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Determination of flakiness index (FI) and shape index (SI) using open source digital image analysis software

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Abstract. The aim of the article was to verify the possibility of using open source digital image analysis software to determine the particle shape. Devices using laser diffraction or dynamic image analysis could be used to determine size and shape of particles. However, the laboratory devices for digital image analysis are relatively expensive. For this reason, it was decided to use open source digital image analysis software Fiji Is just ImageJ and mobile phone with a 12 Mpx camera. Coarse aggregates of basalt and granite were used in the study. Flakiness index (FI) and shape index (SI) were determined using two methods: in accordance with the European Standard and with the use of digital image analysis (reference method). Based on the obtained results it was found that there is an appropriate relationship between the European Standard method and the reference method.

1. Introduction

High quality of aggregate is very important in industries such as road construction and architectural engineering. The size and shape of aggregate depends on processing methods (mainly grinding method) used during the production [1].

Aggregate for road construction and architectural engineering should have regular, cubical shape, since the ratio of length to width of particles has essential impact on their strength. The shape characteristics of aggregate impacts the asphalt performance [2]. The durability, workability, tensile strength, shear resistance, optimum binder content of the mixture and fatigue response of asphalt concrete depends on the shape of coarse aggregate [3]. Grading and shape of aggregate highly affects the strength of concrete [4, 5, 6, 7].

To test geometrical properties of aggregates two European Standard are used: EN 933-4:2012 [8] to determine the flakiness index (FI) and EN 933-4:2008 [9] to determine shape index (SI). However, also digital image analysis is used to assess the aggregate quality [10]. For this purpose, high resolution digital cameras [11] or stereomicroscopes could be used [12]. The latest devices for measuring the size and/or shape of particles are using laser diffraction or dynamic image analysis. A very valuable advantage of this type of devices is high measurement accuracy, speed and automaticity of measurement. The measurement can be carried out on a dry or wet sample. There are many manufacturers of such devices such as:

- Fritsch (Germany) – Analysette 28 ImageSizer (20 µm – 20 mm), Analysette 22 NanoTec (0.01 – 2100 µm) [13, 14)

- Kamika (Poland) – AWK 3D analyzer (200 µm – 31,5 mm), mini 3D analyzer (0.5 µm – 2000 µm), IPS UA analyzer (0.5 – 2000 µm) [15, 16]
- Malvern Panalytical (the Netherlands) – Morphologi G3 analyser (0.01 – 3500 µm) [17]
- Retsch Technology (Germany) – CAMSIZER X2 (0.8 µm – 8 mm), CAMSIZER P4 (20 µm to 30 mm) [18, 19, 20]

2. Materials and methods

Coarse aggregate of basalt and granite were used in the study. At the first stage the material was crushed in a jaw crusher. Afterwards the sieve analysis using square meshes of size 4 mm and 8 mm was carried out (figure 1) in accordance with the European Standard [21]. The particle size fraction 4 – 8 mm was then sieved into three narrow fractions:

- 4 – 5 mm,
- 6.3 – 8 mm,
- 8 – 6.3 mm.

A 100-gram representative samples of each type of coarse aggregate were selected for further analysis.

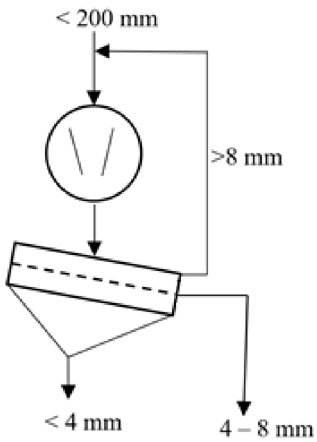

Figure 1. Laboratory-scale comminution circuit.

In accordance with the European Standard [8, 9] to test for geometrical properties of aggregates two indexes were determined:

- FI:

$$FI = \frac{M_2}{M_1} * 100 \quad (1)$$

where:

M_1 – the sum of the masses of the particles in each of the particle size fraction d_i/D_i [g]

M_2 – the sum of masses of the particles in each particle size fraction passing the corresponding bar sieve (figure 2) of slot $D_i/2$ [g]

Particle size fractions (d_i/D_i) is a fraction of an aggregate passing the larger (D_i) of two sieves and retained on the smaller (d_i). The overall flakiness index (FI) shall be recorded to the nearest whole number.

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Figure 2. Laboratory bar sieve.

- SI:

$$SI = \frac{M_2}{M_1} * 100 \tag{2}$$

where:
M_1 – the mass of test portion [g]
M_2 – the mass of the non-cubical particles [g]

Individual particles in a sample of coarse aggregate are classified on the basis of the ratio of their length L to thickness E using a particle slide gauge (figure 3) where necessary. The shape index is calculated as the mass of non-cubical particles (particles with ratio of dimensions L/E more than 3) expressed as a percentage of total dry mass of particles tested.

