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Experimental Study on the Use of Trass as a Supplementary Cementitious Material in Pervious Concrete

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Abstract: The purpose of this paper is to evaluate the suitability of using trass as a supplementary cementing material in pervious concrete. OPC (Ordinary Portland Cement) was replaced in the concrete mix by 15%, 25% and 35% weight percentages and the results were compared with reference mixtures with 100% Portland cement. The variables in this study were trass content, aggregate size and water to cement ratio. Sixteen cases of concrete mixtures were tested to study physical and mechanical properties of hardened concrete, including porosity, permeability, compressive strength, splitting-tensile strength and flexural strength at various ages. Results indicated that mechanical properties of the pervious concrete marginally decreased with the increased content of trass when compared to the reference mixtures. However, at later ages the differences were insignificant.

Key words: Pervious concrete, trass, supplementary cementitious material, permeability, strength, natural pozzolans.

1. Introduction

Sustainability has been a critical issue for over a few decades. The industry is gravitating towards sustainability practices, and the construction industry is not an exception. CO_2 emissions have been a serious problem in the production of cement due to the greenhouse effects. The manufacturing of Portland cement is an energy consuming process (approximately 4GJ energy per ton) releasing a considerable amount of carbon dioxide, which is a major contributor to the greenhouse gas emissions that leads to global climate change [2-4]. Today, many countries agree to reduce the emission of CO_2 [1]. It is sometimes debated whether the concrete can or should be considered as a sustainable option due to its particular properties and characteristics. The use of SCM (Supplementary Cementing Materials), proportioning of concrete mixtures with the minimum content of cement, and enhancement of concrete durability are the main issues towards sustainability in the concrete industry. Moreover, SCMs contribute to the properties of hardened concrete through hydraulic or pozzolanic activity. Natural pozzolans have been commonly used as alternative sources of SCMs for general purpose concrete.

Natural pozzolan is available in some regions of the world. Natural volcanic pozzolans are one of the oldest construction materials known to humanity. Chemical properties and the pozzolanic activities of natural pozzolans vary depending on the region of the source [5]. Trass, pumice and tuff are three types of natural pozzolanic materials consisting of mineral materials and volcanic ash. The pozzolanic activity of these materials is related to their siliceous ingredients and to their physical effects [6, 7]. Iran is very rich in natural pozzolan such as volcanic tuffs (trass Jajrood) [6]. These natural pozzolans might use in industries instead of other natural pozzolans with a high amount of active silica and alumina content.

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Pervious concrete consists of Portland cement, water, coarse aggregate and, often, chemical admixtures and supplementary cementing materials (with low or no fine aggregates). The structure with interconnected voids of pervious concrete allows both water and air to percolate through. The voids content of pervious concrete is usually 15-25%, and its compressive strength is about 2.8-28 Mpa [8, 9]. The desired void content may be achieved either by adjusting the level of compaction or by modifying the aggregate proportions. It is more beneficial to adjust the aggregate proportions and properties, such as gradation, size and amount to reach desired void contents. Since fine aggregates content is low in the pervious concrete, cement paste covers coarse aggregates and preserves the integrity of voids [10].

Pervious concrete has numerous applications in areas such as residential roads, alleys, driveways, sidewalks, pathways, packing areas, low water crossing and artificial reefs to mention but a few. The high flow rate of water via a pervious concrete pavement permits rainfall to be captured and to penetrate the ground, decreasing stormwater runoff, boosting groundwater and supporting sustainable construction. This exceptional capability of pervious concrete offers benefits to the environment, organizations and estate owners via control of rainwater on-site and addressing stormwater runoff concerns, which can be of specific concern in built-up areas, or where land is very expensive.

The purpose of this study is to compare the properties of pervious concrete utilizing trass as a supplementary cementitious material with a conventional pervious concrete. According to some studies [11-13], concrete containing trass had lower compressive strength in comparison with concrete with control concrete. However, this strength difference decreased gradually at later ages. On the other hand, the strength increased with age. This is reasonable due to the reduction of cement content in the mixtures with the increase of natural pozzolans content. The finely divided silica in natural pozzolans can combine with calcium hydroxide (liberated by the hydrating portland cement) in the presence of water to form stable compounds such as calcium silicates, which have cementitious properties. Such pozzolanic reactions of natural pozzolans contribute to the enhancement of strength and long-term durability. The effect of a partial replacement of cement with trass (15%, 25% and 35%) on the properties of pervious concrete was examined. In addition, two water to cement (w/c) ratios of 0.27 were 0.37 were evaluated. Also, the results of an experimental examination of the properties of pervious concrete with different aggregate sizes were also discussed. As the aggregate size decreases, the number of particles per unit of volume increases. As the amount of particles increase, the binding area increases, resulting in improved strengths [14]. Specification requirement for permeability and strength of pervious concrete can also be satisfied. In other words, by determining the void ratio, it would be possible to establish a balance between permeability and strength of pervious concrete. The strength and durability of pervious concrete were examined in this study.

2. Material and Methods

All mixture properties were adjusted according to ACI Committee 522, which has shown a good balance between permeability and strength or durability. In this study, various properties of pervious concrete, such as compressive, splitting-tensile, flexural strength and permeability are investigated. The test variables are the water to cement ratio and the percentage of trass as a partial substitution of cement. Sixteen concrete mixtures that were prepared had different cement replacement levels (by mass) of trass as summarized in Table 1.

2.1 Material

The cement used as a binder in this study was Type I Portland, which satisfied the requirements of ASTM C150 [15]. Trass, as a natural pozzolan was obtained from pozzolanic deposits located in the north of Iran

Table 1 Mixture proportions.

Specimen	Aggregate size (mm)	w/cm	Replacement ratio of Trass (%)	Unit weight (kg/m^3)			
				Cement	Trass	Water	Aggregate
S1-27-1-0	4.75-9.5	0.27	0	307.7	0.0	83.0	1,672.2
S2-27-1-15	4.75-9.5	0.27	15	261.5	46.2	83.0	1,668.7
S3-27-1-25	4.75-9.5	0.27	25	230.8	76.9	83.0	1,666.4
S4-27-1-35	4.75-9.5	0.27	35	200.0	107.7	83.0	1,664.1
S5-37-1-0	4.75-9.5	0.37	0	267.7	0.0	97.2	1,672.2
S6-37-1-15	4.75-9.5	0.37	15	227.5	40.2	97.2	1,669.2
S7-37-1-25	4.75-9.5	0.37	25	200.8	66.9	97.2	1,667.2
S8-37-1-35	4.75-9.5	0.37	35	174.0	93.7	97.2	1,665.2
S9-27-2-0	12.5-19	0.27	0	307.7	0.0	83.0	1,565.0
S10-27-2-15	12.5-19	0.27	15	261.5	46.2	83.0	1,561.5
S11-27-2-25	12.5-19	0.27	25	230.8	76.9	83.0	1,559.2
S12-27-2-35	12.5-19	0.27	35	200.0	107.7	83.0	1,556.9
S13-37-2-0	12.5-19	0.37	0	267.7	0.0	97.2	1,565.0
S14-37-2-15	12.5-19	0.37	15	227.5	40.2	97.2	1,562.0
S15-37-2-25	12.5-19	0.37	25	200.8	66.9	97.2	1,560.0
S16-37-2-35	12.5-19	0.37	35	174.0	93.7	97.2	1,558.0

Table 2 Chemical composition of portland cement and trass.

