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The Dependence of Physical Mechanical Properties of Concrete Pavement Blocks on Coarse Aggregate Type

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

Abstract **– The aim of this research is to determine the dependences of the physical mechanical properties of vibro-pressed concrete (pavement blocks) on the type of coarse aggregate used in the main layer. Sustainability of concrete pavement blocks is a really important matter. Five different batches of pavement blocks were produced, changing the consistence ratio of coarse aggregate in the main layer. There are two types of course aggregate: crushed gravel and granite. The consistence of a facing layer was not changed. All tests: density, tensile split strength, water absorption for vibro-pressed concrete units were made according to EN 1338:2003+AC2006.**

Keywords **– Concrete pavement blocks, density, water absorption, strength, statistical analysis.**

I. Introduction

Recently, more and more concrete pavement blocks deterioration problems have been identified. Concrete blocks are mostly used in the places where cars going along. Different reasons are given, such as the impact of salt scattered in winter, the low frost resistance of blocks; the density and strength of concrete pavement blocks are also important.

In order to avoid early deterioration of concrete, some plastificating, active mineral and nano-sized additives are added to the concrete mixture. Fly ash and SiO_2 fume are often used. The scientists [1] studied how the properties of concrete depend on the additives of nano-sized SiO_2 and Al_2O_3 particulates. It was determined that the compressive strength of concrete slightly increases by using nano-alumina as a substitute for cement materials. It was found that the compressive strength of concrete increased by 8 % by replacing cement materials by nano-alumina. Nano-silica greatly improves the compressive strength of concrete. In order to increase the compressive strength of concrete, the optimum amount of nano-silica in concrete is 5 % (by the weight of cement materials). The compressive strength of concrete improves as much as by 30 % by using 5 % nano-silica (by the weight of cement materials).

Another method for increasing the durability of concrete is the improvement of the properties of the top layer using a variety of additives, changing the formation parameters, or otherwise processing the surface of concrete blocks. The scientists [2] determined that the quality of concrete pavement always improves by polishing. Surface hardeners also improve the resistance of the pavement. It was found considering different dry-shaking treatments studied that quartz and silica offer better quality for general purposes.

The authors [3] tried to create a mathematical model of concrete pavement blocks to describe the deterioration process. The main finding of their work [3] is that empirical design procedures for concrete block pavements ensure that the pavement will fail by excessive deterioration without pavement blocks cracking. The experimental data that were obtained from tests on elements of pavements that were constructed in a custom built test frame in the laboratory, showed the importance of "rotational interlock" in dissipating the applied stress so that the transmitted stress to the subgrade is significantly reduced. The "rotational interlock" depends on the applied stress that unfortunately is not accounted for in the existing mathematical models.

The scientists [4] have examined whether it is possible to add the waste of old buildings to the concrete composition of pavement elements. Water absorption and strength of the samples were analyzed. Water absorption of kerbs will increase significantly if ceramic or concrete waste is used as aggregate. This effect is more important when the percentage of replacement goes over 50 %. The flexural strength of floor blocks decreased when recycled aggregates were used. However, the obtained values of the flexural strength when the replacement was 100 % were acceptable for both types of aggregates used. The decrease never exceeded 40 % with respect to the floor blocks manufactured with the control concrete.

The scientists [5–8] studied how the strength of concrete used to manufacture the elements for the improvement of surroundings changes by adding some fly ash and other waste to their composition. Compressive strength decreases when increasing fly ash replacement ratio for each series. Also, the replacement of CSS (specific gravity of the crushed gravel) with CW (concrete waste) and MW (marble waste) decreases the compressive strength of pavement blocks. Despite the fact that pavement blocks with CSS, CW and MW have splitting tensile strength of around 2 MPa, they all have good splitting tensile strength in 28 days. Pavement blocks with CSS and MW fulfil the requirements of strength (3.6 MPa) following the standard, except for the replacement ratio of 40 % fly ash [5]. The combination effect, i.e. the replacement of both coarse and fine fractions with RCA (recycled concrete aggregate), was examined in the laboratory. The target mean flexural strength of 5.0 N/mm^2 was still achieved at the age of 28 days by replacing up to 60 % of the coarse or 40 % of the fine fractions with RCA [6]. Borax and fly ash can be added as effective retarders to concrete pavements but with limited extension for the time of setting, whereas a big amount of aluminate cement can significantly delay the time of setting, and it also reduces strength [7], but fly ash significantly increases the workability of the concrete [8].

