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Evaluation of a method based on image analysis to obtain shape parameters in crushed sand grains

Avaliação de um método baseado em análise de imagens para obtenção de parâmetros de forma em grãos de areia de britagem

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Abstract

The objective of this paper is to evaluate a method based on image analysis to obtain shape parameters in crushed sand grains. There is no consensus about standards and rules for testing aggregates, the lack of methodology to prepare and conduct tests may produce incorrect results, which do not satisfactorily represent the aggregate characteristics. One way to perform these analyzes is the use of images obtained with magnifying glasses or similar equipment. To contribute to this, three experiments were prepared with samples of crushed sand from the city of Passo Fundo. The fixed and evaluated parameters were: samples preparation, zoom used for image acquisition and number of grains representative of the shape parameters. The results were statistically analyzed and significant differences were obtained to the shape factor regarding the fixed parameters, except for the number of grains needed to characterize it, which differs from the currently literature used by academic studies. According to this work it is possible to realize that it is necessary to standardize the tests for shape analysis to eliminate errors generated by the interpretation of incorrect results, which may have been generated by changes in the methodology for conducting the tests.

Keywords: crushed sand, crushed sand grain shape, image analysis.

Resumo

Esse trabalho avalia um método de análise de imagens para obtenção de parâmetros de forma em grãos de areia. Avaliando-se os ensaios utilizados em trabalhos científicos, pode-se considerar a não existência de um consenso nos parâmetros utilizados para avaliação da forma dos grãos de agregados miúdos, ressalta-se que a falta de metodologia definida para a realização dos ensaios pode gerar resultados equivocados, que não representem satisfatoriamente as características dos agregados. Uma das maneiras de realizar essas análises trata-se da utilização de análise de imagens obtidas a partir do uso de lupas ou equipamentos semelhantes. Para contribuir nesse sentido, foram preparados três experimentos, com amostras de areia de britagem da cidade de Passo Fundo. Os parâmetros fixados foram a preparação das amostras, os aumentos utilizados para aquisição das imagens e o número de grãos representativos dos parâmetros de forma. Os resultados dos experimentos elucidaram a necessidade de estudos mais aprofundados a respeito da padronização do ensaio. E comprovaram a necessidade da padronização dos ensaios para análises de forma em agregados miúdos. Os dados obtidos foram analisados estatisticamente e obtiveram-se diferenças significativas para o fator de forma em relação aos parâmetros fixados, exceto em relação ao número de grãos necessários para caracterizá-lo, o que difere da bibliografia atualmente utilizada por trabalhos acadêmicos. Com o presente trabalho pode-se perceber que existe a necessidade de padronizar os ensaios para análises de forma, de modo a eliminar erros gerados pela interpretação de resultados equivocados, que podem ter sido gerados por pequenas variações na metodologia utilizada para a realização dos ensaios.

Palavras-chave: areia de britagem, forma dos grãos de areia de britagem, análise de imagens.

