Effect of Mix Proportion on Strength and Permeability of Pervious Concrete for Use in Pavement

Emiko LIM[a] , Kiang Hwee TAN[b] , Tien Fang FWA[c]

[a,b,c] *Department of Civil and Environmental Engineering, National University of Singapore, Singapore.*

[a]*Email: a0012487@nus.edu.sg*

[b]*Email: ceetankh@nus.edu.sg*

[c]*Email: ceefwatf@nus.edu.sg*

Abstract: A study to achieve high-strength, high porosity and permeability pervious concrete pavement was carried out. Mix proportions in terms of cement content, coarse aggregate-cement ratio (CA/C) and water-cement (W/C) ratio were varied. A mix proportion providing the optimal combination of strength and porosity was chosen, and polymer superplasticizers were added to examine their effect on the strength and porosity. Results showed that a water-cement ratio of 0.2 resulted in a dry and brittle mix that led to compressive strength less than 15MPa but a high permeability rate of approximately 20mm/s. A mix with w/c ratio of 0.3 and CA/C ratio of 4.25 resulted in compressive strength of 13.9MPa, flexural strength of 3MPa and high porosity of more than 20%. The use of high cement content of 495kg/m^3 in the mix resulted in high compressive strengths of 51.8MPa, flexural strength of more than 4MPa, however permeability was reduced to approximately 1mm/s.

Keywords: Compressive strength; flexural strength; permeability; pervious concrete pavement; porosity; polymer superplasticier.

1. INTRODUCTION

In Singapore, heavy rainfall imposes varying constraints on its drainage systems. Extreme discharges can result from high intensity storms lasting less than an hour to prolonged rainstorm with moderate rainfall intensities. Based on the rainfall intensity records over the past 30 years, there is a strong probability of higher rainfall intensities and frequency of intense rains in the years to come. Singapore's drainage systems also need to cope with megatrends such as climate changes, extreme storms and water scarcity. An imminent problem in Singapore now is flash flooding during periods of heavy rainfall. One of the solutions to prevent flooding in Singapore is the use of pervious concrete pavements. (Report on Key Conclusions and Recommendations of the Expert Panel on Drainage Design and Flood Protection Measures, January, 2012).

The advantage of using pervious concrete pavement is its good water permeability. It reduces rain puddles and splash on the pavement which are not favorable for driving. It also eliminates the glare from the road surface thus improving road safety. Pervious concrete is increasingly used in the United States because of its various environmental benefits such as controlling storm water runoff, restoring groundwater supplies and reducing water and soil pollution (Kajio *et al.* 1998; Youngs, 2005; Tennis *et al.*, 2004). Generally, the void content of pervious concrete is between 15% and 25%, and the water permeability is typically about 2–6 mm/s (Tennis *et al*., 2004 and Schaefer *et al.*, 2006).

Huang *et al.* (2010) and Kevern (2008) found that the addition of polymer styrene butadiene rubber (SBR) enabled a higher strength to be obtained with lower cement content and it resulted in relative higher porosity. SBR also improved the workability, strength, permeability and freeze–thaw resistance of pervious concrete. Huang et al also found that with latex polymer, a permeability range of 10 – 20mm/s and compressive strength range of 5 -15MPa could be obtained.

2. MATERIALS AND TEST METHODS

2.1 Materials

The cementitious material used was ASTM Type I ordinary Portland cement of which the chemical composition and physical properties complied with ASTM C 150-07 requirements. Coarse aggregates were natural crushed granite complying to the grading requirements of ASTM C 33-11a and having a specific gravity of 2.65. Two coarse aggregate sizes were used. The small coarse aggregates complies to ASTM C33/C33M- 11a size 89 (9.5 to 1.18mm) range, whereas the large coarse aggregate complies to the ASTM size 67 (19.0 to 9.5mm) range. A conventional superplasticier meeting the requirements of ASTM C494 Type F and G and ASTM C1017 Type I was used. The comb and acrylic polymer superplasticiers contained no added chloride and is formulated to comply with the following chemical admixture specification for concrete: SS320- 1987, ASTM C494, Type F; BS5075 Part 3, 1985.

