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EFFECT OF SUPPLEMENTARY CEMENTITIOUS MATERIALS ON THE PROPERTIES OF PERVIOUS CONCRETE WITH FIXED POROSITY

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ABSTRACT

Pervious concrete is significantly different to that of conventional concrete as it has the ability to allow water to percolate through it large sized pores. This unique ability presents many environmental benefits such as minimising storm water run-off, recharging groundwater and reducing the heat absorption in the pavement. This paper reports the results of an experimental investigation into the use of supplementary cementitious materials on the properties of pervious concrete (compressive strength, stiffness and water permeability) having the porosity of about 20%. The investigation considered four mixes with the following combinations of cement and supplementary cementitious materials, by weight proportion: (a) 100% cement; (b) 75% cement and 25% fly ash; (c) 92.6% cement and 7.4% silica fume; and (d) 84.2% cement, 8.2% fly ash and 7.6% silica fume. The results showed that the cement replacements with supplementary cementitious materials had improved the compressive strength, reduced modulus of elasticity and decreased the water permeability of pervious concrete with fixed porosity.

KEYWORDS

Pervious concrete, supplementary cementitious materials, porosity, cement, fly ash, silica fume, compressive strength, modulus of elasticity.

INTRODUCTION

Pervious concrete is a special type of concrete with a high proportion of large sized pores, typically 2 to 8 mm. Water permeable pores are achieved by balancing the volume of voids present in an open-graded coarse aggregate with enough cement paste for load carrying capacity. The water permeable void content ranges from 15% to 30%. With an increase in void content, the compressive strength decreases linearly whereas the permeability increases exponentially. The presence of interconnected large voids contributes to the rapid flow of water through the pervious concrete which has been used for many years to reduce the runoff in urban settings. Most designs appropriate for traffic have void contents around 20% and the pervious concrete is rapidly gaining acceptance by the construction industry, as a suitable material for the construction of low volume pavements, residential roads, parking lots, tennis courts and patios.

The pervious concrete is generally proportioned with the conventional concrete making materials either without or with a reduced amount of fine aggregate (ACI, 2006). In recent times, there has been a significant focus on providing sustainable and environmentally friendly solutions for concrete construction. Aoki et. al. (2012) investigated the engineering properties and permeability of pervious concrete with and without fly ash. Replacement of natural aggregate with recycled concrete aggregate in pervious concrete of given porosity was reported to have no effect on the water permeability, however the compressive strength was reduced significantly due to the inherent weakness of the recycled aggregate (Murao et. al. (2002) and Sriravindrarajah et. al. (2012)).

Considering the necessity to find the ways to improve the strength of pervious concrete, an experimental investigation on pervious concrete was continued at the University of Technology, Sydney. The purpose of this study is to investigate the effect of partial replacement of cement with supplementary cementitious materials (fly ash and silica fume) on the mechanical properties and permeability of pervious concrete, having a fixed porosity of about 20%. The following properties of the pervious concrete were studied: (a) density; (b) porosity, (c) compressive strength, (d) modulus of elasticity, (e) water permeability and (f) water infiltration rate.

EXPERIMENTAL INVESTIGATION

Materials and Mix Compositions

A total of four pervious concrete, having the porosity of about 20%, were produced with different combinations of the binder materials. The binder materials used were General purpose Portland cement, low calcium fly ash from NSW and condensed silica fume. Crushed granite, having a maximum aggregate size of 10mm, was used as coarse aggregate and no fine aggregate was used. The design for the control pervious concrete mix (Mix 1) was derived using the mix design approach reported by Sriravindrarajah et. al. (2012). Table 1 shows the composition of the pervious concrete mixes. The cement replacement level with supplementary cementitious materials were 24.7% (fly ash), 7.4% (silica fume) and 15.8% (8.2% fly ash and 7.6% silica fume), by weight in the Mixes 2, 3 and 4, respectively. The water requirements for the mixes were determined to achieve workable pervious concrete, determined by the ball rolling method described by Tennis et. al. (2004). The water to binder ratio was varied between 0.30 and 0.32, by weight and the aggregate to binder materials ratio was varied between 4.41 and 4.80, by weight.

