Construction Science
doi: 10.2478/cons-2014-0004
2014/15

Variation of Characteristics of Vibropressed Concrete Pavement Blocks

Gintautas Skripkiūnas[1], Giedrius Girskas[2], Jurgita Malaiškienė[3], Evaldas Šemelis[4],
[1–4] *Vilnius Gediminas Technical University*

Abstract: **Concrete pavement blocks were formed and the following properties were investigated after 7 days of curing: density, tensile splitting strength, freezing-thawing resistance, using de-icing salts in one-sided way, and abrasion resistance. The scattering of the values of density and tensile splitting strength of the concrete pavement blocks in the pallet during the process of manufacture was examined. It was determined that the values of density and splitting tensile strength were similar in the diagonals of the pallet. Bigger changes were seen on the edges of the tray. The variation coefficients of the examined properties ranged from 0.5 % to 15.6 %. The biggest scattering of research results was noted in strength.**

Keywords: **concrete pavement blocks, density, tensile strength, statistical analysis**

I. Introduction

Nowadays concrete block pavements have become an attractive engineering and economical alternative for flexible and stiff pavements. The properties such as strength, durability and aesthetically pleasing surfaces have made paving blocks attractive for many commercial, municipal, industrial surroundings and places such as parking areas, pedestrian walks, traffic intersections, and roads [1]. This type of paving is evaluated for being a hard surface which is aesthetically pleasing, comfortable to walk on, trafficable, extremely durable and easy to maintain. Paving blocks are manufactured in factory conditions, ensuring consistency and accuracy. After being situated with an edge restraint over a granular bedding course, individual blocks interlock themselves and acts compositely, which distributes large loads evenly [2].

The fabricated concrete blocks can be in various sizes, strength and durability, depending upon their usage and construction needs. For achieving better durability, high utility, consistent quality, and good appearance of blocks, the production is mainly based on the combination of water-cement (w/c) ratio and parameters of compaction method. Using different combinations, changing parameters leads us to final product which has higher density, better strength as well as lower permeability and lesser pore structure [3].

The following three block manufacturing techniques that ensure that the articles manufactured are of high quality and meet the standards are used:

- Manual compaction;
- Manual or mechanical tamping;
- High-frequency vibropression.

The technique of high-frequency vibropression, which is fully automated, fast, and energy efficient, is certainly the most popular and commonly used at the factories. Using this technology, products of greater strength, less porous and more resistant to the environmental impact are produced [4].

The requirements for concrete pavement blocks are categorized into classes that are used for labelling. According to the class of the required resistance to atmospheric effects, it is recommended to ensure the longevity in the country on whose market the product will be used.

Scientists all over the world conduct tests and experiments with concrete blocks, trying to make them more durable and resistant to atmospheric effects. Most of them are directed to waste materials utilization. There are a number of investigations done on concrete pavement adding marble waste to its composition. It is a popular topic of investigations done in the countries where marble is one of the main levers of their economy. It is used to replace up to 40 % of the coarse aggregate in the mixture [5–6]. There are a number of investigations done on concrete pavement resistance to atmospheric causes. Basically, scaling from freeze-thaw cycles is the biggest problem. The ice melting salt aggravates this process [7–9].

In scientific studies, the regression analysis is commonly used, which shows how the physical mechanical properties depend on the amount of w/c and other raw materials [10–11]; the impact of waste on the properties of concrete pavement blocks is also examined [12–15]. However, the scattering of the values of physical-mechanical and other properties of concrete pavement blocks is rarely examined when manufacturing the products at the factory.

The aim of the study was to determine the changes in density, tensile splitting strength of concrete pavement blocks, evaluating the results of the whole batch and the results of the concrete paving blocks on a separate pallet in accordance with their arrangement. Moreover, we aimed to evaluate statistical indicators and variation coefficients of other properties.