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1. Introduction

Many studies have concluded that the aggregates used in concretes and mortars are not just inert materials. Among the various functions performed by them there are filling voids, contributing to a continuous grading curve of solids, restricting plastic shrinkage, etc.; there is a consensus that these aggregates are responsible for several of these properties, whether they are in fresh or hardened state. These materials are present in significant proportions in concretes and mortars – in the latter they can correspond to up to 80% of the total mass of the mixture (CINCOTTO, CARNEIRO [1]).
Compared with the aggregate obtained with crushing processes, natural sand has always been the main minute aggregate used for manufacturing mortars and concretes. According to some authors, such as Mehta and Monteiro [2] this preference for natural sand comes from its grains, which are rounder, and from its low content of powder material. This low content of fine material decreases the mixture consumption of water, improving some of the key properties of concretes, such as mechanical and cracking resistance.
The fact that the uncontrolled exploitation of natural sand in quarries and rivers is an activity that caused environmental degradation in many regions generates the need to search for alternative materials. Crushed sand has for years showed itself as a solution to the problem of exponential increases in transportation costs of natural sand, a material which is increasingly difficult to obtain in large centers.
For years, several authors have studied the properties of natural sand and its influence in concrets and mortars. For crushed sand, the studies are more recent. Among the properties of sand there are granulometric and morphologic characteristics, surface texture, and others derived from these, such as the compactness and the swelling coefficient. The main properties addressed in these papers are the granulometric composition and the compactness, and generally little relevance is given to the grain shape, since traditional studies do not normally carry out characterization tests for shape and texture. There is a consensus in literature that the grains from aggregates generated by crushing feature shape and surface texture different from those of aggregates from natural origin. With the use of crushed sand, the study of shape and texture of large aggregates becomes more important to allow sorting, observing the changes and identifying the influence of form in the properties of materials produced with it.
The main factors which influence the grain shape of an aggregate are its original rock and the process of fragmentation the material went through. In relation to the crushing process, several companies employ advanced technological crushers, and processes that improve the shape of the grains, to obtain aggregates with better quality and performance. Moreover, it can be affirmed that, frequently, the crushed sand angular form is a justification for its bad performance in relation to the consumption of cement and water. With precise tools and in-depth studies of its influence, it is believed to be possible to define the real importance of the form in the performance of concrete and mortars.
Normally, the evaluation of the aggregates is centered in the features of granulometry and fineness; this, according to Chaves [3] and Silva [4], is considered one of the main limitations to gauging the real influence of sand in mortars and concretes. The same authors also commented on the lack of simple and fast methods to analyze the shape and to quantify the characteristics of the grains. Since there are no national standards for testing the characterization of form in minute aggregates, each author uses a different method for sample preparation, thus, possibly, not giving margin for significant results. It is still questioned whether these differences regarding tests in works that study the form of minute aggregates generate differences in results and, if so, if it is possible to compare these works.
Therefore, gaps, in methods for determining the shape, still exist, justifying this work. Among the issues to be clarified for the understanding of aggregate grain shape are: if there is an effect regarding the type of sample preparation, which should be the increases used in image obtention and, especially, what would be the required number of grains to be used.

1.1 Objective

This study intends to analyze the results obtained in an analysis method of sand grain shape characterization, checking their variability with image capture changes (augmentation), grain organization and grain number.

2. Methodology

2.1 Selection and preparation of sand

The sand which was used to obtain the images for this work was collected in the city of Passo Fundo, in Rio Grande do Sul, and it matches the type most widely used in the region. Among the sample preparation steps were: collecting, washing, drying in a heater, sample reducing and sand sifting in order to separate it into granulometric fractions.
The sand was washed in a 0.6 mm sieve, resulting in fractions used in this work, corresponding to 0.6 mm, 1.2 mm and 2.4 mm grains. Heater drying took place during 24 hours, and sample reducing was performed with a sample splitter, obtaining 10g of sand to the confection of each blade.

2.2 Definition of the number of necessary grains

Equation 1 was used to calculate the number of grains:

$$n = \frac{t_{x_2}^2 * CV^2}{Er^2} \quad (1)$$

Where:
$t_{x_2}^2$ = Significance value from the Student's T table.
CV = Coefficient of variation
Er = relative error

2.3 Grain preparation for image collection

In order to verify the influence of sample preparation, two means of preparation were analyzed: one with oriented grains and the other with the grains randomly arranged. The grains of each fraction were pasted on double-sided tape over glass plates, which were then placed under the magnifying glass to collect images, always seeking to put the larger grain dimension in the frame. The randomly arranged examined grains were released on a glass plate at a constant height of approximately 3 cm. The sand was then divided into the 3 fractions of sieves in regular series (2.4 mm 1.2 mm; 0.6 mm).