2.2 Mechanical Tests

The NUS constant head permeameter (Singapore Patent number 67286, 2001) was used to test the permeability of the specimens. The Avery Denison machine was used to test the compressive and flexural strengths. The flexural strength test was done according to ASTM C78-10. The test specimens were made and cured according to ASTM C 192/C 192M-02. Concrete cubes (100 x 100 x 100 mm) were used to obtain the compressive strengths. Concrete prisms (100 x 100 x 400mm) were used for the flexural tests. The permeability samples have a diameter of 150mm and a height of 50mm. The molds were filled with freshly mixed concrete in three layers of approximately equal volume. Each layer was tamped 25 times. The mixes were then covered with a non-absorptive, non-reactive sheet of tough, durable impervious plastic for 24 $\pm$ 8 hours, after which they were demolded and moist cured in a fog room for 28 days. The average of 3 samples was taken for each test. The compressive test cube, permeability test sample and flexural test prism are shown below in Figures 1 and 2.

Figure 1: Compression test cube (left) and permeability test sample (right).

Figure 2: Flexural test prism.

2.2.1 Permeability Test

For the constant head permeability test, with reference to ASTM D4511-11: Standard Test Method for Hydraulic Conductivity of Essentially Saturated Peat, the equation for permeability is shown below.

$$k = L\,(Q/t) / (A\,\Delta H) \tag{1}$$

where : k = hydraulic conductivity, m/s; Q/t = rate of water outflow, m^3/s, A = cross-sectional area of specimen, m^2; L = length of specimen, m and ΔH = value of constant hydraulic head, m, required to maintain a sustained flow rate, Q/t.

The test set-up is shown in shown Figure.3. A submersible pump provides constant inflow of water into the inlet cylinder such that a constant head of water can be maintained at the desired water head in the inlet cylinder. The flow of water can be controlled using valves. The flow rate of water is determined by measuring the volume of water collected in the water tank over time. The permeability samples are sealed with waterproof thread tape to prevent side-flow of water and to enable only 1-D flow. Plasticine was used to seal off any leakage that would occur in the setup.

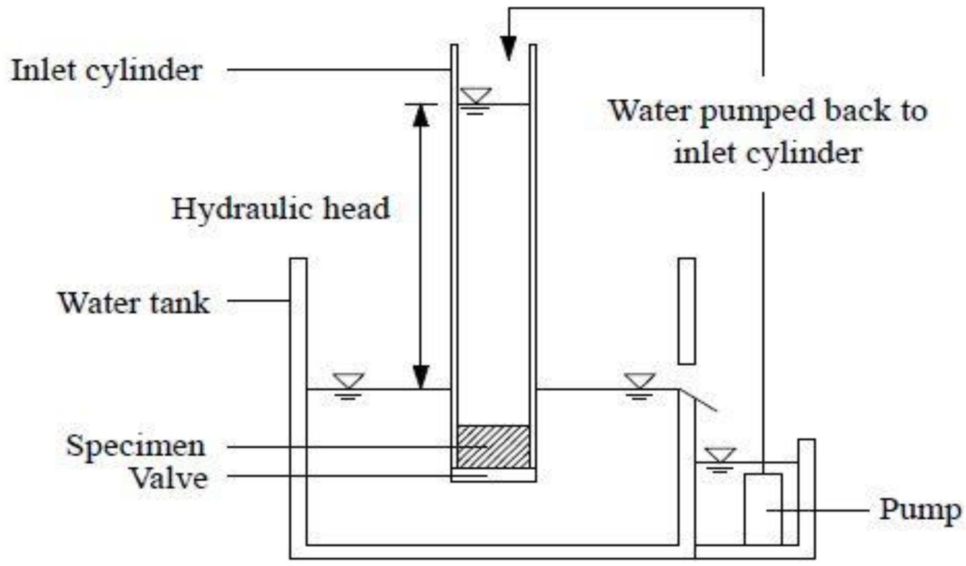


Figure 3. Constant-head permeability test set-up schematic diagram.

2.2.2 Porosity Test

The equation for the porosity is shown below. (Lian *et al.* 2011)

$$V_r = \left[1 - \frac{W_2 - W_1}{\rho_w V} \right] \text{ x } 100\% \quad (2)$$

Where: V_r = total void ratio in %; W_1 = weight of sample immersed in water; W_2 = Weight of sample in air; ρ_w = density of water; V = volume of sample.