II. Materials and methods

The concrete pavement blocks with the dimensions of (200 mm × 100 mm × 100 mm) were selected from the blocks manufactured in a factory using vibropression. Firstly, one pallet was taken to evaluate the scattering of the values of density and tensile splitting strength of the concrete pavement blocks, and then more specimens were selected to determine the average characteristics of the batch. Concrete pavement blocks of two layers were manufactured, their compositions are shown in Table I. The strength was determined in accordance with EN 1338 method, just after 7 days.

TABLE I

THE COMPOSITION OF THE CONCRETE PAVEMENT BLOCKS

Raw material	The base layer	The cladding layer
Cement CEM I 42.5R, kg	371	500
Crashed gravel 2/8, kg	408	–
Crashed granite 2/8, kg	403	–
Granite screenings 0/4, kg	–	560
Sand 0/2, kg	–	1,004
Sand 0/4, kg	1,158	–
Water, l	120	128
Plasticizer (Plastolith), l	1.13	1.5
V/C	0.32	0.26

Measurement of the dimensions of the concrete pavement blocks was carried out in accordance with EN 1338 + AC requirements. Measurement of the dimensions of the concrete pavement blocks was carried out using electronic callipers DIN862 and mechanical callipers with the measuring range of 0 mm – 200 mm. Millimetre accuracy in the measurement of thickness of the block was ensured. It was measured in the positions of 4 opposite sides at least 20 mm from the edge of the block. The average thickness was calculated using four dimensions and rounded off to the millimetre accuracy. The blocks were weighed using the laboratory scales KERN KB, with the maximum weight of 6,500 g and 0.1 g accuracy.

The density was determined in accordance with DIN 12390-7. Natural moisture blocks were taken to determine the density. Water absorption tests were conducted in accordance with EN 1338:2003 + AC: 2006 Annex E. The specimens are immersed in the potable water at a temperature of (20 ± 5) °C and are left in the water until the constant M1 mass is reached. Minimum soaking time should be 3 days, and the constant mass is reached when the results of two weightings every 24 h differ by less than 0.1 %.

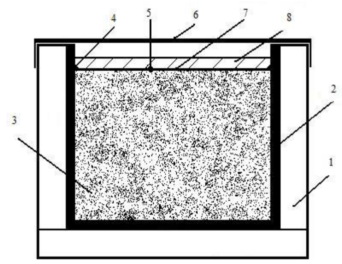

Fig. 1. The specimen prepared for freezing-thawing test is shown from the side (1 – thermoisoliation 2 – rubber sheet, 3 – specimen 4 – sealant tape, 5 – temperature gauge, 6 – polythene sheet, 7 – pilot surface, 8 – salt solution).

Before weighing the specimens are wiped with moistened and wrung cloth to expel excess water. The tensile splitting strength was determined in accordance with EN 1338:2003 + AC: 2006 Annex F.

The freezing-thawing resistance of the concrete pavement blocks and abrasion tests were carried out in accordance with BS EN 1338 + AC requirements. The scheme of the freeze-thawing resistance of the concrete pavement blocks is shown in Fig. 1.

The main raw material is Portland cement without additives (CEM I) 42.5 R complying with EN 197-1 requirements. Table II presents the basic characteristics of cement.

The fine and coarse aggregates meet EN12620:2003 requirements. Weak rock (sandstone, limestone, etc.) content does not exceed 2 %. Aggregates were tested in accordance with EN 1097-2, EN 1097-3, EN 1367-2, EN 933-1.

TABLE II

PORTLAND CEMENT CHARACTERISTICS

Designation	Bulk density, kg/m^3	Specific gravity, kg/m^3	Specific surface, cm^2/g
CEM I 42.5 R	1,200	3,200	3,700

The granulometric compositions and the bulk density of 2/8 granite rubble, 2/8 pebble rubble, 0/4 sand, 0/2 sand and 0/4 granite screenings are shown in Table III.