2.4 Obtention and analysis of images

This phase was preceded by the resolution selection and increases (zoom) appropriate for the analysis of images. The equipment used for this research was a magnifying glass of model XTL-101, with a zoom ranging between (0.7 and 4.5) times, direct and indirect lighting possibility and intensity adjustment, in addition to a support for a digital camera, which processes the images in digital format for computer analysis.
The next stage was to obtain the images with the magnifying glass and the LABView software. At the time of collection, multiple configurations were tested, such as brightness, contrast and saturation. The objective was to obtain a standardization of the process and to specifically eliminate some distortions on the grain edges, a recurrent problem in images obtained with a digital camera. The edges feature a different color from the rest of the grain, a fact that can cause them not to be processed by the image analysis program as the grain limit.
Similarly, another important adjustment required was the choice of the lighting to be used in the image collection: direct lighting, indirect lighting or both at the same time; it was also necessary to determine the intensity that would result in better definition at the time of the capture.
The obtention of the images for calculating the parameters of grain shape in crushed sand was made under the conditions of ideal brightness, saturation, contrast and lighting.
Parameters of shape calculation were preceded by an image treatment and by using an image analysis program. The program, used in this work, was the Image J program found in the World Wide Web.
Image analysis procedure consists of the following steps:

- Changing the format of the original image to 8 bits;
- Closing the edges of the open grains with a program command;
- Filling the grains that will be measured with a determined color;
- Painting the background with a different color;
- Obtaining a bicolor design, which serves as basis for the program to automatically attain values of area, perimeter and cross-sectional dimension of grains;
- Applying the equations 2, 3 and 5 to calculated form parameters.

$$E = \frac{d_c}{D_c} = \frac{\sqrt{\frac{4A}{\pi}}}{d_{\max}} \quad (2)$$

Where:
E: sphericity;
$D_c = d_{max}$: diameter of the smallest circle circumscribed in the grain, which corresponds to the maximum diameter or Feret's diameter, directly measured in grain projection (mm);
d_c: diameter corresponding to the projection area of the grain, calculated from the area of the circle (A_{circle}) using Equation (3):

$$A_{circulo} = \frac{\pi \cdot (d_c)^2}{4} \quad \therefore \quad d_c = \sqrt{\frac{4A}{\pi}} \quad (3)$$

Where:
A: the projection area of the grain (mm^2), measured directly on the two-dimensional projection image of the grain.

$$Ar = \frac{4A_p}{\pi \cdot (d_{\max})^2} \quad (4)$$

Where:
Ar: rounding;
A_p: projection of grain area, measured directly on the image of grain (mm^2);
A_c: area of the circle circumscribed in the grain, calculated with equation (5):

$$A_c = \frac{\pi \cdot (d_{\max})^2}{4} \quad (5)$$

Where:
d_{max}: maximum diameter or Feret's diameter, also measured on the projection of grain (mm^2).

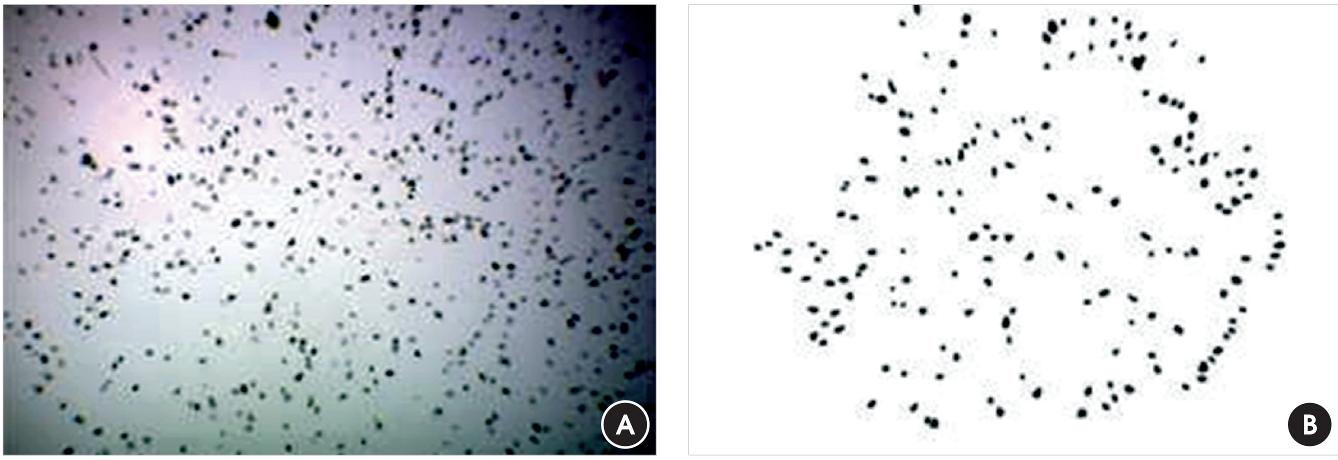
$$F_{forma} = \frac{4\pi A}{P^2} \quad (6)$$

