TEXTURE ANALYSIS OF MINERAL AGGREGATES USING ENTROPY

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Abstract. *This paper presents entropy as a method for texture analysis of Scanning Electron Microscope (SEM) images obtained from mineral aggregates. SEM images were used in order to avoid the interference of inherent color variations on aggregates surfaces. Three types of aggregates (gabbro, basalt and gravel) were used for surface texture analysis. Entropy was used to analyze and quantify the roughness of rock fragments (aggregates). The presented method was able to distinguish aggregates with different levels of roughness and to group aggregates with similar levels of roughness.*

Keywords. *Image analysis. Texture analysis. Mineral aggregate roughness.*

1. Introduction

Shape properties of aggregates are recognized to influence the functional and structural properties of paving materials, such as hot-mix asphalt, hydraulic cement concrete, and unbound base and subbase layers of highway pavements [18, 13]. Shape properties can be decomposed into three independent scales: shape, angularity, and texture. The approach that has been followed for the development of specifications for shape properties of aggregates consists almost entirely of correlations between indirect measures of these characteristics and laboratory measurements of physical and mechanical properties of the pavement layers [12, 9].

Despite the importance of this approach, some problems regarding identifying and separating the fundamental features of shape, angularity and texture of aggregates are observed in indirect aggregate tests [10, 16, 11, 6]. Generally, current methods used

in practice for measuring these characteristics are laborious, subjective, lack a direct relationship with performance parameters, and are limited in their ability to separate the influence of angularity from that of texture [11, 6, 5, 9, 8]. Therefore, specifications that are developed based on these tests may emphasize the need for aggregates with better characteristics or, in contrast, allow the use of marginal shape properties [9]. It is important to develop accurate methods for measuring and classifying aggregate characteristics, which make it possible that the relationship between aggregate characteristics and performance is better understood.

Several image analysis methods to quantify the texture, angularity, and form of particles have been suggested and shown to be promising for shape analysis [10, 19, 13, 2, 20]. A critical review of these methods was shown by [11]. This review emphasized the need for a suitable method to capture particle texture and the difficulties of separating inherent color variations present on the surface of a particle that can manifest themselves as texture in gray images. Also, it has been found to be problematic to analyze and to quantify texture using black and white images due to the high resolution necessary to capture the texture on particle boundary [3]. Methods for quantifying texture-based measure particle boundary irregularity can lose some important information when converting the grayscale image to a black-and-white image. Therefore, aggregate texture details are best represented when the texture analysis is made with the image in its original grayscale format, because surface irregularities can manifest themselves as variations in grayscale intensities [13].

This paper presents entropy as a method for texture analysis using Scanning Electron Microscope (SEM) images. SEM images were used in order to avoid the interference of inherent color variations on surface aggregate. Entropy was used to analyze and quantify the surface texture or roughness of rock fragments (aggregates). The entropy method presented for analysis and quantification of surface texture of aggregates of different origins takes into account the particularities of this heterogeneous material, which is one of the most used in construction work.

2. Methodology

Three types of aggregates, gabbro, basalt and gravel, were used for surface texture analysis. Gabbro and basalt were selected because they have similar surface texture, and gravel was chosen to have a completely different surface texture from the first two. The purpose of using a small amount of material types is to obtain quantitative and comparative data between samples of aggregates that are very similar and others that are quite different for checking the sensitivity of entropy in the analysis of surface texture of aggregates.

We analyzed nearly 64 images of particles for each type of aggregate, obtained by SEM (see Figure 1). A problem of imaging methods for the analysis of surface texture of aggregates is to use images that contain color characteristics and roughness features (relief). The color characteristics are peculiar to the mineralogical composition of each material, which should not be confused with roughness at the time of processing the image.