Chemical composition	Type I portland cement	Trass
SiO_2	22.52	24.24
Al_2O_3	5.24	4.25
Fe_2O_3	3.86	3.8
MgO	4.16	3.8
CaO	59.8	58.8
SO_3	2.12	3.8
Na_2O	0.43	06
K_2O	0.78	0.7
LOI	0.85	-
C_3S	25.53	-
C_2S	45.31	-
C_3A	7.35	-

(Alborz Mountain). The chemical composition of the cement and trass are summarized in Table 2.

Also, the physical properties of the cement are given in Table 3. The particle size distribution of crushed stone used in this study was uniform. Pervious concretes investigated in this study incorporated two sizes of aggregate including 4.75 to 9.5 mm or 12.5 to 19 mm, which mean sieve No # 4 and ½″. Summary of aggregate properties is presented in Table 4.

2.2 Methods

The workability and consistency of the concrete mixtures were measured using the slump cone test ASTM C143 [16]. Before initiating the process of mixing, the specimen molds were oiled. Concrete mixtures were mildly compacted with tapping rod as much as possible to increase the void ratio, although the compressive strength probably would be reduced. All specimens were placed and compacted lightly with a steel tamping rod, 600 mm long, rounded at one end to provide low compaction at the top of the cylinder and ensure uniform compaction from each lift. Each sample was compacted 20 times and in 3 layers of each specimen in accordance with the procedures

Table 3 Physical properties of portland cement.

Fineness (cm^2/gr)	Retained on sieve # 70 (%)	Autoclave expansion (%)	Normal consistency (%)	Setting time		Compressive strength (kg/cm^2)		Flow (%)
				Initial (minutes)	Final (minutes)	3 days	7 days	
2848	11.41	0.51	25.2	165	225	159	216	145

Table 4 Summary of aggregate properties.

Test description	# 4	½″	ASTM Code No.
Absorption (%)	1.707	1.505	C 127
Specific gravity, bulk	2.55	2.68	C 127
Specific gravity, saturated surface dry	2.57	2.69	C 127
Specific gravity, apparent	2.59	2.71	C 127
Bulk density, kg/m^3	1,689	1,581	C 29

outlined in ASTM C192 [17]. After casting, all the specimens were covered with plastic sheets to prevent the water from evaporating at the temperature of approximately 24 °C to cure.

The specimens were demolded after 24 h of casting and labeled and kept in a lime-water tank to cure until the age of testing. Once, after the concrete was mixed homogeneously, the mixture was put in a cylindrical mold in three layers of about equal volume. The top periphery of the concrete was leveled to make sure an even distribution of concrete was within the mold. The concrete mixture was compacted by applying at least 25 strokes to each layer with a tamping rod. The strokes were applied equally over the cross-section of the mold. Since the test specimens were cast with low compaction, the surface of the specimens needs sulfur mortar capping before the testing.

2.2.1 Mechanical Properties

Specimens were placed under the hydraulic testing machine at the ages of 7, 28 and 90 days. The standard compressive, splitting-tensile and flexural strength tests were performed on the cylinders and cubes in accordance with the procedures given in ASTM C39 [18], ASTM C496 [19] and ASTM C78 [20], respectively. The reported results were an average of three specimens at each testing date to get reliable results. For compressive, splitting-tensile, and flexural strengths, the loading rate was maintained at 0.25, 1.1 and 0.9 Mpa/s, respectively, which were within standard range.

2.2.2 Water Permeability

The most important feature for a pervious concrete is permeability. The permeability is measured by the amount of fluid that penetrates through a unit area per unit time under a unit hydraulic gradient. For the permeability test, because the falling-head apparatus have been used to measure permeability [11, 13], the same method is adopted in this study as well. Specimens were prepared for the permeability test by sawing off 10.0 mm from each side. The permeability test sample was confined by sealing it with bitumen insulation to prevent water from going out the side and further samples wrapped with a rubber sleeve to prevent leakage along its edges and ensure that the water only flows through the cross. A rubber seal was applied using a glue gun at the upper and lower boundary between a rubber sleeve and the sample to ensure water flow through the sample [21]. The standpipe has an inside diameter of 45.4 mm. The test was initiated by saturating the pervious concrete sample to release the entrapped air in the specimens. At an initial head above the sample, the time was taken until the water level reached a final head. This process was repeated three times for each specimen under falling head for water permeability to improve the accuracy of the results. The coefficient of water permeability k of the specimens was calculated using Eq. (1) [22]:

$$K = \frac{a \times L}{A \times t} Ln(\frac{h_0}{h_1}) \quad (1)$$

where k is the permeability coefficient, a is the cross-sectional area of the standpipe (1,618.01 mm^2), L is the vertical distance of the measuring points of the specimen (200 mm), A is the cross area of the pervious concrete specimen (7,850 mm^2), t is the time taken for the head to fall from h_0 to h_1, h_0 is the initial water head and h_1 is the final water head.

2.2.3 Void Ratio and Porosity

Porosity is defined as the percentage amount of the number of pores in the total volume of a specimen. The porosity of the specimens was measured by calculating the difference in weight of oven dry and saturated, submerged under water [23]. Two types of void ratio were measured based on porous concrete void ratio experiment method [24]: opened void ratio and closed void ratio. Cylindrical specimens of 100 mm in diameter and 200 mm in length are used. The void ratio was calculated using Eqs. (2) and (3), respectively [25]:

$$A_{open} = \left(1 - \frac{W_2 - W_1}{V_1 \times \rho_w}\right) \times 100 \quad (2)$$

$$A_{close} = \left(1 - \frac{W_3 - W_1}{V_1 \times \rho_w}\right) \times 100 - A_{open} \quad (3)$$

where

A_{open}= Opened total void ratio of concrete (%);

A_{close}= Closed total void ratio of concrete (%);

W_1 = the weight of the specimen under water;

W_2 = the weight of the specimen following 24 h exposure to the air;

W_3 = the weight of the oven dried specimen;

V_1 = the volume of the specimen;

ρ_w= the density of water.

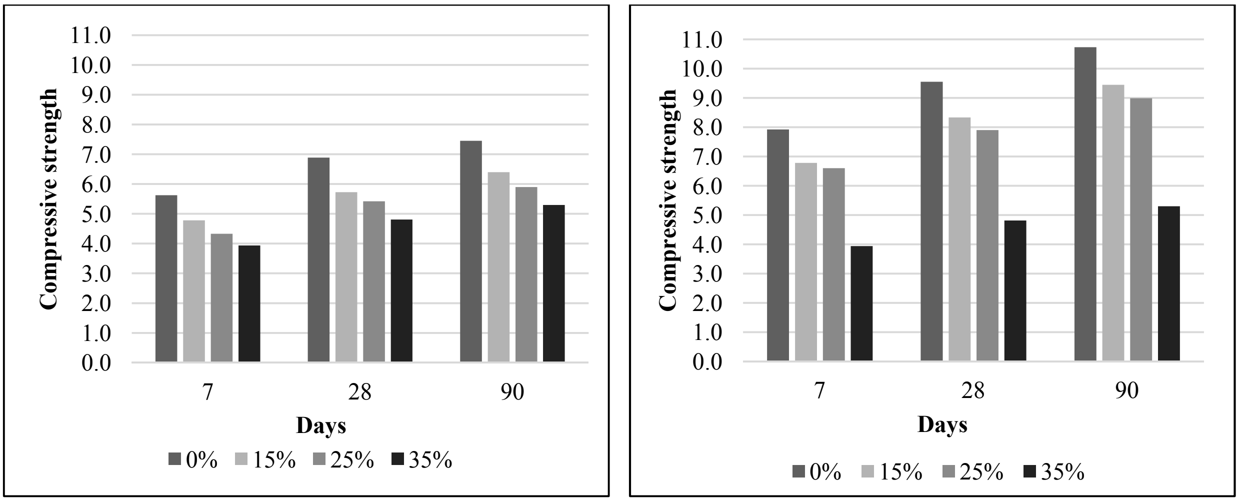
3. Results

In terms of microstructure, concrete is composed of three phases: aggregate, cement paste and transition zone. Although the greatest proportions of concrete are aggregate and cement paste, the transition zone is more important in determining the mechanical properties of concrete in spite of its smaller volume in comparison to the other two phases and thus plays a critical role in the concrete structure [26-28]. Incorporating trass as cementitious material could improve the zone.

