INFLUENȚA UNOR PARAMETRI COMPOZIȚIONALI ASUPRA PROPRIETĂȚILOR FIZICO - MECANICE ALE BETONULUI CU PERMEABILITATE RIDICATĂ
INFLUENCE OF COMPOSITIONAL PARAMETERS ON PHYSICAL AND MECHANICAL PROPERTIES OF PERVIOUS CONCRETE

RADU VOINIȚCHI[1], CONSTANTIN DORINEL VOINIȚCHI[2], VIOREL CRĂCIUN[1], ALINA BĂDĂNOIU [1*]
[1]University "Politehnica" of Bucharest, 1-7 Polizu street, Bucharest, 011061, Romania
[2] Technical University of Civil Engineering, Bucharest, Romania

This paper presents new insight regarding the influence of aggregate particles dosage and shape on the main properties of pervious concretes.

The results presented in this paper show a correlation between the permeability coefficients assessed on aggregate mixture and corresponding pervious concretes with various cement contents. This suggests that is possible to design pervious concretes with a prescribed permeability value, using as input values the results obtained in permeability test of aggregate mix and applying a correction coefficient which depends on cement matrix content.

The replacement in the coarse aggregate fraction (8/16 mm) of polyhedral particles with flat particles (length to thickness ratio higher than 3) do not exert a major influence on the values of permeability coefficient of aggregate mixtures and derived pervious concretes. Nevertheless, a significant decrease of compressive strength is observed when the polyhedral aggregate particles of the coarse aggregate fraction (8/16 mm) are replaced with flat particles.

În această lucrare se prezintă influența dozajului și a formei granulelor de agregat asupra principalelor proprietăți ale unor betoane cu porozitate ridicată (BPR). Rezultatele prezentate în această lucrare permit stabilirea unei corelații între valoarea coeficientului de permeabilitate a amestecului de agregate și a BPR corespunzatoare, preparate cu diferite dozaje de ciment. Această corelație poate fi folosită pentru proiectarea compoziției unui BPR, cu o anumită valoare a permeabilității, folosind ca date inițiale rezultatele obținute la testarea permeabilității amestecului de agregate, cu aplicarea unui coeficient de corecție care depinde de dozajul de ciment.

Înlocuirea fracțiunii 8/16 mm a agregatului (format din particule poliedrale) cu particule plate (caracterizate printr-un raport lungime/grosime mai mare ca 3) nu exercită o influență majoră asupra valorilor coeficientului de permeabilitate a amestecului de agregate și a BPR derivate. Totuși, s-a inregistrat o importantă scădere a rezistenței la compresiune a BPR atunci când particulele poliedrale de agregat (fracțiunea 8/16 mm) au fost înlocuite de cele plate.

Keywords: *pervious concrete, aggregate shape, water permeability, compressive strength*

1. Introduction

Pervious or permeable concrete has an interconnected pore structure which permits the fast drainage of water, avoiding flash flooding or surface runoff. This type of concrete is produced with narrowly graded coarse aggregate (with little or no sand) bound by a thin layer of cement paste/mortar.

The pervious concrete with lower compressive strengths can be used for pavements (driveways or walkways) and parking lots. Other applications include sport courts, swimming pools decks, etc.

If pervious concrete is used as pavement it can contribute to the storm water management in urban areas and to the reduction of noise generated by the interaction with tires (acoustic absorption) [1, 2].

Moreover, this type of pavement have a superior slip-resistance in icy conditions reducing in this way the health problems connected with slip related falls [3].

Generally, the size of interconnected voids in pervious concrete ranges from 2 to 8 mm and the void content from 15% to 35% [3]. As a result, the compressive strength values are comprised between 2.8 MPa and 28 MPa and the water flow rate can vary from 0.1 to 0.34 cm/s [3-6].

The size of the voids in the pervious concrete depends on the aggregate packing in the structure of the concrete as well as the amount of cement matrix. In general, the packing of aggregate grains in concrete depends on particles sizes and shape parameters as well as their packing method [7-9].

* Autor corespondent/*Corresponding author*,
E-mail: alina.badanoiu@upb.ro

Huang and co-workers [7] showed, by computer simulation, that polyhedral aggregates with larger sphericity can be packed to a higher density. Therefore, in this study two types of aggregates (polyhedral and flat grains) were used in order to prepare the pervious concrete and to estimate their influence on the size and connectivity of voids. Also, the paper presents correlations between size and form of aggregate grains and the water permeability and compressive strength of resulted pervious concrete.

