Primljen / Received: 6.11.2013.
Ispravljen / Corrected: 4.1.2014.
Prihvaćen / Accepted: 27.1.2014.
Dostupno online / Available online: 10.3.2014.

Effect of aggregate grading on pervious concrete properties

Authors:

Silvija Mrakovčić, PhD. CE
University of Rijeka
Faculty of Civil Engineering
silvija.mrakovcic@gradri.uniri.hr

Nina Čeh, mag.ing.aedif.
University of Rijeka
Faculty of Civil Engineering
nina.ceh@uniri.hr

Vedrana Jugovac, mag.ing.aedif.
University of Rijeka
Faculty of Civil Engineering
vedranajugovac@gmail.com

Preliminary note

Silvija Mrakovčić, Nina Čeh, Vedrana Jugovac

Effect of aggregate grading on pervious concrete properties

Fresh and hardened pervious concrete properties are experimentally determined in the paper. The correlation between the compressive strength, flexural tensile strength, flow coefficient, and aggregate grading is analysed. As there is no approved method for determining the flow of water through pervious concrete, the testing was conducted in accordance with the already known methods, but using own apparatus. Optimum strength and flow capacity results were obtained on gap graded samples with the 0-2 mm sand content of less than 15 %.

Key words:
pervious concrete, strength, aggregate grading, flow coefficient

Prethodno priopćenje

Silvija Mrakovčić, Nina Čeh, Vedrana Jugovac

Utjecaj granulometrijskog sastava na svojstva procjednog betona

U radu su eksperimentalno određena svojstva svježeg i očvrsnulog procjednog betona. Analizirana je zavisnost tlačne čvrstoće, vlačne čvrstoće savijanjem te koeficijenta protočnosti o granulometrijskom sastavu agregata. Budući da ne postoji propisani način određivanja protjecanja vode kroz procjedni beton, ispitivanje je provedeno sukladno poznatim metodama, ali s pomoću samostalno izrađenih pomagala. Na uzorcima s diskontinuiranom granulometrijskom krivuljom, gdje udio frakcije pijeska 0-2 mm u sastavu mješavina nije prelazio 15 %, dobiveni su optimalni rezultati čvrstoće i protočnosti.

Ključne riječi:
procjedni beton, čvrstoća, granulometrijski sastav, koeficijent protočnosti

Vorherige Mitteilung

Silvija Mrakovčić, Nina Čeh, Vedrana Jugovac

Einfluss der Kornzusammensetzung auf die Eigenschaften durchlässigen Betons

In dieser Arbeit sind Eigenschaften frischen und gehärteten durchlässigen Betons durch experimentelle Versuche ermittelt worden. Der Zusammenhang zwischen Druckfestigkeit, Biegezugfestigkeit, Durchflusskoeffizient und Gesteinskörnung ist analysiert worden. Da kein bestimmtes Verfahren zur Ermittlung des Wasserflusses durch durchlässigen Beton vorgeschrieben ist, sind in den Versuchen bekannte Vorgehensweisen mittels der eigenen Ausrüstung angewandt worden. Optimale Resultate in Bezug auf Festigkeit und Durchlässigkeit sind an Proben mit diskontinuierlichen Sieblinen erzielt worden, die einen 0-2 mm Sandkorngehalt unter 15 % nachweisen.

Schlüsselwörter:
durchlässiger Beton, Festigkeit, Gesteinskörnung, Durchflusskoeffizient

1. Introduction

Pervious concrete is a concrete with the voids content much greater than that of the ordinary concrete, which increases velocity of water flow through its structure. The fraction of mutually connected voids 2 to 8 mm in size, which account for 15 to 35 % of the total hardened concrete volume [1], is acquired by making a single grain graded concrete, or by a special aggregate gradation with a gap, i.e. where one of central fractions is missing. Aggregate grain sizes suggested for this concrete range from 9.5 to 19 mm [2], and fine aggregate is either omitted or added in a smaller percentage. Due to such composition, pervious concrete made without additives has a relatively low compressive strength varying from 2.8 to 28 MPa [2, 3, 4]. To avoid filling of voids with cement paste, its quantity is regulated by prescribing a lower water to binder ratio, usually between 0.26 and 0.5 [5, 6, 7].