2.3 Concrete Mixtures

Only one parameter was varied within the mixtures in each series to investigate the effect of the varied parameter. The mixes are named R, A, B, C and D. R represents the reference mix and the parameters varied are respectively CA/C ratio, w/c ratio, polymer and cement content for A, B, C and D. The mix proportion design is shown in Table 1.

Table 1. Mix Proportion Design

Mix	Test Variable	w/c ratio	Cement (C)/[kg]	Water/[kg]	Coarse Aggregate (CA)/[kg]	CA/C	Additives
R1a,b	Reference	0.3	367	110.1	1560	4.25	SP
A1a,b	CA/C	0.3	242	72.6	1560	6.45	SP
B1a,b	w/c ratio	0.2	367	73.4	1560	4.25	Comb Polymer SP
C1a,b	Polymer	0.3	367	110.1	1560	4.25	Comb Polymer SP
C2a,b							Acrylic Polymer SP
D1a,b	Cement content	0.3	430	110.1	1560	3.63	Comb Polymer SP
D2a,b			495	148.5		3.15	

* a: denotes small coarse aggregates; b: denotes large coarse aggregates being used.

3. TEST RESULTS AND DISCUSSION

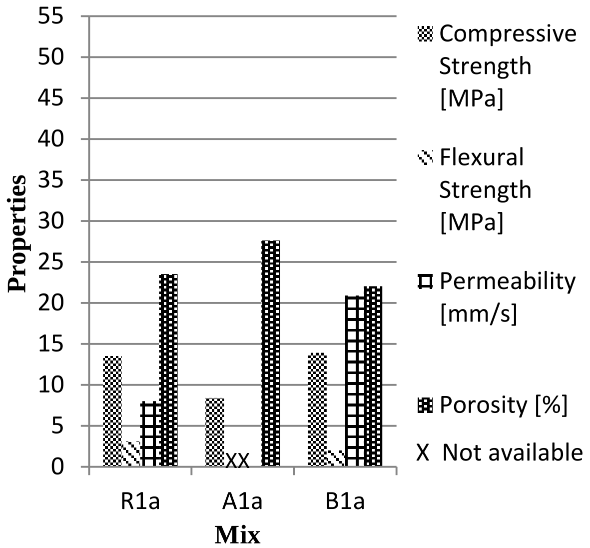
Table 2 shows the compressive strength, flexural strength, permeability and porosity test results

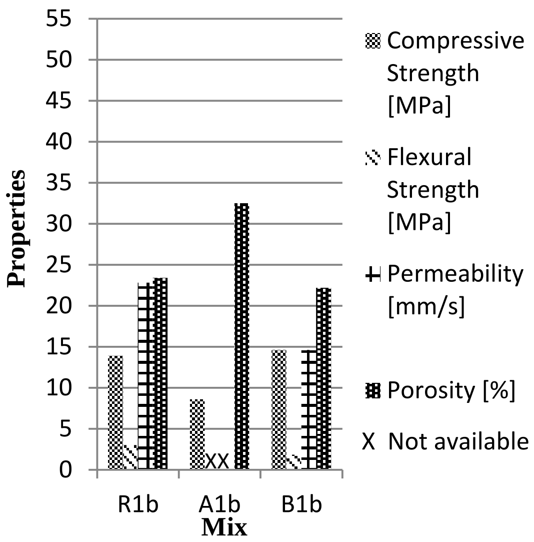
Table 2. Tests Results

Mix	Test Variable	Compressive Strength [MPa]	Flexural Strength [MPa]	Permeability [mm/s]	Porosity [%]
R1a	Reference	13.5	3.07	8.0	23.5
R1b		13.9	3.00	22.8	23.4
A1a	CA/C	8.4	-	-	27.6
A1b		8.6	-	-	32.5
B1a	w/c ratio	13.9	1.98	20.9	22.0
B1b		14.6	1.86	14.6	22.2
C1a	Polymer	13.6	3.18	19.4	22.1
C1b		14.6	3.25	10.4	21.6
C2a		10.9	2.15	14.4	23.8
C2b		12.6	2.24	13.3	22.2
D1a	Cement Content	28.9	3.63	2.19	8.36
D1b		35.8	3.73	1.40	7.42
D2a		35.6	4.48	4.05	12.9
D2b		51.8	4.07	1.13	5.24