Where:
A: area of grain projection, measured directly on the image of grains (mm^2);
P: perimeter of the projection of grain, measured directly on the image of grains (mm).

- To evaluate the influence of sample preparation, images of the three fractions of sand were obtained: (2.4 - 1.2 - 0.6) mm, captured in two arrangements, randomly positioned and oriented. The choice was related to the fact that it is difficult to orient the smaller fractions (0.3 mm, 0.15 mm and 0.075 mm);
- To assess the influence of the *zoom,* the fraction 1.2 mm was chosen, for its possibility of being photographed with a larger number of increases without any harm to the visualization. Increases of (0.7-1.5-3.0) times were used.
- To evaluate the number of grains, the 0.6 mm fraction was chosen; being the smallest fraction, it enabled to capture more grains per image and therefore resulted in fewer images, which perfected the work.

After image analysis, a statistical analysis of the results was performed with the MiniTab program. Analysis of variance ANOVA was employed, and the real influence of various factors in the tests and of their interaction with the parameters of the form presented in the results were obtained.

Figure 1 – Captured images: (a) before treatment and (b) after treatment with the Image J program



3. Presentation and examination of the experimental results

After the application of the image analysis method, the appearance of the observations can be seen in Figure 1, both before and after the treatment described in the method. The images with this configuration permitted to obtain the results used in the statistical analysis.

3.1 Influence of sample preparation

Figure 2 presents the images of the 0.6 mm fraction grains randomly distributed (a) and oriented (b). A small difference can be noted, which could be attributed to the fact that the oriented grains can be placed with their greatest dimension in the frame.
The average results of rounding, sphericity and form factor obtained for the three parameters studied are shown in table 1, as well as the standard deviation and coefficient of variation (CV).
Evaluating the coefficient of variation presented in table 1, it is observed that the rounding is the parameter with the highest values. This can be related to the fact that the parameter takes into account the square of the maximum observed diameter, thus any variation in measure generates a greater difference.

In variance analysis, the form factor was the only parameter to show significant difference between the oriented and random samples, as it can be observed in the value obtained with the F test in table 2.
It is believed that the significant effect of sample preparation can be attributed to the perimeter of the grains, the only information that is not taken into account in the equations that determine rounding and sphericity. Thus, it can be affirmed that the measurement of the perimeter is the main element subjected to variability, for as previously stated there have been distortions at the edges that may not have been eliminated entirely, making it harder for the program to recognize the image captured by the camera.

3.2 Influence of the applied increases

To evaluate the influence of the increases (zoom) used to obtain the images of the grains, the 1.2 mm fraction was selected, since it presented the best framing with the chosen increases. The adopted increases were of (0.7-1.5-3.0) times. Figure 3 presents the pictures of the grains of chosen fraction captured with different increases.
The average results obtained for the three form factors calculated are shown in table 3.
The study initiated with the idea of working with a minimum of 30

Figure 2 – Images for analysis of the influence of sample preparation: (a) random 0.6 mm, before and after treatment and (b) oriented 0.6 mm, before and after treatment