Table 1. Compositions of the pervious concrete mixes

Mix No.	Cement (kg/m^3)	Fly Ash (kg/m^3)	Silica Fume (kg/m^3)	Coarse agg. (kg/m^3)	Water (kg/m^3)
Mix 1	348	-	-	1536	103
Mix 2	238	78	-	1516	102
Mix 3	302	-	24	1501	101
Mix 4	267	26	24	1493	100

Mixing, Casting and Curing of Test Specimens

The volume of the pervious concrete batch was about 65 litres for each mix. Pan-type of concrete mixer was used to achieve uniform fresh concrete. The fresh concrete was tested for its wet density. and a number of test specimens were cast with minimum compaction. For each mix, three 150mm cubes were cast in steel moulds to determine the compressive strength. For pervious concrete, Sriravindrarajah et. al. (2012) suggested the use of 150mm cube specimens for compressive strength testing (instead of 100mm cube specimens) to reduce the variability of the test results. Two 150mm diameter by 200mm high cylinders were cast to determine the modulus of elasticity of concrete. Four 100mm by 300mm by 300mm square prisms were also produced in wooden moulds for water permeability and infiltration rate studies.

During the preparation of the test specimens, minimum compaction was applied with a small timber piece. The prisms were compacted through the use of a custom made scarping tool. This procedure was adopted to ensure even distribution of fresh concrete in the moulds. The specimens were covered with polythene sheets to prevent moisture loss immediately after casting and demoulded after 24 hours. The specimens were then stored in water at 20^oC until testing at the age of 28 days.

Testing of Pervious Concrete

Fresh pervious concrete was tested for its wet density in accordance with AS1012.5, with minimum compaction. The cube specimens were tested in compression in accordance with EN 12390-3 procedure. The loading faces of the cubes were capped with dental plaster to achieve uniform load application due to honeycomb appearance of the cube faces. The modulus of elasticity was determined using the procedure given in AS 1012.17. The void content of the prism specimens was determined using the procedure outlined by Deo and Niethalath (2010).

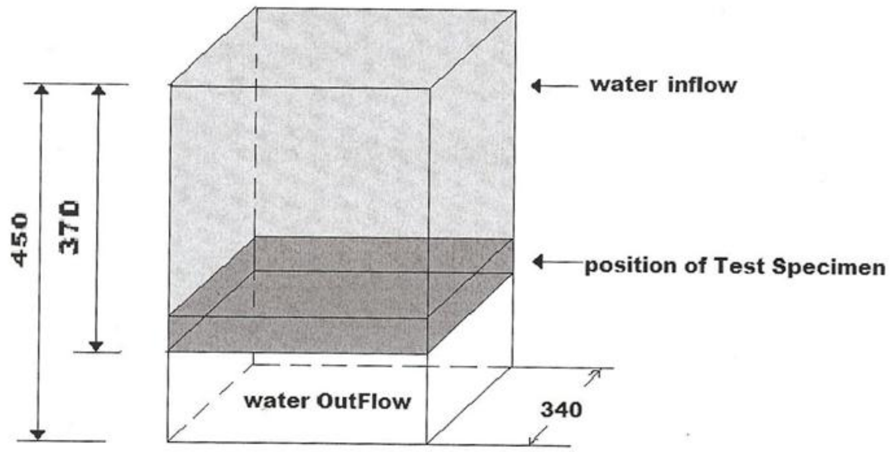

Figure 1. Schematic diagram of water permeability apparatus

Water permeability of pervious concrete was carried out using falling head method as described by Sriravindrarajah et. al. (2010, 2013). Figure 1 shows the schematic diagram of the water permeability test set up. The time taken for the water head to fall from 200mm to 50mm was measured and the permeability coefficient was calculated using Darcy's First Law. In addition, the times taken for the water head to drop from 200mm to 150mm, 150mm to 100mm and 100mm to 50mm were also monitored. For each mix, three square prisms were used for the water permeability test.

Figure 2. Infiltration test set-up on pervious concrete specimens

The infiltration rate of pervious concrete was determined using ASTM C1701C/C1701M method. The time taken for 2 litre water to infiltrate through pervious concrete was recorded using a custom made set-up, as shown in Figure 2. The diameter of the rubber cap used was 82mm. For each specimen, the infiltration test was carried out on four quarters.

