

## **DETERMINATION OF COARSE AGGREGATE SURFACE TEXTURE USING IMAGE ANALYSIS**

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### **EXTENDED ABSTRACT**

The physical properties of coarse aggregates have an impact on the mechanical properties of the pavement layer they form part of. Physical properties such as shape, size and gradation, angularity, and surface texture have in turn been correlated to the performance of both asphalt concrete (AC) and Portland cement concrete (PCC) pavements. From as far back as the 1930s, surface texture was identified as a critical aggregate characteristic to influence the frictional resistance of the material. Past literature shows that little distinction was made between the effects of aggregate angularity and surface texture on material strength. Standard procedures, such as the Particle Index test (ASTM D 3398-00) and uncompact air void test (ASTM C 1252-98), were developed in order to obtain indirect measures of particle shape, angularity, and surface texture. Further, a standard test method to determine aggregate angularity as a measure of number of crushed faces (ASTM D 5821-01) is practiced widely by State highway agencies. Although both coarse aggregate angularity and texture improve the stability and shear strength of AC and granular layers, or improve the aggregate interlock and load transfer characteristics of PCC layers in a pavement, they are both very different physical properties of a particle. While aggregate angularity relates to fractured faces or irregularity of the surface profile at a macro level, aggregate surface texture refers to roughness or irregularity at a micro level. The research work presented here focuses on a methodology to determine the surface texture properties of coarse aggregates using image analysis techniques.

The development of image analysis techniques to determine aggregate physical properties has given engineers viable tools to perform coarse aggregate tests in a time and labor-efficient manner. Several image analysis systems have been developed with

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varying levels of capabilities to determine critical coarse aggregate shape and size properties: flatness ratio, elongation ratio, flat and elongated ratio, gradation, angularity and surface texture. These image analysis techniques have been validated against results from manual test methods, and in some instances, correlated to material strength properties. An ongoing research project sponsored by the National Cooperative Highway Research Program (NCHRP), NCHRP 4-30, is aimed at identifying test methods, including direct measurement methods such as imaging, for characterizing aggregate shape, texture and angularity.

The currently existing standard manual test procedures do not make an objective measurement of surface texture but provide an indirect estimation of surface profile roughness or irregularity at both a macro and micro level combined. Whereas, digital imaging techniques offer a direct and objective measurement of surface irregularities or surface texture from images of aggregate particles to quantitatively determine various roughness (or smoothness) levels. The development of a methodology is however needed to determine surface texture using a quantifiable index that should be validated using representative aggregate samples with varying levels of texture characteristics. This will allow further investigation of the effects of aggregate surface texture on material strength characteristics and pavement performance from image analysis based indices.

Recent advances in image analysis applications to characterize aggregates have led to the development of methodologies for surface texture evaluation. A morphological descriptor based on Fourier analysis of the particle profiles was developed by Wang et al. (1997) to characterize the shape, roughness, and surface texture of coarse aggregates. Masad et al. (1999) utilized erosion and dilation techniques to obtain fine aggregate angularity and surface texture characteristics with the use of images with two different resolutions. Algorithms to determine surface texture were also developed by Masad et al (2001) based on intensity histogram and Fast Fourier Transform of gray scale images of particles. Kim et al (2002) have developed a wavelet-based descriptor for the measurement of surface texture in the processing of 3-dimensional laser-scanned data. Fletcher et al. (2002) have also developed a similar methodology based on wavelet decomposition.

An aggregate image analyzer, referred to as the University of Illinois Aggregate Image Analyzer (UIAIA), was recently developed at the University of Illinois to provide an automated means to determine coarse aggregate size and shape properties (Tutumluer et al., 2000; Rao, 2001). The UIAIA uses three orthogonally positioned cameras to capture the front, top, and side views of each coarse aggregate particle as it moves along a conveyor. It is equipped with image analysis capabilities to determine the volume (Rao et al., 2000), flat and elongated ratio and sieve size (Rao et al., 2001), and angularity (Rao et al., 2002) of each aggregate particle of a sample, and has been validated using several coarse aggregate samples with a wide range of specific gravity, gradation, size, and angularity. The research work presented here focuses on the addition of a new module to measure the surface texture characteristics of coarse aggregates. The applicability of erosion and dilation techniques, previously applied to fine aggregates by Masad et al. (1999), has been investigated to determine the surface texture of coarse

aggregate particles. As a result, a surface texture index has been developed and calibrated to distinguish particles with smooth and rough surface texture properties.

Erosion is a morphological process by which all boundary points or image pixels are deleted from an object leaving the object one pixel less dense along the perimeter or outer boundary. Therefore, by a single erosion operation, objects or images that are less than two pixels wide in any direction are eliminated. Dilation is the reverse process of erosion and a single dilation cycle increases the particle shape or image dimension by one pixel around its boundary.