2. Materials and methods

Type I 42.5N portland cement and river aggregates (polyhedral and flat grains – Fig.1) were used for the preparation of pervious concrete mixtures. The fraction 4/8 mm contained only polyhedral particles and for the fraction 8/16 mm were used flat and polyhedral particles. The flat (non-cubical) particles (8/16 mm) were selected from entire quantity of natural river aggregates, using a caliper. According to European Norm EN 933-4 [10] non-cubical particles (flat or elongated) are those for which the length (L) to thickness (E) ratio is higher than 3.

The apparent density and water absorption after 24 hours of immersion (WA_{24}) of coarse aggregate (Tab. 1) were determined by the method described in European Norm EN 1097-6 [11].

Pervious concrete was produced by mixing water, cement and graded coarse aggregate (Tabs 2 and 3).

In order to study the influence of aggregate shape on mechanical and physical properties of pervious concrete, for the mix design in which aggregate fraction 4/8 mm represents 60% and fraction 8/16 mm represents 40%, for the fraction 8/16 mm the polyhedral aggregate particles were replaced in various proportions of flat particles (Tab. 3).

The concrete mixtures were prepared using a mixer, poured in molds and compacted with few shocks using a rubber hammer. After 24 hours the specimens were demoulded and cured in water at 20°C.

Cylinders with 100 mm (diameter) x 100 mm (height) prepared with the pervious concrete mixtures (Tabs.2 and 3) were used for the assessment of compressive strength (after 7 and 28 days of curing) and water permeability - determined after 28 days of curing.

Compressive strength was determined according to EN 12504-1 [12] using correction coefficients for height to diameter ratio from Romanian Norms NP-137 [13]. The specimens were capped with a sulfur compound.

Determination of the permeability coefficient (k) was performed with the device presented in

a b

Fig. 1 - Polyhedral (a) and flat (b) aggregates (fraction 8/16 mm)/ *Agregate poliedrale (a) și plate (b) – fracțiunea 8/16 mm.*

Table 1

Apparent density and water absorption (WA_{24}) of river aggregate / *Densitatea aparentă și absorția de apă (WA_{24}) a agregatului de râu*

Aggregate fraction	Apparent density (kg/m³)	WA_{24} (%)
4/8 mm	2635	0.17
8/16 mm	2638	0.17

Table 2

Pervious concrete mix design made with 4/8 mm and 8/16 mm polyhedral aggregate particles/*Compozițiile de betoane cu porozitate ridicată, realizate cu agregate de râu cu forma poliedrală, fracțiunile 4/8 mm și 8/16 mm.*

Mix	Aggregate 8/16 mm (kg/m^3)	Aggregate 4/8 mm (kg/m^3)	Cement (kg/m^3)	Water (l/m^3)	Water to cement ratio (w/c)
100S$_1$	1563	0	150/200	42/60	0.28/0.30
80S$_1$-20S$_2$	1260	325			
60S$_1$-40S$_2$	995	660			
50S$_1$-50S$_2$	813	813			
40S$_1$-60S$_2$	650	975			
20S$_1$-80S$_2$	320	1260			
100S$_2$	0	1575			

S_1 – 8/16 mm polyhedral aggregate; S_2 – 4/8 mm polyhedral aggregate

Table 3

Pervious concrete mix design made with aggregate fractions 4/8 mm (60%) and 8/16 mm (40%) /*Compozițiile de betoane cu porozitate ridicată, preparate cu un amestec de agregate – 60% fracțiunea 4/8 mm și 40% fracțiunea 8/16 mm.*

Mix	4/8 mm polyhedral aggregates (kg/m^3)	8/16 mm polyhedral aggregates (kg/m^3)	8/16 mm flat aggregates (kg/m^3)	Cement (kg/m^3)	Water (l/m^3)	Water to cement ratio w/c
100S$_{1,\ ref}$	1002	668	0	150/200	42/60	0.28/0.30
80S$_1$-20S$_{1F}$	1003	535	134			
60S$_1$-40S$_{1F}$	1094	438	292			
40S$_1$-60S$_{1F}$	1075	287	430			
20S$_1$-80S$_{1F}$	1062	142	566			
100S$_{1F}$	1081	0	720			