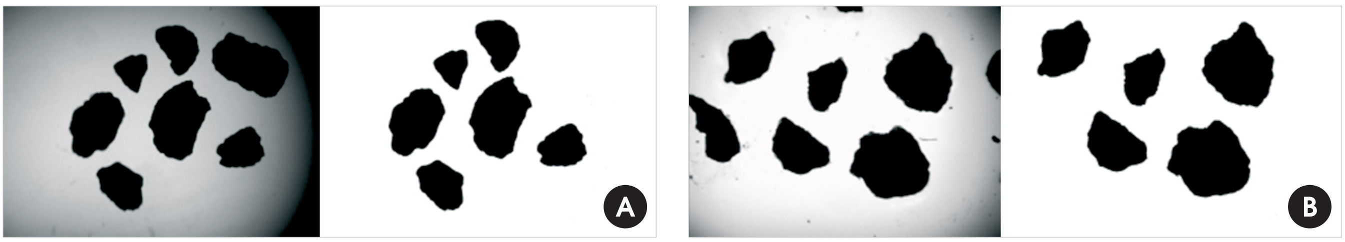


Table 1 – Forms factors calculated to evaluate the influence of sample preparation - 30 grains

Fraction	Grains	Ar	s	CV (%)	E	s	CV (%)	Ff	s	CV (%)
2.4 mm oriented	30	0.67	0.09	14	0.82	0.06	7	0.61	0.07	11
2.4 mm random	30	0.63	0.10	15	0.79	0.06	8	0.63	0.05	7
1.2 mm oriented	30	0.66	0.11	16	0.81	0.07	8	0.65	0.08	8
1.2 mm random	30	0.62	0.10	16	0.79	0.06	8	0.64	0.06	9
0.6 mm oriented	30	0.66	0.09	14	0.81	0.06	7	0.65	0.06	9
0.6 mm random	30	0.66	0.08	12	0.81	0.05	6	0.67	0.04	6

Ar: rounding (dimensionless); E: sphericity (dimensionless), Ff: form factor (dimensionless); s: standard deviation (dimensionless); CV: coefficient of variation (dimensionless).

Table 2 – Variance analysis for the form factor – influence of sample preparation

Treatments	Degrees of freedom	Sum of the squares	Average of the squares	F	P	Significance level
Orientation	2	0.101058	0.050529	9.54	0.000	S
Error	51	0.270159	0.005297	–	–	–
Total	53	0.371216	–	–	–	–

Factor F or Test F = square mean of treatment/square mean of error; P: Probability or Value-p: from Student's distribution t.

grains, but since some grains were not recognized by the program during the image treatment, the number of grains that could be used in the statistical analysis was limited to 18. The coefficient of variation had higher values to those seen in the preparation analysis, but similar values to those observed in the analysis of grain number, being the rounding the value that presented most differences.
Observing table 4, it can be noticed that, once again, only in the form factor the zoom had a significant effect: the form factor decreases as the zoom increases, as shown in Figure 4.
This can be explained by the increase in the level of detail of the grain contour with the highest zooms, increasing the value of the perimeter and, thus, reducing the value of the form factor. This does not occur for sphericity and rounding.

3.3 Influence of the number of grains

Using Equation 1, as suggested by Bussab and Morettin [5], with a standard confidence level of 95%, a standard deviation of approximately 0.1, and 0.01 precision, the representative number of 386 grains was obtained. This number approached the 400 grains

Figure 3 – Zoom effect used for the obtention of the images of the grains: (a) 3.0X, before and after treatment, (b) 1.5X, before and after treatment and (c) 0.7X, before and after treatment

Table 3 – Form parameters calculated to evaluate the influence of different increases – 18 grains

Increase	Grains	Ar	s	CV (%)	E	S	CV (%)	Ff	s	CV (%)
0.7x	18	0.67	0.13	20%	0.82	0.09	11%	0.68	0.07	11%
1.5x	18	0.60	0.11	18%	0.77	0.07	9%	0.63	0.07	11%
3.0x	18	0.65	0.14	21%	0.80	0.09	11%	0.57	0.08	13%

Ar: rounding; E: sphericity, Ff: form factor; s: standard deviation; CV: coefficient of variation.

