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Analysis of pervious concrete properties

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Professional paper

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Analysis of pervious concrete properties

Various properties of pervious concrete, such as the compressive strength, split tensile strength, flexural strength, porosity and permeability, are studied in this paper for two aggregate gradations with different aggregate to cement ratios. Although the higher cement content exhibited better results for strength properties, the porosity and permeability results were lower. This study also aims to evaluate the balance between the porosity, permeability and compressive strength of pervious concrete for different aggregate size and cement content values. The test results show that it is possible to produce a pervious concrete mixture with acceptable permeability and strength values.

Key words:
pervious concrete, porous concrete, porosity, permeability

Stručni rad

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Analiza svojstava procjednog betona

U radu se analiziraju svojstva procjednog betona poput tlačne čvrstoće, vlačne čvrstoće cijepanjem, vlačne čvrstoće savijanjem, poroznosti i propusnosti, i to za dvije frakcije agregata i za različite udjele agregata i cementa. Iako se pokazalo da se s višim udjelom cementa postižu bolji rezultati u pogledu čvrstoće, na taj se način dobivaju niže vrijednosti poroznosti i propusnosti. Ocjenjuje se i odnos između poroznosti, propusnosti i tlačne čvrstoće procjednog betona za različite veličine agregata i različite udjele cementa. Rezultati ispitivanja pokazuju da se može postići mješavina procjednog betona koja ima prihvatljive vrijednosti propusnosti i čvrstoće.

Ključne riječi:
procjedni beton, porni beton, poroznost, propusnost

Fachbericht

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Analyse der Eigenschaften von Sickerbeton

In dieser Arbeit werden Eigenschaften von Sickerbeton, insbesondere die Druckfestigkeit, die Spaltzugfestigkeit, die Biegezugfestigkeit, die Porosität und die Durchlässigkeit, für zwei Fraktionen von Gesteinskörnungen und zwei verschiedene Zementanteile analysiert. Obwohl sich gezeigt hat, dass bei höheren Zementanteilen bessere Reaultate bezüglich der Festigkeit erzielt werden, zeigen sich dementsprechend tiefere Werte der Porosität und der Durchlässigkeit. Ebenso wird das Verhältnis zwischen Porosität, Durchlässigkeit und Druckfestigkeit von Sickerbeton für verschiedene Gesteinskörnungen und Zementanteile beurteilt. Die Resultate der Untersuchungen zeigen, dass eine Sickerbetonmischung mit akzeptablen Eigenschaften erzielt werden kann.

Schlüsselwörter:
Sickerbeton, Gasbeton, Porosität, Durchlässigkeit

1. Introduction

Natural resources are nowadays increasingly depleting due to rapid urbanization and infrastructure developments. In recent years, due to urbanization in Indian cities, most areas are occupied with buildings and air proof concrete pavements. Rain water does not pass into the underground because of the lack of water permeability and air permeability in concrete pavements. Various strategies are being followed by engineers to protect and restore the world's natural ecosystem. One such strategy is the application of pervious concrete, which is a special type of concrete characterized by high permeability and porosity. Pervious concrete is a mixture of cement, uniform coarse aggregate, a low quantity of fine aggregate (which can be omitted), water and, optionally, admixtures. Appropriate amounts of water and cementitious material are used to make a paste that forms a thin coat around aggregate particles, but leaves free space between aggregates. A complete elimination or drastic reduction of fine aggregates creates large and continuous voids. The main important function is its ability to transport large volumes of water through its pores to the underlying strata. Pervious concrete is also known as a no-fines concrete, porous concrete, and permeable concrete. Pervious concrete pavements have become popular as an effective storm water management tool to reduce the volume of storm water runoff and concentration of pollutants. It is used at parking areas, low traffic areas, pedestrian pathway etc., because of its attractive storm water mitigation capabilities, and also in other applications. Apart from this, pervious concrete may be used as a wall concrete in structural applications for lightweight or better thermal insulation, as surface course for parking lots, tennis courts, zoo areas, stalls, etc., and for greenhouse floors to keep the floor free of standing water [1-3].