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 [9–10]. The variation of strength, density and water absorption was examined in a batch of concrete blocks [11].

However, it is rare to find a publication on coarse aggregate type used in production and its effect on the properties of vibro-pressed concrete pavement units.

The aim of this work was to analyse the influence of coarse aggregate type on physical mechanical properties of vibro-pressed concrete (pavement blocks).

II. Materials and Methods

Concrete pavement blocks (200 mm × 100 mm × 80 mm) were used for tests. For each batch was made approximately 100 pavement blocks. Vibro-pressed concrete blocks consist of two layers. The surface layer was formed of the cement CEM I, granite middlings, sand, water and plasticizer, and the main layer was made of cement CEM I, coarse aggregates (granite, crushed gravel), sand, water and plasticizer. Pavement blocks were made in a factory, using high compaction vibro-pressing technology. It was decided to produce 5 batches of concrete pavement blocks, changing the main layer of coarse aggregate (granite and crushed gravel) ratio:

I 50 % crushed gravel and 50 % granite;
II 100 % crushed gravel;
III 100 % granite;
IV 70 % granite and 30 % crushed gravel;
V 70 % crushed gravel and 30 % granite.

TABLE I

Composition of Surface Layer

Material	Amount for 1 m^3
Cement CEM I 42.5 R, kg	500
Granite middlings, 0/4, kg	800
Sand 0/2, kg	800
Water, l	120
Plasticizer (Plastolith), l	1.5
W/C ratio	0.24

As mentioned above, pavement blocks were used for the tests. Each block has two layers. The composition of surface layer is presented in Table I.

The compositions of five different batches are presented in Table II.

The one of the main materials for making pavement blocks is Portland cement CEM I 42.5 R complying with EN 197-1:2011 requirements. The mechanical and physical properties are presented in Table III.

The used fine aggregate was 0/4 fraction sand and granite middlings. The used coarse aggregate was 2/8 fraction crushed gravel and 2/8 fraction granite.

TABLE II

Composition of Main Layer for Five Batches

Material	Amount for 1 m^3				
	I	II	III	IV	V
Cement CEM I 42.5 R, kg	350	350	350	350	350
Granite 2/8, kg	**400**	**0**	**800**	**560**	**240**
Crushed gravel 2/8, kg	**400**	**800**	**0**	**240**	**560**
Sand 0/4, kg	1100	1100	1100	1100	1100
Water, l	120	120	120	120	120
Plasticizer (Plastolith), l	1.05	1.05	1.05	1.05	1.05
W/C ratio	0.34				

TABLE III

Portland Cement Characteristics

Cement properties	CEM I 42.5 R
Compressive strength, MPa	
After 2 days	28 ± 2
After 28 days	54 ± 3
Initial setting time, min	160
Amount of water for normal consistency, %	25.3
Specific surface area, cm^2/g	3700
Bulk density , kg/m^3	1200
Specific gravity, kg/m^3	3200

The specifications of fine and coarse aggregate used in the surface and main layer are presented in Table IV. Both fine and course aggregates comply with EN 12620:2013 requirements.

TABLE IV

The Granulometric Compositions and the Bulk Density of Aggrgates

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	
Crushed granite 2/8	0.04	0.07	0.10	0.14	0.35	3.90	28.65	55.47	97.93	100	1,410
Crushed gravel 2/8	0.01	0.10	0.18	0.26	0.46	0.70	25.10	53.45	99.70	100	1,559
Sand 0/4	0.17	0.93	10.01	41.17	69.91	90.39	99.45	99.98	100	100	1,620
Sand 0/2	0.61	2.64	12.38	43.30	76.64	96.64	99.57	99.82	99.93	100	1,550
Granite middlings 0/4	0.92	3.18	5.98	18.31	37.56	64.13	79.14	89.53	100	100	1,500

The water used for composition meets EN 1008:2002 requirements. Plasticizer "Plastolith" complying with EN 934-2:2009 requirements were used as a technological additive, which forms a hydrophobic coating of capillaries and reduces the migration of calcium hydroxide.