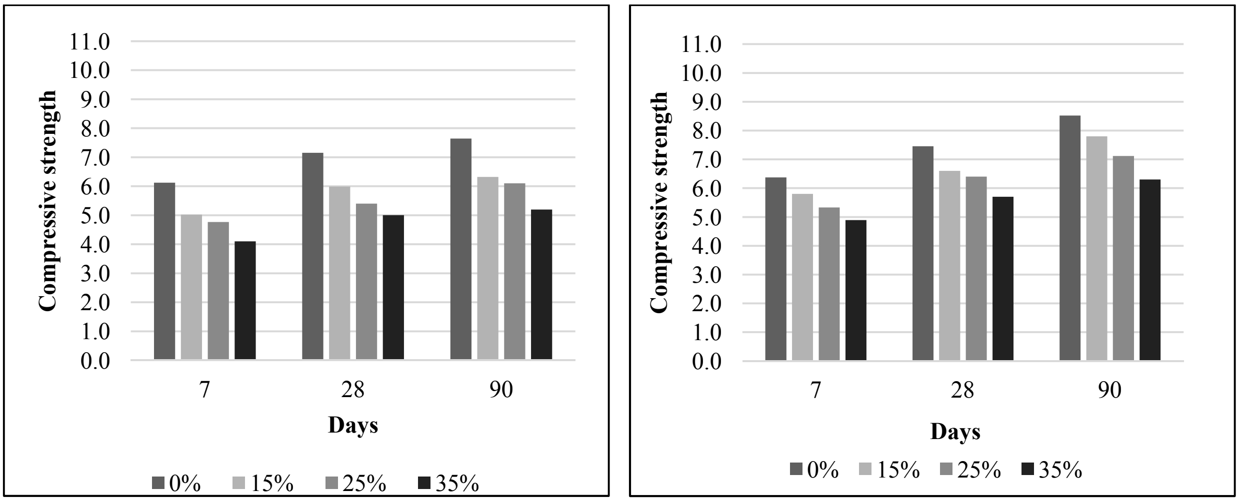
3.1 Compressive Strength

Compressive strength test results for pervious concrete mixtures are presented in Fig. 1. The compressive strength of all concrete mixtures is above 5 Mpa at 90 days, regardless of w/cm ratio. As expected, the relatively higher strength was observed in the case of 100% type I portland cement concrete mixtures in comparison to the control mix. From the results, the compressive strength of all concrete specimens increased during the period of curing. A gradual decrease in compressive strength with increased natural pozzolanic (trass) content at all ages was observed for concrete mixes. This reduction in strength may be a result of lack of water in the mixing process. It can also be observed that the decrease in compressive strength is less at later ages (90 days after mixing).

As shown in Figs. 2 and 3, compressive strength decreases as the replacement levels of cement with supplementary material increased. This reduction trend depends on the percentage of trass as a cementitious material, the ratio of w/cm and aggregate size. For example, the compressive strength at 90 days of control mixtures with the aggregate size of 4.75-9.5 mm and by w/cm of 0.27 is 7.5 Mpa. Usage of trass as 15%, 25% and 35% substitution of cement generally caused approximately 14.1%, 20.8% and 28.9% reductions in the compressive strength, respectively. The reduction appears not critical from a long-term perspective. It should be mentioned that the strength difference was much larger at 7 days of curing: 15%, 23% and 29.9% lower strength in the same order, respectively. According to Fig. 4, this trend demonstrates that incorporating trass typically reduced the hydration process of concrete, leading to the slower development of early strength over time.



(a) (w/cm = 0.27 and aggregate size = 4.75-9.5) (b) (w/cm = 0.27 and aggregate size = 12.5-19)



(c) (w/cm = 0.37 and aggregate size = 4.75-9.5) (d) (w/cm = 0.37 and aggregate size = 12.5-19)

Fig. 1 Compressive strength of concrete versus age.

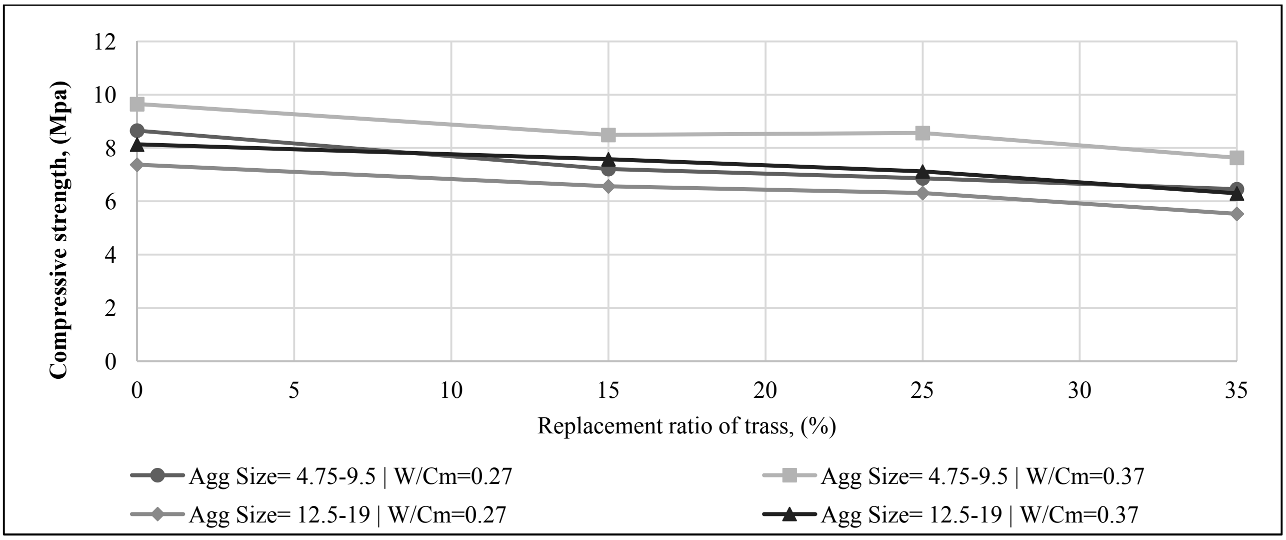


Fig. 2 Relationship between compressive strength and replacement ratio of trass.

