Changes of strength characteristics of pervious concrete due to variations in water to cement ratio

M Kovac¹ and A Sicakova¹
¹Technical University of Košice, Faculty of Civil Engineering, 042 00, Košice, Slovakia
Email: marek.kovac@tuke.sk

Abstract. Pervious concrete is considered to be a sustainable pavement material due to high water permeability. The experiment presented in this paper was aimed at study the influence of water to cement ratio on both the compressive and splitting tensile strength of pervious concrete. Typically, less water content in concrete mixture leads to less porosity of cement paste and thus it provides desirable mechanical properties. In case of conventional dense concrete, the lower is the water to cement ratio, the higher or better is the strength, density and durability of concrete. This behaviour is not quite clear in case of pervious concrete because of low amount of cement paste present. Results of compressive and splitting tensile strength of pervious concrete are discussed in the paper while taking into account values measured after 2 and 28 days of hardening and variations in water to cement ratio. The results showed that changes of water to cement ratio from 0.25 to 0.35 caused only slight differences in strength characteristics, and this applied to both types of tested strength.

1. Introduction

Portland cement pervious concrete (PCPC) allows water to penetrate its structure through a series of interconnected voids. This characteristic goes against all design criteria for conventional concrete, whose typical focus is on remaining impermeable. If designed, compacted, and maintained correctly, many sustainability benefits can be seen through the use of pervious concrete. Various other types of pervious/porous pavements show similar benefits. Permeable pavements can be divided into nine different categories, including porous aggregate, porous turf, plastic geo-cells, open-jointed paving blocks, open-celled paving grids, pervious concrete, porous asphalt, soft paving materials and decks [1]. All of these permeable systems are similar in nature, typically consisting of a granular base that not only acts as storage for excess storm water, but also as structural support [2]. The use of these types of pavements has been increasing in recent years due to their many environmental benefits. Like pervious concrete, the long-term performance of these pavements is still a concern and further research is needed to understand these pavements to a depth that traditional pavements are understood [3].

Pervious concrete mixtures have little to no slump [4]. This inherent property is due to the low cement paste content, which only allows for a thin film coating of cement paste around the aggregates [5]. High viscosity paste is needed so that the aggregates can be coated, while resisting the drain-down of the paste. The mitigation of drain-down is pertinent so that the matrix porosity is maintained throughout the width of the concrete section. The structure relies on the stone-to-stone contact achieved through compaction, which allows for the cement paste coated aggregates to bond with one another. It is recommended that the appropriate cement paste, to achieve the proper void structure,
should possess a low water to cement ratio (w/c), about 0.20 to 0.25, in addition to superplasticizer and adequate mixing [6]. Experiment given in [7] shows decrease of compressive strength along with decrease of w/c ratio what is contrary with conventional dense concrete behaviour. 

\( \text{W/c ratio in published experimental works varies in wide range from 0.2 to 0.4 usable for pervious concretes. In principal, pervious concrete mixtures with w/c ratios under 0.3 requires usage of water reducing admixtures while w/c above 0.3 can be mixed without plasticizer [5,7]. In general, w/c in range from 0.27 to 0.34 can be assumed as the most common and wide range applicable for pervious concrete mixtures [8].} \)

This article presents a study that has been conducted to confirm the applicability of the w/c ratio in the range of 0.25 to 0.35 for locally available concrete components. Influence on both the compressive and splitting tensile strength of pervious concrete is evaluated, while taking into account values measured after 2 and 28 days of hardening.

2. Materials and methods

The experiment was focused on the utilization of locally available materials (Eastern Slovakia), given in following list:

- cement CEM II/A-S 42.5 R in accordance with [9];
- natural aggregate (siliceous gravel type) in accordance with [10]. To create open structure of concrete, single size coarse aggregate of fraction 4/8 was used. To maintain desirable performance of concrete, 7% of sand was added to aggregate mixture. Properties of aggregate are given in table 1.

| Properties | Aggregate fraction |
|------------|--------------------|
| 0/4        | 4/8                |
| Density [kg/m\(^3\)] | 2600 | 2580 |
| Dry rodded unit weight [kg/m\(^3\)] | 1830 | 1580 |
| Water absorption [%] | 1.2 | 1.4 |
| Void content [%] | 30 | 39 |

The sieve analysis of aggregate was conducted to get the information about granulometric composition of used aggregate (table 2).