The pavement blocks measurements were done complying with EN 1338+AC requirements. The measures were taken using mechanical "Vernier caliper", the measuring range of which is 0 mm – 200 mm. Each pavement block height was measured 4 times from different sides. The average was rounded to one millimetre accuracy. The weight was measured with laboratory scale KERN KB (maximum measured weight 5000 g, with 0.01 g accuracy).

The density was determined according to EN 12390-7 requirements. The normal moisture accidental selected 40 blocks used for the test. The water absorption test was done according to EN 1338:2003+AC: 2006 annex E requirements. Five blocks of each batch were desiccated, scaled and immersed in water (20 °C ± 5 °C). The duration of a test was 72 hours, additionally to this, samples were scaled after 5 min; 15 min; 30 min; 60 min; 120 min; 240 min; 300 min, 24 h; 48 h and 72 hours. Samples were cleaned with damp cloth removing water excess before weighing.

Tensile split strength was determined according to EN 1338:2003+AC: 2006 annex F. Samples were immersed in water (20 °C ±5 °C) for 24 hours before test. The scheme of the test is represented in Fig. 1. The block placed in the mechanical press is shown in Fig. 2.

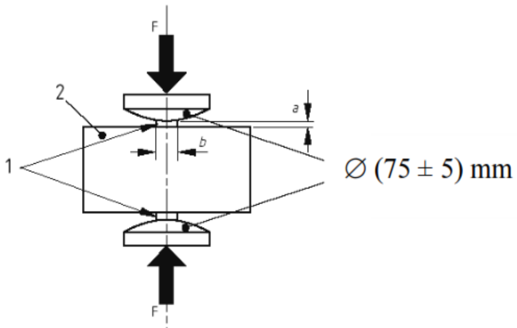

Fig. 1. Scheme of tensile split test (1 – load distribution strips; 2 – pavement block; 3 – rigid support).

Fig. 2. Tensile split test in progress.

First, a statistical analysis of all parameters was performed: minimum, maximum and average values were determined, a table of frequencies was developed, histograms were drawn and the matrixes of pair correlation were constructed [12]. It was defined that physical-mechanical parameters adequately represented the analysed set. The character of parameter distribution was normal. Normality was obtained by literature [13–14]. Next, the regression analysis of data was performed deriving empirical equations [15]. The adequacy of equations was verified applying Fisher's criteria [16]. The significance of equation variables was determined adopting the student's criteria (if the values are higher than those found in the tables, the coefficient of regression is significant) [13], [15]. The intensity of linear interdependence was estimated according to the numerical values of the coefficient of correlation. The suitability of the model was evaluated calculating the coefficient of determination [17].

III. Results

The results of density are presented in Fig. 3. Standard deviation of density in the batch was approximately 22 kg/m^3 (about 1 %). As we can see from the results (Fig. 3), the highest density (2,373 kg/m^3) was observed in batch II, where 100 % crushed gravel was used as the coarse aggregate. The bulk density of crushed gravel (1,559 kg/m^3) is higher than that of granite (1,410 kg/m^3) (Table IV). Moreover, if you use 70 % granite and 30 % crushed gravel, you will get higher result (2,361 kg/m^3) than vice versa (2,352 kg/m^3). Supposedly, as it can be seen from Table IV, the particles of crushed gravel have a better distribution according to their form and size, causing less air filled pores and higher density.

