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Research Article

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Size and Shape Analysis of Soil Fine Particles by Static Image Processing Method

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Abstract

The particle size distribution provides important information about soil engineering properties. Finer particles are usually determined by classical sedimentation methods such as hydrometer tests. These methods are based on simplifying assumptions and despite operational complexities, the obtained results are not precise. At this time, Image Processing methods were used in different industries to obtain various information about size distributions and particle shape analysis. The present research suggests the image processing method based on the analysis of microscopic images of stable particles (static method) for determining the size and shape distribution of the fine-grained fraction of the soil. The images of fine-grained soil particles prepared with optical microscopes were analyzed to generate information about particle size and shape. By comparing gradation curves obtained with image processing and hydrometric methods, we found that there is more adaptation in the range of 40 to 70 microns of particle sizes. Investigations have shown that in this range, the shape of the particles has less diversity and is closer to the perfect sphere form. This study found that image processing while reducing costs, could provide more comprehensive information and would be expected to be used in geotechnical laboratories.

Keywords : Static Image Processing method; Soil Fine Particles; Size; Shape.

1 Introduction

INformation obtained from soil size analysis can be used to identify permeability, shear strength, compressibility, sensitivity to freezing, and capillary properties, as well as for filter and drainage design. [1]. The coarse part of the soil is evaluated by a standard sieving test, while to determine the fine particle size, the standard hydrometric test is performed in soil mechanic laboratories. Sedimentation methods rely on Stokes' law and define the particle size with a spherical bullet diameter equal to that of a particle that settles in the same fluid with the same velocity. Because spherical shapes are assumed for soil particles in this experiment, accurate results are not obtained. On the other hand, fine soil particles are generally not spherical and are in plate form, in which case the sedimentation velocity changes from side to side due to increased fall resistance and change of direction during fall. This

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means that the sedimentation method underestimates the size of the flat particles and this error increases with increasing the flatness of the particles [2].

Among new measurment techniques, the laser diffraction method is used in various industries to measure the size of fine particles. Laser diffraction has also attracted the attention of civil engineers in recent years, but for various reasons, it could not replace the traditional methods in geotechnical laboratories [3].Each of these methods is based on a different principle of measurement and is applicable only in a certain range of particle sizes. In general, all of these measurement techniques provide different results for the size of non-spherical particles, but none provide a complete description of the morphological properties of the particles. Some of these techniques require the dispersion of soil particles in liquids, which in turn affects the behavior of the soil and causes deviations in the results. In some of these methods, such as laser diffraction, the equipment used is expensive, and the method is not able to provide additional information about the shape of the particles. Therefore, it is necessary to use a method based on the direct and unmediated observation that can determine the shape of particles with their size [4].

Nowadays, particle size and shape characterization systems based on image analysis have been widely developed and are commonly used in various fields such as the food industry, sedimentology, pharmacy, etc. [5]. Brewer and Ramsland (1994) conducted a study to determine the particle size distribution of powders used in pharmacy, compared microscopic image processing and laser diffraction methods, and concluded that the image processing method has good reproducibility and the particle shapes are an important factor in aligning the results in this method [6].

With the development of high-speed computers and high-resolution digital cameras, geotechnical engineers have been fascinated by the potential of digital imaging technologies to determine soil grain size. Over the last three decades, many researchers have used new digital technologies on the subject of coarse-grained soil (gravel to sand) size analysis and have shown some innovative methods that can be used in geotechnical laboratories [7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18]. Also, review studies by (Ohm et al. 2013, Cherian and Arnepalli 2016) are excellent sources to study in the field of measuring geomaterials by imaging methods. They emphasized the economic and environmental problems of the traditional sieving method, documented the details of commercial imaging systems, and pointed out the inevitability of adopting imaging techniques for soil identification [19, 20]. Moreover, the dynamic image analysis method which is based on the mesurment of particles in moving conditions, has been used for the size distribution of sandy soils by [21, 22]. The review of previous studies shows the lack of appropriate methods for measuring fine soil particles, despite the development of different methods in other industries. Abbireddy and Clayton (2209) and Roostaei et.al (2020) have presented a thoughtful overview of particle measurement techniques by testing on samples of different sizes and shapes by traditional and modern methods. They concluded that image processing can produce more comprehensive results by obtaining shape parameters in addition to particle size determination [2, 4]. However, the determination of the size of the fine particles of soil remains in the shadow of traditional and common standard methods or other expensive new methods that do not have economic justification for general use in soil laboratories. In the present study, an alternative method for this purpose has been obtained with the help of microscopic imaging techniques and computer facilities, to improve the accuracy of determining the size and shape of fine soil particles.

