PARTICLE SIZE DISTRIBUTION ANALYSIS IN AGGREGATE PROCESSING PLANTS USING DIGITAL IMAGE PROCESSING METHODS

MERT TERZI *

Istanbul University Cerrahpasa, Faculty of Engineering, Department of Mining Engineering, 34320, Istanbul, Turkey

Sensitive determination of the particle size distribution is an important procedure in terms of efficiency as well as affordability in mining operations which includes many stages such as blasting and mineral processing. Digital image processing methods used in mineral processing discipline found different application areas due to providing accurate data in relatively short time. In this study, the particle size distribution analysis of the samples taken from privately owned aggregate processing plants using sieve analysis and digital image processing methods were conducted and accordingly a comparison of these methods in terms of the applicability on industrial scale were realized. In this context, a pilot setup was assembled for the laboratory and plant scale image processing analysis purposes. Particle size distribution measurements of the samples were conducted by digital image processing method using this pilot setup and conventional sieve analysis methods. As a result, d_{20}, d_{50} and d_{80} sizes of a crushed stone plant product were determined with confidence levels of 94.75%, 88.45% and 80.00%, respectively. The obtained results showed that a system based on digital image processing method can be applied in particle size analysis with high success as alternatives to conventional methods.

***Keywords:** aggregate, particle size distribution, digital image processing*

1. Introduction

As it is the case in various industrial processes, determination of particle size distributions of various raw materials reduced to fine particles such as glass, cement, paper, plastic, ceramic, which are process input and/or output, is of great importance also in mining. An accurate determination of particle size distribution in many phases of mining which is consisting of a series of operations from blasting to mineral processing is important both in terms of efficiency and also economy [1].

There are several methods are being used for determination of particle size distribution and shape factors. Sieve analysis is a common method used for determination of particle size distributions in mineral processing practices. The method is based on the principle of determination of passing particles through a certain aperture size. However, while using sieve analysis method in processing plants, taking representative samples from certain process flows such as conveyor belts is only possible through means of stopping the process completely. Therefore investigation of alternative methods for the determination of particle size distribution by without disturbing the process has become of interest in many recent studies [2-9].

One of the alternative methods that can be used for determination and analyzing of particle size distribution and shape factors is digital image processing. Image processing is a practice which carried out for in order to transform a measured or captured digital image data by use of a computer software according to the application areas. Image processing is commonly used for processing available captured images by means of altering, splitting or enhancing available pictures and graphics [10-13].

There are several studies conducted on the application digital image processing for the determination of particle size distribution. Jenkins et al. (1991) and Tovey (1995) used image processing techniques for determination of the particle size distribution of the mineral masses at different sizes. In this context, micro-dimensional studies were performed and size determination were realized on images taken from optic and electron microscope [14, 15]. Goodchild and Fueten (1998) studied and analyzed grain boundaries of grained rock images from electron microscopy using image processing techniques [16].

Makinacı and Sinecen (2010) were aimed to classify the descriptive vectors obtained by using image processing techniques with the help of artificial neural networks. The results show that image processing and artificial neural networks are

* Autor corespondent/*Corresponding author*,
E-mail: mert.terzi@istanbul.edu.tr

effective methods for the determination and separation of aggregate properties. Additionally they have suggested that the automation systems in aggregate quarries will affect efficiency, cost and time factors with such approaches [17]. Edizer (2006) analyzed the grain size distribution analysis by using digital image processing method and analyzed the images obtained by digital techniques using open source code IMAGEJ software. As a result, the particle sizes, quantities and measured values of the particles were successfully obtained [18]. Karakuş (2006) developed an image analysis program using Visual Basic programming language. Mineral fractions and grain size distributions were determined from thin section images with the help of special functions that allow analysis on the rocks in the program. In addition, the size distribution of the pile after blasting was successfully determined by using image processing methods [19].