Due to its relatively low strength and high permeability, pervious concrete is suitable for the construction of less trafficked pavement structures, footpaths and parking areas, namely in regions with frequent downfalls. Pervious concrete enables fast runoff from traffic surfaces thus eliminating the need to build complicated drainage systems. Also, when passing through concrete, water penetrates down to tree roots, which favours growth of vegetation in urban environments and prevents formation of urban heat islands.

This study of pervious concrete is conducted in order to obtain appropriate flow rates with acceptable compressive and flexural tensile stress values. The influence of gradation and aggregate grain size on the porosity, flow rate and compressive and flexural tensile stress values is analysed in the paper. Based on laboratory test results, mix proportions are optimized so as to obtain satisfactory properties important for this type of concrete.

2. Own pervious concrete mix proportions

2.1. Cement

The cement CEM I 42.5R, which is a pure general purpose Portland cement with 42.5 MPa in compressive strength and with rapid early hardening, was used in the preparation of pervious concrete mixes. The mixes were made with 300 kg of cement per cubic meter of concrete. Characteristic parameters of cement used are shown in Table 1.

Table 1. Characteristic cement parameters [8]

Characteristic	Achieved value	Standard demand
Density	3,25 kg/m^3	
Calcination loss	2,0 ± 0,5 %	≤ 5,0
Undissolved remains	0,25 ± 0,05 %	≤ 5,0
SO_3	3,2 ± 0,3 %	≤ 4,0
Chlorides	0,02 ± 0,01 %	≤ 0,1
Binding time (start) at 20°C	125 ± 35 min	≥ 60
Early strength (2 days)	29 ± 2 MPa	≥ 20
Standardized strength	54 ± 2 MPa	≥ 42,5; ≤ 62,5

Table 2. Ground limestone proportions [9]

Description of stone or mineral	Mineral-petrographic content per fraction [%]				
	0,5-1	2-4	4-8	8-16	16-32
Limestone		100,00	100,00	100,00	100,00
Limestone (micrite)	75,80				
Limestone (micrite with sparite)	13,23				
Limestone (sparite)	10,97				

Table 3. Properties of ground limestone [10]

Physicomechanical properties	Standard	Value obtained
Resistance to wear	HRN EN 1097-1:2004	M_{DE} = 14
Resistance to fragmentation	HRN EN 1097-2:2004	$LA_{(10-14)}$ = 26 $LA_{(8-16)}$ = 28
Resistance to abrasion	HRN EN 1097-8:2009	AAV = 9,33
Freeze - thaw resistance	HRN EN 1367-1:2008	F = 0,2 %
Presence of chlorides soluble in water		0,003 % (0-4)
Presence of lightweight pollutants		nije evidentirano (0-4)
Presence of vegetable soil		nije evidentirano (0-4)
Dried aggregate grain density	HRN EN 933-6:2004	ρ_{rd} = 2,67 g/cm^3

2.2. Aggregate

The ground limestone used in the analysis was produced at the Garica Quarry on the Island of Krk. Its proportions and properties are shown in Tables 2 and 3. Depending on mix design, the following aggregate fractions were used in the mixes: 0-4, 4-8, 8-16, 11-16 and 16-22. Thus, the grading curves of mixes differ from one another.

2.3. Water

Potable tap water was used in the preparation of pervious concrete mixes, which is why additional quality testing was not needed. Depending on the mix type, the water to cement ratio varied between 0.3 for specimens without fine aggregate to 0.35 for specimens with sand.

3. Pervious concrete mix preparation

Twenty-two pervious concrete mixes were made in the experimental part of the research. Fourteen of these mixes were made in the first phase and after obtaining the compressive strength and flow rate data. Another four mixes were made in the second phase, and the final four mixes were made in the third phase of the project. Mix proportions are shown in Table 4.
Concrete mixes were made in the Laboratory for Materials of the Faculty of Civil Engineering in Rijeka. The primary specimen was consolidated by vibration for 15 s to prove that pervious concrete mixes are not suitable for such a consolidation, because a larger amount of cement paste segregates at the bottom of the mould (Figure 1.a). Such consolidation would negatively influence pervious properties of this kind of concrete. For that reason, pervious concrete mixes were consolidated in moulds in layers that were uniformly flattened by pounding with a steel rod, taking care not to apply an excessively strong force on the mould bottom during consolidation of the first layer, and not to penetrate deeply into the previous layer when consolidating subsequent layers. Twenty-five blows were applied for each layer which occupied 1/3 of the mould height. This kind of consolidation prevented segregation of the cement paste (Figure 1.b). Three cubes measuring 150x150x150 mm