- Test result not available

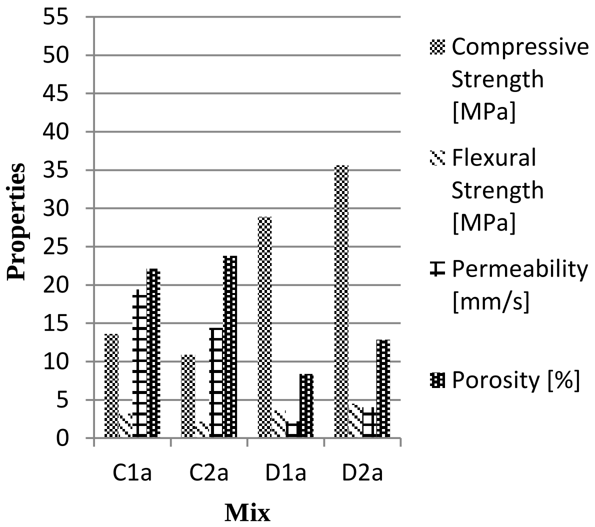
For the present study, Figure 4 depicts the compressive and flexural strength, permeability and porosity of mixes with different mix proportions. Due to the higher cement content from Mixes D, results from the present study included compressive strengths ranging from 10.9 MPa to 51.8 MPa; flexural strengths ranging from 1.86 MPa to 4.48 MPa and porosity ranging from 5.24% to 23.8%. From Figures 5 and 6, it can be noted that there is an almost linear relationship between flexural strength and compressive strength as well as between flexural strength and porosity. The results compared well with those obtained by Meininger (1988) and Neithalath (2004).

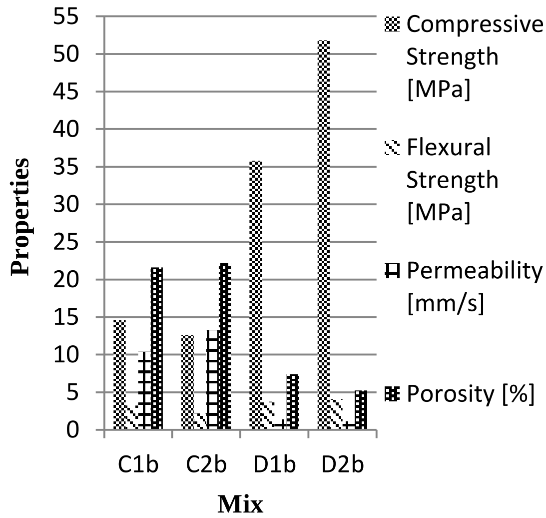




(a) Mixes with small aggregates

(b) Mixes with large aggregates





(a) Mixes with small aggregates

(b) Mixes with large aggregates

Figure 4. Compressive and flexural strength, permeability and porosity of mixes with different mix proportions.