In the images produced by SEM, the electron beam interacts with atoms in the sample in order to produce signals that contain information about the surface relief of the aggregate, eliminating the problem of confusing the texture properties ("true" texture) with inherent color on the surface of the particle ("false" texture) due to the concept of operation and image capture of the equipment. The terms "true" and "false" texture were used in [3] to differentiate the inherent colors of the aggregates or the presence of dust on the surface aggregate that might show up as texture and distort the true texture content of the aggregate. Therefore, the images in grayscale obtained by SEM show the true texture of each sample, without confusing it with the appearance of colors, which allows one to quantitatively measure and comparatively evaluate aggregates from different sources.
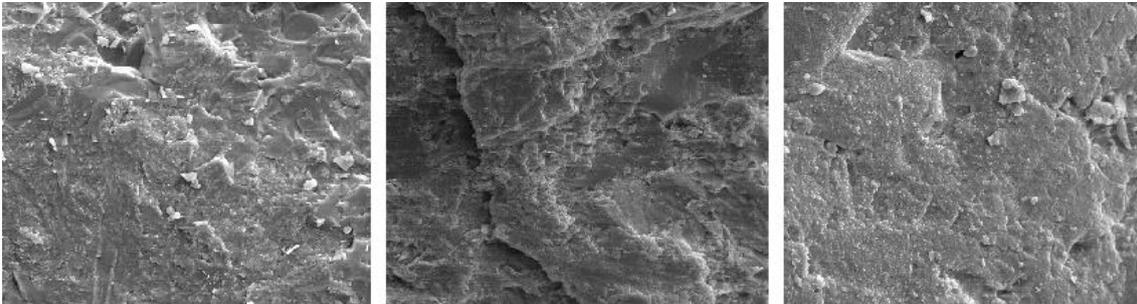
Figure 1. Basalt, gabbro and gravel SEM images

2.1 Histogram

After the capture of images, information about texture can be obtained from histograms of grayscale images. The surface irregularities that define the texture manifest themselves as variations in grayscale intensities that range from 0 to 255. Large variation in grayscale intensity represents a rough surface texture and a smaller variation represents a surface texture proportionately more smooth.

The representation of an image in terms of a respective histogram involves the association of a value $h(n)$ to the frequency of occurrence of the intensity n in the image ($0 \leq n < 255$). We also considered equalized versions of histograms, which are henceforth represented as $he(n)$.

Histogram equalization is a image processing method that increases the local contrast of images, so that the intensities can be better distributed along the histogram, i.e. equalization spreads the gray-level distribution in the histograms as much as possible [15, 4]. Algorithms to perform the histogram equalization are presented in [15, 14, 4].

2.2 Gaussian Smoothing

We also consider images with Gaussian smoothing. This smoothing allows control of the level of detail of these images. The amount of smoothing depends on the value of the spread parameter (i.e., the standard deviation) of the bidimensional Gaussian function, with zero mean and standard deviation equal to σ:

$$G_{(x,y)} = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{\left(x^2 + y^2\right)}{2\sigma^2} \right)$$

2.3 Entropy

Conceptually, entropy, based on information theory historically developed by Claude E. Shannon, is the number of bits, on average, required to describe a random variable [17]. In image analysis, an image is regarded as a random process with p(i) probability of a pixel assuming a value $0 \leq i < N$. Thus, Shannon's entropy is a measurement of statistical randomness that can be used to characterize the texture of the image, being calculated as:

$$E = -\sum_{i=0}^{N} p(i) \log_2 p(i)$$

where p(i) is the relative frequency of the i-th intensity level of an image.

Entropy, used as a statistical measure [1, 7], expresses the disorder contained in the texture, in other words, it can be used as a measure of the information contained in the texture image, in contrast to the image that is redundant. The lowest value that can be obtained for E is zero, which corresponds to a picture which has the same intensity for each pixel (a completely smooth texture). The largest value for E corresponds to an image that contains the same amount of pixels for all possible intensities, corresponding to a texture with a high degree of roughness.

3 Results and discussion

Table 1 shows the results of entropy obtained for the original images ($IMG_{original}$); Gaussian smoothed images, $\sigma = 1$ ($IMG_{\sigma1}$) and $\sigma = 2$ ($IMG_{\sigma2}$); equalized images (IMG_{equal}); equalized and smoothed images, $\sigma = 1$ ($IMG_{equal\sigma1}$); equalized and smoothed images, $\sigma = 2$ ($IMG_{equal\sigma2}$).

Table 1. Entropy values

Entropy	E_{basalt}	E_{gabro}	E_{gravel}
$IMG_{original}$	4,681	4,628	4,583
Standard Deviation	86	116	161
$IMG_{\sigma1}$	4,777	4,692	4,593
Standard Deviation	94	131	178
$IMG_{\sigma2}$	4,677	4,573	4,457
Standard Deviation	99	143	178
IMG_{equal}	4,682	4,669	4,559
Standard Deviation	90	113	151
$IMG_{equal\sigma1}$	5,499	5,488	5,193
Standard Deviation	18	24	38
$IMG_{equal\sigma2}$	5,430	5,399	5,339
Standard Deviation	40	52	72