In an exemplary study by Thuley (2011) on the determination of particle sizes of crushed stone samples in a belt conveyor process flow by digital methods; measurements were made with a 3D image processing system. Various decision methods have been used for the evaluation of the particles that are overlapping and not in the system, and the size of the particles has been determined separately. In the study carried out, grain size distributions of two different materials loaded to conveyor belts with different grain size distributions were determined and compared with the sieve analysis results. A very good correlation was obtained between 3D image processing and sieve analysis in the measurements made on 40-70 mm material, but deviations were found between the results of 3D image processing and sieve analysis in measurements made on 20-40 mm material [20]. Another example of work in this area, grain size distributions of coarse size aggregates were determined by digital image processing method. Three different types of aggregate samples were investigated and the grain size distribution obtained by digital image processing was compared with the results of classical sieve analysis. A good correlation was obtained between the digital image processing results converted to mass classification and the results of conventional screen analysis after the measurements made [21]. In Liao and Tarng's 2009 work, a new online machine vision optical system based on digital image processing method was developed in order to determine grain size distributions of coarse sized materials. The system has a grain discrimination module, an image acquisition module, an image processing and analysis module and a PLC-based control module. The experiments carried out within the scope of the study used particles with a size range of 1-100 mm; the particle size distributions, number and cumulative weights of the grains were determined in the said system. The system is based on the principle of displaying free falling particles, with the error margin being a fairly low value of 1.5% [22].

The main objective of this study is to make particle size measurements in crushed stone plants by use of digital image processing techniques. In this context, a lab scale digital image processing set-up was assembled as a first step in order to test the reliability of planned final set-up in a simulated plant conditions. Systematic imaging for image processing and processing of the captured images was realized using this set-up, and then finally, reliability and accuracy analyses were made on the obtained data and results were discussed. Plant-scale image processing analyzes were performed at a privately owned aggregate facility operating in Istanbul Kemerburgaz region, Turkey. A pilot scale set-up assembled at the plant and images were periodically taken from the conveyor belt of rotary crusher throughout shift, and then these images were processed with the help of a computer software. The obtained results were compared to each other to achieve reliable and reproducible particle size distribution values of the representative samples.

2. Materials and methods

2.1.Particle Size Distribution Analyses with Digital Image Processing

Split Desktop software was used for PSD analysis of the sample with DIP method. Principal stages used in image processing by the software are as follows:

- Obtaining digital images automatically or manually: Images taken in this study were obtained as video recording using a high resolution CMOS network camera (Hikvision, China) and the images were captured from the video recording and transferred to the computer.
- Pre-processing of the unacceptable images that have lighting problems: The image transferred to the software for image analysis needs to have necessary quality and clearness, so the lighting condition and sharpness should be adjusted after the picture is taken if necessary.
- Defining the fragments within DIP algorithm: The delineation parameters such as noise size, watershed ratio and gradient ratio and the coloring of the fine particles that are too small to include in the analysis are defined by the user in this step.
- Applying statistical algorithms to two-dimensional fragment areas to define three-dimensional fragment volumes of each image: In this step the software converts particle area data created by delineation/fragmentation to volumes by applying an internal statistical algorithm to produce the data to be used for PSD.

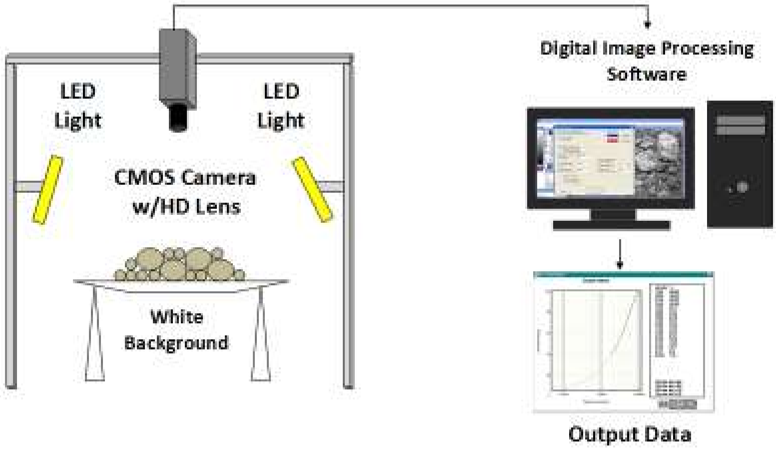

Fig. 1 - Schematic view of the lab set-up.

- Processing various images together for average distribution: In this stage, multiple images taken from one sample can be analyzed at the same time to increase the accuracy of analysis.
- Transmitting output data to the screen, hard disc and network control systems.