TABLE III

THE GRANULOMETRIC COMPOSITIONS AND THE BULK DENSITY OF 2/8 CRASHED GRANITE, 2/8 CRASHED GRAVEL, 0/4 SAND, 0/2 SAND AND 0/4 GRANITE SCREENINGS

Raw material	Passing by sieve opening size, %										Bulk density kg/m^3
	0.063	0.125	0.25	0.5	1	2	4	5.6	8	11.2	
Crashed granite (fr. 2/8)	0.04	0.07	0.10	0.14	0.35	3.90	28.65	55.47	97.93	100	1,410
Crashed gravel (fr. 2/8)	0.01	0.10	0.18	0.26	0.46	0.70	25.10	53.45	99.70	100	1,559
Sand (fr. 0/4)	0.17	0.93	10.01	41.17	69.91	90.39	99.45	99.98	100	100	1,620
Sand (fr. 0/2)	0.61	2.64	12.38	43.30	76.64	96.64	99.57	99.82	99.93	100	1,550
Granite screenings (fr. 0/4)	0.92	3.18	5.98	18.31	37.56	64.13	79.14	89.53	100	100	1,500

Superplasticizer "Plastolith" complying with EN 934-2 was used as a technological additive. Water complied with EN 1008 requirements.

The grouping of data and the preparation for the research were performed using Microsoft Excel software. Statistical analysis was done according to the literature data [16–18].

The coefficient of variation δ evaluates experimental values, i.e. the deviation of a certain random value from the average value of a sample [19].

$$\delta = \frac{S'}{\bar{y}} \cdot 100. \quad (1)$$

where

$\bar{y}$ – the average of the values set in the experiments,

S' – the average squared deviation is calculated using the following formula:

$$S' = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n-1}}. \quad (2)$$

where

y_i – the value of a specimen,

n – the number of specimens.

III. Results

The obtained results of the density and the splitting strength in accordance with the arrangement on the pallet are presented in Figure 2 and Figure 3.

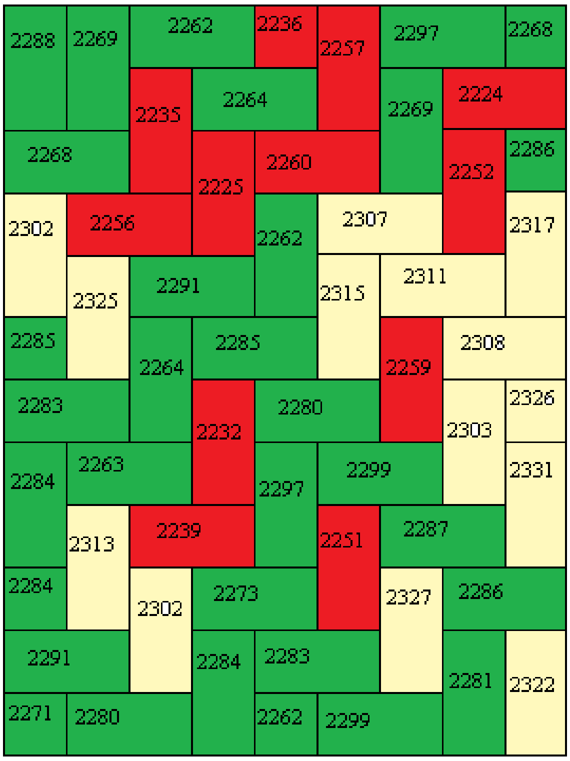

Fig. 2. The distribution of the density of the concrete blocks on the pallet (yellow – high density, green – medium density, red – low density).

The concrete blocks were divided into the following three groups according to their density: high density, medium density and low density. Firstly, the average was calculated, then the average standard deviation and the intervals were taken when it was considered that the blocks were of high, medium and low density. A similar distribution according to splitting strength was also done. The distribution results are shown in Table IV.