Pervious concrete mix proportions

Designation of mix	w / c	Voids* [%]	Coarse aggregate [mm] / share [%]	Sand [mm] / share [%]
N1	0,3	20	16-32 / 100	/
N2	0,3	20	4-8 / 100	/
N3	0,3	20	8-16 / 100	/
N4	0,3	20	4-8 / 50 16-32 / 50	/
N5	0,35	20	8-16 / 90	0-4 / 10
N6	0,35	20	8-16 / 80	0-4 / 20
N7	0,35	20	8-16 / 70	0-4 / 30
N8	0,35	20	4-8 / 40 8-16 / 40	0-4 / 20
N9	0,3	20	4-8 / 50 16-22 / 50	/
N10	0,35	20	4-8 / 40 16-22 / 40	0-4 / 20
N11	0,3	20	11-16 / 100	/
N12	0,35	20	11-16 / 90	0-4 / 10
N13	0,35	20	11-16 / 80	0-4 / 20
N14	0,35	20	4-8 / 40 16-22 / 40	0-4 / 20
P1	0,35	20	8-16 / 90	0-4 / 10
P2	0,3	20	4-8 / 50 16-22 / 50	
P3	0,35	20	4-8 / 45 16-22 / 45	0-4 / 10
P4	0,35	20	4-8 / 40 16-22 / 45	0-4 / 15
V1	0,35	20	4-8 / 45 16-22 / 45	0-4 / 10
V2	0,35	20	11-16 / 90	0-2 / 10
V3	0,35	20	4-8 / 45 16-22 / 45	0-2 / 10
V4	0,35	20	4-8 / 40 16-22 / 45	0-2 / 15

* assumed during proportion design, not proven experimentally

Figure 1. Preparation of specimens: a) vibrated concrete cube specimens; b) unvibrated concrete prism specimens; c) specimens for flow rate testing

were made for each mixture (N1 to N14) in accordance with the standard [11] for subsequent flow rate and compressive strength testing. In case of mixes P1 to P4 and V1 to V4, three cubes were made for compressive strength testing, three prisms measuring 100x100x400 mm were made for the flexural tensile strength testing, and three cylinders in plastic pipes 110 mm in diameter and 250 mm in height were used for the flow rate testing (Figure 1.c). According to requirements specified in the standard [11], specimens were cured for 28 days. During the first 24 hours, they were cured in moulds at the temperature of 21°C and, after that, they were unmoulded and cured in water at 20 ± 2°C for the remaining period. Specimens in plastic pipes were not unmoulded and were kept in water for 28 days to obtain total specimen saturation for the flow rate testing.

4. Experimental testing of fresh concrete properties

The consistency and porosity testing of fresh concrete mixes, and the permeability and tensile strength testing of hardened concrete specimens, was conducted according to [12] at the Laboratory for Materials of the Faculty of Civil Engineering in Rijeka. Tensile strength tests according to [13] were carried out at the Laboratory of Goran graditeljstvo d.o.o. in Kukuljanovo.

4.1. Consistency tests

In case of ordinary concrete, consistency is usually tested using one of the methods according to [14-17]. For pervious concrete, consistency tests based on such standard methods would give unrealistic results (Figure 2.a). Thus, consistency should be tested using a method designated specifically for pervious concrete, taking into consideration its specific properties. According to [2], pervious concrete consistency testing can be conducted in two ways, i.e. using the reversed slump method [18] or by shaping a clump out of fresh concrete by hand [19].
The method of clump shaping was chosen for testing consistency of fresh pervious concrete mixes. A small amount of mix was extracted by hand and a clump was shaped and observed with palm open. The concrete mix consistency is satisfactory if the clump preserves its shape, if grains do not segregate from the clump, and if there is no "bleeding" of cement milk. The consistency is satisfactory for all mixes tested (Figure 2.b).

