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Particle shape analysis of industrial sand using traditional and computational geometry methods

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Abstract. Silica sand is widely used as a raw material in the manufacture of building and construction products. Particle shape parameters such as sphericity and roundness were determined using both the Krumbein-Sloss diagram and the ImageJ processing algorithm. A total of 10 samples from production plants were comprehensibly analyzed. Olympus SZX16 microscope was used for image acquisition. Image analysis was performed separately for each grain size fraction ranging from 0.063 mm up to 2.0 mm. The microscope images showed that there was a visible difference in color and shape between manufactured sands. For sand shape parameters, the computerized method was significantly faster and with a high probability of accuracy compared to the Krumbein-Sloss diagram method.

Keywords: sphericity, circularity, roundness, silica sand, microscopy, ImageJ

1 Introduction

Silica sand, also known as white sand, quartz sand, or industrial sand, is a widely used raw material for manufacturing building and construction products, glass, electronics, and even renewable materials. In the case of building materials, silica sand is used in mortar, roofing shingles, asphalt mixtures, epoxy-based compounds, sealants, joint compounds, etc. Among many properties, morphology and shape are of great importance to study its usability for industrial and commercial applications. Although shape studies have received much less attention than size studies, particle shape can have a direct influence on mechanical abrasion, weathering and hydraulic grading [1]. Traditionally visual charts like Krumbein / Sloss [2], and Powers [3] have been the most extensively used methods for determining shape parameters. However, extensive time requirements for diagram evaluation and the poor repeatability have given new impetus to the development of modern, computer-aided methods [4].
The paper discusses the easy and open-source componential method that was used to derive shapes like the Sphericity (S), Roundness (R), circularity (C), and solidity (So) in the range from 0.063 mm up to 2.0 mm.

2 Measuring methods

Particle shape parameters were determined using both the Krumbein-Sloss diagram and the image processing algorithm. The Olympus SZX16 microscope with stream imaging software was used for image acquisition, which provides all the necessary tools for simple 2D measurements to complex analyzes (**Fig. 1**). The microscope is equipped with two light sources that can move freely. To produce a clear particle contour, it was necessary to dry the samples for 24 hours at 110 ˘C to remove surface water that can interfere with clear acquisition. It was also necessary to prevent the particles from sticking together in clusters. For each type of sand sample, at least 50 sand particles were comprehensively analyzed using microscopy under different magnifications. Image analysis was performed separately for each particle size fraction ranging from 0.063 mm to 2.0 mm. A total of 10 samples from production plants were analyzed comprehensively.

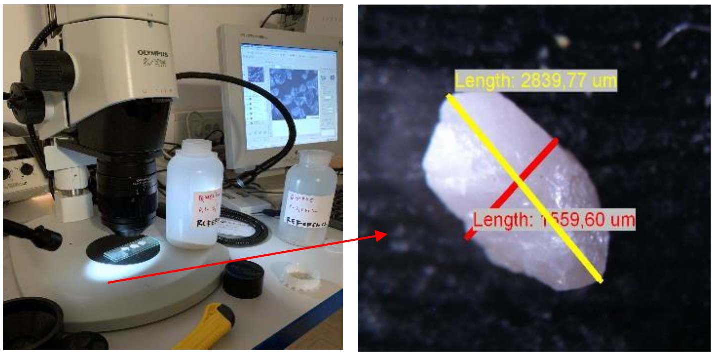

Fig 1. Microscopy and sphericity (S) calculation.

2.1 Krumbein / Sloss diagram

The Krumbein-Sloss diagram is probably the most commonly used because it provides a simple way to estimate both roundness and sphericity [2]. Krumbein-Sloss Sphericity (Sc) is quantified as the diameter ratio between the largest inscribed sphere and the smallest circumscribing sphere. Krumbein-Sloss roundness (Rc) is quantified as the average radius of curvature of surface features relative to the radius of the largest inscribable sphere in the particle. The chart contains 20 reference particles with Sc ranging from 0.3 to 0.9 and Rc ranging from 0.1 to 0.9, each in increments of 0.2. However, a person comparing particles to the chart Krumbein-Sloss may differ from another operator, and the analysis is very time-consuming.