The coefficient of variation of the density is 1.2 %, the tensile splitting strength is 13.2 % (of the pallet). The coefficient of variation shows that there are no significant changes in the density of the products on the pallet, whereas the scattering of the strength values is higher.

Evaluating the results according to the arrangement of the products on the pallet, it was discovered that the results of the density and the splitting strength in diagonals were similar. Bigger changes are seen on the edges of the pallet. The lower density and splitting strength dominated on the top edge and on the lowest edge; the higher values of these parameters were obtained on the left edge and on the right edge (Fig. 2–3).

It is supposed that this is caused by different impact of the pressing force.

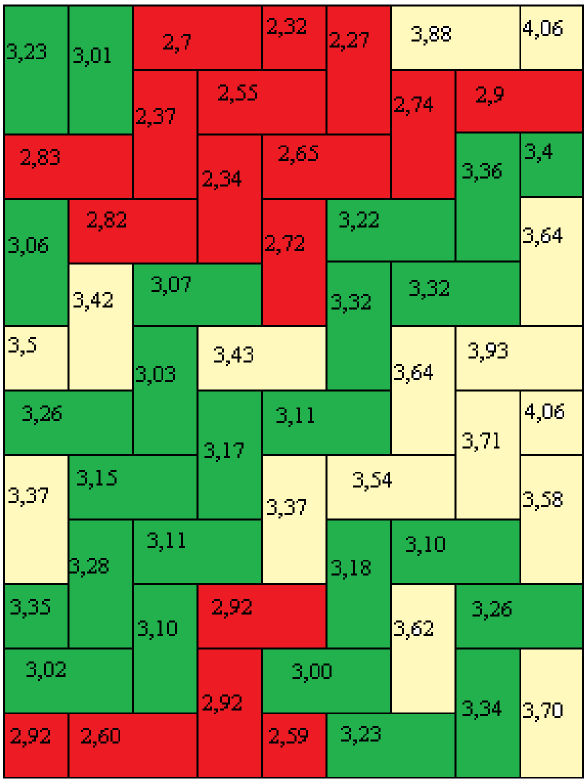

Fig. 3. The distribution of the tensile splitting strength on the pallet (yellow – high density, green – medium density, red – low density).

When the results of the whole batch were evaluated (measuring more than 100 blocks), it was determined that the average density of the batch was 2,311 kg/m^3 and the splitting strength after 7 days of curing was 3.17 MPa (analyzed paving blocks were done in winter conditions). After 7 days of curing, concrete blocks acquire about 70 % of their strength, consequently, after 28 days, their strength will reach approximately 4.6 MPa as required by the standard EN (after 28 days, the strength has to be at least 3.6 MPa).

TABLE IV

The results of the density and the tensile splitting strength

Property	**Average**	**The average standard deviation**	**Range**		
			Low	Medium	High
Density, kg/m^3	2,281	27	2,236 – 2,261	2,262 – 2,301	2,302 – 2,331
Tensile splitting strength, MPa	3.16	0.41	2.27 – 2.96	2.97 – 3.36	3.37 – 4.06

Data distribution is presented in the histograms Fig. 4–5. It was determined that the variance of the values was normal, their reliability was 95 %. The coefficient of variation of the whole batch to the density was 1.4 %, and to the tensile splitting strength – 15.6 %. The values of the coefficients of variation, when calculating all products in the batch, are bigger because of the greater scattering of the values. Particularly big coefficient of variation of the tensile splitting strength was obtained. As a result, it is necessary to take into account the selection of the formation parameters when manufacturing concrete blocks.