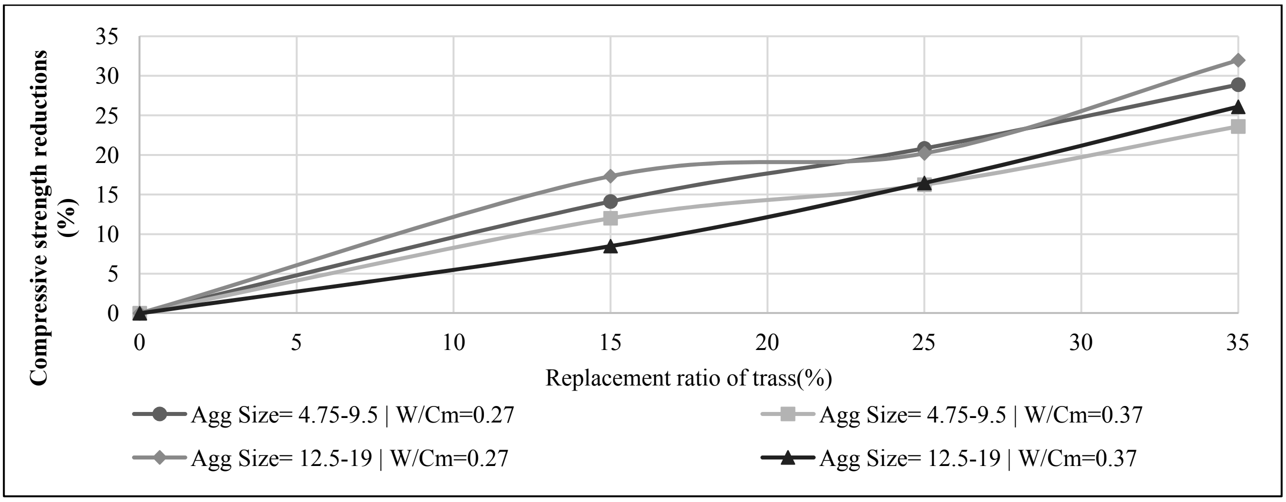


Fig. 3 Compressive strength reduction by incorporating different ratio of trass.

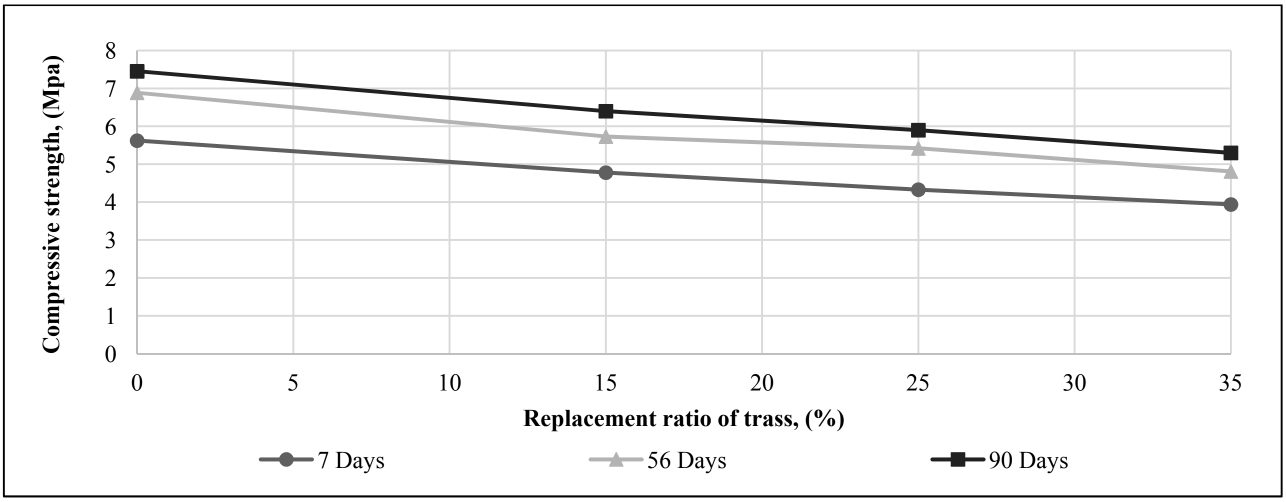


Fig. 4 Compressive strength by incorporating different ratio of trass versus ages.

3.2 Splitting-Tensile Strength

The results of splitting-tensile strength tests for all sixteen mix designs are shown in Figs. 5 and 6. The splitting-tensile strength of concrete generally decreased when the ratio of trass increased, as observed in the compressive strength. However, the degree of reduction in the tensile strength was greater than in the compressive strength. For instance, in the case of water to the cementitious material ratio of 0.27 and aggregate size of 4.75-9.5, the use of 15% trass caused approximately 15% and 20.6% reductions in the compressive and tensile strength respectively.

Fig. 7 represents the relationship between compressive and tensile strengths of pervious concrete. The same as normal concrete, by increasing the compressive strength, the tensile strength also increases.

3.3 Flexural Strength

Results of flexural strength tests are depicted in Figs. 8 and 9. In the same fashion as that of compressive and splitting strength, the flexural strength of pervious concrete generally decreased by incorporating many ratios of trass. The results of flexural strength obtained are shown in Table 5.

3.4 Effect of Water to Cementitious Material Ratio

In order to study the effect of the w/cm ratio on the mechanical characteristic of pervious concrete

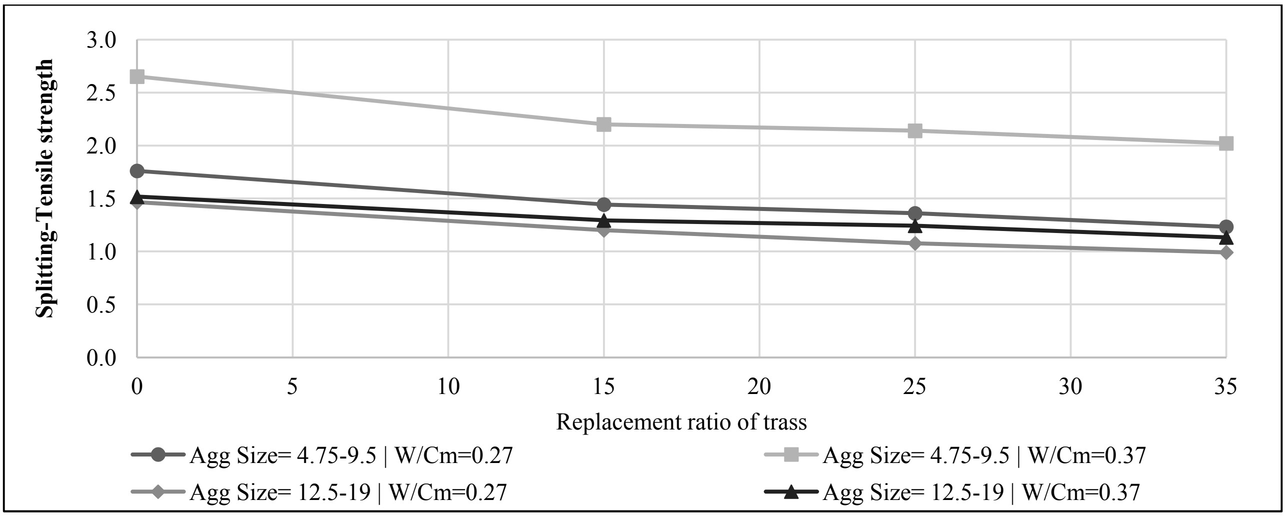


Fig. 5 **Relationship between splitting-tensile strength and replacement ratio of trass.**

Fig. 6 **Splitting-tensile strength reduction by incorporating different ratios of trass.**