2 Materials and methods

The soil sample used in this research was selected from the site of Andisheh town in Miyaneh city in Iran. The soil was dried in the open air and then passed through a standard sieve No. 200 in the laboratory to obtain the required fine-grained (less than 75 microns) soil sample. A hydrometer test according to ASTM D442 standard method

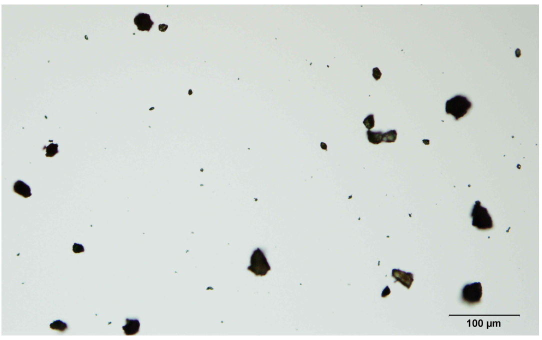

Figure 1: Microscopic image of fine soil particles

Figure 2: Optical microscope with a digital camera connected to the computer

in the soil mechanics laboratory is performed [23]. The basis of imaging techniques begins with the sample preparation process, which is an important step in the transfer of particles to measuring devices [24]. For static or microscopic image analysis, the operator should spray a small amount (approximately 1 mg) of the sample onto a clean surface of a microscope aperture. Ideally, the sample particles should not come into contact with each other. After placing the slide on the microscope and mechanically fixing it, the operator can observe the particles through the eyepiece of the microscope and separate the cohesive particles with small tweezer. In this method, the soil particles are placed on a flat surface in their most stable state, and the three-dimensional particles are observed and measured in two dimensions conditions. To more clearly observation all the particles in the image, you need to adjust the microscope object lenses distance, which will take about 30 to 60 seconds to capture each image. Lower image magnification reduces image sharpness and prevents accurate particle size and shape calculations. At higher image magnifications, however, the image is captured from a smaller number of sample particles, which also increases the test time. For this experiment, 71 microscopic images of about 12,000 fine particles of soil were prepared. Figure 1 shows an image of fine soil particles.

In this study, the images were obtained by an optical microscope connected to a digital camera computer system with a Charged-Coupled Device (CCD) processor. These instruments are shown in Figure 2. The recorded images are 8-bit (bits per pixel) and have 256 grey levels. The microscope had four objective lenses with different magnifications, each magnification having its own depth of field (DOF). At each of these magnifications, only a certain range of particle sizes can be observed and measured with good resolution. The specified ranges are determined based on the pixel size. These specifications are given in Table 1. In this study, the 10x objective lens was selected with magnification (100) so that it could cover the desired range of particle sizes and the image analysis process could proceed at a good speed. There are three modes of light radiation in microscopes. In this experiment, the diascopic method has been applied to create ideal conditions for observing and measuring particles [5].

Table 1: Range and depth of field of the objective lens

Range of Particle Sizes (μm)	Depth of field (μm)	Magnification	Objective Lens
7-450	59	50	5x
3.5-200	15	100	10x
2-100	5.2	200	20x
0.5-30	1.3	400	40x

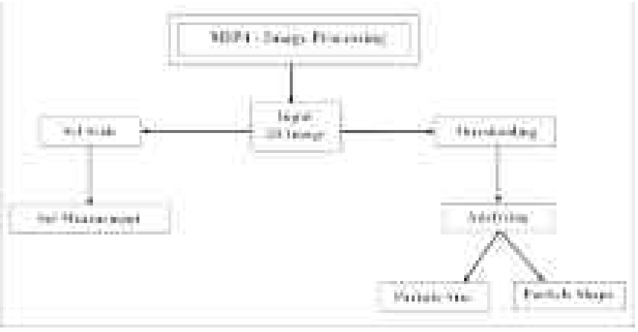

Figure 3: Flowchart of the image processing by MIP4 software

3 Image processing

After preparing the sample and recording the microscopic images of soil particles, it is time to process and analyze the images and present the results with the image processing software. Currently, there are various programs for image processing, the MIP4 software is chosen in this study