Pervious concrete has been increasingly used due to several sustainability-related benefits offered by this material [4]. Pervious concrete includes other environmental benefits such as reduced noise generated by tire-pavement interaction, reduced urban heat-island effect, minimized road splash, improved skid resistance, recharge of ground water table, reduced storm water runoff, limited pollutant penetration into the ground water and preservation of native eco systems [5]. Despite these benefits, the potential for lower compressive strength, clogging, ravelling, and susceptibility to freezing and thawing damage, have limited the use of pervious pavements in cold climatic conditions [6]. When compared to conventional concrete, pervious concrete exhibits sustainability, because of its properties [7]. Some notable characteristics of pervious concrete are lower unit weight and drying shrinkage, higher permeability, higher thermal insulation, lower compressive, tensile and bond strength, lower pressure on framework during construction, and longer curing time required prior to form removal, elimination of capillary attraction, and economy in materials. At higher porosity, water permeability increases, but compressive strength decreases due to lack of fine aggregate [8]. Hence, it is essential to optimize the porosity in order to achieve the desired strength and permeability characteristics.

The objective of this study is to investigate mechanical and hydraulic properties using various parameters. The parameters varied are coarse aggregate size and coarse aggregate content with the same cement and water content. The effect of these parameters on mechanical properties such as compressive strength, split tensile strength, and flexural strength, and on hydraulic properties such as the porosity and permeability of all mixes, were tested according to ASTM standards. The relationship between different properties was studied.

2. Materials

The strength of pervious concrete is dependent on the cement content, water to cement ratio, compaction level, and aggregate gradations. Pervious concrete made with angular aggregate generally requires more paste to produce the specified workability, compared to pervious concrete made with uniformly sized round aggregate. But pervious concrete made with angular aggregate has a higher tensile strength than the concrete produced with round aggregate, as established when comparing pervious concrete specimens of similar density and porosity. Angular aggregate provides better paste for aggregate bonding. Hence, the locally available granite was selected as coarse aggregate. Two different grades, i.e. the aggregate passing through the 9.5 mm sieve and retained on the 4.75 mm sieve, and the aggregate passing through the 12.5 mm sieve and retained on the 9.5 mm sieve, were used in this research. The ordinary grade 53 Portland cement was used in casting the specimens. Potable water available in laboratory with the pH value of no less than 6, conforming to IS 456-2000 requirements, was used for mixing concrete and curing the specimens. Fundamental tests for cement, water and coarse aggregate were conducted and the parameters obtained were incorporated in mix design.

2.1. Material properties obtained from test results

Material properties obtained from test results are presented in Table 1 and Table 2.

Table 1. Test results for coarse aggregate

Description	Obtained result	
	9,5 mm – 4,75 mm	12,5 mm – 9,5 mm
Specific gravity	2,87	2,68
Bulk density [kg/m^3]	1600	1538
Water absorption [%]	1	1

Table 2. Test results of cement

Description	Obtained result
Specific gravity	3,15
Fineness (by dry sieving, IS 4031-part 1,1996)	8 %
Standard consistency	31 %
Initial setting time	35 minuta
Final setting time	570 minuta
Bulk density	1411 kg/m^3

2.2. Mix proportion

It is important to select suitable concrete ingredients and determine their relative proportions, so as to achieve, as economically as possible, an appropriate concrete of adequate strength, porosity and permeability. Material properties of pervious concrete depend on both materials and placement technique. The coarse aggregate content [9] was varied to achieve the proper thickness of paste surrounding the aggregate by trial and error, based on mix proportion of no-fines concrete. A total of ten sets of mixes were designed in a standard manner, as shown in Table 3. As an illustration, A3C1S1 stands for specimen made of concrete mix with Aggregate 3 parts and Cement 1 part, while S1 stands for the aggregate size passing through the 9.5 mm sieve, and retained on the 4.75 mm sieve. Similarly, S2 stands for the aggregate size passing through the 12.5 mm sieve, and retained on the 9.5 mm sieve. If the mixture is too wet or over compacted, it will not exhibit the pervious concrete properties and penetration capacity. Hence, a constant water to cement ratio of 0.33 was considered in the mix proportion for all ten sets of mixes [10, 11].