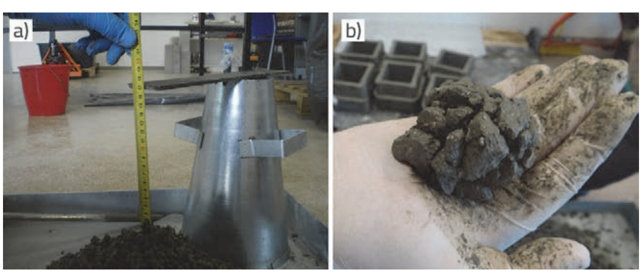

Figure 2. Pervious concrete consistency test using: a) subsidence method; b) clump method

4.2. Definition of permeability coefficient

The hydraulic permeability of pervious concrete is directly related to concrete porosity and pore size. Previous tests [20] show that hardened concrete should contain no less than 15 % of voids in order to enable significant filtration through its matrix. According to [3], pervious concrete containing between 20 % and 30 % of voids shows satisfactory properties, and so the 20 % voids content was chosen for the concrete mix design. The permeability coefficient for pervious concrete varies from 0.2 to more than 1.2 cm/s [19], but a standard method for flow rate determination has not as yet been established.

4.2.1. Defining permeability coefficient using falling head permeability test

The permeability coefficient for the first fourteen pervious concrete mixes was established using the falling head permeability test according to [21], while the test procedure was designed by our laboratory (Figure 3). Cube shaped concrete specimens were cured in moist conditions until 28 days of age, and so they were completely saturated when the test was carried out. The objective was to annul the entrapped air which resists water flow through voids. A glass plate was placed in the middle of the upper plane of each sample, and a calibrated bottomless beaker filled with water to the level of 300 mm was placed on that glass plate. After filling the beaker, the glass plate was promptly removed and the dial gauge was activated. The time in which all water from the beaker passed through the sample and reached the receptacle was measured.

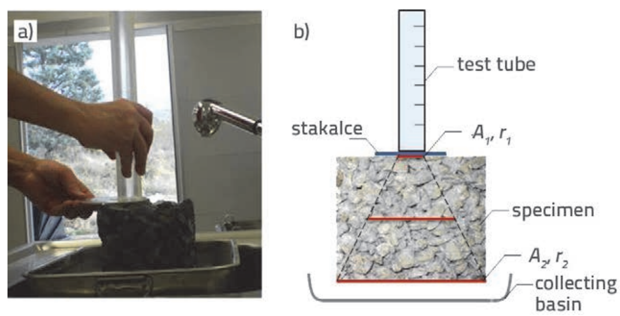

Figure 3. Determination of permeability coefficient for first 14 mixes: a) test in progress; b) schematic view of the test

In order to take into consideration the effective area of water flow through specimen, several experimental tests were carried out. These tests showed that water does not flow out through side surfaces of the cube specimen, but that it flows out through the whole bottom plane. Based on these observations, an effective area of water seepage was approximated as:

$$r_{eff} = \frac{r_1 + r_2}{2} \tag{1}$$

$$A_{eff} = r_{eff}^2 \cdot \pi \tag{2}$$

where are:
r_{eff} – the effective or average radius,
r_1 – the cross-section radius of the beaker,
r_2 – the inscribed circle radius of square base of the cube specimen,
A_{eff} – the effective flow-through area.

The permeability coefficient was calculated as:

$$k_p = \frac{V}{A_{eff} \cdot (t_2 - t_1)} \quad (3)$$

where are:
k_p – the permeability coefficient obtained during the falling head permeability test [cm/s],
t_1 – the time when the testing starts [s],
t_2 – the time when the testing ends [s],
V – the volume of water collected during the time Δt [cm^3].

4.2.2. Defining permeability coefficient using constant head permeability test

The permeability coefficient for mixes P 1-4 and V 1-4 was determined by testing cylinder-shaped specimens described in 2.4 using the constant head permeability test presented in [6]. The method is convenient for materials with the permeability coefficient of $k > 10^{-4}$ cm/s and based on Darcy's law. Permeability coefficient can be obtained according to:

$$k_s = \frac{L}{\Delta h} \cdot \frac{V}{A \cdot (t_2 - t_1)} \quad (4)$$

where are:
k_s – the permeability coefficient [cm/s],
L – the sample height [cm],
Δh – the hydraulic difference in water levels [cm],
t_1 – the experiment start time [s],
t_2 – the experiment end time [s],
V – the volume of water collected during the time t_2 - t_1 [cm^3],
A – the area of filtration [cm^2].

Tests were carried out on samples P1 - P4 i V1 - V4. Our own test apparatus, shown in Figure 4, was made for the testing.