| Sieve mesh size [mm] | Cumulative percent passing [%] | 7% 0/4 + 4/8 |
|----------------------|--------------------------------|--------------|
| 0                    | 0                              | 0            |
| 0.063                | 0.9                            | 0.1          |
| 0.125                | 3.3                            | 0.3          |
| 0.25                 | 10.4                           | 0.8          |
| 0.5                  | 31.8                           | 2.3          |
| 1                    | 54.0                           | 4.0          |
| 2                    | 75.8                           | 5.6          |
| 4                    | 98.2                           | 14.4         |
| 8                    | 100.0                          | 93.3         |
| 16                   | -                              | 100          |

Proportions of materials were calculated by method given in [11]. Three recipes of pervious concrete mixtures were designed and mixed in this experiment. The first step in calculation was determination of voids content. Voids content was intended as constant in each of mixtures and the value was selected using following criteria: voids content for pervious concrete in accordance with [12] is within 18% to 23% and in accordance with [8] it should range between 15% and 25%.
Assuming these boundaries, 20% voids content was considered in further calculations. Hence, volume of aggregate (0.575 m³) and volume of cement paste (0.225 m³) were constant for all mixtures. Mixtures differed by each other only in w/c ratio (0.25, 0.30 and 0.35). The final proportions of mixtures for 1 m³ of fresh pervious concrete are given in Table 3.

### Table 3. Proportions of pervious concrete mixtures.

| Material      | Units          | Mixture W35 | Mixture W30 | Mixture W25 |
|---------------|----------------|-------------|-------------|-------------|
| Cement        |                | 327         | 354         | 384         |
| Water         |                | 115         | 106         | 96          |
| Aggregate 0/4 | [kg/m³]        | 96          | 96          | 96          |
| Aggregate 4/8 |                | 1375        | 1375        | 1375        |
| Plasticizer   | [-]            | 0.3         | 1.4         | 4.2         |
| w/c           | [-]            | 0.35        | 0.30        | 0.25        |
| Calculated unit weight | [kg/m³] | 1913       | 1931        | 1951        |

Samples of pervious concrete were mixed in the forced action concrete mixer. The first step was mixing aggregate for about 15 seconds then, cement was added and mixed another 15 seconds and finally the water with superplasticizer were added and mixed thoroughly. Pervious concrete specimens of 100 mm in diameter and 200 mm height were made by constant compacting (15 hits). After the curing in water, specimens were tested in 2 and 28 days of setting and hardening to compressive and splitting tensile strength.

### 3. Results and discussion

During the mixing, the nature of fresh mixture workability was controlled visually. Mixture W35 (w/c = 0.35) showed the slightly runny character immediately after mixing however after few next minutes the excessive water has been soaked by aggregate. On the other hand, mixture W25 (w/c = 0.25) showed very stiff nature and despite of higher dosage of plasticizer (lignosulphonate base), it was difficult to process.

#### 3.1. Compressive strength

The results of compressive strength after 2 and 28 days of setting and hardening are given in figure 1. After 2 days of curing, mixtures W35 and W30 reached 9.5 MPa and 9.0 MPa respectively. Mixture W25 with the lowest w/c (0.25) achieved the highest compressive strength 10.5 MPa. After 28 days of curing, mixtures W35 and W30 reached 14.5 MPa and 16 MPa respectively. Mixture W25 with the lowest w/c (0.25) achieved highest compressive strength 17.5 MPa. Difference between the compressive strength values of samples after 2 days of curing (1.5 MPa) and after 28 days of curing (3 MPa) was very slight despite significant w/c variation (from 0.35 to 0.25).

#### 3.2. Splitting tensile strength

The results of splitting tensile strength after 2 and 28 days of setting and hardening are given in figure 2. After 2 days of curing, mixtures W35 and W25 reached 1.3 MPa and 1.4 MPa respectively. Mixture W30 with w/c = 0.30 achieved the highest splitting tensile strength 1.5 MPa. After 28 days of curing, mixtures W25 and W30 reached 1.6 MPa and 1.7 MPa respectively. Mixture W35 with w/c ratio 0.35 achieved the highest splitting tensile strength 2 MPa. Difference between the splitting tensile strength values of samples after 2 days of curing (0.2 MPa) and after 28 days of curing (0.4 MPa) was very slight despite significant water to cement ratio variation (from 0.35 to 0.25).