To perform image analysis, the image must first be calibrated. Image calibration means introducing the actual size of the particles to the computer. Because the only computer data about this is the number of pixels in the image. The size of one pixel per micrometer is called the calibration number. This number plays a very important role in the calculation of variables
In order to obtain the correct shape of a particle and an accurate result, some morphological functions such as Fill, Erosion, Dilation, Opening, and Closing are used, which are very important in image processing. Morphological functions extract and modify the particle structure in a binary image. These operators are functions that can be used to improve the binary image. The binary image generated by the thresholding process may contain unwanted information such as troublesome particles such as particles touching the image border, and particles sticking together. This unwanted information can be corrected by using these morphological functions or removed in the binary image so that the particles are not falsely represented as large or small. Figure 4 shows the various steps of image analysis operations to determine the size of fine soil particle

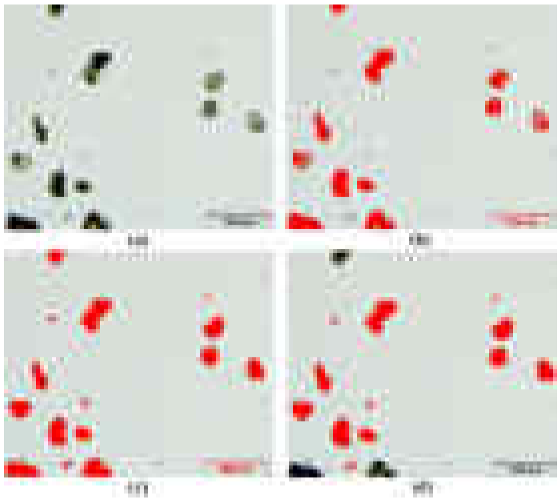

Figure 4: The image analysis stages in MIP4 software (a) origin microscopic image (b) binary image obtained from threshold (c) filling, erosion, dilation, opening, closing (d) noise border killing and separating particles by the watershed algorithm.

parameters.

It is worth noting the part of the stuck particles that do not overlap with each other, could separate by the watershed algorithm to prevent the waste of a significant part of the sample particles. Finally, image analysis operations by image processing software were performed on all images, and desired characteristics of particles such as area, length, perimeter, and sphericity were extracted. Then, these data and the generated parameters were transferred to Excel spreadsheets to analyze the particle size and shape distribution. The raw data obtained from the particle size distribution is converted from the number distribution to the volume distribution by image processing software based on the number of particles reported according to Equation 3.1 [25]. Assuming the density of soil particles is the same, the grain size distribution curve based on particle volume can be considered equivalent to the standard weight gradation curve. This conversion is an accepted method between different standards [26].

$$W_i = \frac{n_i {D_i}^2}{\sum n_i {D_i}^2} \tag{3.1}$$

Where:

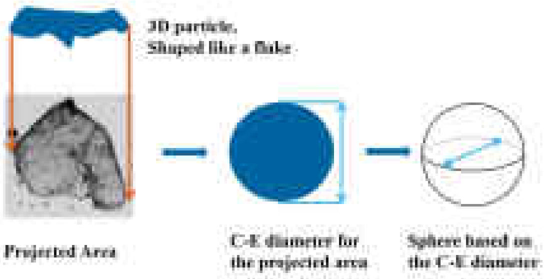

Figure 5: The definition of a sphere equivalent to a three-dimensional particle [5]

W_i is the volume of the particles, n_i is the number of particles, and D_i as shown in Figure 5, is the diameter of a circle equivalent to the surface of the image.

4 Parameters of particle size and shapes

The size and shape of the soil particles can be expressed by various mathematical descriptors. According to ISO13322-1, the initial values obtained from the image analysis are the area, length, and width of the Fret [24]. Based on the two-dimensional images taken by the microscope, the particle area and perimeter are obtained by counting the number of pixels constituting each particle in the image. It should be noted that the length and width of the Fret depend on how the particle is placed on the x and y planes. The measurement concepts used in the software

- The circle equivalent diameter: is determined as the diameter of an equivalent circle to the area of the projected image of the three-dimensional particle.

$$\text{Circle equivalent diameter} = 2\left(\frac{\text{Area}}{\pi}\right)^{0.5} \tag{4.2}$$

- The length and width of the Fret: is the length and width of the smallest circumscribed rectangle containing the particle shape.