2.3. Sample preparation

Pervious concrete is prepared by mixing water, cement and coarse aggregate. A total of 120 cube specimens, 30 cylindrical specimens, and 30 prism specimens, were prepared to conduct the test. The mixing was done using pan mixer. The coarse aggregate was first mixed with one third of the total mixing water. The cement was then added and blended with coarse aggregate, and the remaining water was poured into the mixing pan until a homogeneous mixture was obtained. Concrete was poured in moulds and manually compacted using a tamping rod. During compaction, twenty five blows were uniformly distributed on the surface of concrete for each layer. All specimens were demoulded after 24 hours and cured in water from the time of demoulding until the time of testing. All pervious concrete specimens used in the tests were prepared according to the ASTM C192 guidelines [12], "Standard Practice for Making and Curing Concrete test Specimens in the Laboratory".

3. Test methods

Compressive strength

Compressive strength is a very important parameter for deciding on the concrete quality and performance. The compressive strength test was conducted according to ASTM C 39 [13]. Cube specimens measuring 150 mm x 150 mm x 150 mm were prepared for each mix and tested. The compressive strength was reported based on the average of three cube specimens tested.

Split tensile strength

The split tensile strength was tested on cylindrical specimens 150 mm in diameter and 300 mm in height, after 28 days of curing according to ASTM C496 [14].

Flexural strength

Flexural strength was tested on a prism specimen measuring 150 mm x 150 mm x 700 mm, according to ASTM C78/ C496 [15].

Porosity

Porosity is the ratio of volume of voids to the total volume of specimens. The total porosity [16-18] was measured using the

Table 3. Mix proportion

Mix	Aggregate size	Aggregate to cement ratio	Cement [kg/m^3]	Coarse aggregate [kg/m^3]
A3C1S1	9,5 mm – 4,75 mm	3:1	330	1178
A4C1S1		4:1	263	1251
A5C1S1		5:1	219	1300
A6C1S1		6:1	187	1334
A7C1S1		7:1	163	1360
A3C1S2	12,5 mm – 9,5 mm	3:1	321	1237
A4C1S2		4:1	255	1311
A5C1S2		5:1	212	1360
A6C1S2		6:1	181	1395
A7C1S2		7:1	158	1421

water displacement method based on the Archimedes' principle of buoyance, which states that the buoyancy force is equal to the weight of fluid displaced. The total porosity includes both closed and open pores and can be measured using the buoyancy float apparatus. The dry mass, submerged mass, and total volume, must be known to calculate the porosity value.

$$p = \left[1 - \left(\frac{W_1 - W_2}{\rho_w V}\right)\right] \times 100\% \quad (1)$$

where:
p - total porosity of pervious concrete [%]
W_1 - weight of a pervious concrete sample air-dried for 24 hours [kg]
W_2 - weight of a pervious concrete sample submerged in water [kg]
V - volume of a pervious concrete sample [mm³]
r_w - density of water [kg/mm³].

Permeability
The test setup was designed based on the constant head permeability method [19-21] and the permeability testing was conducted as shown in Figure 1.

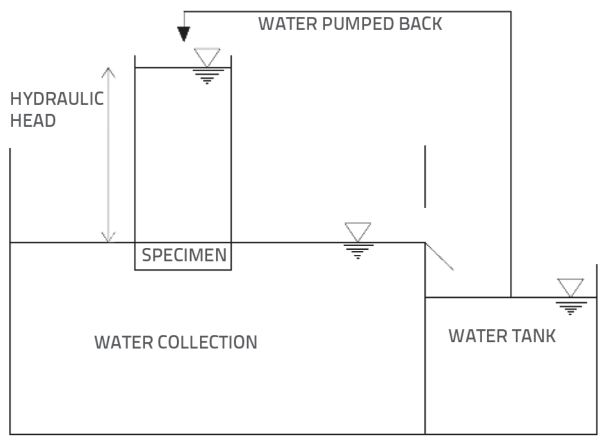

Figure 1. Permeability test

One of the most important features of pervious concrete is its ability to allow percolation of water through the matrix. The percolation rate of pervious concrete is directly related to the air void content. The Polyvinyl chloride (PVC) pipe was placed on the pervious concrete specimen and was properly sealed with the contact surface of the specimen in order to avoid leakage. The permeability test was carried out when the quantity of water allowed to flow into the specimen through the PVC pipe was such that the constant head of water could be maintained at the desired water head in the inlet pipe. The water flow rate can be controlled by means of a valve. The flow rate of water can be determined by measuring the volume of water collected in the water tank over time for a particular head of water. The coefficient of permeability k in mm/sec can be expressed as,

$$k = \frac{QL}{Aht} \quad (2)$$

where:
k - permeability [mm/s]
Q - total volume of water [mm³]
L - specimen length[mm]
A - cross sectional area of specimens [mm²]
h - water head [mm]
t - time [s].