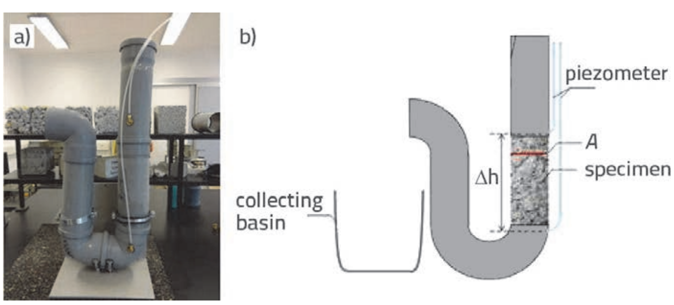

Figure 4. Determination of permeability coefficient for the first fourteen mixes: a) apparatus; b) schematic view of the apparatus

4.3. Compressive strength test

Compressive strength tests were carried out according to [13] on cube-shaped specimens measuring 150x150x150 mm. Tests were conducted on 28-day old specimens without preparatory grinding of cube planes, which is believed to be the reason for not obtaining the maximum possible compressive strength of pervious concrete specimens. When it comes to pervious concrete, the procedure of grinding sample surfaces on which the load will be applied is essential. The evenness of the surface is dependent on the size and amount of voids and, if the surface is uneven, the load is transferred unequally, mainly over protruding single grains or group of grains. Due to grain displacement, the compressive strength test apparatus can inaccurately record sample failure.

4.4. Flexural tensile strength test

Flexural tensile strength tests were carried out according to [22] on prism-shaped specimens measuring 100x100x400 mm. Tests were conducted on 28-day old specimens.

5. Analysis of tests results

Laboratory tests were carried out on fresh concrete mixes and hardened concrete specimens. The consistency of fresh concrete was tested for all the mixes and all the results were satisfactory.
Hydraulic permeability tests were carried out using two methods: samples N1 – N14 were tested using the falling head permeability procedure (Figure 5), while all other samples were tested using the constant head permeability method (Figure 6). Results gained using the second method were taken as relevant values, since the water was flowing under the fixed pressure, and through the fixed cross-sectional area of the sample. In case of single grain graded concrete mixes, the permeability is higher for mixes with a greater nominal fraction, where the highest results are obtained for mixes with less sand, and for mixes with a greater ratio between the largest and the smallest grain diameter (Figure 5). Two-fraction concrete mixes with gap (4-8 and 16-22) showed that the permeability decreases with an increase in sand ratio, or with the reduction of the largest grain of sand (Figure 6). Mixes containing more than 15 % of sand exhibit unsatisfactory results in hydraulic permeability tests, according to [19].
Compressive strength tests for all samples were conducted according to the standard [13]. In case of the single grain graded pervious concrete, mixes with a lower nominal fraction presented a higher compressive strength (Figure 7.a). As expected, all concrete mixes with a higher sand ratio showed a higher compressive strength (Figure 7.b). Flexural tensile strength tests were carried out on specimens taken from mixes P1 to P4 and V1 to V4. Figure 8 shows results obtained by the flexural tensile strength testing of double-size grain graded specimens (4-8 and 16-22) with different ratios of 0-4 graded sand.

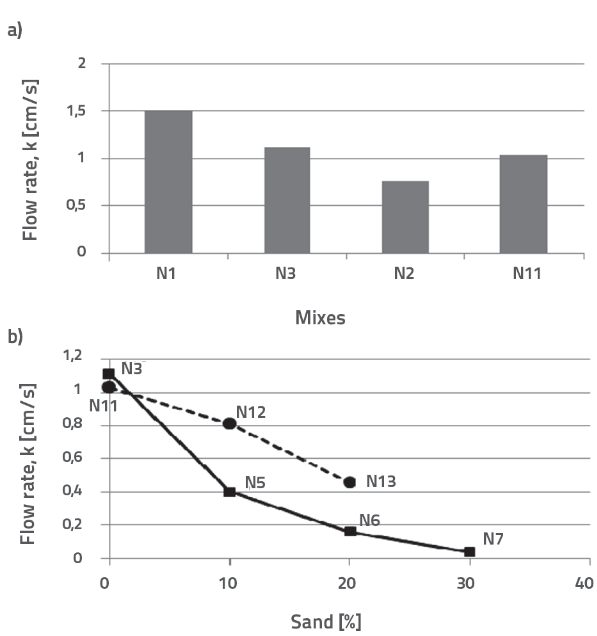

Figure 5. Single-fraction concrete: a) flow rate to fraction diagram; b) flow rate to sand ratio in concrete mix diagram