Working principle of the software is based on the segmentation of particles by the border determination, and subsequently, calculation of each particle diameter in a 2D image. After this process, the software gives user a chance to correct the errors such as border of the particles. For example, if the user observing an aggregate of particles which needs a further fragmentation or a particle which erroneously fragmented into several smaller particles, it can be manually corrected by user using provided erasing and drawing tools [23-24].

The PSD analysis results determined by DIP method and the PSD analysis results determined by sieve analysis method were compared by using "%Fault" formula given in Equation 1 and the percentage of error was determined.

$$\%Fault = \frac{[DIP\ Result - Sieve\ Analysis\ Result]}{Sieve\ Analysis\ Result}\ X\ 100$$

2.2.Laboratory Scale Studies

As previously stated, laboratory scale digital image processing set-up was assembled as a first step in order to test the reliability of planned final set-up in a simulated plant conditions. The laboratory-scale digital image processing set-up was consisting of a CMOS camera with high-resolution lens, mounting parts, telescopic support legs, a white background, LED lights, a computer and an image processing software. Schematic view of the set-up is given in Figure 1.

The unsized aggregate samples with particles size range of 325×4 mm used for laboratory scale test-work were supplied from a crushed stone plant operating in Cendere Region of Istanbul, Turkey. In the scope of digital image analysis, the aggregate sample was homogenous scattered irregularly on the white background of the laboratory set-up, which imitates the conveyor belt to a degree, and high resolution images of the aggregates were taken. Additionally, the sample was not arranged in any way to prevent overlapping of particles. Subsequently, obtained images were divided to different sections in order to increase the sensitivity of the analyses and these different sections were processed and subjected to PSD analysis individually using a computer software. The image of a sample captured using the set-up is given in Figure 2. In order to allow processing of these images by software, an object with known dimensions was positioned in the center.

Fig. 2 - Raw image obtained with the lab set-up.

Different sections of the irregularly distributed aggregate samples were captured using the set-up and these images were processed with the help of Split Desktop software (Figure 3).


(a) (b)
Fig. 3 - Actual (a) and processed (b) images.

Subsequently, particle size distribution of the sample was also determined by sieve analysis method. The results from sieve analysis were used as a reference for reliability of the PSD results determined by digital image analysis method.

Several methods for evaluating a crushing process have been developed throughout the years. Most of these methods are based on comparing the metrics of particle size distribution of the material before and after granular crushing [25]. The most commonly used metrics when describing particle size distributions are D-Values [26]. Hagerty et al. (1993) used the ratio $d_{50crushed}/d_{50uncrushed}$ to illustrate how crushing evolves when increasing the applied stresses [27]. In addition to the median particle size, the width of the particle size distribution is usually calculated in order to obtain information on the size homogeneity of the particles. Various evaluation methods have been used for this. The ratios between cumulative weight passing particle sizes d_{20} and d_{80} (d_{80}/d_{20}) or d_{16} and d_{84} (d_{84}/d_{16}) are used to evaluate the spread of the particle size distribution [28]. Accordingly, d_{20}, d_{50} and d_{80} sizes were used for the comparison of the PSD of the crushed aggregates.

Fig. 4 - Appearance of apparatus in plant environment.

Fig. 5 - Actual (a) and adjusted (b) images taken from conveyor belt.

2.3.Plant Scale Studies

The same set-up that has been tested in laboratory was assembled over the conveyor belt of the vertical mill crusher output in the plant. In plant scale studies, the camera was adjusted to be positioned at a height of about 1 m from the conveyor belt with facing it from a 90° angle (Figure 4).

36 images were captured from the vertical mill crusher output conveyor belt with 10 minute intervals throughout the shift. In order for these images to be processed in the program, an object with known dimensions were positioned in the same level as conveyor belt. A sample image obtained from conveyor belt using the setup, and adjustment of the images for DIP procedure are shown in Figure 5a and Figure 5b, respectively.

Images taken from vertical mill crusher output conveyor belt with plant setup were processed with Split Desktop software (Figure 6).

