Applicability of two different methods for determining particle shape

Uporabnost dveh različnih metod za določevanje oblike delcev

Damjan Hann[1]

[1]University of Ljubljana, Faculty of Natural Sciences and Engineering, Aškerčeva cesta 12, SI-1000 Ljubljana, Slovenia; E-mail: damjan.hann@ntf.uni-lj.si

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Abstract: This report presents two methods for determining the shape of coarse aggregate grains with grain size ranging from 4 mm to 8 mm, and describes the shape index and shape factor. The method for determining the shape index according to SIST EN 933-4:2000 standard and the method for determining shape factor in two-dimensional space using computer software Leica Image Manager IM 50, used for processing of digital images, are presented. Particle shape plays a significant role in using rock aggregates for various purposes, both in terms of quality management and product price. Due to their isometric shape and consequently relatively high strength, cubic-shaped particles are often favoured. In this study we used three samples from different surface excavation sites in Slovenia. Each sample consisted of 80 randomly selected grains of coarse rock aggregate. The purpose of the research was to determine the advantages and disadvantages of both methods for determining the particle shape and to suggest the optimal method for quick and objective quality control in production with regard to particle shape.

Izvleček: Članek govori o določevanju oblike delcev grobega kamenega agregata frakcije velikosti delcev 4–8 mm oz. o indeksu in faktorju oblike, ki sta bila določena po dveh med seboj različnih metodah. Predstavljena je metoda določevanja indeksa oblike po evropskem standardu SIST EN 933-4:2000 ter metoda določevanja faktorja oblike v dvodimenzionalnem prostoru s pomočjo računalniške programske opreme Leica Image Manager IM 50, ki je bila uporabljena pri obdelavi digitalnih posnetkov. Oblika delcev ima sicer velik pomen pri uporabi kamenih agregatov za različne namene, opredeljuje lahko tudi kakovost in ceno nekega proizvoda. Zaradi svoje izometrične oblike in posledično relativno visoke trdnosti so najpogosteje zaželena kubična zrna. V raziskavo so bili vključeni trije vzorci iz različnih slovenskih površinskih kopov. V vsakem vzorcu je bilo 80 naključno izbranih delcev grobega kamenega agregata. Cilj raziskave je bil določiti prednosti in pomankljivosti izbranih metod za določanje oblike delcev oz.

Review paper

določiti ustrezno metodo za hitro in objektivno kontrolo kakovosti proizvodnje z ozirom na obliko delcev.

Key words: particle shape, shape index, shape factor, isometricity of particles
Ključne besede: oblika delcev, indeks oblike, faktor oblike, izometričnost delcev

Introduction

Rocks appear in different particle shapes in nature. For example, particles which have been formed by the process of physical weathering of rocks are much more angular than the particles which have been subjected to the activity of water, glaciers or waves, which are more round-shaped. Particles of rock aggregates, obtained by crushing or milling of the excavated material also produce a specific shape[1].

Particle shapes play a significant role in processes and influence the quality of the product and hence its price. In crushing rocks it is necessary to select a suitable crusher. Some crushers produce large amounts of unwanted shapes, i.e. elongated and flat grains[2]. The most desirable shapes are cubic grains due to their isometric form and relatively high strength.

Almost all processing industries require cubic grain forms. In road construction, for example, elongated and flat grains will crush after first rolling. Such grain shapes cause problems in bituminizing, leaving faults in the coating which are further exposed to weather impacts. If we use cubic-shaped grains for making concrete, we can achieve better and more even strength of cubes, use less cement and achieve better shapability of concrete.

In our project we focussed on determining the shape of particles in coarse rock aggregate which is usually incorporated in the material for making road fundations and as an aggregate in making concrete. The objects of research were the shape index and shape factor of particles in coarse rock aggregate (fractions with particle size ranging from 4–8mm), which were determined by two different methods.

We present the method for determining the shape index according to the European standard SIST EN 933-4:2000[3] and the method for determining the shape factor in two-dimensional space, using computer software Leica Image Manager IM 50[4] for digital image processing.