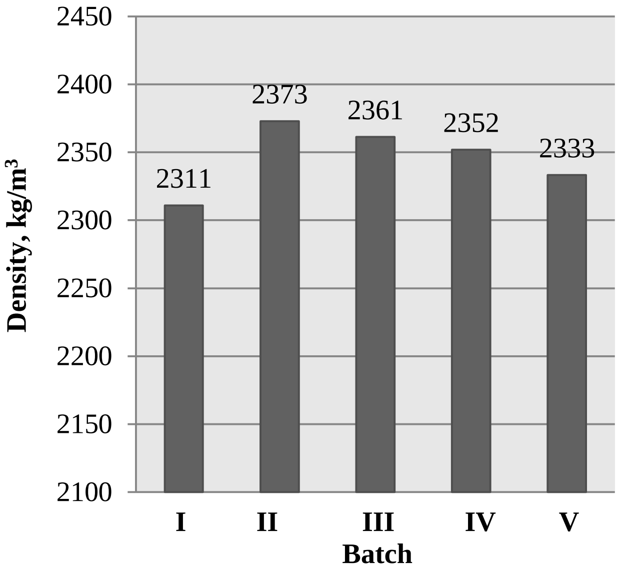

Fig. 3. Average density of each batch.

The results of water absorption test are presented in Fig. 4. The standard deviation of water absorption was approximately 0.1 % (about 2.5 %). The water absorption test results respectively represent the results of density test. The highest water absorption is linked with the lowest density of a pavement block. The lowest average water absorption was received in batch II (3.87 %). This also highlights that a lower density block has a more porous structure, and can absorb more water than the one with a higher density.

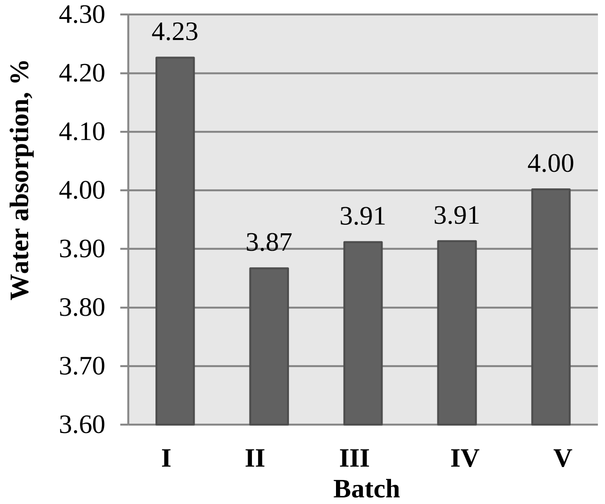

Fig. 4. Average water absorption of each batch.

The regression analysis performed has shown strong dependence between density (D) and water absorption (W). The linear equation presented in equation (1), correlation coefficient (R) is −0.95 and determination coefficient is 0.91. Standard error estimate is 0.05 The Student coefficient value of density is 5.08, which indicates that this indicator is extremely significant. (The Student criteria table value is 2.04).

$$W = 17.17 - 0.00562\,D \quad (1)$$

Additionally to these results, kinetics of absorption is presented in Fig. 5. From a diagram we can see that to pavement blocks absorb water eventually, but all batches absorb water at different speed so water absorption curve differs. But it was similar to all batches that water absorption reached almost maximum level already after 24 hours.

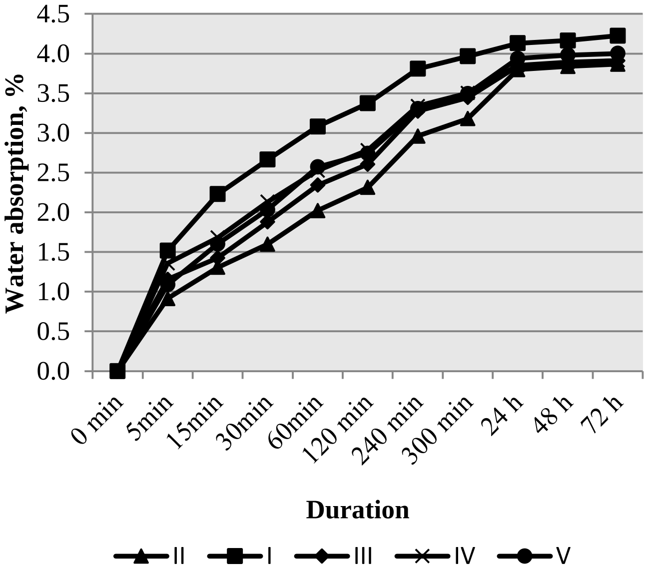

Fig. 5. Average water absorption of a batch at different time of soaking.