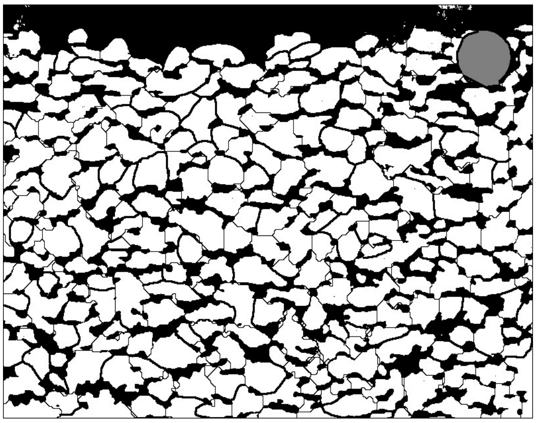

Fig. 6 - An exemplary processed image taken from conveyor belt.

3. Results and discussion

3.1. Results of Laboratory Scale Studies

3.1.1. Sieving Analysis

The result of the PSD analysis using sieving method showed that d_{20}, d_{50} and d_{80} sizes of the sample used in laboratory scale studies were 9.60 mm, 12.72 mm and 17.30 mm, respectively. Cumulative undersize graph of the sample is given in Figure 7.

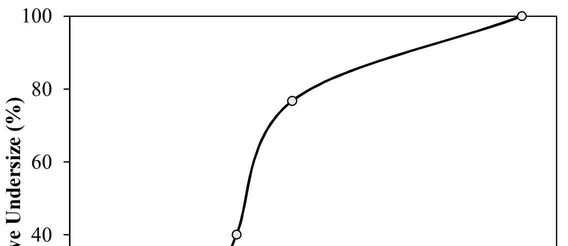

Fig. 7 - Result of PSD analysis using sieving method.

3.1.2. Digital Image Processing

The results of the PSD analyses using the DIP method of the four different sections obtained by division of the images taken from lab scale studies are given in Figure 8.

According to particle size analysis of the Section 1 realized by digital image processing; d_{20}, d_{50} and d_{80} sizes of the sample were determined as 8.49 mm, 12.34 mm and 16.74 mm, respectively. d_{20}, d_{50} and d_{80} sizes of the sample were determined as 9.36 mm, 13.50 mm and 18.55 mm, respectively according to particle size analysis by digital image processing of the Section 2. According to particle size analysis of the Section 3 realized by digital image processing; d_{20}, d_{50} and d_{80} sizes of the sample were determined as 9.21 mm, 13.39 mm and 18.43 mm, respectively. d_{20}, d_{50} and d_{80} sizes of the sample were determined as 9.17 mm, 13.24 mm and 18.20 mm, respectively according to particle size analysis by digital image processing of the Section 4.

Table 1

Results of percentage error in laboratory studies (particle size range 325×4 mm)

Section No	Particle Size (mm) Sieve Analysis d_{20}	d_{50}	d_{80}	Digital Image Processing d_{20}	d_{50}	d_{80}	Error (%) d_{20}	d_{50}	d_{80}
1	9.60	12.72	17.30	8.49	12.34	16.74	11.53	2.99	3.24
2				9.36	13.50	18.55	2.55	6.13	7.23
3				9.21	13.39	18.43	4.11	5.27	6.53
4				9.17	13.24	18.20	4.52	4.09	5.20
						Mean	5.68	4.62	5.55

Table 2

d_{20}, d_{50}, and *d_{80}* results for images taken from conveyor belt

Image No	d_{20}	d_{50}	d_{80}	Image No	d_{20}	d_{50}	d_{80}
1	7.85	11.03	14.76	19	8.64	11.99	16.04
2	7.09	10.18	13.94	20	7.54	10.50	14.04
3	7.04	10.00	13.68	21	7.76	10.86	14.59
4	7.55	10.73	14.82	22	8.45	11.74	15.81
5	7.24	10.22	13.80	23	8.41	11.54	15.18
6	6.57	9.409	12.90	24	8.37	11.51	15.07
7	7.59	10.73	14.48	25	8.69	11.94	15.65
8	7.81	11.26	15.47	26	9.16	12.47	16.19
9	7.58	10.66	14.27	27	8.98	12.43	16.59
10	7.22	10.59	14.76	28	8.56	11.92	15.91
11	7.81	11.10	14.98	29	8.93	12.74	17.58
12	6.39	9.193	12.64	30	8.99	12.69	17.06
13	6.97	9.902	13.34	31	8.55	11.96	15.86
14	6.89	9.835	13.35	32	8.70	12.05	15.86
15	6.75	9.622	13.01	33	8.97	12.21	15.99
16	6.73	9.585	12.99	34	7.02	10.11	13.69
17	6.88	9.88	13.42	35	6.51	9.25	12.49
18	7.35	10.53	14.37	36	6.43	9.16	12.44
Average	7.72	10.87	14.64				
S.D.	0.86	1.08	1.34				

The error data obtained by the comparison of the averages of the particle sizes of different sections obtained by DIP method and particle sizes obtained by sieving method are given in Table 1.