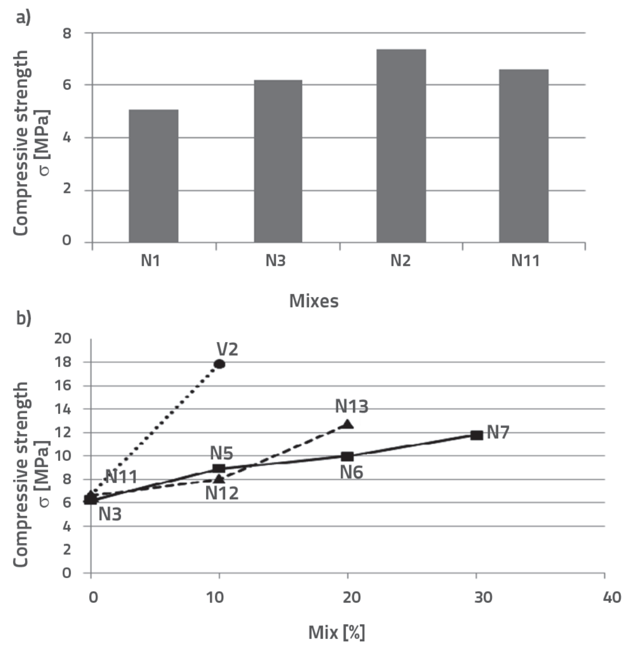

Figure 7. Single-fraction concrete: a) compressive strength to fraction diagram; b) compressive strength to sand ratio diagram

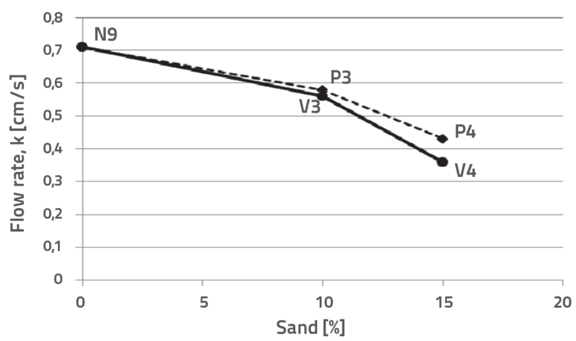

Figure 6. Flow rate to sand ratio diagram for double size grain graded pervious concrete mixes

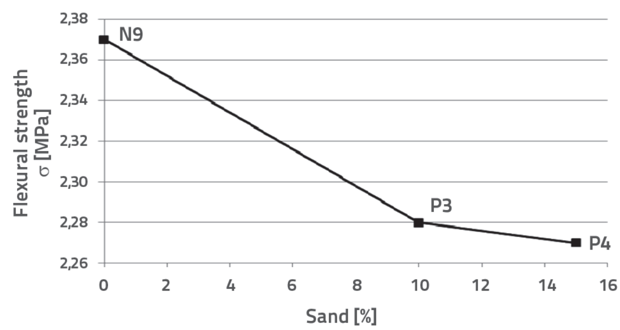

Figure 8. Flexural tensile strength to sand ratio diagram for two-fraction pervious concrete mixes

6. Conclusion

Pervious concrete is suitable for surfaces with inferior vehicle loads, as it enables rainwater drainage without the need for installing complex drainage systems. The grading of aggregate for pervious concrete influences the permeability coefficient and tensile strength. A higher permeability can be obtained by leaving out fine aggregate, designing single grain graded mixes or double size grain graded mixes with the gap in the grading. A higher compressive strength can be obtained by adding up to 15 % of sand, since further increase in sand content causes decrease in permeability properties of pervious concrete. It was established that single - grain graded concrete samples, with the 11-16 mm aggregate and 10 % of 0-2 graded sand, have the highest compressive strength of 17.90 MPa. The highest hydraulic permeability of 2.19 cm/s was obtained with the single grain graded pervious concrete mixes containing 8-16 mm aggregate, and 10 % of 0-2 sand. The biggest grain suitable for the single- and double- grain graded concrete mixes is 22 mm. Consistency tests of fresh concrete mixes showed that the slump method is inadequate for testing consistency of pervious concrete. The clump shaping method according to [19] was proven to be suitable for this testing. Permeability coefficient tests were carried out using two methods: the falling head permeability test and the constant head permeability test. The latter method proved to be better because the water pressure remained constant throughout the testing.