4. Results and discussion

The effects of compressive strength, split tensile strength, flexural strength, porosity and permeability were tested on samples with two different aggregate sizes, and the corresponding results are tabulated in Table 4 and in figures 2 to 12.

4.1. Compressive strength

The compressive strength of pervious concrete at 7 days ranges from 11 N/mm² to 4 N/mm² for both aggregate sizes, i.e. 9.5mm – 4.75mm (S1) and 12.5mm – 9.5mm (S2),

Table 4. Properties of pervious concrete

Mix	Compressive strength [N/mm²]		Split tensile strength [N/mm²]	Flexural strength [N/mm²]	Porosity [%]	Permeability [mm/s]
	7 days	28 days				
A3C1S1	11,38	15,87	1,70	3,21	20,95	8,60
A4C1S1	8,36	12,28	1,53	2,86	22,08	11,64
A5C1S1	5,73	8,56	1,40	2,62	23,47	14,13
A6C1S1	4,81	6,46	1,29	2,22	24,43	15,08
A7C1S1	3,78	5,94	1,17	1,93	26,19	16,67
A3C1S2	11,08	13,73	1,66	2,96	21,50	13,09
A4C1S2	8,19	10,07	1,47	2,81	22,54	15,75
A5C1S2	5,56	6,89	1,32	2,37	24,43	17,39
A6C1S2	4,65	5,64	1,23	2,02	25,27	18,45
A7C1S2	3,70	5,05	1,15	1,88	28,16	19,80

with different aggregate to cement ratio of 3:1 to 7:1. The compressive strength at 28 days ranges from 16 N/mm^2 to 6 N/mm^2 for the aggregate S1, and 14 N/mm^2 to 5 N/mm^2 for the aggregate S2, with different aggregate to cement ratio of 3:1 to 7:1. The variation in compressive strength between the two aggregate types is 3 % at 7 days, and up to 16 % at 28 days, as shown in figures 2 and 3. An average increase of the 7 day compressive strength to the 28 day compressive strength is 20 % for the aggregate S1 and 31 % for S2. The failure was predominantly observed at the cement to aggregate interface, resulting in a lower average compressive strength.

The interfacial transition zone (ITZ) between the cement paste and aggregate is a critical factor that greatly affects concrete properties. The failure of pervious concrete occurs at the cement paste to aggregate bond interface. The ITZ mainly depends on the distribution of cement paste around the aggregate and it is not uniform, but varies from point to point along each aggregate particle. Increased cement content and smaller size aggregates create lesser intensity of ITZ than larger size of aggregates, since the level of porosity is high for large size aggregates.

4.2. Split tensile strength

The split tensile strength ranges from 1.70 N/mm^2 to 1.17 N/mm^2 for the S1 type aggregate and 1.66 N/mm^2 to 1.15 N/mm^2 for the S2 type aggregate with different aggregate to cement ratio of 3:1 to 7:1. The split tensile strength followed the same trend for both S1 and S2 type aggregates. The variation in split tensile strength between the two different aggregate sizes is 4 %, as shown in Figure 4.

4.3. Flexural strength

The flexural strength ranges from 3.21 N/mm^2 to 1.93 N/mm^2 for the S1 type aggregate and 2.96 N/mm^2 to 1.88 N/mm^2 for the S2 type aggregate with different aggregate to cement ratio of 3:1 to 7:1. The average variation in flexural strength between the two different aggregate sizes is 6 % as shown in Figure 5.