S_1 – 8/16 mm polyhedral aggregate; S_{1F}– 8/16 mm flat aggregate

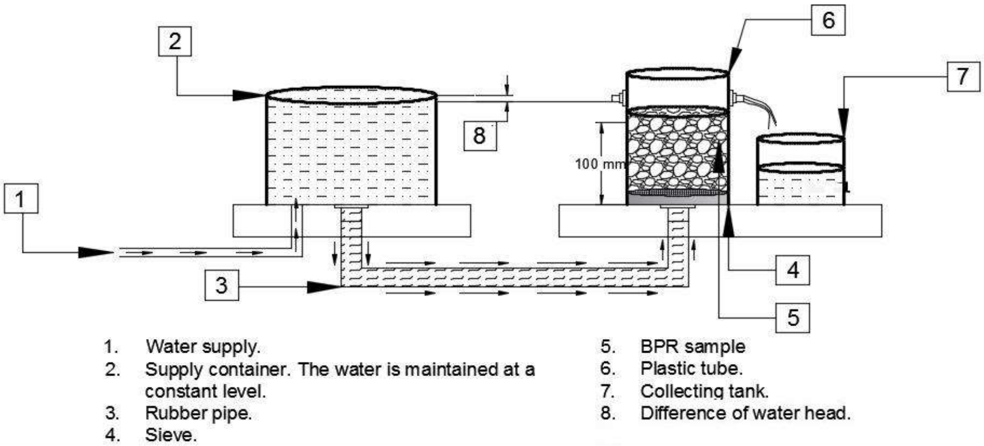


Fig. 2 - Set-up test for the assessment of permeability coefficient for pervious concrete (BPR) or aggregate mixtures/*Instalația folosită pentru evaluarea coeficientului de permeabilitate al betonului cu porozitate ridicată sau al amestecului de agregate*

Figure 2; it consists of a plastic tube with two clutches for water evacuation and one clutch for water supplying. The pervious concrete layer had a thickness of 100 mm (sample height).

The permeability test was performed on pervious concrete specimens as well as on the aggregate mixtures (without cement matrix) corresponding to the dosages presented in Tables 2 and 3.

Permeability coefficient (k) of aggregate mixture/pervious concrete was determined using Darcy Law [14].

$$k = \frac{Q \cdot h}{S \cdot \Delta l} \text{ (m/s), where:}$$

k – permeability coefficient (m/s);
Q – volume of water which pass through the specimen in one second (m^3/s);
h – sample height (m);
S – sample area (m^2);
Δl – difference of water head (m).

3. Results and discussions

3.1. Physical properties of pervious concretes

In Figure 3 are presented the values of densities of pervious concretes prepared with polyhedral aggregates (4/8 mm and 8/16 mm fractions) and two cement dosages i.e. 150 kg/m^3 and 200 kg/m^3.

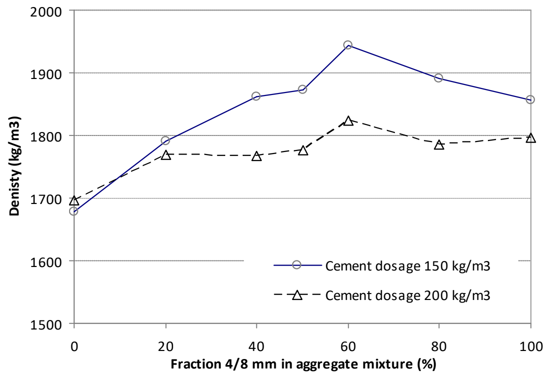


Fig. 3 - Densities of pervious concretes with polyhedral aggregate particles (4/8 mm and 8/16 mm fractions) /*Densitatea betoanelor cu porozitate ridicată cu conținut de agregate poliedrale, fracțiunile 4/8 mm și 8/16 mm.*

The values of density of pervious concretes decrease with the increase of cement dosage. This suggests that for a low value of water to cement ratio (i.e. 0.28-0.30), fresh cement paste seems to have a high enough viscosity in order to not allow aggregate particles to be in direct contact (Fig. 4a). This behavior could be possible for a low energy compaction – which is the case of our experiment. One can also assume that water/cement ratio is even lower due to aggregate particle absorption of water (Tab. 1).

The highest value of density is obtained for an aggregate mixture containing polyhedral aggregate particles (60% of 4/8 mm fraction and 40% of 8/16 mm fraction), which probably results in the closest packed structure.