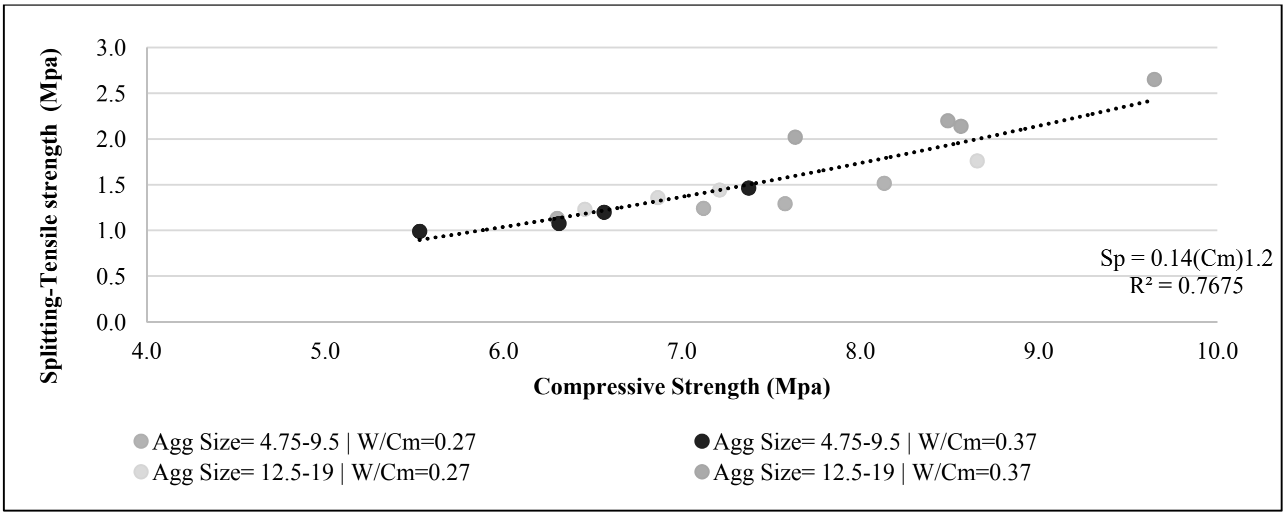


Fig. 7 **Relationship between compressive and tensile strength of pervious concrete.**

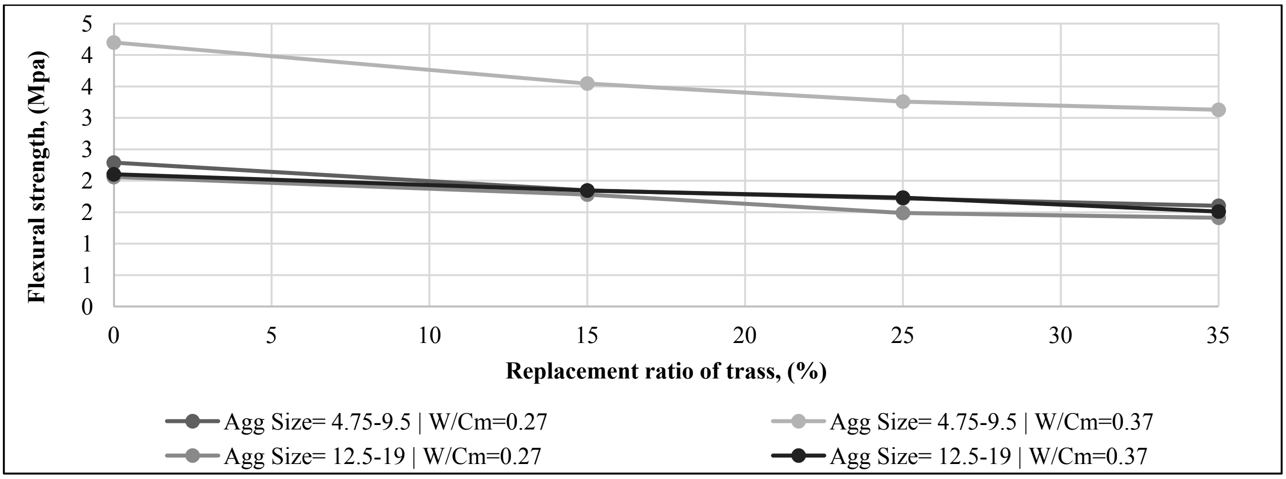


Fig. 8 Relationship between flexural strength and replacement ratio of trass.

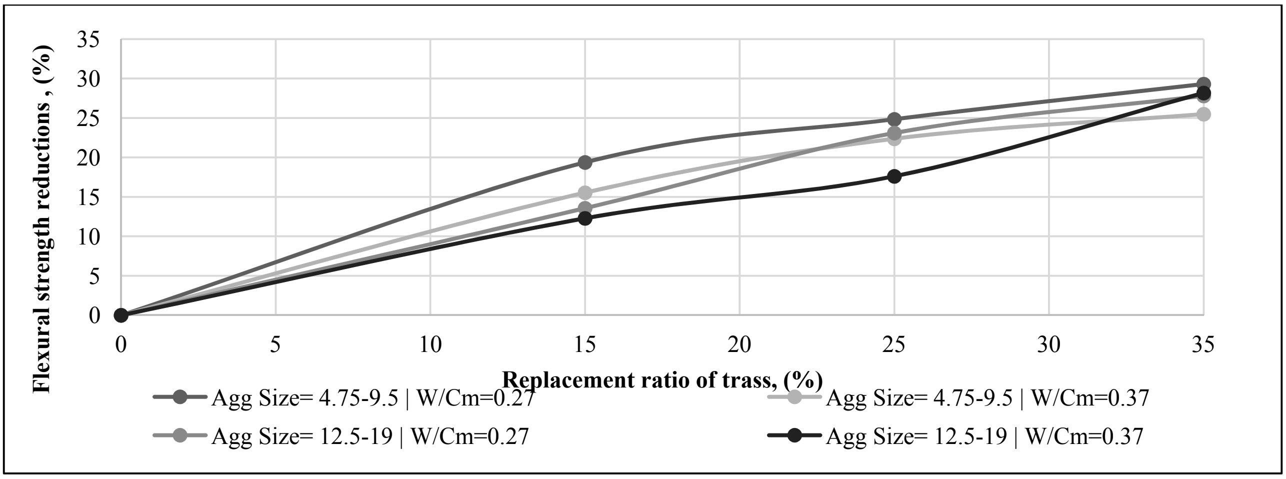
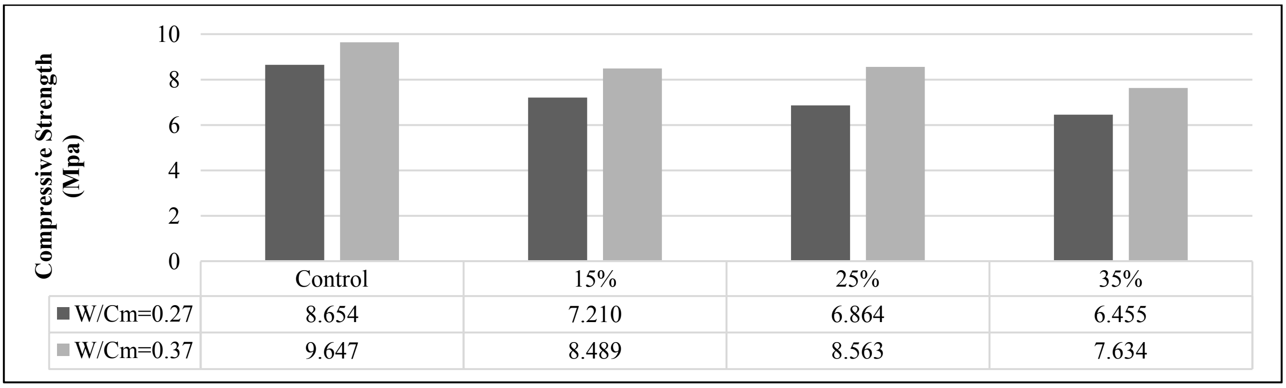


Fig. 9 Flexural strength reduction by incorporating different ratios of trass.