Erosion cycles followed by the same number of dilation cycles do not necessarily rebuild the original image, unless it is a smooth sphere. The rougher the particle, the less close the rebuilt image is to the original as the erosion process removes the “roughness” (i.e., the pixels that correspond to the surface irregularities) from the particles. The dilation process tends to reconstruct the particle with a smooth edge. This phenomenon is utilized in the determination of the coarse aggregate surface texture of the particles using the UIAIA.

The methodology first thresholds the image corresponding to each of the three views of the particle. Next, the surface texture is computed for each view independently as:

$$ST = \frac{A_1 - A_2}{A_1} * 100 \quad (1)$$

where

$ST$  = Surface texture parameter for each image;

$A_1$  = Area (in pixels) of the 2-dimensional projection of the particle in the image;

$A_2$  = Area (in pixels) of the particle after performing a sequence of “ $n$ ” cycles of erosion followed by “ $n$ ” cycles of dilation.

The surface texture,  $ST$ , of the particle is computed as the average of the surface texture values for each view weighted by their individual areas as follows:

$$ST_{particle} = \frac{ST(front) * Area(front) + ST(top) * Area(top) + ST(side) * Area(side)}{Area(front) + Area(top) + Area(side)} \quad (2)$$

The extent of surface irregularity to be removed or “scratched off” during the erosion process directly correlates to the number of erosion and dilation cycles,  $n$ , adopted in the algorithm.

The surface texture parameter,  $ST$ , was calibrated and the optimum value for  $n$  was determined using two aggregate samples, representative of smooth and rough textured particles and are referred to herein as smooth gravel and crushed stone respectively. Each of these two samples, at the two extreme levels of surface texture,

consisted of 100 coarse aggregate particles ranging in size from the US Standard No. 4 to 1-inch sieve (4.76 mm to 25.4 mm). The main objective of this calibration process was to determine the optimum value for  $n$  that would best distinguish smooth from rough textured particles and yet keep the algorithm computationally efficient. Further, it was also important that the ST values for all particles in each of the samples not be statistically different from each other. That is to say that at an optimum value of  $n$ , the difference between the mean ST values of the two samples has to be as large as possible while the standard deviation of the ST values within each sample has to be minimal.

The selection of a constant number for  $n$  (i.e.,  $n = \text{constant}$ ), did not offer a satisfactory solution that would make the ST values statistically different for the smooth gravel and crushed stone samples. Furthermore, the ST values varied with particle sizes even for the aggregate particles analyzed from the same source of gravel or crushed stone samples. This necessitated the use of a dynamic  $n$ -value to increase or decrease in value depending on the particle size. The physical significance of this calibration process is then simply that the larger the particle size is, the greater is the extent of its micro level surface irregularities that are evaluated to determine the surface texture. As such, a thorough parametric study based on statistical analysis was performed and the number of erosion and dilation cycles was determined as a function of the maximum dimension of the projected area for each image expressed by the following relation:

$$n = L/\beta \quad (3)$$

where

$L$  = Longest or maximum feret dimension of a particle in image;  
 $\beta$  = Scaling factor for erosion and dilation operations.

The parametric study included varying values of  $\beta$  from 3 to 90 to compute ST values for each particle in the two samples. The range of ST values varied for each value of  $\beta$  (and therefore each value of  $n$ ). To make the ST values comparable across different  $\beta$ -values, the ST values determined were further normalized on a scale of 0 to 100. This way, the optimum value of  $\beta$  was selected as that which yielded in the maximum difference in the mean of normalized ST values for each sample. Further, the requirement of minimizing the standard deviation in the ST values of each sample could be satisfied by determining a value of  $\beta$  for which the sum of variances of each individual sample is the minimum. At the end, an optimum  $\beta$ -value of 20 was found to maximize the difference in the means that also kept low the sum of variances of the two samples as shown in Figure 1. Based on the calibration procedure, the ST values of all particles in the two representative samples are shown in Figure 2. The ST values for smooth gravel particles are shown to be typically less than 1 with major grouping around 0.3 to 0.7, while the rough crushed stone particles with several fractured faces yield ST values generally ranging from 1 to 3.