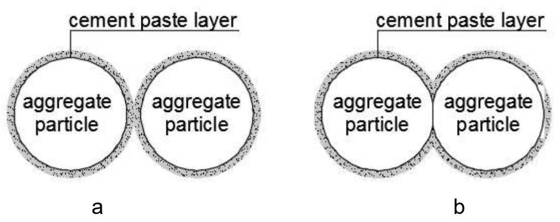


Fig. 4 - Contact between the aggregate particles: a) indirect contact (through the binding matrix layer); b) direct contact /*Contactul între particulele de agregat: a) indirect (prin intermediul matricei liante); b) direct.*

The influence of the shape of aggregate grains on physical and mechanical properties was determined for the concrete mixture with 60% fraction 4/8 mm and 40% fraction 8/16 mm (40S_1-60S_2); the polyhedral particles from the 8/16 mm fraction were replaced gradually by flat particles (see Tab. 3).

The values of density for pervious concretes made with various mixtures of flat and polyhedral particles (fraction 8/16 mm) are presented in Figure 5.

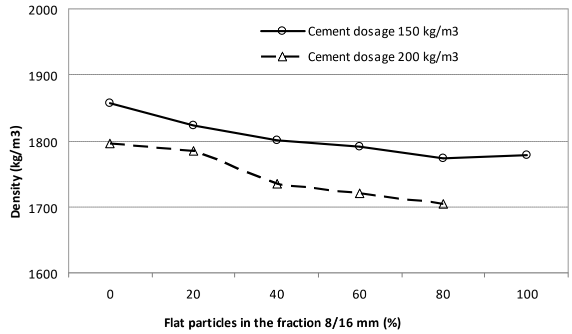


Fig. 5 - Density for pervious concretes made with various amounts of flat aggregate particles in the 8/16 mm fraction/*Densitatea betoanelor cu porozitate ridicată preparate cu diferite dozaje de agregat cu particule plate (fracțiune 8/16 mm).*

Figure 5 shows the same decrease of density values with the increase of cement dosage as noticed for the pervious concretes with polyhedral aggregates (Fig. 3). The lower value of apparent density was recorded for the concrete mixture with 80% flat particles (20S_1-80S_{1F}).The increase of density values with the increase of polyhedral particle amount (in the fraction 8/16 mm) suggests an increase of the packing density of the aggregate particles; this data are in good correlation with the data reported by Huan and co-workers [7] i.e. aggregates with larger sphericity can be packed better (to a higher density); the sphericity is defined as the ratio of surface area of a sphere and the surface area of the particle (both sphere and particle having the same volume) [7,15].

The results of permeability tests for aggregate mixtures (polyhedral particles) and the corresponding pervious concretes (with different cement dosages) are presented in Figure 6.

One can see a similar evolution of permeability coefficient for aggregate mixtures and derived concretes (with 150 kg/m^3 and 200 kg/m^3 cement dosage) with the increase of the amount of coarser aggregate grains (fraction 8/16 mm).

The increase of cement dosage from 150 kg/m^3 to 200 kg/m^3 determines a decrease of permeability coefficient most probably due to enlargement of the bridging points (cement matrix) between particles and reduction of the real section for water flow.

The average value of k_{agg}/k_{150} ratio is 0.94 and for k_{agg}/k_{200} is 0.89 suggesting a good correlation between the permeability of aggregate mixtures and the corresponding pervious concretes; therefore, one can assume a composition design of pervious concrete based on permeability coefficient of aggregate mixture for a specified cement dosage.

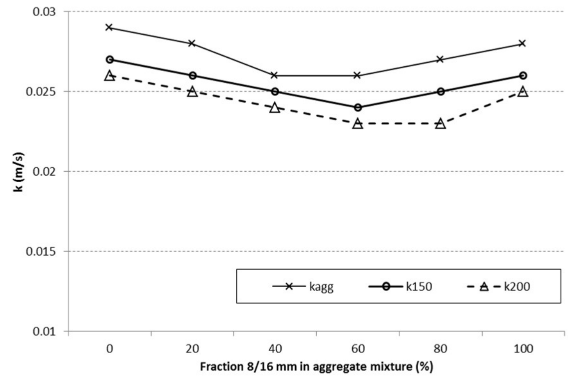


Fig. 6 - Influence of aggregate composition on the permeability coefficient of aggregate mixtures (k_{agg}) and derived pervious concretes (k_{150}=permeability coefficient assessed on pervious concretes prepared with 150 kg/m^3 cement dosage; k_{200}=permeability coefficient assessed on pervious concretes prepared with 200 kg/m^3 cement dosage)/ *Influența compoziției agregatului asupra coeficientului de permeabilitate al amestecului de agregate (k_{agg}) și al betoanelor cu porozitate ridicată care le conțin (k_{150}=coeficient de permeabilitate a betonului cu porozitate ridicată, preparat cu un dozaj de ciment de 150 kg/m^3; k_{200}=coeficient de permeabilitate a betonului cu porozitate ridicată, preparat cu un dozaj de ciment de 200 kg/m^3).*