Results obtained during this research can be taken as guidelines for further study of pervious concrete properties. Additional optimization of pervious concrete properties is planned, including analysis of possible use of additives and recycled aggregate.

REFERENCES

[1] Report on Pervious Concrete, American Concrete Institute, Farmington Hills, 2011.

[2] Report on Pervious Concrete, American Concrete Institute, Farmington Hills, 2010.

[3] Huang, B., Wu, H., Shu, X. & Burdette, E.G.: Laboratory evaluation of permeability and strength of polymer-modified pervious concrete, Construction and Building Materials, 24, pp. 818-823, 2010, doi:10.1016/j.conbuildmat.2009.10.025

[4] Deo, O. & Neithalath, N.: Compressive behaviour of pervious concretes and quantification of the influence of random pore structure features, Material Science and Engineering, 528, pp. 402-412, 2010, doi:10.1016/j.msea.2010.09.024

[5] Bhutta, M.A.R., Hasanah, N., Farhayu, N., Hussin, M.W., Tahir, M.M., Mirza, J.: Properties of porous concrete from waste crushed concrete (recycled aggregate), Construction and building materials, 47, pp. 1243-1248, 2013.

[6] Kuo, W-T., Liu, C-C, Su, D-S: Use of washed municipal solid waste incinerator bottom ash in pervious concrete, Cement & Concrete Composites, 37, pp. 328-335, 2013.

[7] Chindaprasirt, P., Hatanaka, S., Chareerat, T., Mishima, N., Yuasa, Y.: Cement paste characteristics and porous concrete properties, Construction and Building Materials, 22, pp. 894-901, 2008, doi:10.1016/j.conbuildmat.2006.12.007

[8] Katalog rasutih cemenata http://www.cemex.hr, 01.02.2013.

[9] Izvještaj o ispitivanju broj 61051-50-2418/12, Dokumentacija GP Krk d.d., 26.10.2012.

[10] Izvještaj o ispitivanju broj 61053-20-2862/12, Dokumentacija GP Krk d.d., 29.11.2012.

[11] HRN EN 12390-2 Ispitivanje očvrsnuloga betona - 2. dio: Izrada i njega ispitnih uzoraka za ispitivanje čvrstoća (EN 12390-2:2009), Hrvatski zavod za norme, 2009.

[12] HRN EN 12390-5 Ispitivanje očvrsnuloga betona - 5. dio: Čvrstoća ispitnih uzoraka na savijanje (EN 12390-5:2009), Hrvatski zavod za norme, 2009.

[13] HRN EN 12390-3 Ispitivanje očvrsnuloga betona - 3. dio: Tlačna čvrstoća ispitnih uzoraka (EN 12390-3:2009), Hrvatski zavod za norme, 2009.

[14] HRN EN 12350-2 Ispitivanje svježeg betona - 2. dio: Ispitivanje slijeganjem (EN 12350-2:2009), Hrvatski zavod za norme, 2009.

[15] HRN EN 12350-3 Ispitivanje svježeg betona - 3. dio: Vebe ispitivanje (EN 12350-3:2009), Hrvatski zavod za norme, 2009.

[16] HRN EN 12350-4 Ispitivanje svježeg betona - 4. dio: Stupanj zbijenosti (EN 12350-4:2009), Hrvatski zavod za norme, 2009.

[17] HRN EN 12350-5 Ispitivanje svježeg betona - 5. dio: Ispitivanje rasprostiranjem (EN 12350-5:2009), Hrvatski zavod za norme, 2009.

[18] Kevern, J.T., Schaefer, V.R., Wang, K.: Predicting Performance of Pervious Concrete using Fresh Unit Weight, Proceedings oft he 2009 NRMCA Concrete Technology Forum: Focus on Performance Prediction, Cincinnati, 2009.

[19] Tennis, P.D., Leming, M.L., Akers, D.J.: Pervious Concrete Pavements, Portland Cement Association, Skokie, 2004.

[20] Meininger, R.C.: No-Fines Pervious Concrete for Paving, Concrete International, V, 10, pp. 20-27, 1988.

[21] Yang, J., Jiang, G.: Experimental study on properties of pervious concrete pavement materials, Cement and Concrete Research, 33, pp. 381-386, 2003.

[22] HRN EN 12390-5 Ispitivanje očvrsnuloga betona - 3. dio: Čvrstoća ispitnih uzoraka na savijanje