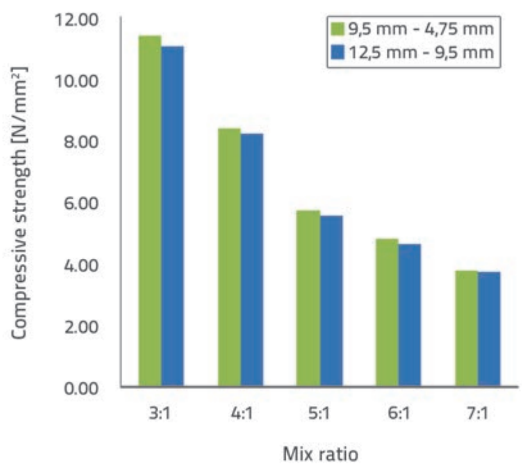

Figure 2. Compressive strength at 7 days

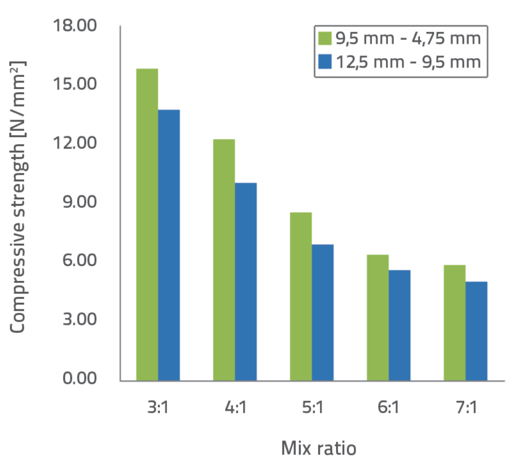

Figure 3. Compressive strength at 28 days

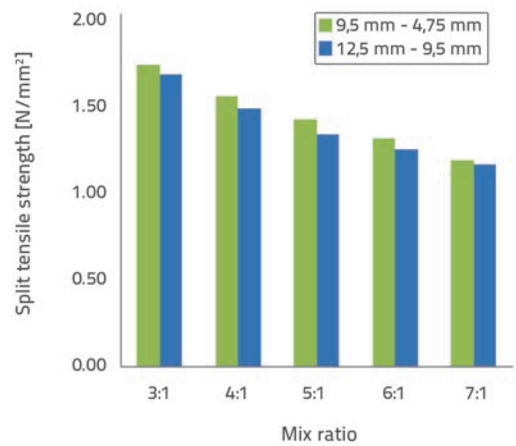

Figure 4. Split tensile strength

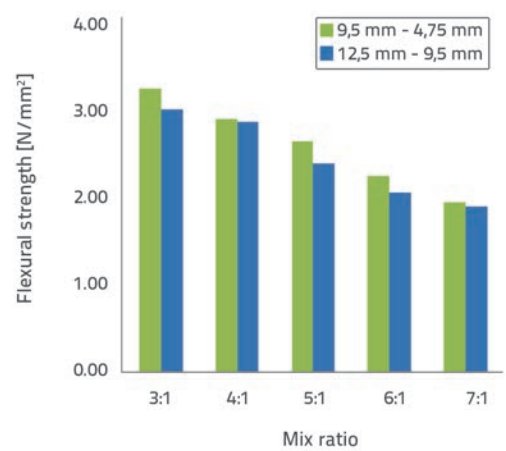

Figure 5. Flexural strength

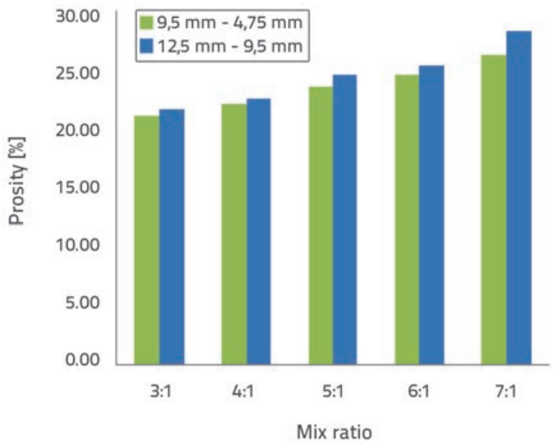

Figure 6. Porosity

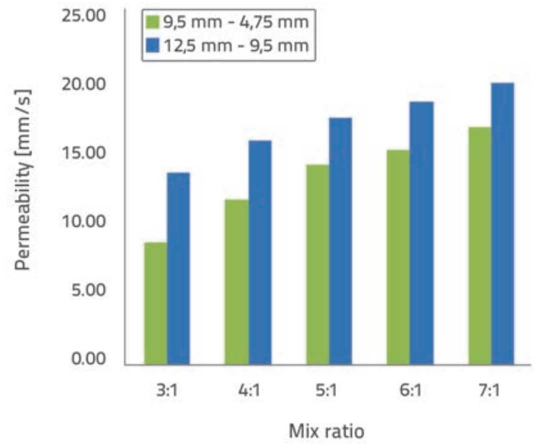

Figure 7. Permeability

4.4. Porosity

Porosity ranges from 20.95 % to 26.19 % for the S1 type aggregate and 21.50 % to 28.26 % for the S2 type aggregate with different aggregate to cement ratio 3:1 to 7:1, as shown in Figure 6. It can be seen that porosity ranges from 21 % to 29 % in most mixes, which falls within the acceptable limit of 15 % to 30 % for pervious concrete [22, 23].

4.5. Permeability

Permeability values for all mixes are listed in Table 4. Permeability ranges from 8.60 mm/s to 16.67 mm/s for the S1 type aggregate and 13.09 mm/s to 19.80 mm/s for the S2 type aggregate with different aggregate to cement ratio of 3:1 to 7:1, as shown in Figure 7. Permeability mainly depends on the size of interconnected pores. The pervious concrete mix with small aggregates showed a lower permeability when compared to the mix with large-size aggregates. The permeability value varies from 8 to 20 mm/s, which is enough for using pervious concrete as a drainage layer for pavement structures [24, 25].

4.6. Relationship between individual properties of pervious concrete

The relation between the compressive strength and split tensile strength, and between the compressive strength and flexural strength was obtained as shown in figures 8 and 9.

The relationship obtained shows a good correlation between the compressive strength and flexural strength. The testing revealed that strength properties decrease with an increase in aggregate content. Pervious concrete with high porosity exhibits a low compressive strength and high permeability, as shown in figures 10 and 11. In this study, the strength to porosity relationship, and the porosity to permeability relationship, were established for pervious concrete, as shown in Figure 12. Based on the relationship between the compressive strength, porosity and permeability, an optimum compressive strength of 12 N/mm^2 was obtained, with the porosity of 22 % and permeability of 12 mm/s for the S1 type aggregate at the aggregate to cement ratio of 4:1. An optimum compressive strength of 10 N/mm^2 was obtained with the porosity of 23 % and permeability of 16 mm/s for the S2 type aggregate at the aggregate to cement ratio of 4:1.