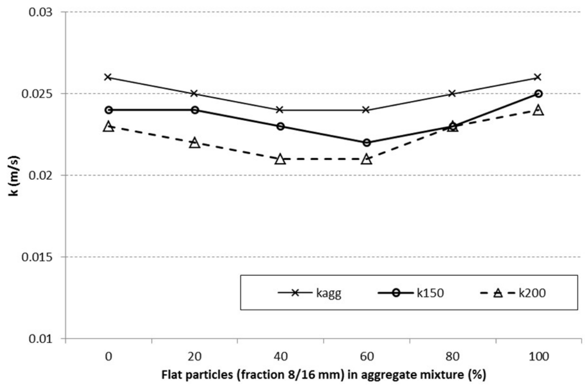


Fig. 7 - Influence of the replacement of polyhedral aggregate particles with flat particles (fraction 8/16 mm) on the permeability coefficient of aggregate mixtures (k_{agg}) and derived pervious concretes prepared with two diferent cement dosage (k_{150}-150 kg/m^3 and k_{200}-200 kg/m^3) / *Influența înlocuirii agregatului cu particule poliedrale cu agregat cu particule plate (fracțiunea 8/16 mm) asupra coeficientului de permeabilitate a amestecului de agregate (k_{agg}) și betoanelor cu porozitate ridicată care le conțin (k_{150}= dozaj de ciment de 150 kg/m^3; k_{200}= dozaj de ciment de 200 kg/m^3).*

The results of permeability tests for pervious concretes made with mixtures of polyhedral and flat particles (8/16 mm fraction) are presented in Figure 7.

The replacement of polyhedral particles with flat particles generates a minimum for pervious concretes permeability coefficient at about 40-60% content; nevertheless, the variations of the values of permeability coefficient of aggregate mixtures and derived pervious concretes are not significant.

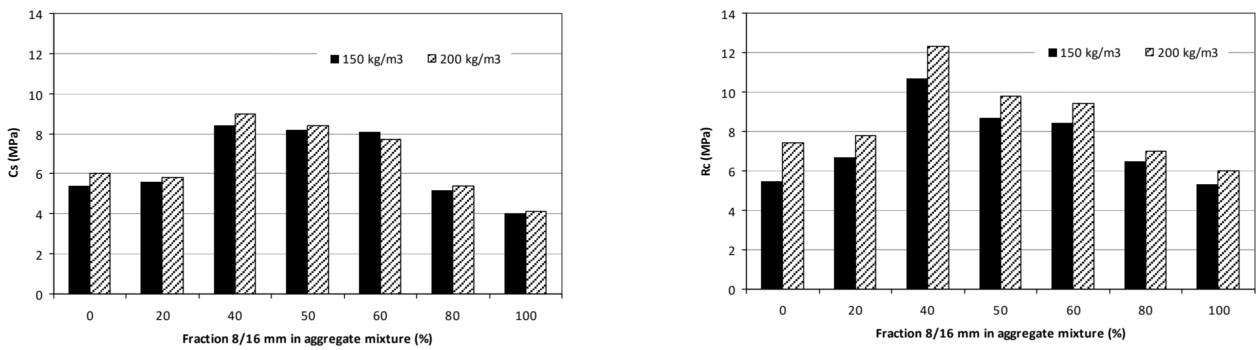
The results obtained in this study suggest that variation of shape index for coarse aggregates seems to not have a significant influence on permeability coefficient of pervious concretes.

3.2. Compressive strength of pervious concretes

The values of compressive strength after 7 and 28 days of curing of pervious concretes prepared with various mixtures of polyhedral aggregates (fractions 4/8 mm and 8/16 mm) and two different cement dosages are presented in Figure 8.

The values of compressive strength are in good correlation with the values of density (Fig. 3), with a maximum for the aggregate composition with 40% 8/16mm aggregate fraction ($40S_1$-$60S_2$). The differences in compressive strengths are not important at 7 days for the studied cement dosages (150 and 200 kg/m^3) but become significant after 28 days of curing.