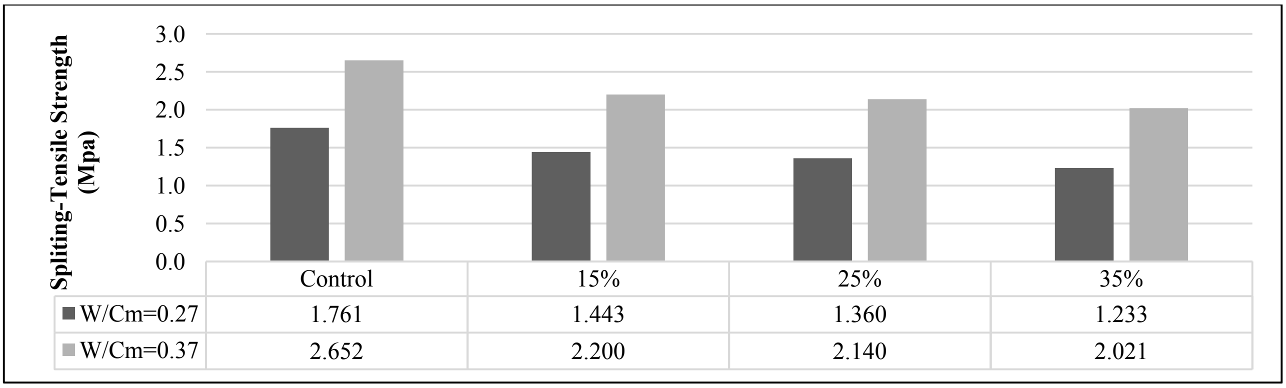
Table 5 Pervious concrete strength results at 7, 28 and 90 days.

Mix designs	Compressive strength (Mpa)			Tensile strength (Mpa)			Flexural strength (Mpa)		
	7-day	28-day	90-day	7-day	28-day	90-day	7-day	28-day	90-day
S1-27-1-0	5.6	7.4	8.7	1.3	1.6	1.8	1.4	1.9	2.3
S2-27-1-15	4.8	6.3	7.2	1.0	1.3	1.4	1.1	1.5	1.8
S3-27-1-25	4.3	5.8	6.9	1.0	1.2	1.4	1.0	1.5	1.7
S4-27-1-35	3.9	5.3	6.5	0.9	1.1	1.2	1.0	1.1	1.6
S5-37-1-0	7.9	9.2	9.6	2.0	2.4	2.7	3.1	3.8	4.2
S6-37-1-15	6.8	8.3	8.5	1.7	2.1	2.2	2.7	3.3	3.5
S7-37-1-25	6.6	7.9	8.6	1.6	2.0	2.1	2.5	3.1	3.3
S8-37-1-35	5.9	7.0	7.6	1.5	1.8	2.0	2.4	3.0	3.1
S9-27-2-0	6.1	7.2	7.4	1.1	1.3	1.5	1.6	1.9	2.1
S10-27-2-15	5.0	6.0	6.6	0.9	1.1	1.2	1.3	1.6	1.8
S11-27-2-25	4.8	5.4	6.3	0.8	1.0	1.1	1.2	1.4	1.5
S12-27-2-35	4.1	5.0	5.5	0.7	0.8	1.0	1.0	1.3	1.4
S13-37-2-0	6.4	7.5	8.1	1.2	1.4	1.5	1.6	1.9	2.1
S14-37-2-15	5.8	6.6	7.6	1.1	1.2	1.3	1.4	1.6	1.8
S15-37-2-25	5.3	6.4	7.1	1.0	1.2	1.2	1.3	1.5	1.7
S16-37-2-35	4.9	5.7	6.3	0.9	1.0	1.1	1.2	1.4	1.5



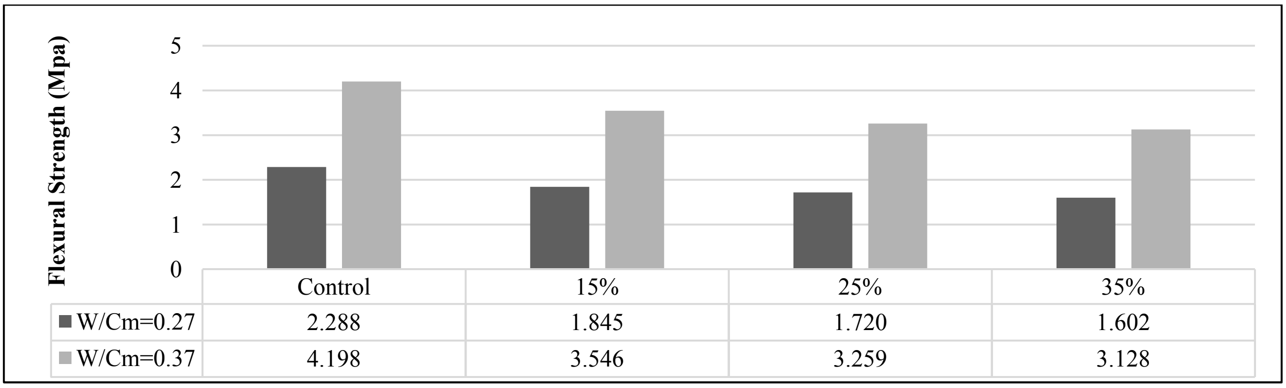
	Control	15%	25%	35%
■ W/Cm=0.27	8.654	7.210	6.864	6.455
■ W/Cm=0.37	9.647	8.489	8.563	7.634

(a) Compressive strength



	Control	15%	25%	35%
■ W/Cm=0.27	1.761	1.443	1.360	1.233
■ W/Cm=0.37	2.652	2.200	2.140	2.021

(b) Splitting-tensile strength



	Control	15%	25%	35%
■ W/Cm=0.27	2.288	1.845	1.720	1.602
■ W/Cm=0.37	4.198	3.546	3.259	3.128

(c) Flexural strength

Fig. 10 Bar chart strength of pervious concrete containing trass.

incorporating trass, a bar graph for compressive, splitting-tensile and flexural strength is illustrated in Fig. 10. Specimens with a higher w/c ratio (0.37) have higher strengths rather than those with the w/c ratio of 0.27. The probable reason may be insufficient water content for cement hydration. The higher w/c ratio enhanced the workability and the hydration of cement paste. According to previous experiments on the pervious concrete, increasing the w/c ratio to a value of 0.34 increases the compressive strength, and then a further increase of the w/c ratio will decrease the compressive strength [29].

3.5 Aggregate Size

Based on experimental results, it is evident that the size of the aggregate had a serious effect on all strength properties. The 4.75-9.5 mm had the maximum compressive strength of 8.7 Mpa corresponding to the lowest porosity. The 12.5-19 mm had the lowest compressive strength of 5.5 Mpa. By increasing the aggregate size, the strength of the pervious concrete decreases due to the reduction in bulk density of aggregate and the connection between the aggregate. This reduction in strength of pervious concrete is attributed to the weak contact forces among the aggregates.

3.6 Porosity and Permeability

Uniform gradationled to a lesser range of aggregate sizes and resulted in a higher void content and reduced paste content. The results of density, porosity and permeability are presented in Table 6 and Fig. 11.