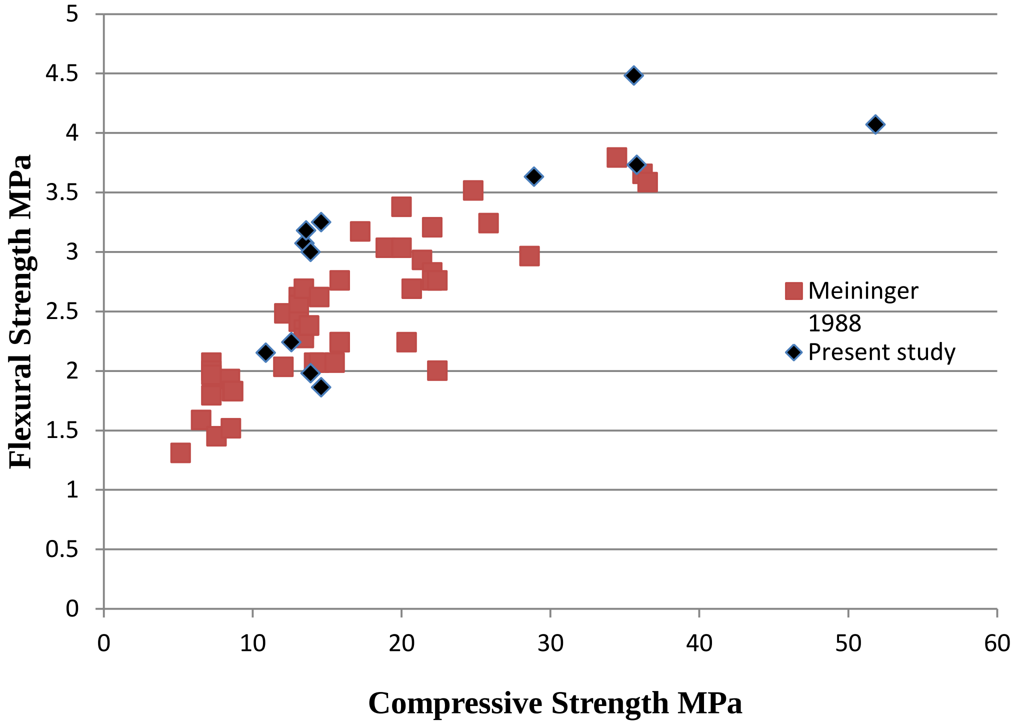


Figure 5. Relationship between flexural strength and compressive strength for pervious concrete.

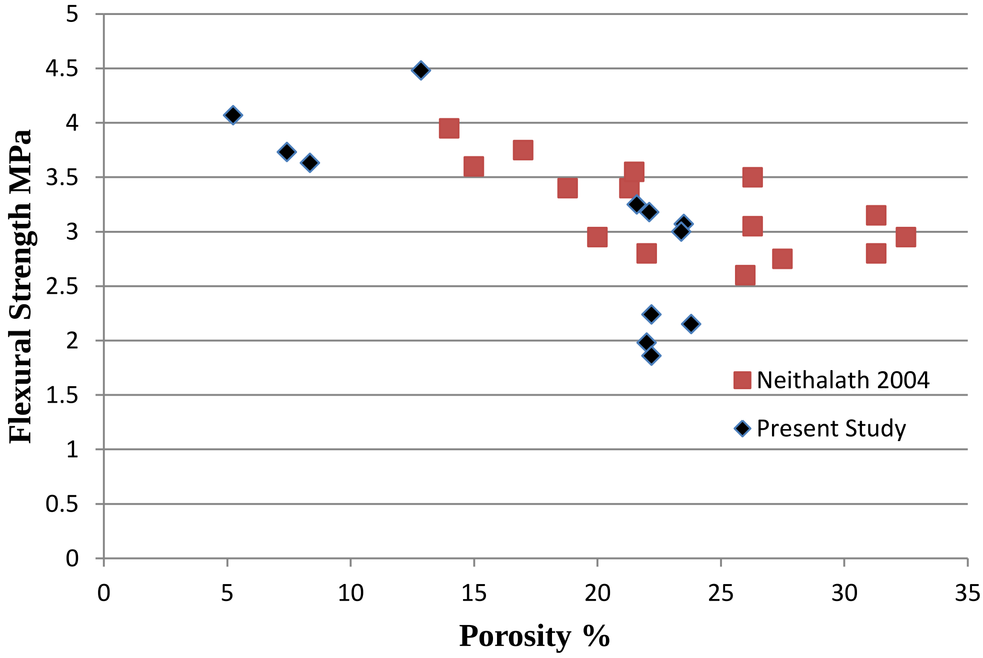


Figure 6. Relationship between flexural strength and porosity for pervious concrete.

3.1 Effect of CA/C ratio

The specimens R1a and R1b had a CA/C ratio of 4.25, within the ACI 522R-10 recommended range for pervious concrete. The porosity was above 20%. The compressive and flexural strengths were smaller and equal to 13.9 MPa and 3.0 MPa respectively. Mix A1a and A1b with a coarse aggregate- cement (CA/C) ratio of 6.45 had a high porosity of about 30%. The large amount of coarse aggregate present in the specimen resulted in large pore gaps and thus higher porosity rates. However the accompanying compressive strength of less than 10MPa was considered to be the low.