Table 4 – Analysis of variance for the form factor

Treatments	Degrees of freedom	Sum of the squares	Average of the squares	F	P	Significance level
Fraction	2	0.101058	0.050529	9.54	0.000	S
Error	51	0.270159	0.005297	–	–	–
Total	53	0.371216	–	–	–	–

Factor F or Test F = square mean of treatment/square mean of error; P: Probability or Value-p: from Student's distribution t.

used by Persson [6], Araújo [7] and Tristan [8] in their experiments for form analysis.
The calculation resulted in a relatively high number, which in practice demands a lot of time to obtain the images. Considering a relative error of 0.02, the value would remain around 90 grains, a number that this study aimed to decrease. It was then decided to work with a reduced number of thirty grains to enable the analysis. To evaluate this and facilitate the analysis, reducing the demanded time, it was designed an experiment that evaluated the influence of the number of grains analyzed in the calculated form parameters. To evaluate the influence of the number of grains used, the 1.2 mm fraction was chosen, for it was the one which presented the best framings with the applied increases. The average results obtained for the three form factors calculated are shown in table 5.
Once more, the standard deviation and the coefficient of variation are greater for rounding, and have the same value for sphericity and the form factor.
The analysis of variance showed that the number of grains adopted has no significant effect on any of the form parameters, which might be attributed to the tendency of population distribution normality. The sampling seemed to well represent the population – the quartile dosage of the material appears to have helped, so that it became difficult not to generate a significant sample.

Figure 4 – Zoom effects on the form factor

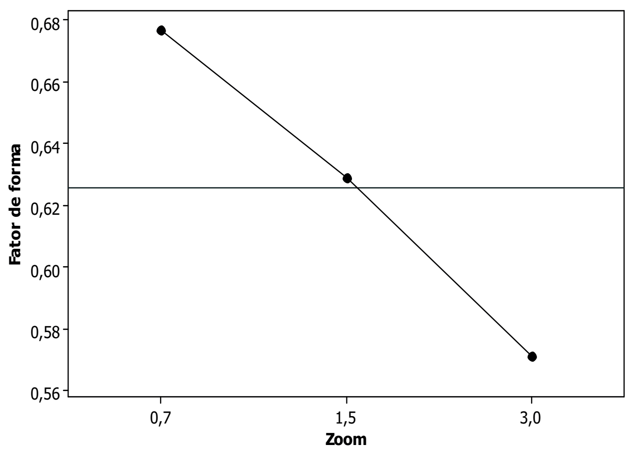


Table 5 – Form factors calculated for samples with different numbers of grains

Grains	Ar	s	CV (%)	E	s	CV (%)	Ff	s	CV (%)
30	0.65	0.11	18%	0.80	0.07	9%	0.62	0.08	12%
60	0.63	0.11	17%	0.79	0.07	9%	0.60	0.07	12%
90	0.66	0.09	14%	0.81	0.06	10%	0.62	0.06	10%

Ar: rounding; E: sphericity, Ff: form factor; s: standard deviation; CV: coefficient of variation.

4. Conclusions

It can be stated that the form analysis of minute aggregates requires standardization, so that its results might not be influenced by the method of image obtention, especially regarding the increases adopted in the process.
In sample preparation and in augmentation choice, it can be observed that the form factor was the only affected parameter, and that the perimeter seems to influence this atypical result. Depending on the number of pixels that the edge of the grain presents, it is believed that the program reads inaccurate or even incorrect values, regardless of the number of grains.
In relation to the sample size, it can be noted that the number of around 400 grains cited by the studied authors can be decreased, since the form factors corresponding to 30, 60 and 90 grains showed no significant difference in their values.
Considering the measured parameters, the one which presented the most problems related to the image analysis method was the form factor – with variations in the sample preparation and the image amplification, values that do not realistically represent the true characteristic of the sand being measured were obtained.
When it comes to pointing a parameter which is best for the analysis, the rounding and sphericity, which are not affected by the method employed, are indicated.
It is suggested to extend the experiments to other sand fractions and to analyze all the results, therefore obtaining the interaction regarding all the factors involved in the analysis.
There is also the need of applied experiments to indicate what can be the indicated value of shape variation parameters for sand, concrete and mortars.

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