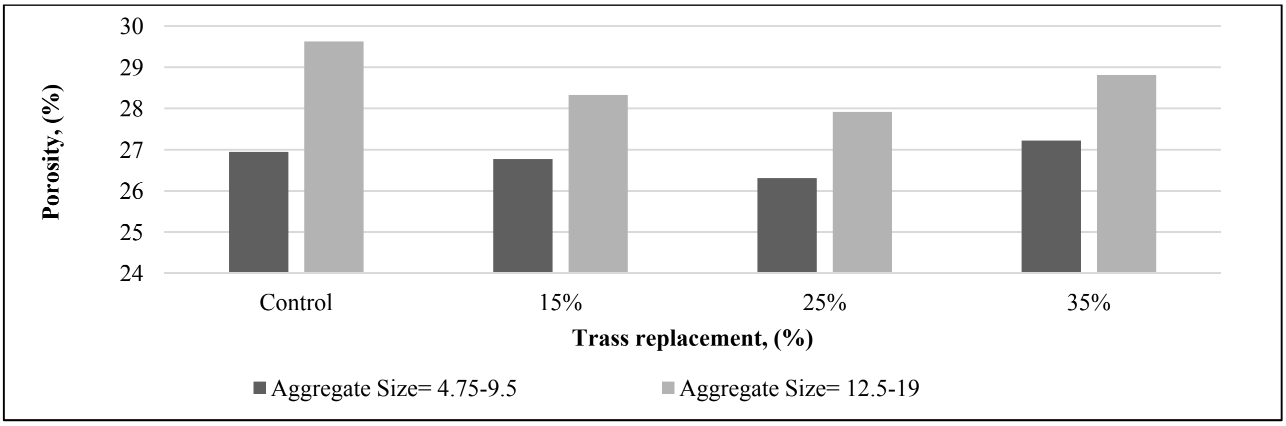
These properties were more in concrete with the w/cm ratio of 0.27 than that of 0.37. The permeability was approximately between 5.5-10.2 mm/s and porosity ranged from 26-30%, which are enough to pass water through the pavement. The porosity and the permeability rate decreased as the amount of trass used as supplementary material go northwards. The reason for the reduction could be attributed to the decrease in the thickness of the transition zone as the amount of trass increased. As expected, the permeability and porosity had a direct relationship with each other [30] in which the permeability rate increases by increasing porosity. Trass react with calcium hydroxide in the hydration process and as the amount of trass which replaces cement increased (like 35%), and C-S-H gel was produced. Hence, porosity and permeability rate increased by increasing trass. However, using a further amount of trass reduces the strength. High specific surface area and lack of required water absorption by trass particles could be reasons for these changes.

The pervious concrete mixtures that were expected to have the highest permeability rates were those made from single-sized aggregates. The permeability of the pervious concrete mixtures is illustrated in Fig. 12. Effective porosity trends were opposites of the concrete strength trends. Also, the void ratio of specimens was slightly higher when larger size aggregates were used, but the difference was not significant. Fig. 12 also depicts the correlation between the porosity and permeability of pervious concrete. The lowest permeability was recorded with the aggregate size of 4.75-9.5 mm which had the lowest porosity of 26.2%.

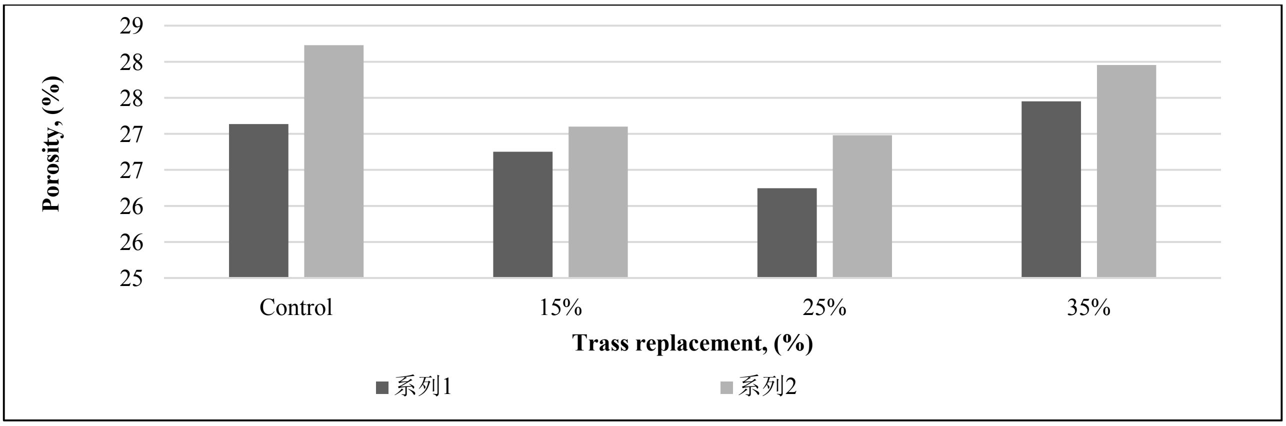
It can be concluded that the permeability of the pervious concrete is almost linear with the void percentage. In addition, it can also be found in Fig. 12

Table 6 Density and types of void ratio of the pervious concrete mixtures.

Mix designs	Target void ratio (%)	Open void ratio (%)	Close void ratio (%)	Total void ratio (%)	Permeability (mm/s)
S1-27-1-0	25	23.5	3.4	26.9	6.9
S2-27-1-15	25	22.5	4.2	26.8	7.2
S3-27-1-25	25	21.7	4.6	26.3	6.8
S4-27-1-35	25	23.7	5.1	27.2	7.4
S5-37-1-0	25	22.2	5.0	27.1	7.3
S6-37-1-15	25	22.9	3.9	26.8	6.1
S7-37-1-25	25	21.5	4.7	26.2	5.5
S8-37-1-35	25	23.4	5.0	27.5	7.1
S9-27-2-0	25	24.6	5.1	29.6	10.2
S10-27-2-15	25	24.9	5.3	28.3	10.1
S11-27-2-25	25	23.0	4.9	27.9	9.2
S12-27-2-35	25	25.4	3.4	28.8	9.7
S13-37-2-0	22	23.3	4.3	28.2	9.4
S14-37-2-15	25	25.7	4.2	27.1	9.3
S15-37-2-25	25	24.2	4.1	27.0	9.1
S16-37-2-35	25	24.0	4.0	28.0	7.9



w/cm = 0.27



w/cm = 0.37

Fig. 11 Porosity of pervious concrete by replacement of trass with different w/cm.

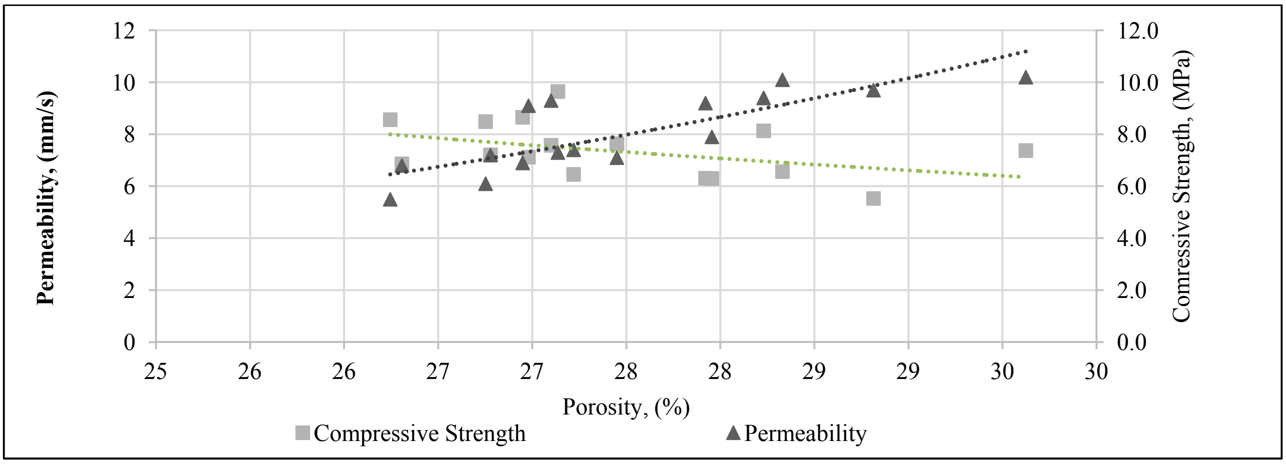


Fig. 12 Relationships among porosity, strength and permeability of pervious concrete.

the relationships between porosity, strength, and permeability of pervious concrete. As expected, the permeability of concrete increases with increasing the porosity. One of the issues of pervious concrete is to reach an appropriate balance between the permeability and compressive strength.