Figure 3 illustrates the entropy values obtained for each sample using the original images. The best results were obtained after the original images had been equalized and then smoothed with Gaussian smoothing with $\sigma = 1$. One can see that entropy has been able to distinguish aggregates with different roughness and to group aggregates with similar roughness.
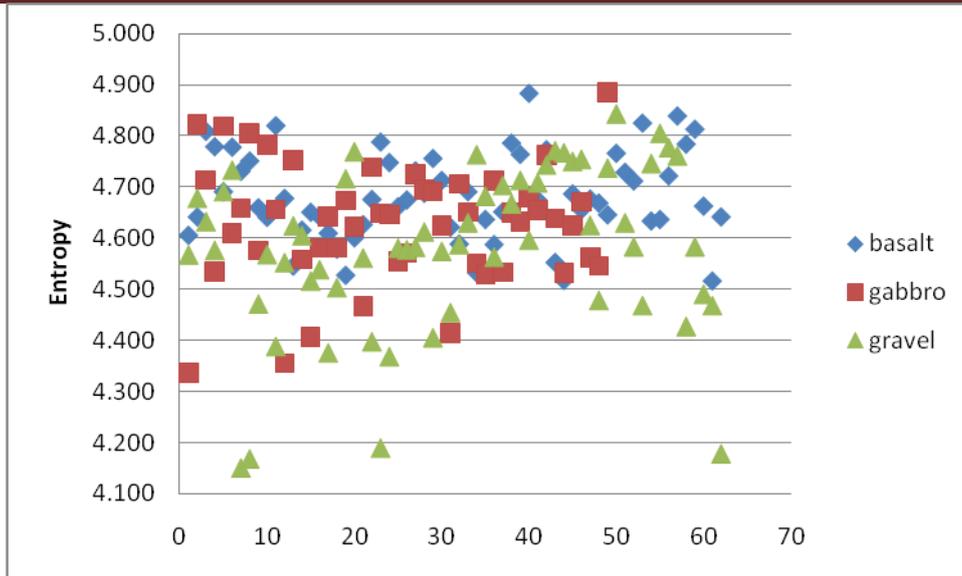
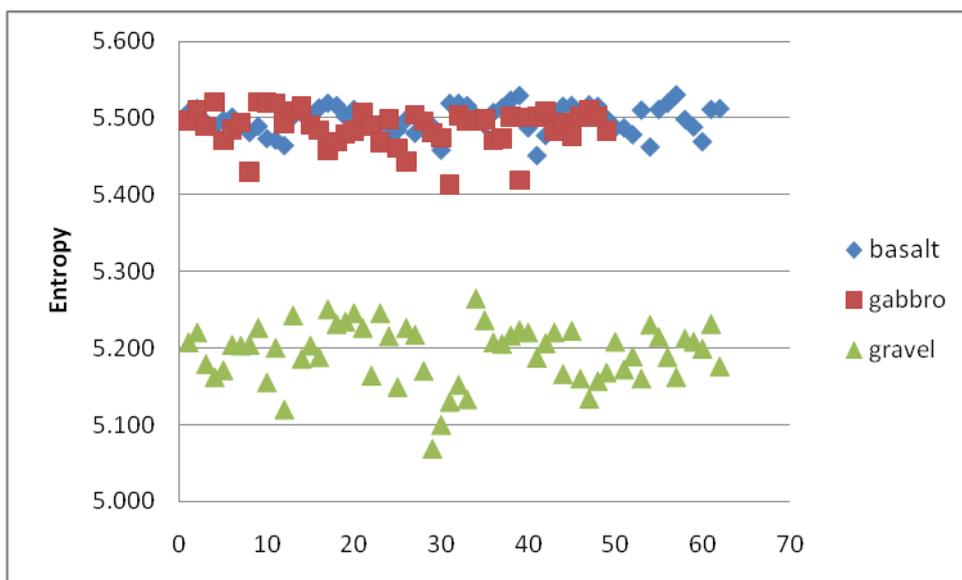**Figure 2. Entropy values obtained from original images**

Figure 3.   Entropy values obtained from images with histogram equalization and Gaussian smoothing (σ = 1)

4. Conclusion

This paper presents entropy as a method of texture analysis using Scanning Electron Microscope (SEM) images. Entropy was used to analyze and quantify the surface texture or roughness of aggregates. Entropy has been able to differentiate aggregates with different roughness and cluster aggregates with similar roughness. Moreover, entropy has reduced the cost of machine operation, ease of use and interpretation of results.

Acknowledgments

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