Materials and methods

Determining the shape index of particles following the European SIST EN 933-4:2000 standard

The European SIST EN 933-4:2000 standard describes the method of determining the shape index in coarse aggregates. This testing method is useful for fractions with particle size between 4–63 mm, or fractions $D_i \leq 63$ mm and $d_i \geq 4$ mm, where:

D_i/mm maximum particle size,
d_i/mm minimal particle size.

The shape index, obtained by the standard above, classifies particles based on the ratio between the particle length and its thickness, and gives two categories of particle shape: cubic in non-cubic particles. Individual particles in the sample of coarse aggregate are classified based on the ratio between the length of the particle *L* and its thickness *E* using a particle slide gauge for determining category (Figure 1).

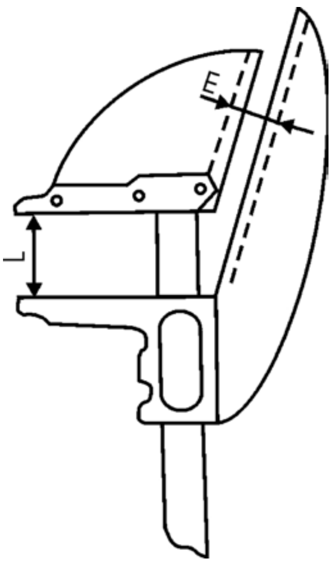

Figure 1. Scheme of the slide gauge
Slika 1. Skica pomičnega merila

The particle length *L* represents the maximum dimension of the particle, which is defined as the gratest distance between two parallel planes, tangential to the surface of the particle. The thickness of particle *E* represents the minimum dimension of the particle, as defined by the least distance between two parallel planes, tangential to the surface of the particle. Slide gauge has two openings: one is used for measuring the length *L*, and the other for measuring the thickness of the particle *E*.

Prior to analysing the shape index of particles it is necessary to prepare a sample. The sample must be passed through sieves with mesh sizes of 4 mm, 8 mm, 11,2 mm, 16 mm, 22,4 mm, 31,5 mm, 45 mm, and 63 mm. This allows for suitable separation of particles, i.e. larger than 4 mm and smaller than 63 mm. According to the standard, minimum quantities of sample are required considering the upper size limits of particles (Table 1).

Table 1. Minimum mass of the sample with regard to the maximum size of the aggregate
Tabela 1. Minimalna masa vzorca glede na maksimalno velikost agregata

Maximum size of aggregate D_i/mm	Minimum mass of the sample m/kg
63	45
32	6
16	1
8	0,1

Non-cubic particles are those in which the ratio between the length and the thickness is $L/E > 3$. The shape index is calculated as a mass of particles with the ratio of dimensions $L/E > 3$ against the total dry mass of the particles tested and is expressed in percentage.

The shape index is defined by the following equation:

$$SI = \frac{M_2}{M_1} \cdot 100 \qquad (1)$$

where:

SI/%	shape index
M_1/g	mass of the sample
M_2/g	mass of non-cubic particles

Determining the shape of particles in two-dimensional space using computer supported image processing

Computer processing of images has greatly contributed to the development of determining the shape of particles. The method for determining the shape of particles in two-dimensional space using computer software Leica Image Manager IM 50 is a method by which geometrical parameters of individual particles are determined by computer processing of digital images.

The shape factor of the particle in two-dimensional space can be determined using the following equation[5, 6]:

$$F = \frac{4 \cdot \pi \cdot A}{P^2} \quad (2)$$

Where the symbols mean:

F	shape factor
A/m^2	surface of particle
P/m	circumference of particle
π	constant

Shape factor F denotes the roundness of the sample: it tells how close the shape of the particle is to the shape of a regular circle. In particles with spherical shape F = 1, while for all other shapes $FO < 1$. For easier presentation, the shape factors for some basic shapes are given:

- CIRCLE
  1.0
- SQUARE
  0.785
- RECTANGLE (a/b = 1/2)
  0.698
- EQUILATERAL TRIANGLE
  0.605
- TRIANGLE (base/altitude = 1/3)
  0.376

Selection of samples

In our study we used samples from three surface excavations sites in Slovenia. Each sample consisted of 80 randomly selected particles of coarse rock aggregate fractions 4–8 mm in size, which we obtained by quartering. The first sample contained well-rounded gravel, the second sample consisted of crushed dolomite, and the third of crushed limestone.