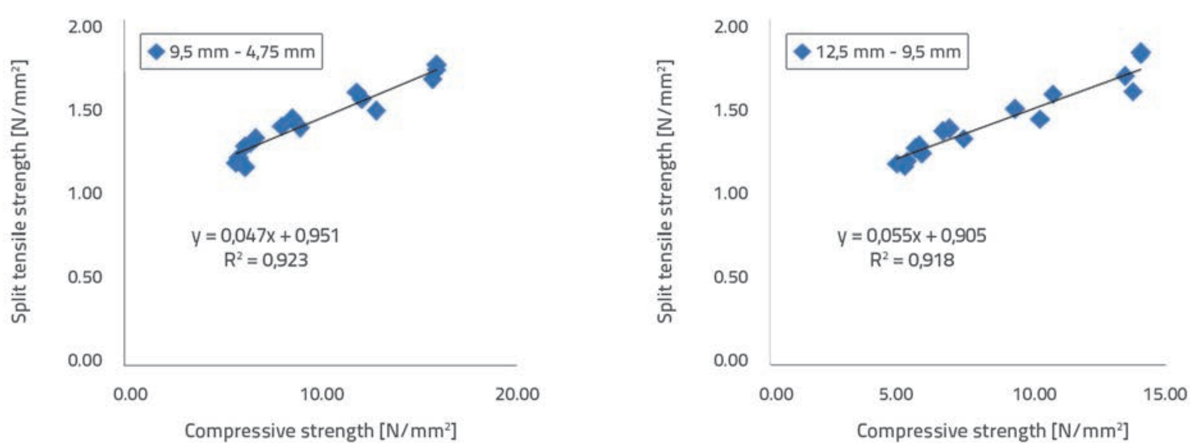

Figure 8. Relationship between compressive strength and split tensile strength

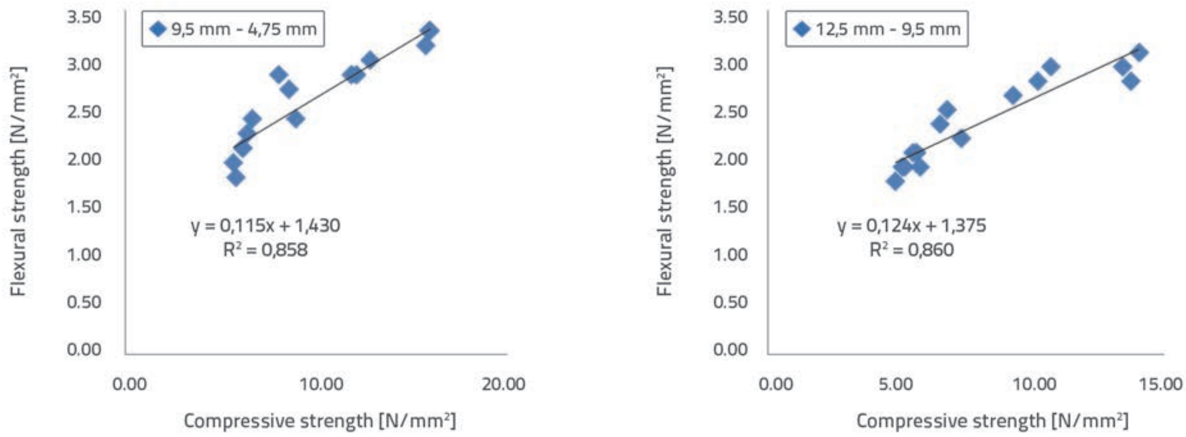

Figure 9. Relationship between compressive strength and flexural strength

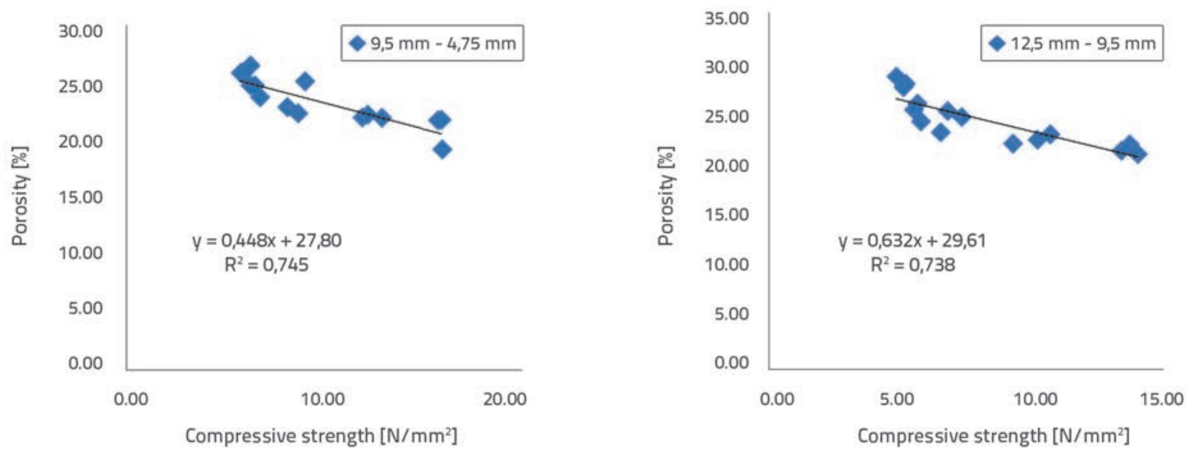

Figure 10. Relationship between compressive strength and porosity

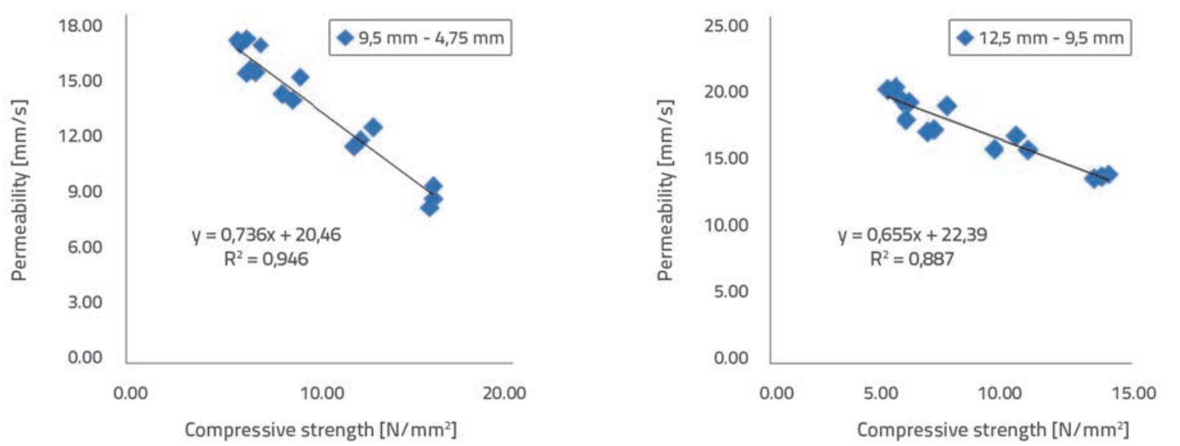

Figure11. Relationship between compressive strength and permeability

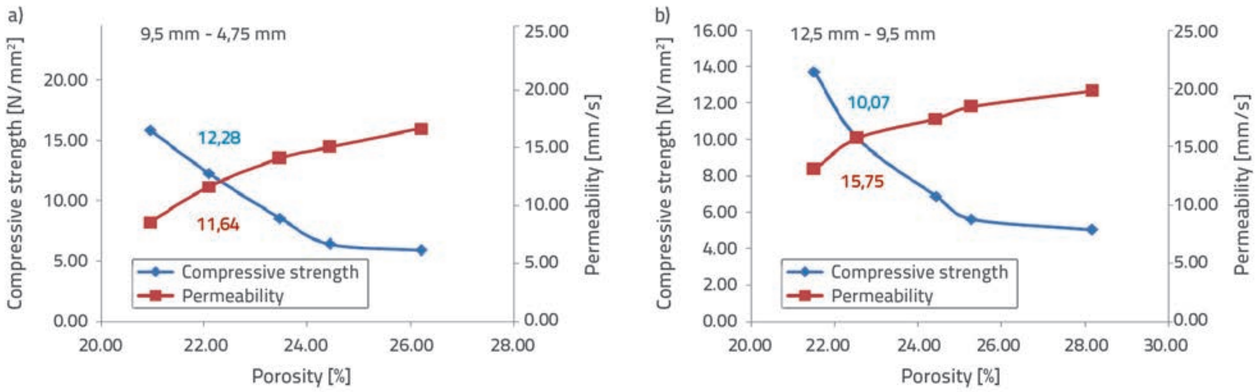

Figure 12. Relationship between porosity, compressive strength and permeability

5. Conclusion

The strength and hydraulic properties of pervious concrete containing two aggregate sizes of different aggregate content, without any fine aggregate and admixtures, were investigated in this paper. The experimental investigations were carried out to determine the compressive strength, split tensile strength, flexural strength, porosity, and permeability. Ten different pervious concrete mixes were tested. The compressive strength, split tensile strength, and flexural strength values change with aggregate content and aggregate sizes.

The compressive strength, split tensile strength and flexural strength values varied from 5 N/mm^2 to 16 N/mm^2, 1.15 N/mm^2 to 1.7 N/mm^2, and 1.88 N/mm^2 to 3.21 N/mm^2, respectively, for two aggregate sizes with different mixes. It was established that porosity varies between 20.95 % to 28.26 %, and permeability between 8.60 mm/sec to 19.80 mm/sec.

The increase in porosity leads to an increase in permeability and decrease in compressive strength. An optimum aggregate to cement ratio of 4:1 was obtained for both S1 and S2 aggregate types. From the curves obtained at this selected mix ratio of 4:1, an optimum result for the S1 aggregate type was obtained at the porosity of 22 %, compressive strength of 12 N/mm^2, and permeability of 12 mm/s. Similarly, the optimum result for the S2 aggregate type was obtained at the porosity of 23 %, compressive strength of 10 N/mm^2, and permeability of 16 mm/s. Based on experimental results, it can be concluded that, when runoff collection is of primary concern and strength is not a governing issue, the use of pervious concrete can be regarded as a suitable and sustainable choice in various storm water management applications.

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