4. Conclusion

The primary objective of this research was the evaluation effects of incorporating trass as a partial replacement (15%, 25% and 30%) of cement on the mechanical properties of pervious concrete. From the results obtained in this investigation, the following conclusions can be drawn from the experimental data:

In the account of both strength and permeability, the optimum percentage of trass in the specimens is 35%. Although the compressive tensile and flexural strengths in concrete with 35% of trass were a little lower than other mixtures, the permeability rate reached the optimum and is considerably higher than other specimens. So, it seems that 35% of trass could be more applicable for pervious concrete, when compared to the properties of pervious concrete.

The mechanical properties including the compressive, tensile, and flexural strengths were found to be higher at a w/cm ratio of 0.37.

Incorporating more trass in the specimen reduced the strength of pervious concrete. For example, in the case of the w/c ratio of 0.27, compressive strength of pervious concrete by adding 15%, 25% and 35%, decreased 16.7%, 20.7% and 25.4% respectively.

For 35% replacement of trass, the compressive strength of pervious concrete decreases by 23-26% in age 90 days. Also, for this percentage of cement, the tensile and flexural strength decreased by 24-32.3% and 25-29.3% respectively. Similar trends were observed for the tensile and flexural strengths of concrete containing trass. The compressive strength of the pervious concrete increases linearly with the increase of the tensile strength.

The void ratio of specimens was slightly higher when larger size aggregates were used, but the difference is not significant. These results are related to the surface area of the aggregates.

The pervious concrete permeability rate was found in the range of 5.5 mm/s and 10.2 mm/s, and the porosity was found between 26.2% and 29.6%, which were suitable for drainage. The compressive and splitting-tensile strengths are inversely related to the permeability. As the permeability is increased, the strength properties of pervious concrete mixtures decreased.

The permeability of concrete decreases with incorporating trass until the 25% replacement of cement by trass. So, the permeability increases and the strengths are reduced.

Although incorporating trass was found to reduce the strength and other properties of the concrete. However, the products in this study still met the requirement of pervious concrete.

References

[1] Ozer, B., and Ozkul, M. H. 2004. "The Influence of Initial Water Curing on the Strength Development of Ordinary Portland and Pozzolanic Cement Concretes." *Cement and Concrete Research* 34 (1): 13-8.

[2] Mehta, P. K. 2002. "Greening of the Concrete Industry for Sustainable Development." *Concrete Int.* 24 (7): 23-8.

[3] Malhotra, V. M., and Mehta, P. K. 2014. *High-Performance, High-Volume Fly Ash Concrete: Materials, Mixture Proportioning, Properties, Construction Practice, and Case Histories.* Supplementary Cementing Materials for Sustainable Development, Ottawa, Canada.

[4] Gartner, E. 2004. "Industrially Interesting Approaches to "Low-CO_2" Cements." *Cement Concrete Research* 34 (9): 1489-98.

[5] Malhotra, V. M. 1987. *Supplementary Cementing Materials for Concrete*. Canada Centre for Mineral and Energy Technology, Canmet, Ottawa.

[6] Ramezanianpour, A. A., and Ghazimoradi, A. 1992. "Evaluation of Pozzolans of Iran." *Building and Housing Research Center Press.*

[7] Monteiro, P. 2006. *Concrete: Microstructure, Properties, and Materials.* New York, NY: McGraw Hill.

[8] Tennis, P. D., Leming, M. L., and Akers, D. J. 2004. "Pervious Concrete Pavements. EB302 Portland Cement Association." *Skokie Illinois and National Ready Mixed Concrete Association, Maryland: Silver.*

[9] Chindaprasirt, P., Hatanaka, S., Chareerat, T., Mishima, N., and Yuasa, Y. 2008. "Cement Paste Characteristics and Porous Concrete Properties." *Constr Build Mater* 22 (5): 894-901.

[10] Joshaghani, A., Ramezanianpour, A. A., and Jaberizadeh, M. 2014. "Mechanical Characteristic of Pervious Concrete Considering the Gradation and Size of Coarse Aggregate." *Research Journal of Environmental and Earth Science* 6 (9): 437-42.

[11] Tasdemir, C. 2003. "Combined Effects of Mineral Admixtures and Curing Conditions on the Absorptivity Coefficient of Concrete." *Cement and Concrete Research* 33 (10): 1637-42.

[12] Yetgin, S., and Çavdar, A. 2006. "Study of Effects of Natural Pozzolan on Properties of Cement Mortars." *Journal of Materials in Civil Engineering* 18 (6): 813-6.

[13] Rahmani, H., and Ramazanianpour, A. A. 2008. "Effect of Binary Cement Replacement Materials on Sulfuric Acid Resistance of Dense Concretes." *Magazine of Concrete Research* 60 (2): 145-55.

[14] Yang, J., and Jiang, G. 2003. "Experimental Study on Properties of Pervious Concrete Pavement Materials." *Cement and Concrete Research* 33 (3): 381-6.

[15] Standard, A. S. T. M. 2015. "Standard Specification for Portland Cement." *ASTM Annual Book of ASTM Standards.*

[16] Standard, A. S. T. M. 2015. "Standard Test Method for Slump of Hydraulic-Cement Concrete." *ASTM Annual Book of ASTM Standards.*

[17] Standard, A. S. T. M. 2016. "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory." *ASTM International.*

[18] Standard, A. S. T. M. 2016. "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." *ASTM International.*

[19] Standard, A. S. T. M. 2016. "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." *ASTM International.*

[20] Standard, A. S. T. M.2016. "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)." *ASTM International.*

[21] Joshaghani, A., Ramezanianpour, A. A., Ataei, O., and Golroo, A. 2015. "Optimizing Pervious Concrete Pavement Mixture Design by Using the Taguchi Method, Constr Build Mater." *Contruction and Building Materials* 101: 317-25.

[22] Das, B. M. 2001. *Principles of Geotechnical Engineering* Fifth Edition. Thomson Learning. pp. 608.

[23] Meininger, R. C. 1988. "No-fines Pervious Concrete for Paving." *Concrete International* 10 (8): 20-7.

[24] Eco-Concrete Research Committee. 1995. "Report of the Eco-Concrete." *Japan Concrete Institute*, Tokyo.

[25] Seo, D. S. 2006. "An Experimental Study on Sound Absorption Properties of Multifunctional Porous Concrete for Building Materials." Ph.D. Thesis, Chungnam National University, Daejeon, South Korea.

[26] Prokopski, G., and Halbiniak, J. 2000. "Interfacial Transition Zone in Cementitious Materials." *Cement and Concrete Research* 30 (4): 579-83.

[27] Poon, C. S., Shui, Z. H., and Lam, L. 2004. "Effect of Microstructure of ITZ on Compressive Strength of Concrete Prepared with Recycled Aggregates." *Constrution of Building Materials* 18 (6): 461-8.

[28] Lian, C., and Zhuge, Y. 2010. "Optimum Mix Design of Enhanced Permeable Concrete—An Experimental Investigation." *Constrution of Building Materials* 24 (12): 2664-71.

[29] Joshaghani, A. 2016. "The Effects of Zeolite as Supplementary Cement Material on Pervious Concrete." International Concrete Sustainability Conference. Washington, D. C..

[30] ACI 2013. "Specification for Pervious Concrete Pavement." American Concrete Institute.