3.2 Effect of w/c ratio

Specimens B1a and B1b had a water-cement ratio of 0.2 that was below the ACI 522R-10 recommended values of w/cm ratio of 0.27 to 0.34. For normal weight concrete, lowering the water-cement ratio would lead to higher compressive strengths, however in the case of pervious concrete, the mix became too dry and brittle despite using higher dosages of polymer superplasticier. As a result a comparatively low compressive strength of less than 15MPa was achieved. Permeability on the other hand was still relatively high at 20.9 mm/s.

3.3 Effect of polymer

Specimens C1a and C1b were tested with acrylic polymer while specimens C2a and C2b were tested with comb polymer superplasticiers. Flexural strength increased with the addition of polymers agreeing with the findings of Onstenk *et al.* (1993). Between the two types of polymers, the comb polymer superplasticier was found to give higher compressive and flexural strengths. Therefore in subsequent mixes, this comb polymer superplasticier was used. With the inclusion of polymers into the mix, the compressive and flexural strengths increased to 14.6 MPa and 3.25 MPa respectively. Porosity was not compromised. It can also be noted that apart from the porosity and pore size, the permeability of the pervious concrete is also influenced by the tortuosity or the degree of connectivity in the pore network (ACI Report, 2010). Therefore an increase in porosity does not always result in an increase in permeability.

3.4 Effect of cement content

Specimens D1a, D1b, D2a and D2b were tested with cement content of 430 kg/m^3 and 495 kg/m^3 respectively. By further increasing the cement content from 430 kg/m^3 to 495 kg/m^3 (upper limit), compressive strengths increased by 23.2% for the small coarse aggregates and 44.7% for mixes with large coarse aggregates; likewise flexural strengths increased by 23.4% and 9.11% respectively. Using the cement content of 495 kg/m^3 can result in a high average compressive strength of 43.7 MPa and flexural strength of 4.28 MPa; however the permeability drops to a low of 2.59 mm/s.

3.5 Mix design trends

By compiling the different mixes, an exponential trend is seen in Figure 7 while Figures 8 and 9 show a power trend. Due to the inclusion of Mix D with the cement content variable, the trend of compressive strength versus porosity differs slightly with Bhutta *et al.* (2012) whom concluded that regardless of types of pervious concrete and aggregate size, their results showed an almost linear relationship between the compressive strength and porosity, and between permeability and porosity for all porous concretes in the range of 15–30% porosity.