For a cement content of 150 kg/m^3 and a water to cement ratio of 0.28 the average value of compressive strengths of pervious concretes is about 6 MPa for compositions containing 0-20% and 80-100% aggregate fraction 8/16 mm and about 8 MPa for compositions containing 40-60% aggregate fraction 8/16 mm.



a b

Fig. 8 - Compressive strength at 7 days (a) and 28 days (b) for pervious concretes with various dosages of 4/8 mm and 8/16 mm aggregate fractions and two different dosages of cement (150 kg/m^3 and 200 kg/m^3) / *Rezistența la compresiune după 7 zile (a) şi 28 zile de întărire (b), pentru betoane cu porozitate ridicată, preparate cu diferite dozaje de agregate – fracțiunile 4/8 mm și 8/16 mm și două dozaje diferite de ciment (150 kg/m^3 şi 200 kg/m^3).*

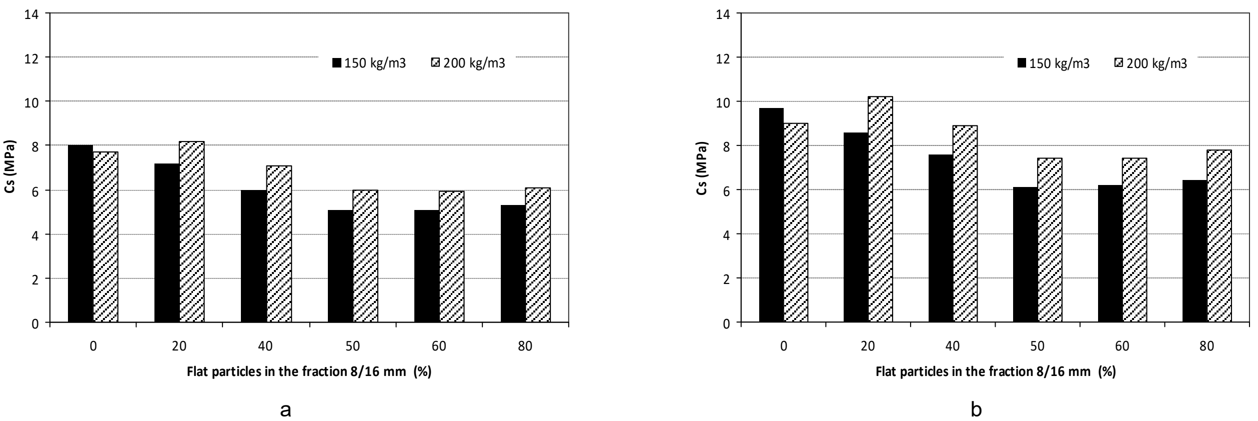


Fig. 9 - Compressive strength at 7 days (a) and 28 days (b) for pervious concretes made with various amounts of flat particles in the aggregate fraction 8/16 mm / *Rezistența la compresiune după 7 zile (a) și 28 zile de întărire (b), pentru betoane cu porozitate ridicată, preparate cu diferite dozaje de agregate plate – fracțiunea 8/16 mm și două dozaje diferite de ciment (150 kg/m^3 și 200 kg/m^3).*

Compressive strengths of concretes with different proportions of flat aggregates in the fraction 8/16 mm (40% in the mix) are presented in Figure 9.

Figure 9 shows a decrease of compressive strength values, for both 7 and 28 days of curing, with the increase of flat particles amount in the concrete mixture; these data are in good correlation with the values of the density (see Fig.5). The decrease is about 35% in the most unfavorable case and could be due to a lower number of bridging points between the cement matrix and aggregate grains. It is also well known the fact that flat and elongated aggregate grains have a lower strength due to their tendency to fracture along their weak, narrow dimension.

4. Conclusions

The results presented in this paper show a correlation between the permeability coefficients assessed on aggregate mixture and pervious concretes made with them. This suggests that is possible to design pervious concretes with a prescribed permeability value, using as imput values the results obtained in permeability test of aggregate mix and applying a correction coefficient which depends on cement paste content.

Reduction of aggregate permeability coefficient with 6% for a pervious concrete mixture with 150 kg/m^3 cement dosage and with 11% for a cement dosage of 200 kg/m^3 could be used to estimate concrete permeability coefficient.

The highest value of the compressive strength of pervious concrete was achieved for an aggregate mixture containing 40% coarse aggregate (fraction 8/16 mm – polyhedral grains). A significant decrease of compressive strength is observed when the polyhedral aggregate particles form the coarse fraction (8/16 mm) are replaced with flat particles. This is probably due to the lower strength of flat and elongated particles (as compared with the polyhedral ones) as well as the decrease of number of bridging points between the aggregate and cement matrix.

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