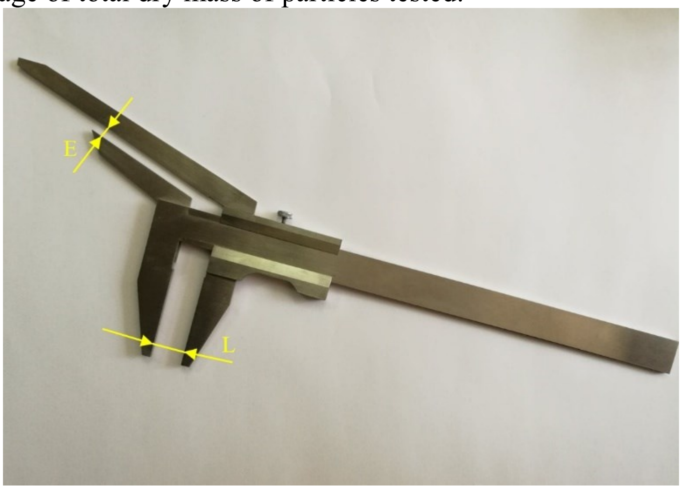

Figure 3. Particle slide gauge.

For digital image analysis high resolution photos with special filter were taken in two projection: from top and front view. A mobile phone with a 12 Mpx camera was used to take pictures. The figure 4 and 5 show examples of the taken photos.

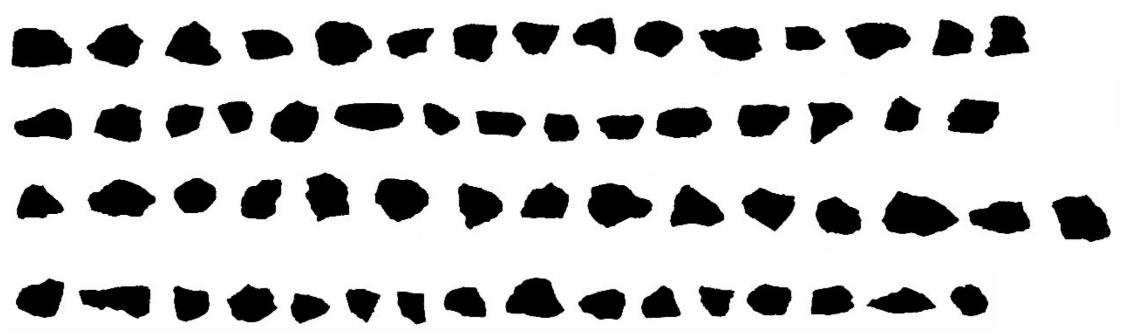

Figure 4. Top view of regular basalt particles (6.3 – 8 mm).

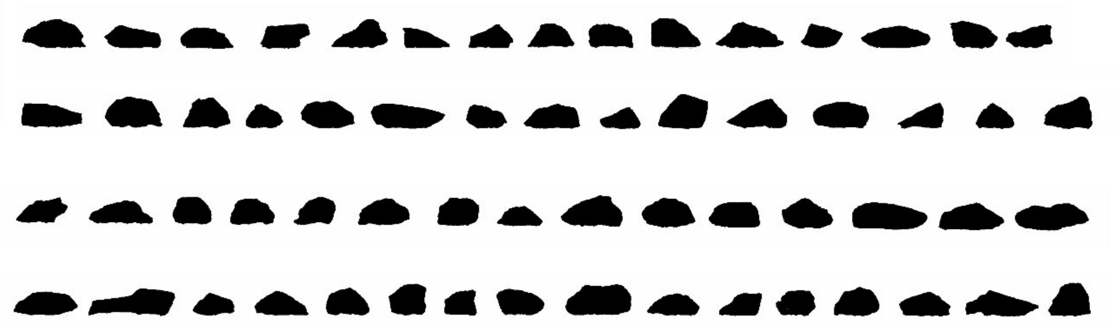

Figure 5. Front view of regular basalt particles (6.3 –8 mm).

Open source software Fiji Is just ImageJ [22] was used to measure the length and width of particles. In order to determine the flakiness index (FI) and shape index (SI) using the digital image analysis the following assumptions were made:

- length (L) of the particle is the higher value of L from top and front view of particle (figure 6 and 7)
- width (W) of the particle is the lower value of W from top and front view of particle (figure 6 and 7)
- a single particle should pass the corresponding bar sieve of slot $D_i/2$ if the value of width (W) is lower than $D_i/2$.
- a single particle is non-cubical when L/W ratio is higher than 3

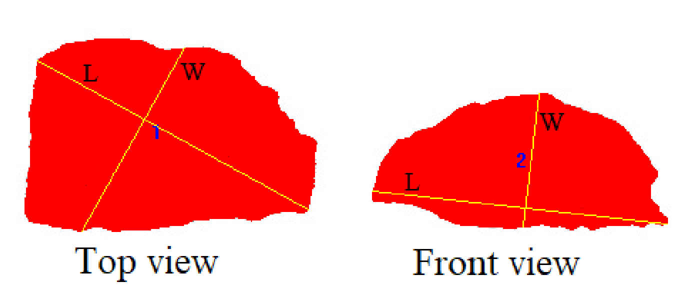

Figure 6. Top and front view of regular basalt particle (6.3 – 8 mm).