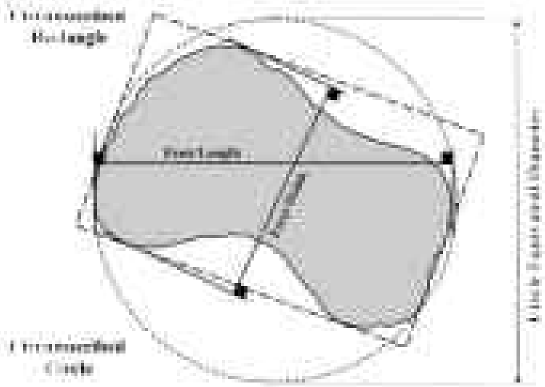

Figure 6: Parameters of particle size and shape

The shape information of each particle can also be obtained from its two-dimensional image. Several shape factors, such as sphericity and aspect ratio, are used to describe the degree of deviation of the particle shape from the shape of a complete sphere. Particle shape descriptors are calculated as follows based on the predefined size parameters:

- Sphericity is one of the most common parameters to describe the degree of deviation of the particle image from the sphere. The value of this numerical parameter is between zero to one, and for the more spherical shape, it will be closer to 1.

$$\text{Sphericity} = \frac{4\cdot\pi\cdot\text{Area}}{\text{Perimeter}^2} \tag{4.3}$$

- Aspect ratio is the ratio of the length of the shape to its width and is calculated from the following equation:

$$\text{Aspect ratio} = \frac{\text{Length of the shape}}{\text{Width of the shape}} \tag{4.4}$$

5 Results and discussion

In this section, we compared the results of the image processing techniques with traditional and standard Hydrometer tests. After analyzing the sample with these two methods, the results are displayed as a curve below in Figure 7. There is a big difference in the size of parameters D_{10} and D_{50}. This difference is reduced by increasing the

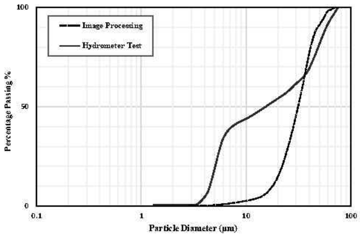

Fig. 7 Comparison of fine soil gradation curve obtained from hydrometer and static image processing methods

Figure 7: Comparison of fine soil gradation curve obtained from hydrometer and static image processing methods

particle diameter and passing the 40 micron diameter in the D90. Image processing shows the majority of particles in the range of 20 to 40 microns, and the hydrometer method, on the contrary, has a lower slope in the range of 10 to 40 microns. The hydrometer method displays the weight percentage of finer particles larger, such that it shows 40 weight percent of entire particles with a diameter smaller than 10 microns. The difference in the fine particles indicates a major difference in the performance of these two methods. This discrepancy may be due to the lack of particle thickness and the assumptions made to obtain the particle volume in the image processing method for plotting the gradation curve. Other causes of error in the visual method include the following: a) Dispersion method in which the overlap of particles causes the particle diameter to appear larger. b) The amount of sample to be tested. c) The amount of magnification when preparing microscopic images. d) effect of soil particle shape.

Among the effective factors in the differences in the results, the effect of shape factors (Aspect ratio and Sphericity) is of special importance. The dispersion of the shape factor can be caused by the actual dispersion in the shape of the particles of the entire sample or by the size description method that only uses the two-dimensional projected image of the particles. Also, each particle can be placed in different random positions, which causes the production of images with unrealistic dimensions [27]. The shape distribution of particles is shown in Figures 8 and 9 The

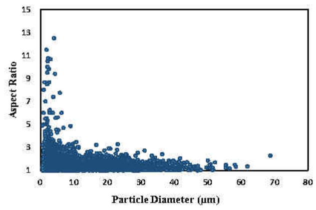

Fig. 8 Correlation between size of particles and aspect ratio

Figure 8: Correlation between size of particles and aspect ratio

distribution of shape factors of particles was investigated as a correlation diagram. In this regard, the dispersion of the shape factors of the particles was obtained according to the diameter of the equivalent circle. The graphs appeared as a cloud of points, which can be used to estimate the relationship between the factors of shape and size of soil particles.