Table 2. Properties of pervious concrete mixes

Property/Mix	Cement (Mix 1)	Cement + Fly Ash (Mix 2)	Cement + Silica Fume (Mix 3)	Cement + Fly Ash + Silica Fume (Mix 4)
Wet density (kg/m^3)	1990	1895	1930	1910
Void content	0.21	0.21	0.18	0.18
Compressive strength (MPa)	12.8	15.5	22.5	17.3
Modulus of elasticity (GPa)	19.1	13.4	18.3	14.2
Permeability coefficient (mm/s)	6.63	5.16	4.98	3.87
Infiltration rate (mm/s)	48.9	41.9	36.8	26.3

RESULTS AND DISCUSSION

Table 2 summarises the properties of the pervious concrete obtained with all four pervious concrete mixes, having different combinations of the binder materials. The mean values for the properties of pervious concrete are presented. As expected, a reasonable variability for the measured properties was observed due the practical difficulties in obtaining identical pervious concrete specimens.

Compressive Strength of Pervious Concrete

The compressive strength for the pervious concrete mixes at 28 days was varied between 12.8MPa and 22.5MPa. The effect of partial cement replacement with supplementary cementitious materials was found to increase the compressive strength, even though the total porosity of the pervious concrete was nearly the same. This could be due to the improvement in the quality of the hardened binder paste due to the pozzolanic reactions of the supplementary cementitious materials (fly ash and silica fume) with the liberated calcium hydroxide from cement hydration. The lowest compressive strength of 12.8MPa was recorded for the pervious concrete with no cement replacement (Mix 1). The highest strength of 22.5MPa was recorded for the pervious concrete containing 7.4% silica fume as cement replacement (Mix 3). This corresponds to an increase of 76 per cent for the compressive strength. When fly ash was used to replace 26.6% of cement (Mix 2), the compressive strength was increased to 15.5MPa, an increase of 21 per cent. When 15.8% of the cement by weight was replaced by equal amounts of fly ash and silica fume (Mix 4), the compressive strength of 17.3MPa was recorded, which corresponds to an increase of 35 per cent for the compressive strength.

Modulus of Elasticity of Pervious Concrete

The highest modulus of elasticity of 19.2GPa was recorded for the control pervious concrete (Mix 1). When cement was partially replaced with fly ash (Mix 2) the modulus of elasticity was decreased to 13.4GPa, which corresponds to a drop of 30 per cent. The pervious concrete with silica fume (Mix 3) recorded the modulus of elasticity of 18.3GPa, which is only 5 per cent lower than that for the control pervious concrete. When cement was partially replaced with a combination of fly ash and silica fume (Mix 4), the reduction of 26 per cent for the modulus of elasticity was noted.

Porosity and Density of Pervious Concrete

The porosity of pervious concrete was marginally reduced when the cement was partially replaced with supplementary cementitious materials (Table 2). Mixes 3 and 4 recorded the porosity of 0.18 compared to 0.21 for the control pervious concrete (Mix 1). Mix 2, having partial replacement of cement with fly ash, showed the porosity of 0.21 which is the same as that for the control concrete mix (Mix 1). The wet density of the pervious concrete mixes varied between 1895kg/m^3 and 1990kg/m^3. This variation in the wet density is due to the combination of the difference in the porosity as well as the use of lower density supplementary cementitious materials compared to cement.