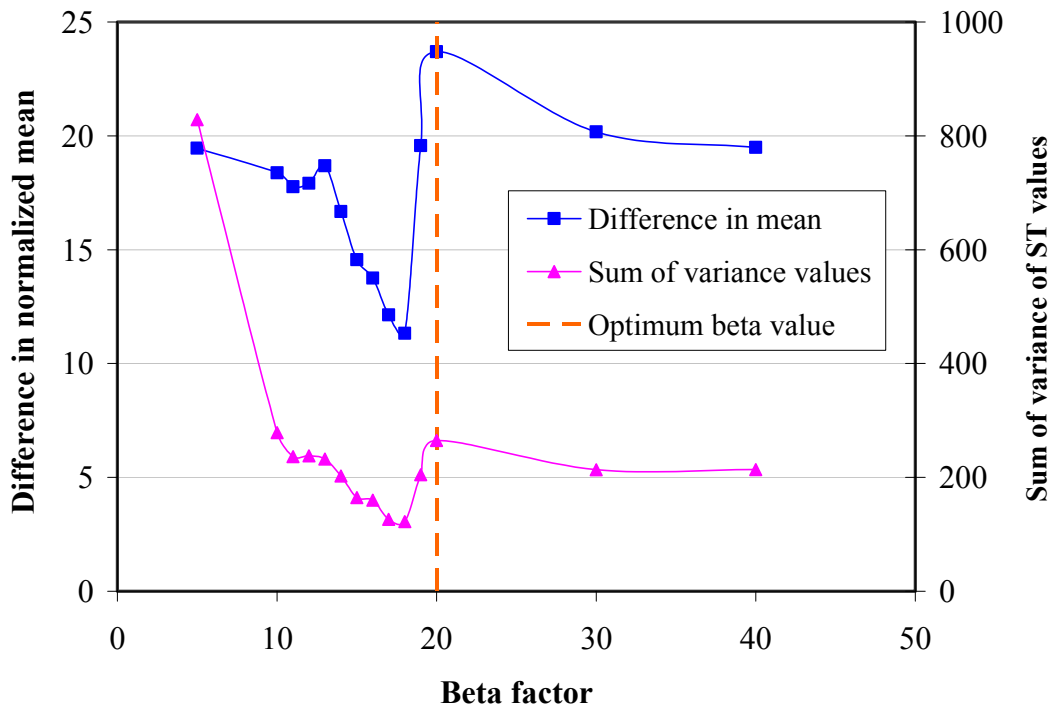


Figure 1. Optimum value for  $\beta$  to compute the number of erosion and dilation cycles  $n$

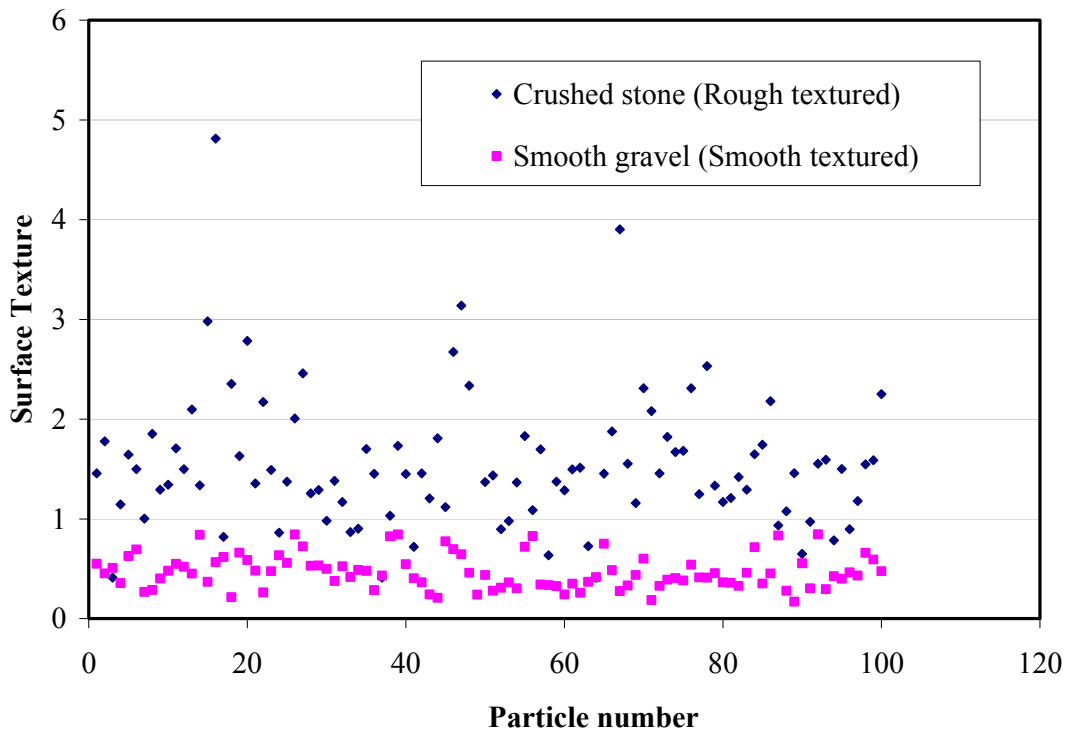


Figure 2. Surface texture values for two representative crushed stone and smooth gravel samples at  $\beta = 20$

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