As shown in Figure 8, the particle aspect ratio has a variety in small sizes and includes different values from 1 to about 13. Here, as we move from

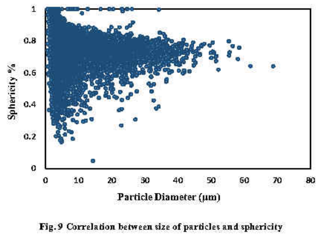

Figure 9: Correlation between size of particles and sphericity

small to larger diameter particles, the aspect ratio of the particles gets closer to 1. By examining the correlation between size and sphericity factor, as seen in Figure 9, most of the particles with a diameter smaller than 10 microns are in the range of 0.4 to 1, and particles larger than 10 microns have a sphericity of 0.6 to 0.8. In general, it can be said that larger particles have more sphericity and less shape dispersion. These results indicate that in the examined sample, larger particles (above 10 microns) are closer to the sphere and also have more roundness and proportionality of dimensions than smaller particles. The standard deviation of the two shape factors in Table 2 shows the greater dispersion of the aspect ratio factor.

In order to achieve the optimal form of particle morphology analysis, it is necessary to determine the minimum number of sample particles to achieve an acceptable result. ISO13322-1 considers the number of particles required to gain appropriate accuracy to be 61000 (assuming a 5% error), regardless of the type of particles.

Table 2: Statistical parameters of shape factors

Shape Factor	Min	Max	Average	Standard Deviation
Aspect Ratio	1	12.8	1.50	0.80
Sphericity	0	1.0	0.84	0.15

Researchers by analyzing the 500 to 9000 particles from samples with different shapes, have concluded that the 6000 particles can be a suitable value for microscopic static image analysis

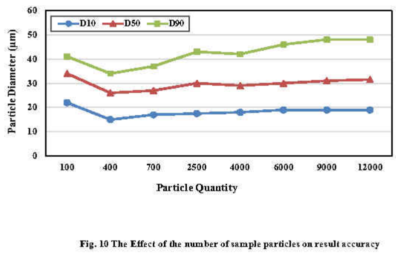

Figure 10: The Effect of the number of sample particles on result accuracy

6 Conclusion

Particle size distribution analysis has been developed using image processing techniques in various fields as well as in civil engineering and most previous research has been performed to measure coarse-grained soil particles. The general purpose of this study is to investigate the possibility of using static image processing to determine the size

of fine soil particles and replace it with the traditional hydrometer test. Image analysis was performed by MIP4 software and particle size and shape factors were extracted from microscopic images. The primary results provided by the software are expressed based on the number of particles, so by considering the assumptions for the thickness and density of the particles, the results were obtained based on the volume. Therefore, the standard grading curve was plotted based on weight percentage. Comparing the image analysis and hydrometer methods has shown that in the size range between d_{50} and d_{90}, both methods are almost close to each other, but in smaller particles, the difference between the results increases. By examining the distribution of shape factors including aspect ratio and sphericity, it was found that particles larger than 40 microns have a more regular and are closer to the full sphere.
According to observations, size distribution with image processing compared to the traditional hydrometer test, in addition to less waste of energy and water, faster process, and less need for a fine-grained soil sample, has a great advantage in that it is possible to get more information. In fact, from the same recorded image of the particles, it is possible to analyze their shape in addition to their size. However, size distribution by image processing also has difficulties in sample preparation. This novel method can be used to adapt the results of laboratory tests in academic research and also replace common traditional methods.

References

[1] H. Ohm, Image-Based Soil Particle Size and Shape Characterization. (2013).

[2] C. Abbireddy, C. Clayton, A review of modern particle sizing methods, *Proceedings Of The Institution Of Civil Engineers-Geotechnical Engineering* 162 (2009) 193-201.

[3] V. Ferro, S. Mirabile, Comparing particle size distribution analysis by sedimentation and laser diffraction method, *Journal Of Agricultural Engineering* 40 (2009) 35-43.

[4] M. Roostaei, M. Soroush, S. Hosseini, A. Velayati, A. Alkouh, M. Mahmoudi, A. Ghalambor, V. Fattahpour, Comparison of various particle size distribution measurement methods: role of particle shape descriptors, *SPE International Conference And Exhibition On Formation Damage Control*, (2020)

[5] R. Rinne, Particle Characterisation Using Image Analysis Tools: Improving and Developing Methods for Polyolefin Catalysts, (Metropolia Ammattikorkeakoulu, 2015).