According to SIST EN 933-4:2000 standard the mass of the sample should be minimum 100 g for the fraction with particle size range 4–8 mm. Since the same sample was also tested by computer method for determining particle shape, the scope of research would be much too large. For this reason we had to quarter the samples until we obtained only 80 grains in each sample. Using the slide gauge we determined the particles with non-cubic shapes and calculated the shape index.

Digital images of coarse rock aggregate particles of fractions with particle size of 4–8 mm were obtained by using a Canon Power Shot S70 digital camera. The images were then transferred and processed by the Leica Image Manager IM 50 computer

Table 2. Results of determining the shape index according to SIST EN 933-4:2000 standard
Tabela 2. Rezultati določanja indeksa oblike po standardu SIST EN 933-4:2000

Sample	Mass of the sample M_1/g	Mass of non-cubic particles M_2/g	Mass of cubic particles M/g	Shape index SI/%
1	23.1	0.8	22.3	3.46 ≈ 4
2	16.6	3.0	13.6	18.07 ≈ 18
3	14.4	2.9	11.5	20,14 ≈ 20

program, where we manually encircled the particles to obtain the information on two geometrical parameters i.e. the surface area and circumference of the particles. This allowed for calculating the shape factor.

RESULTS AND DISCUSSION

Results of determining the particle shape according to SIST EN 933-4:2000 standard

The samples from all three surface excavations were weighed and the mass (M_1 in grams) of each sample was recorded (Table 2). Using a slide gauge we determined the length L and the thickness E for each particle in the sample. The particles with dimension ratio $L/E > 3$ were classified as non-cubic particles. Non-cubic particles in samples were then weighed and the mass of each sample was recorded (M_2 in grams).

Results of determining the particle shape in two-dimensional space using Leica Image Manager IM 50 computer program