The tensile split strength test results are presented in Fig. 6. Standard deviation of tensile split strength was approximately 0.25 MPa or 5.5 %. As expected, the highest average tensile strength (4.93 MPa) was gained from blocks in batch II, which also had the highest density and the lowest water absorption. This can be explained by the less porous structure, and better binding of various size particles in the mixture.

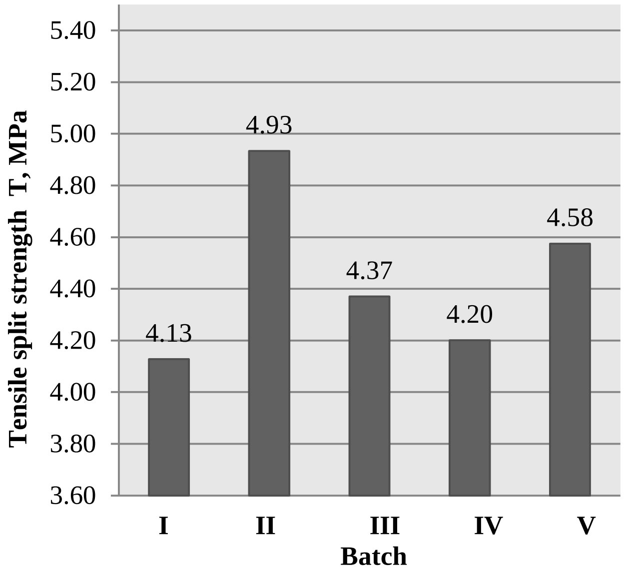

Fig. 6. Average tensile split strength of each batch.

After performing regression analysis, the empirical equation was developed (2), which shows how tensile split is dependent on water absorption (W) and density (D):

$$T = -23.31 + 0.01\,D + 0.46\,W \quad (2)$$

Correlation coefficient of equation is 0.64; coefficient of determination is 0.40, which shows average dependence between variables. Standard error estimate is 0.35. In the literature (for example [18]) is written: if $R < 0.2$ – correlation is very weak, interdependence will not exist; if $0.2<R < 0.4$ – correlation is weak, interdependence will be weak too; if $0.4<R < 0.7$ – correlation is average, interdependence will be average; if $0.7<R < 0.9$ – strong correlation, strong interdependence, if $R > 0.9$ – very strong interdependence.

Equation (3) was also developed, which shows how the value of the strength of concrete blocks depends on the percentage of gravel.

$$T = 4.14 + 0.006\,CG \quad (3)$$

The correlation coefficient of this equation is 0.72, determination coefficient is 0.52, and standard error estimate is 0.26. The quantity of gravel is a significant indicator, because its Student criterion is 2.1. However, when estimating the equation indicators, we can see that the amount of gravel may slightly increase the strength. The dependence of the quantity of gravel on other examined properties was not significant.

IV. Conclusion

The results of density, water absorption and tensile split strength tests show that such coarse aggregate as crushed gravel yields better results. The mixture of batch II where crushed gravel used was 100 % of coarse aggregate demonstrated the highest density (2,373 kg/m^3), lowest water absorption (3.87 %) and the biggest tensile split strength (4.93 MPa). Moreover, batch I (50 % granite and 50 % crushed gravel used as coarse aggregate), which is used for current mass production demonstrated the lowest results of all tests (density – 2,311 kg/m^3; water absorption – 4.23 %; tensile split strength – 4.13 MPa.)

The results are interesting and frustrating, inviting to conduct advanced tests on these batches. Freeze – thaw test will be done next in order to prove its applicability.

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Jurgita Malaiškienė, civil engineer, *Dr. sc. ing.* (2008), research worker, 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

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

Viktor Kizinievič, Main research area: Analysis and quality control of durability and other properties of various building materials.
Address: Linkmenu Str. 28, LT-08217 Vilnius, Lithuania,
E-mail: viktor.kizinievic@vgtu.lt