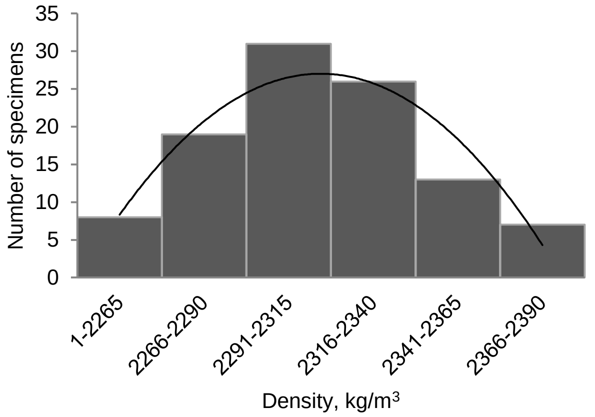

Fig. 4. The distribution of the values of density.

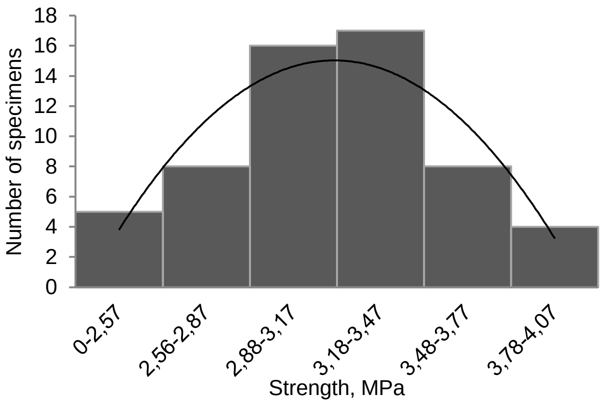

Fig. 5. The distribution of the values of the splitting strength.

The research results of the freezing-thawing of the concrete blocks are presented in Fig. 6. This figure shows how the mass of paving blocks changes over freezing-thawing time.

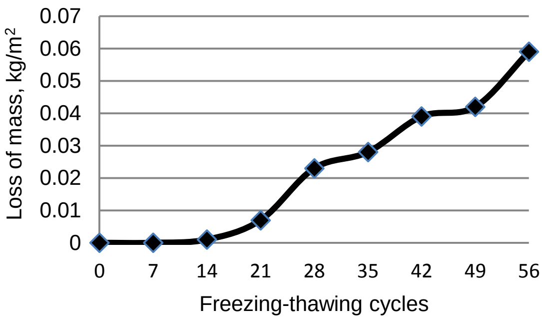

Fig. 6. The results of the frost resistance of the blocks.

The blocks are of a high quality, because even after 56 cycles, the mass loss is only 0.06 kg/m^2, and in accordance with EN standard, it is required that after 28 freezing-thawing cycles the mass loss should not exceed 1 kg/m^2. Then, the concrete blocks were assigned to Class 3, and the marking is D.

The coefficient of variation of the frost resistance of the blocks (after 56 freezing-thawing cycles) is 3.7 %. It was determined using the ultrasound every 7 days during the tests of the frost resistance, in order to see and evaluate the changes in the structure of the products when freezing and thawing them. The results of the ultrasound tests are presented in Fig. 7.

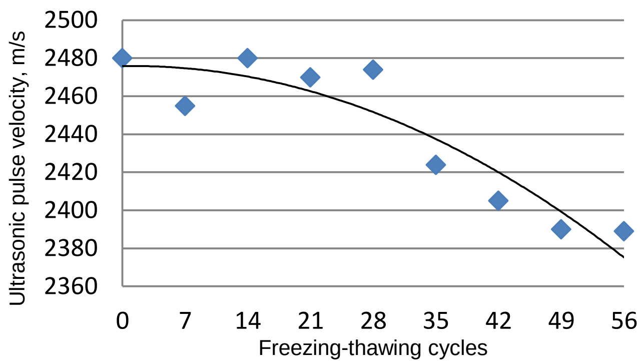

Fig. 7. The changes in the ultrasonic pulse velocity during the freezing-thawing cycles.

Fig. 7 shows that increasing the time of freezing, the ultrasonic pulse velocity decreases. After 56 freezing and thawing cycles the ultrasonic pulse velocity decreases about 3.8 %. This is due to the increase of the porous space and the occurrence of defects in the structure. The coefficient of variation of the ultrasonic pulse velocity, calculated for the whole batch, is 0.5 % (after 56 freezing-thawing cycles), hence the scattering of the values is at a very low level.