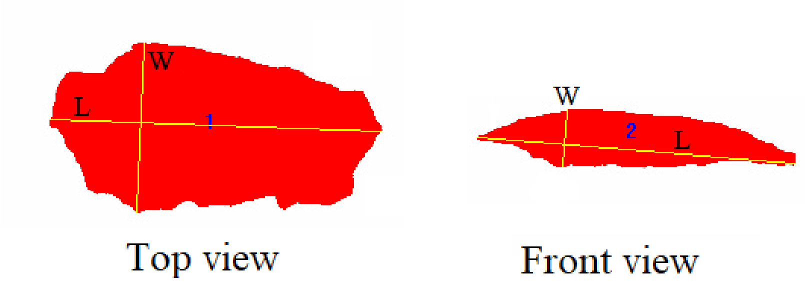

Figure 7. Top and front view of irregular basalt particle (6.3 – 8 mm).

3. Analysis of results

For basalt and granite coarse aggregate (4 – 8mm) FI was determined using two methods: in accordance with the European Standard (table 1) and with using of the digital image analysis (table 2). SI of basalt and granite coarse aggregate (4 – 8 mm) was determined using two methods: in accordance with the European Standard (table 3) and with using of digital image analysis (table 4.)

Table 1. Flakiness index (FI) based on European Standard.

Type of coarse aggregate	Particle size fraction	Mass M_1 [g]	Mass M_2 [g]	Flakiness Index (FI) [%]
Basalt	4 – 8	100	31.7	32
Granite	4 – 8	100	24.1	24

Table 2. Flakiness index (FI) based on digital image analysis.

Type of coarse aggregate	Particle size fraction	Mass M_1 [g]	Mass M_2 [g]	Flakiness Index (FI) [%]
Basalt	4 – 8	100	27.56	28
Granite	4 – 8	100	21.72	22

Table 3. Shape index (SI) based on European Standard.

Type of coarse aggregate	Particle size fraction	Mass M_1 [g]	Mass M_2 [g]	Shape Index (SI) [%]
Basalt	4 – 8	100	30.20	30
Granite	4 – 8	100	28.02	28

Table 4. Shape index (SI) based on digital image analysis.

Type of coarse aggregate	Particle size fraction	Mass M_1 [g]	Mass M_2 [g]	Shape Index (SI) [%]
Basalt	4 – 8	100	25.91	26
Granite	4 – 8	100	26.47	26

When analyzing the results it can be noticed that for both measurement methods the values of FI and SI are higher for basalt than for granite coarse aggregate. It indicates that granite coarse aggregate contains more regular particles than basalt coarse aggregate after same comminution method.

For granite coarse aggregate the difference in the FI and shape index SI value determined in accordance with the European Standard and with the use of the digital image analysis is 2 %. For basalt coarse aggregate the difference is higher. FI and SI values determined in accordance with the European Standard are 4% greater, than the value determined with the digital image analysis. The reason for differences in results for both methods is the occurrence of low width particles with a curved surface (figure 8.). These particles are classified as irregular according to the European Standard. However, based on digital image analysis, some of them are considered as regular particles. Most particles of this type contain basalt coarse aggregate grade 4 – 5 mm. In order to get more accurate results using digital image analysis three projection: from top, front and side view should be used, especially with 4 – 5 mm grade.

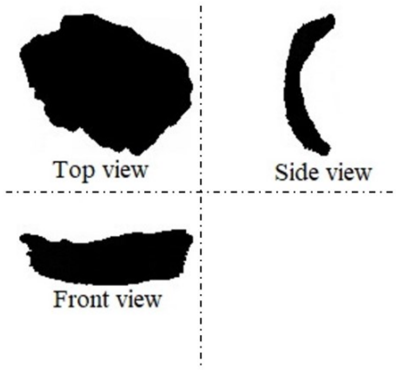

Figure 8. Top, front and side view of the irregular basalt particle (4 – 5 mm).

4. Summary

The results of tests of geometrical properties of aggregates proved appropriate relationship between the European Standard method and the reference method (digital image analysis). The presented method of digital image analysis is a proper tool to determine the FI and SI at low cost. In addition, open source digital image analysis software Fiji Is just ImageJ allows to determine the size (area, diameter, perimeter, width, length) and shape descriptors (circularity, aspect ratio, roundness, solidity) of particles [23, 24].

Experimental work allows to draw the following conclusions:

- With same comminution procedure, the lower values of FI and SI were achieved for granite coarse aggregate,
- The differences between values of FI and SI achieved with the European Standard method and the reference method (digital image analysis) are 2 % for granite coarse aggregate and 4 % for basalt coarse aggregate,
- Results obtained from the photos taken in two projections (top and front view) are sufficient if the coarse aggregate does not contain low width particles with a curved surface.

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