The maximum error in the laboratory work was 11.53% with d_{20} in section 1 and the minimum error was 2.55% with d_{20} in section 2. Average errors for d_{20}, d_{50} and d_{80} sizes were found to be 5.68%, 4.62% and 5.55%, respectively. Although the obtained percentage of errors for all d-sizes were found to be within tolerable limits, d_{50} size values were usually found to be marginally closer to sieve analysis data. The possible cause of the skimming in d_{80} is; when particle boundaries are determined, it is thought that some particles are perceived together as bigger particles and thus larger size values are obtained. On the other hand, skimming in d_{20} can be associated with the possible difficulty in sensitive border detection under certain particle sizes.

3.2. Results of Plant Scale Studies

The *d_{20}, d_{50}* and *d_{80}* sizes obtained after processing of the images taken throughout the shift are summarized in Table 2.

Sieve analysis was carried out on the sample obtained from the plant to determine the average particle size distribution. The error percentages obtained when comparing the data obtained from the processed images with the actual data are given in Table 3.

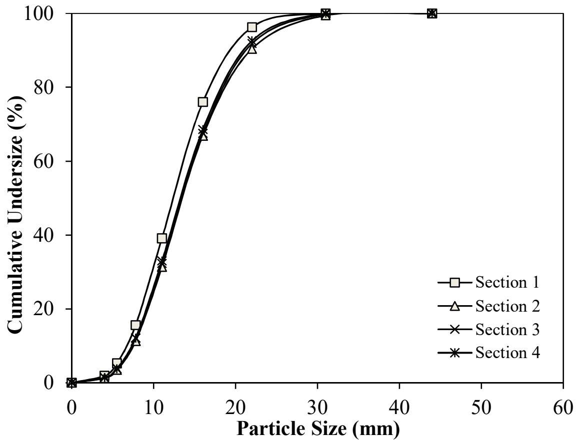

Fig. 8 - Result of PSD analysis using DIP method.

Compared to actual data of 36 different images taken from conveyor belt, the average error of the system; d_{20}, d_{50} and d_{80} sizes were found to be 5.25%, 11.55% and 20.00%, respectively. In parallel to laboratory studies, error percentage of d_{80} size found to be higher than d_{20} and d_{50} sizes. Again, the possible cause of this situation is thought that some particles over the conveyor belt are perceived together as bigger particles.

The images obtained from the aggregates on the conveyor belt flow appear to be more homogeneous because of the large number of images and continuous flowing over the belt. However, such factors as stacking, vibration and dust in the environment constitute constraints in terms of measurement precision.

Table 3

Results of percentage error in plant studies

Image No	Error (%)			Image No	Error (%)		
	d_{20}	d_{50}	d_{80}		d_{20}	d_{50}	d_{80}
1	3.64	15.71	20.98	**19**	6.05	22.97	31.48
2	12.98	5.28	14.26	**20**	7.47	7.69	15.08
3	13.60	3.07	12.13	**21**	4.83	11.38	19.59
4	7.37	12.02	21.48	**22**	3.64	20.41	29.59
5	11.18	5.77	13.11	**23**	3.25	18.36	24.43
6	19.34	4.18	5.74	**24**	2.76	18.05	23.52
7	6.81	12.02	18.69	**25**	6.61	22.46	28.28
8	4.15	18.53	26.80	**26**	12.39	27.90	32.70
9	6.97	11.17	16.97	**27**	10.20	27.49	35.98
10	11.37	10.31	20.98	**28**	4.99	22.26	30.41
11	4.13	16.56	22.79	**29**	9.56	30.67	44.10
12	21.61	6.83	3.61	**30**	10.34	30.15	39.84
13	14.52	1.87	9.34	**31**	4.92	22.67	30.00
14	15.51	1.04	9.43	**32**	6.71	23.59	30.00
15	17.13	1.57	6.64	**33**	10.10	25.23	31.07
16	17.42	2.02	6.48	**34**	13.91	3.69	12.21
17	15.55	1.60	10.00	**35**	20.07	5.12	2.38
18	9.80	9.57	17.79	**36**	21.08	6.06	1.97
				Average	5.25	11.55	20.00

As a result, d_{20}, d_{50} and d_{80} sizes of a crushed stone plant product were determined with confidence levels of 94.75%, 88.45% and 80.00%, respectively. The obtained results showed that a system based on digital image processing method can be applied in particle size analysis with high success as alternatives to conventional methods.