Average shape factor (F) for sample No. 1:
$F_{(\text{sample No.1})} = 0.9$

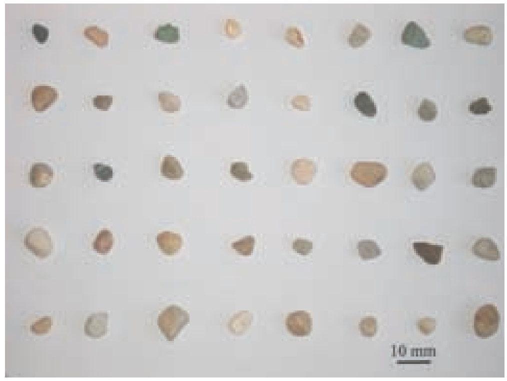

Figure 2. Sample No. 1 – gravel
Slika 2. Vzorec št. 1 – prod

Average shape factor (F) for sample No. 2:
$F_{(\text{sample No. 2})} = 0.84$

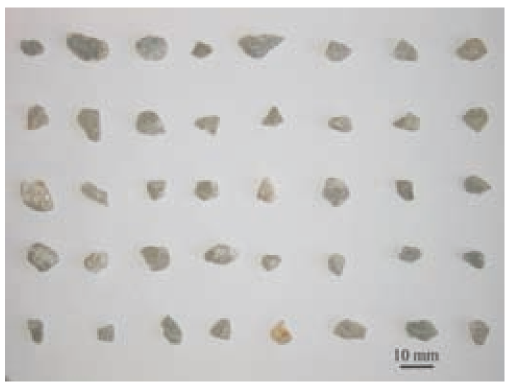

Figure 3. Sample No. 2 – dolomite
Slika 3. Vzorec št. 2 – dolomit

Average shape factor (F) for sample No. 3: $F_{(sample\ No.3)} = 0.83$

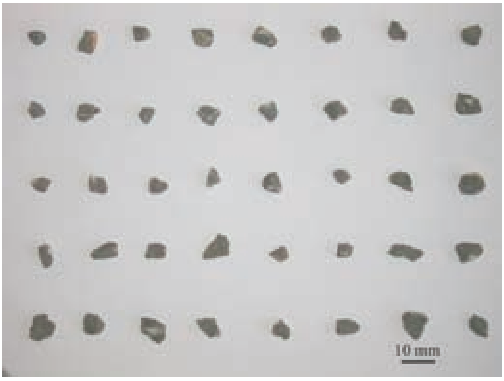

Figure 4. Sample No. 3 – limestone
Slika 4. Vzorec št. 3 – apnenec

Table 3. Research results
Tabela 3. Rezultati raziskave

Sample	Shape index *SI*/%	Shape factor *F*
1	4	0.90
2	18	0.84
3	20	0,83

The shape index for sample No. 1 was 4 % (Table 3), meaning that the share of non-cubic particles in the sample was 4 %, while there were 96 % particles with relatively regular shape and these were considered as cubic particles. The average shape factor for sample No. 1 was 0.90.

The shape index for sample No. 2 accounted for 18 %, meaning that there were 18 % of particles in the sample which were considered as non-cubic and the remaining 82 % were cubic particles. The average shape factor for sample No. 2 was 0.84. The same analogy applies to sample No. 3: there were 20 % of non-cubic particles and 80 % of cubic particles. The average shape factor for this sample was 0.83.

Conclusions

Using the SIST EN 933-4:2000 standard for determining the shape index is an easy and quick method for separating cubic and non-cubic particles from a coarse rock aggregate. This method allows for a rapid and reliable quality control in production. However, this method is not automated; measurements must be done manually, and for this reason the results may be subjective. The downside of this method is that it can be applied only for characterising particles larger than 4 mm and smaller than 63 mm. This method has been developed for determining the particles shape in coarse rock aggregates which are used in the production of asphalt mixtures, production of concrete and construction materials. For these purposes this method for determining particle shape is quite suitable.

The method of determining the shape factor in two-dimensional space using computer processed images is also applicable at micrometer particle size range, which all greatly contributes to the developments in cement, chemical and pharmaceutical industries. This method provides an easy way for measuring geometrical parameters, e.g. surface area, circumference, the length and the width of particles. The weakness of this method is that particles are presented in two dimensions only while the third dimension remains hidden. Therefore, it depends on the position of particles

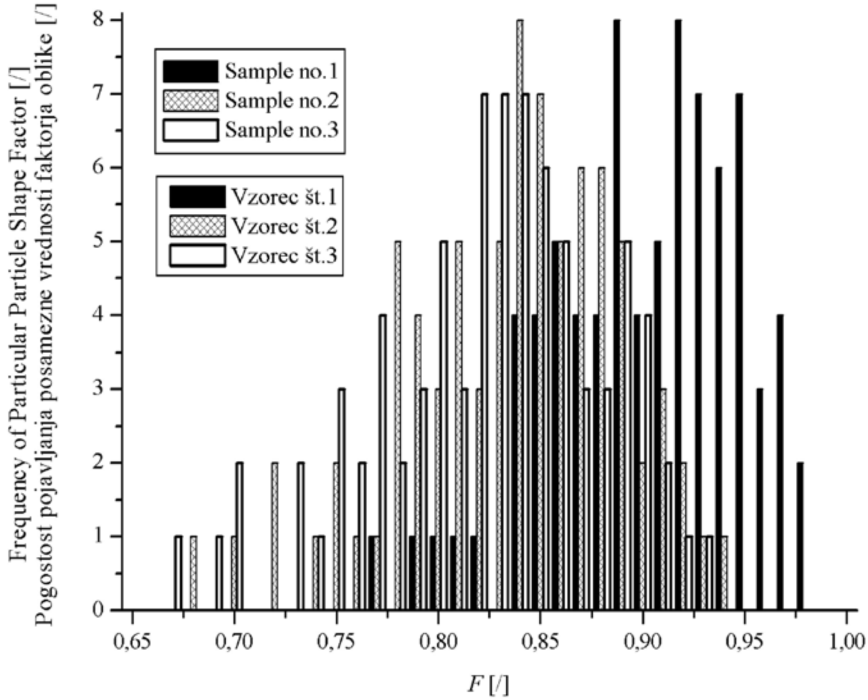

Figure 5. Frequency of particular particle shape factor
Slika 5. Pogostost pojavljanja posameznih vrednosti faktorja oblike

which dimension will be shown. However, this method proved to be quite time-consuming since we had to »manually encircle« every particle. Even though there is a market available software, which allows for automated capturing and processing of data, we found this software of no use in our study.