Mixture with the highest w/c (0.35) obtained the highest splitting tensile strength; it can be explained by better workability and thus better bond between the aggregate and cement paste. In case of mixtures W30 and W25, stiffer cement paste showed weaker adhesion to aggregate grains what resulted in lower splitting tensile strength. Similar behavior was observed and discussed in [13] and [14]. However, due to very slight difference in splitting tensile strength between mixtures (difference
was smaller than measurement accuracy), it can be assumed that present variation in w/c ratio had not significant influence on splitting tensile strength.

Figure 1. Compressive strength development of tested mixtures.

The nature of failure should also be described since it was clearly visible after the splitting tensile strength test. The crack came through most of the aggregate grains (figure 3); this referred to strong cement stone. Therefore next increasing of the cement paste strength by lowering w/c ratio needn’t lead to better strength characteristics because the strength of aggregate can be a limiting factor [14].

Figure 2. Splitting tensile strength development of tested mixtures

Figure 3. View of the inner structure of pervious concrete mixtures W25, W30 and W35 (left to right) after the splitting tensile strength test.
Conclusion
In the case of conventional dense concrete, the lower is the water to cement ratio, the higher or better are the strength, density and durability of concrete. This article presented results of study that has been conducted to confirm the applicability of the w/c ratio in the range of 0.25 to 0.35 for production of pervious concrete made of locally available components. The following conclusions can be formulated:

- very slight difference in strength characteristics between mixtures allows for suggestion that 0.25 to 0.35 range of w/c ratio has no significant influence on strength characteristics of pervious concrete;
- the nature of failure of all samples points to strong cement stone for each of w/c ratio while the strength of aggregate seems to be a limiting factor. This opinion comes from the crack formation that occurs at yield strength of samples;
- analysing the relationship between the compressive and splitting tensile strength, linear correlation with R value 0.63 was found;
- despite the high dose of plasticizer, w/c lower than 0.35 causes difficult working with pervious concrete. Here the next optimization of the kind and dose of chemical admixtures is necessary.

Results of strength characteristics being found within the presented experiment are promising and open for next experimental work focused on various locally available materials.

Acknowledgments
This work was supported by the project ITMS Center of excellent integrated research of progressive building constructions, materials and technologies [grant number 26220120037].

References
[1] Ferguson B K 2005 Porous Pavement Integr. Stud. Water Manag. L. Dev
[2] Hunt P D, W F PE, L S Laura 2006 Urban Waterways, Permeable Pavements, Green Roofs and Cisterns, Stormwater Treatment Practices for Low-Impact Development
[3] Yang J, G Jiang 2003 Experimental study on properties of pervious concrete pavement materials Cem. Concr. Res. 33 381–386
[4] Haselbach L, R Freeman 2006 Vertical Porosity Distribution in Pervious Concrete Pavement ACI J 103
[5] Wang K, V R Schaefer, J T Kevern, M T Suleiman 2006 Development of Mix Proportion for Functional and Durable Pervious Concrete
[6] Chindaprasirt P, S Hatanaka, T Chareerat, N Mishima, Y Yuasa 2008 Cement Paste Characteristics and Porous Concrete Properties Constr. Build. Mater. 22 894–901
[7] Joshi T, U Dave 2016 Evaluation of strength, permeability and void ratio of pervious concrete with changing w/c ratio and aggregate size Int. J. Civ. Eng. Technol. 7 276–284
[8] Tennis P,D, M L Leming, D J Akers 2004 Pervious Concrete Pavements
[9] STN EN 197-1:2011 Cement. Part 1: Composition, specifications and conformity criteria for common cements Slovak Office of Standards, Metrology and Testing Bratislava
[10] STN EN 12620:2008 Aggregates for concrete Slovak Office of Standards, Metrology and Testing Bratislava
[11] Nguyen D H, N Sebaibi, M Boutouil, L Leleyter, F Baurd 2014 A modified method for the design of pervious concrete mix Constr. Build. Mater. 73 271–282
[12] STN 73 6124-2:2013 Road Construction Part 2: Concrete drainage layers Slovak Office of Standards, Metrology and Testing Bratislava
[13] Neamitha M, T M Supraja 2017 Influence of Water Cement Ratio and The Size of Aggregate on The Properties Of Pervious Concrete Int. Ref. J. Eng. Sci. 6 9–16
[14] Chopra M, J Wanielista, A M Mulligan 2007 Compressive Strength of Pervious Concrete Pavements