4. Conclusion

In this study, the particle size distribution analysis of the samples taken from privately owned aggregate processing plants using sieve analysis and digital image processing methods were conducted and accordingly a comparison of these methods in terms of the applicability on industrial scale were realized. In this context, a lab scale digital image processing set-up was assembled. Systematic imaging for image processing and processing of the captured images was realized using this set-up. Subsequently, the same set-up that has been tested in laboratory was assembled over the conveyor belt of the vertical mill crusher output in the plant.

Results of the lab scale studies showed that all d-sizes can be detected with tolerable percentage of error using the proposed set-up. Meanwhile, when we compared the results of plant scale experimental studies with real data; it is observed that real and experimental values for d_{20} and d_{50} sizes were generally determined to be close to each other. However, values of d_{80} size were above real values. The most important reason for this is presumed to be that some particles were detected as a single particle when particle edges were determined and thus larger particle sizes were obtained. Moreover, the difference in the results of lab scale and plant scale studies can be associated with the difference in measurement environment (static measurement in the lab environment/dynamic measurement in the plant environment). Additionally, the resulted deviations between the methods can be attributed to a fact that the DIP method takes only a two dimensional projected image of a particle, therefore elongated particles which were likely to pass a certain sieve size might be considered as oversize in DIP method. Nevertheless, the most important advantage of the system is that the equipment used in the study consists of components with lower costs and easy availability. As a result, particle size distribution data comparable to more advanced techniques such as 2D methods using different methodologies and 3D imaging can be obtained with the digital image processing procedure applied within the scope of this study.

As a conclusion, the obtained results supported that the DIP method can be used, especially with applying a correction coefficient due to varying degrees of error in d_{80} sizes, in PSD analysis of unsized aggregates as an alternative to conventional methods such as the sieve analysis.

ACKNOWLEDGEMENTS

This work was supported by the Scientific and Technological Research Council of Turkey, TÜBİTAK with project number 214M425. The author would like thank Prof. Ilgin KURSUN, Research Assistant Tugba Deniz TOMBAL and Research Assistant Ulas CINAR for their valuable contributions and Akçansa Corp. for their help with plant-scale studies.

REFERENCES

1. I. Kursun, Particle Size and Shape Characteristics of Kemerburgaz Quartz Sands Obtained By Sieving, Laser Diffraction, And Digital Image Processing Methods, Mineral Processing and Extractive Metallurgy Review, 2009, **30**(4), 346.
2. B.A. Wills, Mineral Processing Technology, 1985, Oxford: Pergamon Press.
3. Y. Keskin, Coal Preparation Methods, 1986, Zonguldak: Turkish Hard Coal Enterprise Publications.
4. S. Saklar, I. Bayraktar, M. Oner, Fine Partide Size Analyzing Techniques, Mining Journal, 2000, **39**(2), 29.
5. C. Bernhardt, Particle Size Analyses, Classification and Sedimentation Methods, 2000, Chapman & Hall.