2.2 Computational geometry and calculations

Computational calculations were performed using the image processing algorithm Image J [5]. 2D image analysis methodology for shape classification was developed according to Takashmizu and Liyoshi [6]. All photos were analyzed in threshold mode using the ImageJ algorithm and the BioVoxxel image processing plugin (**Fig.1**).

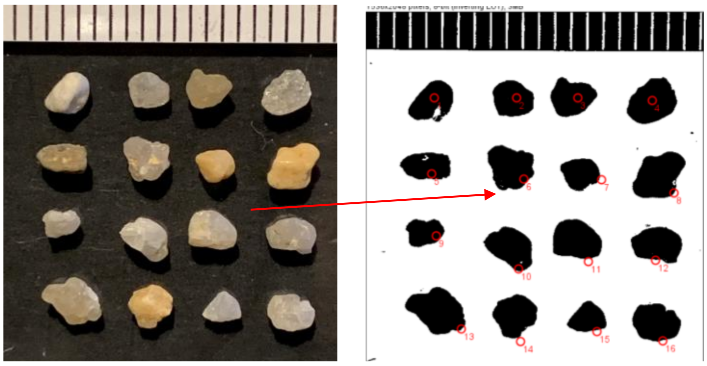

Fig. 1: Threshold adjustment using ImageJ algorithm.

Desired shape parameters were calculated according to the Eq. (1-4):

$$\text{Sphericity (S)} = d_2/d_1 \quad (1)$$

$$\text{Circularity (C)} = 4\pi \circ \text{(Area)/(Perimeter)}^2 \quad (2)$$

$$\text{Solidity (So)} = \text{(Area)/ (Convex Area)} \quad (3)$$

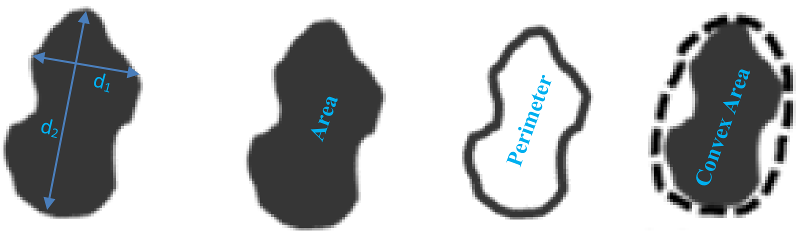

Fig. 2. Definitions of sphericity (S), Particle Area (A), Perimeter, and Convex Area.

3 Results and discussion

3.1 Appearance of silica sand

Microscope images showed that the particles have a wide range of shades, mostly white or colourless, depending on their geological composition. They look like glass with locally coloured inclusions. There was also a visible difference in shape between certain sands produced in the production plant.

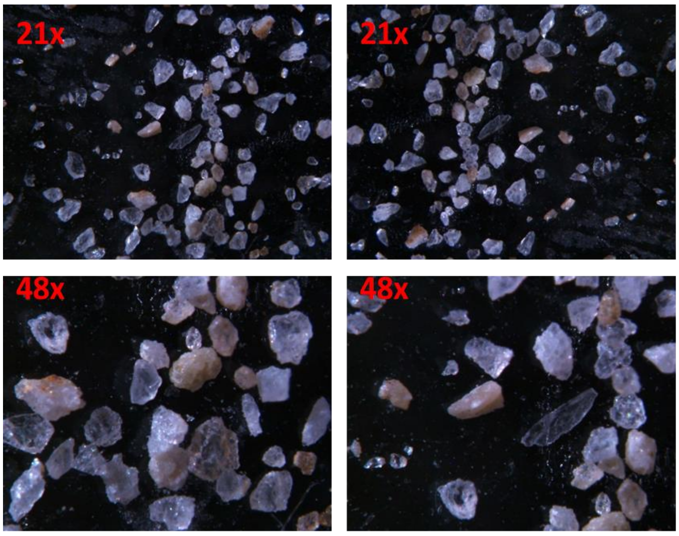

Fig.3. Appearance of Silicate sand sample in grain size fraction from 0.1 up to 0.4 mm at different magnifications.

