ratio	$projected\ area \Big/ convex\ area$	Mora and Kwan 2000
Fullness ratio	$\sqrt{convexity\ ratio}$	Mora and Kwan 2000

These parameters are developed using simple geometrical principles, inscribing or circumscribing an aggregate with some regular geometric shape, and then comparing the surface area or the volume. The expressions of these parameters are not fixed, various alternative expressions (Janoo 1998) are proposed and used by the various researchers. Similarly, for quantifying angularity as a shape parameter, researchers have suggested various criteria (Yudhbir and Abedinzadeh 1991, Mora and Kwan 2000, Rao *et al.* 2002, Chandan *et al.* 2004) for example, (i) the corner angle (ii) height of corner (iii) radius of curvature of corner (iv) concavity or convexivity of corner etc.

Closing remarks

It appears that the DIP based method of aggregate shape characterization is an emerging area, to estimate aggregate shape (as well as mix volumetric parameters) quickly and reliably. DIP method has also been used in shape characterization of fine aggregates and texture analysis. This method has, therefore, a potential application in real-time quality control during mix manufacturing. It is anticipated that this technique will tend to use fresh set of shape parameters than the conventional ones. Thus, there is a need to gather performance data of the mix with reference to these DIP based shape parameters (Kuo *et al.* 1998).

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