6. P. Kippax, Measuring Particle Size Using Modern Laser Diffraction Techniques, Paint & Coating Industry Magazine, 2005, 1.
7. U. Ulusoy, M. Yekeler, C. Bicer, Z. Gulsoy, Combination of the Particle Size Distributions of Some Industrial Minerals Measured by Andreasen Pipette and Sieving Techniques, Particle and Particle Systems Characterization, 2006, **23**(6), 448.
8. U. Ulusoy, Application of ANOVA to Image Analysis Result of Particles Produced by Different Milling, Powder Technology, 2008, **188**(2), 133.
9. I. Kursun, K. Ozdemir, An Example of the Application of Digital Image Processing Methods to Mineral Processing: Determination of Particle Size of Akpinar Quartz Sands, in Proceedings of 21st International Mining Congress and Exhibition of Turkey, Antalya, Turkey, May 2009, (Chamber of Mining Engineers of Turkey), 365.
10. N.K. Tovey, M.W. Hunslow, Quantitative micro-porosity and orientation analysis in soils and sediments, Journal of the Geological Society London, 1995, **152**(1), 119.
11. A. Yılmaz, MSc Thesis, Real time security application with image processing using camera, Halic University, Istanbul, 2007.
12. B. Jähne, Digital Image Processing (6th Ed.), 2005, Berlin: Springer.
13. R.C. Gonzalez, R.E. Woods, Digital Image Processing (3rd Ed.), 2007, USA, New Jersey: Prentice Hall.
14. N.K. Tovey, Techniques to examine the microfabric and particle interactions of collapsible soils, Genesis and Properties of Collapsible Soils, 1995, **65**.
15. B.M. Jenkins, C.Y. Boey, P.L. Philips, Applying image analysis to the automatic characterisation of dead-burnt magnesia, in Proceedings of the Congress on Applied Mineralogy, Pretoria, 1991.
16. J.S. Goodchild, F. Fueten, Edge detection in petrographic images using the rotating polarizer stage, Computer Geoscience, 1998, **24**(8), 745.
17. M. Sinecen, M. Makinacı, Classification of Aggregates Using Basic Shape Parameters Through Neural Networks, Pamukkale University Journal of Engineering Science, 2010, **16**(2), 149.
18. E. Edizer, MSc Thesis, Particle size distribution and analysis using digital image processing, Cukurova University, Adana, 2006.
19. D. Karakus, PhD Thesis, Determination of the structural properties of rocks with image analyzing methods, Dokuz Eylul University, Izmir, 2006.
20. M.J. Thurley, Automated online measurement of limestone particle size distributions using 3D range data, Journal of Process Control, 2011, **21**(2), 254.
21. C.F. Mora, A.K.H. Kwan, H.C. Chan, Particle Size Distribution Analysis of Coarse Aggregate Using Digital Image Processing, Cement and Concrete Research, 1998, **28**(6), 921.
22. C.W. Liao, Y.S. Tarng, On-line automatic optical inspection system for coarse particle size distribution, Powder Technology, 2009, **189**(3), 508.
23. K. Ozdemir, A. Kahriman, T. Dogan, Investigation of the Effect of Particle Size Distribution after Blasting on the Excavation Time, II. Work Machinery Symposium and Exhibition, Istanbul, Turkey, October 2005, 273.
24. K. Ozdemir, G. Tuncer, A. Kahriman, U. Ozer, A. Karadogan, The Relation Between Excavator Bucket Loading Time and Particle Size Distribution of Shot Rock, in Proceedings of the 33rd Annual Conference on Explosives and Blasting Technique, USA, February 2007, 303.
25. S. Lobo-Guerrero, PhD Thesis, Evaluation of Crushing in Granular Materials Using the Discrete Element Method and Fractal Theory, University of Pittsburgh, Pittsburgh, 2006.
26. Z. Baig, O. Mamat, M. Mustapha, A. Mumtaz, M. Sarfraz, S. Haider, An efficient approach to address issues of graphene nanoplatelets (GNPs) incorporation in aluminium powders and their compaction behavior, Metals, 2018, **8**(2), 90.
27. M.M. Hagerty, D.R. Hite, C.R. Ullrich, D.J. Hagerty, One-dimensional high-pressure compression of granular media, Journal of Geotechnical Engineering, 1993, **119**(1), 1.
28. K. Ohenoja, PhD Thesis, Particle size distribution and suspension stability in aqueous submicron grinding of $CaCO_3$ and TiO_2, University of Oulu, Finland, 2014.

****

MANIFESTĂRI ȘTIINȚIFICE / SCIENTIFIC EVENTS

IABSE Symposium: Towards a Resilient Built Environment - Risk and Asset Management

Objectives:

• Place the topic of Sustainability of the Built Environment in an International Discussion Forum;
• Offer a Worldwide discussion in risk assessment and infrastructure asset management with a share of knowledge from different stakeholders;
• Discuss Performance and Costs of built environment assets, with a focus on “Zero Maintenance”;
• Provide the adaptation of Young Engineers to the topics of Risk, Construction, Quality, Resilience and Management.

https://www.rilem.net/agenda/iabse-symposium-towards-a-resilient-built-environment-risk-and-asset-management-1231

****