Both methods are comparable, since both can show the isometricity of particles, as shown by our results. The method according to SIST EN 933-4:2000 standard is faster, while the method of determining the shape factor in two-dimensional space using Leica Image Manager IM50 computer software was more accurate in determining the shape of particles, i.e. the differences in particle shapes were shown more precisely. The shortcoming of this method, however, is that it is time-consuming and limited only to two-dimensional presentation.

POVZETEK

Oblika delcev lahko ima velik pomen pri poteku nekega procesa ter opredeljuje kakovost nekega proizvoda in njegovo ceno. Zaradi svoje izometrične oblike in posledično relativno visoke trdnosti so v industriji običajno najbolj zaželena kubična zrna.

Članek govori o določevanju oblike delcev grobega kamenega agregata, ki se uporablja za vgradnjo v cestne podlage in kot agregat pri izdelavi betona. Predmet raziskav sta bila indeks in faktor oblike delcev grobega kamenega agregata (frakcije velikosti delcev 4–8 mm), ki sta bila določena po dveh med seboj različnih metodah. Predstavljena je metoda določevanja indeksa oblike po evropskem standardu SIST EN 933-4:200 ter metoda določevanja faktorja oblike v dvodimenzionalnem prostoru s pomočjo računalniške programske opreme Leica Image Manager IM 50, ki je bila uporabljena pri obdelavi digitalnih posnetkov.

Indeks oblike, pridobljen s pomočjo pomičnega merila po navedenem standardu klasificira delce na osnovi razmerja med dolžino delca *L* in debelino delca *E* in nam podaja dve kategoriji oblike delcev, kubične in nekubične delce. Nekubični delci so tisti delci, za katere velja, da je razmerje $L/E > 3$. Indeks oblike je izračunan kot masa delcev z razmerjem dimenzij $L/E > 3$ proti celotni suhi masi preskušanih delcev in je izražen v odstotkih.

Metoda določanja oblike delcev v dvodimenzionalnem prostoru s pomočjo računalniške programske opreme Leica Image Manager IM 50 je metoda, kjer s pomočjo računalniške obdelave digitalnih posnetkov določimo geometrične parametre posameznega delca.

Faktor oblike *F* opisuje okroglost delca oz. sporoča, kako blizu ali daleč je oblika delca od oblike pravilnega kroga. Za delce okrogle oblike velja $F = 1$, za vse ostale oblike pa je $FO < 1$.

V raziskavo smo vključili vzorce iz treh slovenskih površinskih kopov. Vsak vzorec je vseboval 80 naključno izbranih delcev grobega kamenega agregata frakcije velikosti delcev 4–8 mm, ki smo jih pridobili s četrtinjenjem. V primeru prvega vzorca je šlo za dobro zaobljene prodnike, v drugem za dolomitne drobljence, v tretjem pa za drobljeni apnenec.

Digitalne slike delcev smo pridobili s pomočjo digitalnega fotoaparata Canon Power Shot S70. Slike smo nato prenesli v računalniški program Leica Image Manager IM 50, kjer smo na podlagi ročnega obkroževanja delcev pridobili informacijo o dveh geometričnih parametrih (površini delca in obsegu delca), s katerima smo lahko izračunali faktor oblike.

Rezultati so pokazali, da sta metodi med seboj primerljivi, ker sta obe sposobni prikazati izometričnost delcev. Metoda po standardu SIST EN 933-4:2000 je hitrejša, metoda določevanja faktorja oblike v dvodimenzionalnem prostoru s pomočjo računalniške programske opreme Leica Image Manager IM50 pa je bolj natančno določila obliko delcev oz. je bolj dosledno razlikovala med posameznimi oblikami delcev. Pomankljivost slednje metode je poleg zamudnosti tudi ta, da gre za dvodimenzionalni prostor, kar prinaša določene omejitve.

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