The average abrasion of the batch of the concrete blocks was 20.7 mm, the average standard deviation was 0.56 mm, the coefficient of variation was 2.7 %. The results of the abrasion of the blocks varied from 20 mm to 21.6 mm, therefore they were assigned to Class 3 (≤ 23 mm, although it is close to Class 4 – ≤ 20 mm).

Specifications of products shaping affect density and strength of pavement blocks. Very big influence has the consistence of the mixture, but it more leads scattering of characteristics in separate pallets. It can be argued that in the ends of the same pallet products are less compacted and strength of pavement blocks is lower. It can be concluded that by pressing the pallet deforms declining ends.

IV. Conclusions

There is almost no significant impact of the arrangement of the pavement blocks on the pallet according to diagonals on the values of the density and the tensile splitting strength. Differences of these characteristics were observed on the sides of the pallet, which were due to the uneven distribution of the pressing force.

The highest coefficient of variation of the values of the tensile splitting strength was obtained and within the batch it reached 15.6 %. The coefficient of variation of the research results of other examined characteristics of the concrete pavement blocks such as density, freezing-thawing resistance, when using de-icing salt in one-sided way, and abrasion resistance, ranged from 0.5 % to 2.7 %.

The mixture of pavement blocks by formation is pouring into the centre of the pallet. Less mixture gets to the ends and the ends are less filled with concrete mixture, it resulting lower density and strength of products.

REFERENCES

[1] Hanan, A., Nouhy, E. *Properties of paving units incorporating slag cement*, HBRC Journal, 2013, Vol. 9, No 1, pp. 41–48. http://dx.doi.org/10.1016/j.hbrcj.2012.12.004

[2] *The concrete center* http://www.concretecentre.com/technical_information/infrastructure/external_hardstanding/block_paving.aspx

[3] Tung-Chai, L. *Effects of compaction method and rubber content on the properties of concrete paving blocks*, Construction and Building Materials, 2013, Vol. 28, No 1, 2, pp. 164–175.

[4] Tung-Chai, L., Chi-Sun, P., Hau-Wing, W. *Management and recycling of waste glass in concrete products: Current situations in Hong Kong Resources*, Conservation and Recycling, 2013, Vol. 70, No. 1, pp. 25–31.

[5] André, A., de Brito, J., Rosa, A., Pedro, D. *Durability performance of concrete incorporating coarse aggregates from marble industry waste*, Journal of Cleaner Production, In Press, Corrected Proof, Available online 1 October 2013.

[6] Gencel, O., Ozel, C., Koksal, F., Erdogmus, E., Martínez-Barrera, G., Brostow, W. *Properties of concrete paving blocks made with waste marble*, Journal of Cleaner Production, 2012, Vol. 21, No. 1, pp. 62–70. http://dx.doi.org/10.1016/j.jclepro.2011.08.023

[7] Deja, J. *Freezing and de-icing salt resistance of blast furnace slag concretes*, Cement and Concrete Composites, 2003, Vol. 25, No. 3, pp. 357–361. http://dx.doi.org/10.1016/S0958-9465(02)00052-5

[8] Penttala, V. *Surface and internal deterioration of concrete due to saline and non-saline freeze–thaw loads*, Cement and Concrete Research, 2006, Vol. 36, No. 5, pp. 921–928. http://dx.doi.org/10.1016/j.cemconres.2005.10.007

[9] Şahin, R., Taşdemir, M.A., Gül, R., Çelik, C. *Determination of the optimum conditions for de-icing salt scaling resistance of concrete by visual examinations and surface scaling*, Construction and Building Materials, 2010, Vol. 24, No. 3, pp. 353–360. http://dx.doi.org/10.1016/j.conbuildmat.2009.08.026