[6] E. Brewer, A. Ramsland, Particle size determination by automated microscopical imaging analysis with comparison to laser diffraction, *Journal Of Pharmaceutical Sciences* 84 (1995) 499-501.

[7] C. Kuo, J. Frost, J. Lai, L. Wang, Three-dimensional image analysis of aggregate particles from orthogonal projections, *Transportation Research Record* 1526 (1996) 98-103.

[8] C. Mora, A. Kwan, H. Chan, Particle size distribution analysis of coarse aggregate using digital image processing, *Cement And Concrete Research* 28 (1998) 921-932.

[9] S. Raschke, R. Hryciw, Grain-size distribution of granular soils by computer vision, *Geotechnical Testing Journal* 20 (1997) 433-442.

[10] A. Ghalib, R. Hryciw, Soil particle size distribution by mosaic imaging and watershed analysis, *Journal Of Computing In Civil Engineering* 13 (1999) 80-87.

[11] S. Shin, R. Hryciw, Wavelet analysis of soil mass images for particle size determination, *Journal Of Computing In Civil Engineering* 18 (2004) 19-27.

[12] R. Hryciw, S. Shin, Y. Jung, Soil image processing: Single grains to particle assemblies, *GeoCongress 2006: Geotechnical Engineering In The Information Technology Age* 5 (2006) 1-6.

[13] Sciences, Medicine & Others Test Methods for Characterizing Aggregate Shape, Texture, and Angularity, (2007).

[14] G. Kumara, K. Hayano, K. Ogiwara, Image analysis techniques on evaluation of particle size distribution of gravel, *GEOMATE Journal* 3 (2012) 290-297.

[15] A. Rajagopal, A comparison of optical gradation analysis devices to current test methodsphase 2, (Infrastructure Management, 2012)

[16] O. Ohm, R. Hryciw, Enhanced soil characterization through advances in imaging technology, *Proc., 18th Int. Conf. On Soil Mechanics And Geotechnical Engineering (ICSMGE)* 34 (2013) 3491-3494.

[17] R. Beemer, L. Li, A. Leonti, J. Shaw, J. Fonseca, I. Valova, M. Iskander, C. Pilskaln, Comparison of 2D optical imaging and 3D microtomography shape measurements of a coastal bioclastic calcareous sand, *Journal Of Imaging* 8 (2022) 72.

[18] P. An, H. Tang, C., Li, K. Fang, S. Lu, J. Zhang, A fast and practical method for determining particle size and shape by using smartphone photogrammetry, *Measurement* 193 (2022) 110-143.

[19] R. Hryciw, J. Zheng, H. Ohm, J. Li, Innovations in optical geocharacterization, *Geo-Congress 2014 Keynote Lectures: Geo-Characterization And Modeling For Sustainability* 97 (2014) 116-224.

[20] C. Cherian, D. Arnepalli, Material characterisation by digital image analysis: a review, *Environmental Geotechnics* 5 (2016) 249-262.

[21] L. Li, Q. Sun, M. Iskander, Efficacy of 3D dynamic image analysis for characterising the morphology of natural sands, *Gotechnique* 73 (2021) 586-599.

[22] L. Li, M. Iskander, Evaluation of dynamic image analysis for characterizing granular soils, *Geotechnical Testing Journal* 43 (2020) 1149-1173.

[23] D. ASTM, Others Standard test method for particle-size analysis of soils. (West Conshohocken, PA, 2007)

[24] B. Standard, Others Particle size analysis-image analysis methodspart 1: static image analysis methods, *BS ISO* 11 (2004) 133-142.

[25] K. Patchigolla, D. Wilkinson, Crystal shape characterisation of dry samples using microscopic and dynamic image analysis, *Particle & Particle Systems Characterization* 26 (2009) 171-178.

[26] M. Said, M. Development of particle sizing based on dynamic image analysis, (University of Leicester, 2011).

[27] M. Ili, I. Budak, M. Vasi, A. Nagode, U. Kozmidis-Luburi, J. Hodoli, T. Pukar, Size and shape particle analysis by applying image analysis and laser diffractionInhalable dust in a dental laboratory, *Measurement*, 66 (2015) 109-117.

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