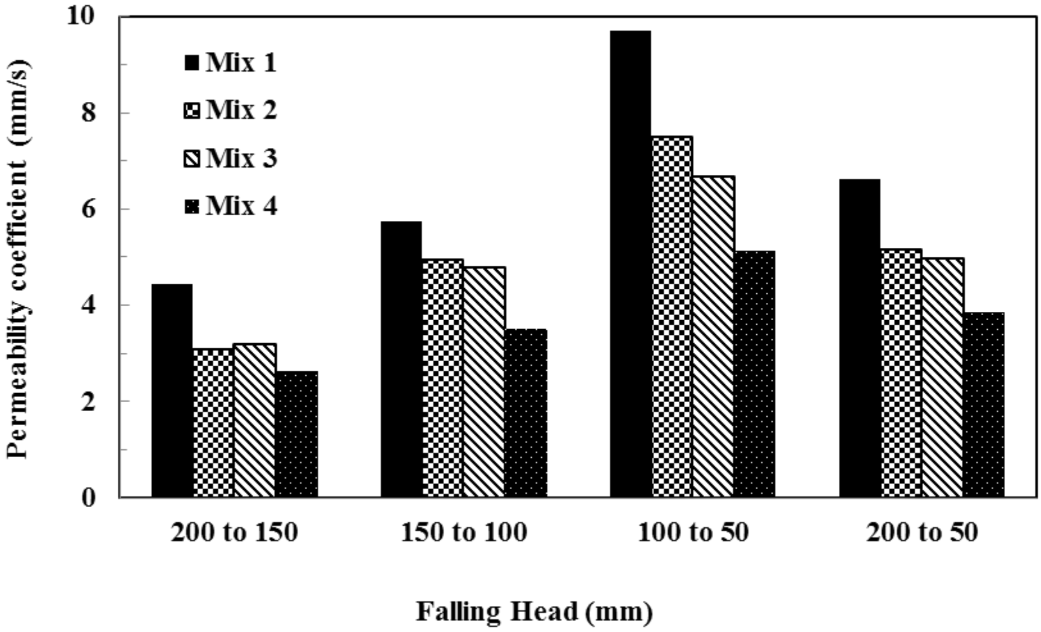

Figure 3. Effect of binder type on the water permeability of pervious concrete

Water Permeability of Pervious Concrete

The water permeability results shown in Table 2 indicate that the permeability coefficient of pervious concrete was dropped significantly when cement was partially replaced with the supplementary cementitious materials. The highest value of 6.63mm/s for the permeability coefficient was recorded for the control pervious concrete (Mix 1). The lowest permeability value of 3.87mm/s was recorded for pervious concrete having a combination of fly ash and silica fume (Mix 4). In relative terms, the permeability of pervious concrete had dropped by 42% (Table 2) when the cement was partially replaced with a combination of fly ash and silica fume.

When cement was partially replaced with fly ash (Mix 2), the permeability coefficient was decreased by 22%. The permeability was reduced by 25% when cement was partially replaced with silica fume (Mix 3). These significant reductions in the permeability are surprising even though the total porosity of the pervious concrete mixes had changed marginally. Hence the results suggest that the use of supplementary cementitious materials as partial replacement to cement have a significant influence on the permeability of pervious concrete, probably due the modification of the permeable pore structure. Further investigation is needed to verify this observation.

Figure 3 shows the permeability coefficient for pervious concrete mixes obtained with falling head method for all four mixes, over a drop of 50mm water head. The control pervious concrete (Mix 1) showed the highest permeability compared to other mixes containing supplementary cementitious materials. The highest rate of water permeability was recorded when the water head dropped from 100mm to 50mm. The permeability coefficient for the pervious concrete mixes when the water head dropped from 200mm to 50mm varied between 3.87mm/s to 6.63 mm/s (Table 2).

Infiltration Rate of Pervious Concrete

For each pervious concrete mix, the water infiltration test was conducted on 3 square prisms and for each prism four readings were taken at four quarters. The mean of 12 readings are presented in Table 2. The analysis of the infiltration results showed that the coefficient of variability for all four mixes was around 15%. Similar to the water permeability, the infiltration rate was 46% lower for the pervious concrete with a combination of cement, fly ash and silica fume (Mix 4) compared to that for the control pervious concrete. This value is comparable with the reduction of 42% obtained for water permeability.

CONCLUSION

The effects of partial replacement of cement with supplementary cementitious materials on the mechanical properties and water permeability of pervious concrete having a fixed porosity of about 20% were investigated. The analysis of the test results indicated that the pervious concrete with supplementary cementitious materials had increased the compressive strength by up to 76% whereas the modulus of elasticity had drop as much as 30%. The water permeability was found to drop up to 42%. The silica fume found to play an important role in strengthening the quality of binding paste and reducing the permeability of pervious concrete, even though the total porosity of pervious concrete has not changed significantly. Further investigation is needed to establish the influence of cement replacement with supplementary cementitious materials on the properties of pervious concrete with a wide range of porosities. The simple test set-ups used in this study are suitable to determine the water permeability and infiltration rates for pervious concrete using falling head method.

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