3.2 Shape parameters

Both methods have been successfully implemented to represent shape parameters. When comparing these two methods, there is a clear difference in the magnitude scale of the R parameter. In the case of sphericity, there is no visible difference between the methods used. The mean values of the shape parameters are shown in Table 1. Sample 1 and 2 have the highest circularity and roundness. The lowest shape parameters were calculated in the case of samples 4, 6, 9 and 10. In the computer aided method, it was possible to process the data much faster with a high probability of accuracy. Circularity vs sphericity data distribution for sample #1 (left) and sample #10 (right) are shown in Fig. 4. From the distribution data, one can easily see the difference between one sample and the other. Moreover, the proposed computational geometry method is based on an open-source algorithm and is an excellent alternative for all traditional and payable componential methods.

Table 1: Shape parameters for 10 sand samples from industrial plat.

	Computational geometry					Krumbein / Sloss Chart	
Sample	**Area (mm^2)**	**Solidity (So)**	**Circularity (C)**	**Spher. (S)**	**Round. (R)**	**Spher. (S^c)***	**Round. (R^c)***
1	0.02	0.95	0.79	0.72	0.74	0.72	0.60
2	3.97	0.96	0.73	0.77	0.76	0.77	0.60
3	0.02	0.94	0.75	0.71	0.72	0.71	0.50
4	2.29	0.95	0.72	0.71	0.72	0.71	0.40
5	2.72	0.95	0.69	0.75	0.72	0.75	0.60
6	0.04	0.92	0.71	0.72	0.70	0.72	0.40
7	0.02	0.92	0.71	0.69	0.71	0.69	0.40
8	3.36	0.93	0.73	0.71	0.71	0.71	0.40
9	0.01	0.91	0.69	0.68	0.69	0.68	0.30
10	2.94	0.93	0.71	0.74	0.69	0.74	0.30

*(S^c) and (R^c) was obtain by Krumbein / Sloss Chart

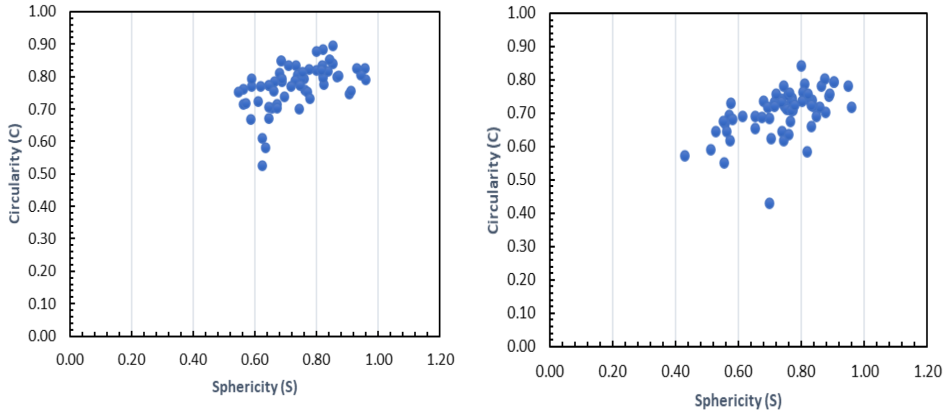

Fig. 4 Circularity vs sphericity data distribution for sample no.1 (left) and sample no.10 (right) that were obtain using ImageJ algorithm.

4. Conclusions

In this paper, the morphology and shape of industrial sand were analyzed. Both conventional and computational methods were successfully used to represent the shape parameters. Microscope images showed that industrial sand looks like glass with locally colored inclusions. There is also a significant difference between calculated and determined shape parameters from different batches. The shape parameters can help us understand how the particles will affect the final industrial and commercial product. There is also a significant advantage in using computational methods over traditional methods. In the case of the computational method, it was possible to process the data much faster, with a high probability of accuracy.

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