[10] Ohemeng, E.A., Yalley, P.P. *Models for predicting the density and compressive strength of rubberized concrete pavement blocks*, Construction and Building Materials, 2013, Vol. 47, pp. 656–661. http://dx.doi.org/10.1016/j.conbuildmat.2013.05.080

[11] Sonebi, M., Bassuoni, M.T. *Investigating the effect of mixture design parameters on pervious concrete by statistical modeling*, Construction and Building Materials, 2013, Vol. 38, pp. 147–154. http://dx.doi.org/10.1016/j.conbuildmat.2012.07.044

[12] Uygunoğlu, T., Topcu, I.B., Gencel, O., Brostow, W. *The effect of fly ash content and types of aggregates on the properties of pre-fabricated concrete interlocking blocks (PCIBs)* Construction and Building Materials, 2013, Vol. 30, pp. 180–187. http://dx.doi.org/10.1016/j.conbuildmat.2011.12.020

[13] Sukontasukkul, P., Chaikaew, Ch. *Properties of concrete pedestrian block mixed with crumb rubber*, Construction and Building Materials, Vol. 20, No 7, pp. 450–457. http://dx.doi.org/10.1016/j.conbuildmat.2005.01.040

[14] Lam, C. S., Poon, C. S., Chan, D. *Enhancing the performance of pre-cast concrete blocks by incorporating waste glass – ASR consideration*, Cement and Concrete Composites, Vol. 29, No 8, pp. 616–625. http://dx.doi.org/10.1016/j.cemconcomp.2007.03.008

[15] Tung-Chai, L. *Prediction of density and compressive strength for rubberized concrete blocks*, Construction and Building Materials, 2011 Vol. 25, pp. 4303–4306. http://dx.doi.org/10.1016/j.conbuildmat.2011.04.074

[16] Gatti, P. L. *Probability theory and mathematical statistics for engineers*. London: Spon Press. 2005, p. 356.

[17] Kleinbaum, D.G., Kupper, L.L., Muller, K.E., Niram, A. *Statistical analysis.* Brooks/Cole Publishing Company, 1998, p. 798.

[18] Manita, A.D. *Teorija verojatnostej i matematicheskaja statistika* (*Theory of chance and mathematical statistics*). Moskva: Izdat. otdel UNC DO, 2001, s. 120 (in Russian).

[19] Lvovskij, B.N. *Statisticheskije metodi postrojenija empiricheskih formul (Statistical methods for creation empirical formulas).* 2-e izd., pererab. i dop. Moskva: Vishaja shkola, 1988, s. 239.

Gintautas Skripkiūnas, Civil Engineer, Dr. sc. ing. (1994), prof. VGTU Faculty of Civil Engineering, Department of Building Materials (2010). Publications: ~ 50 scientific and methodological works.
Address: Sauletekio Av. 11, Vilnius LT-10223, Lithuania
E-mail: gintautas.skripkiunas@vgtu.lt

Giedrius Girskas, PhD student, VGTU Faculty of Civil Engineering, Department of Building Materials (2010). Publications: 5 scientific works.
Address: Sauletekio Av. 11, Vilnius LT-10223, Lithuania
E-mail: giedriusgirskas@yahoo.com

Jurgita Malaiškienė, Civil Engineer, Dr. sc. ing. (2008), research worker, assoc. prof. VGTU Faculty of Civil Engineering, Department of Building Materials (2008). Publications: ~ 20 scientific and methodological works.
Address: Sauletekio Av. 11, Vilnius LT-10223, Lithuania
E-mail: jurgita.malaiskiene@vgtu.lt

Evaldas Šemelis, PhD student, VGTU Faculty of Civil Engineering, Department of Building Materials (2010). Publications: 1 scientific work.
Address: Sauletekio Av. 11, Vilnius LT-10223, Lithuania
E-mail: evaldas@sivysta.lt