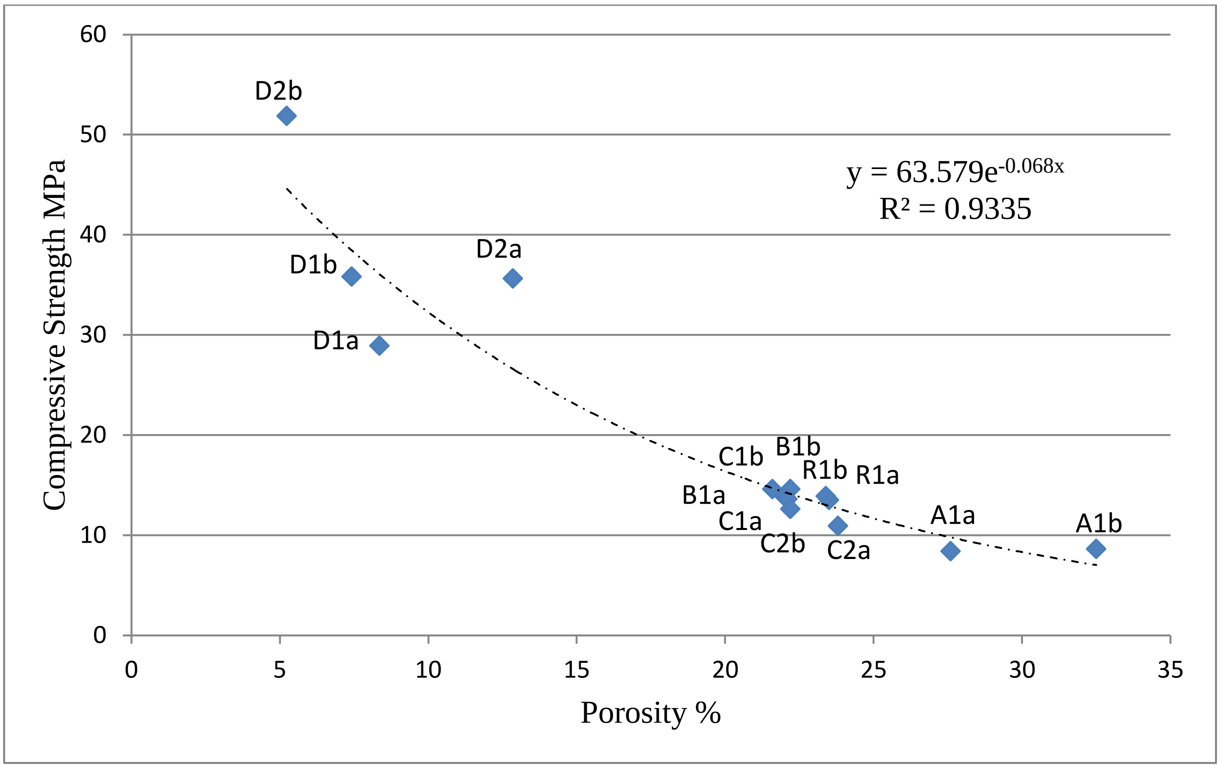


Figure 7. Compressive strength [MPa] versus porosity [%].

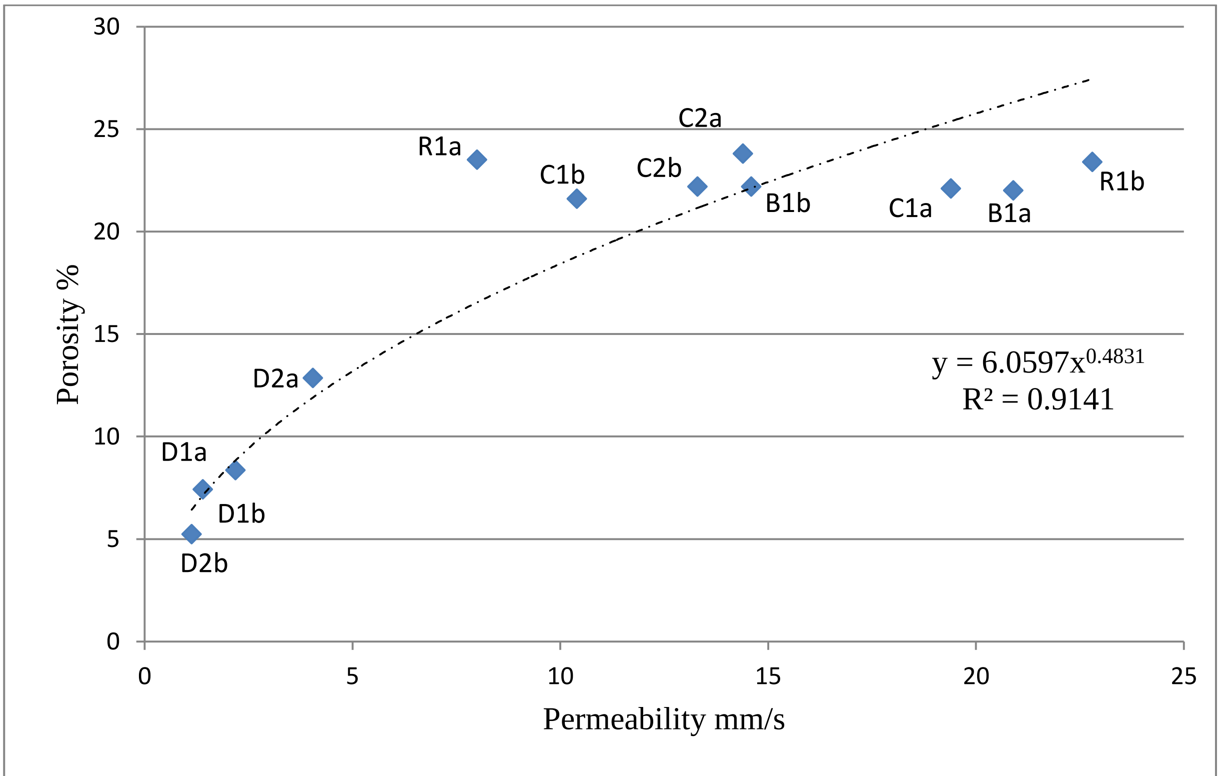


Figure 8. Porosity [%] versus permeability [mm/s].

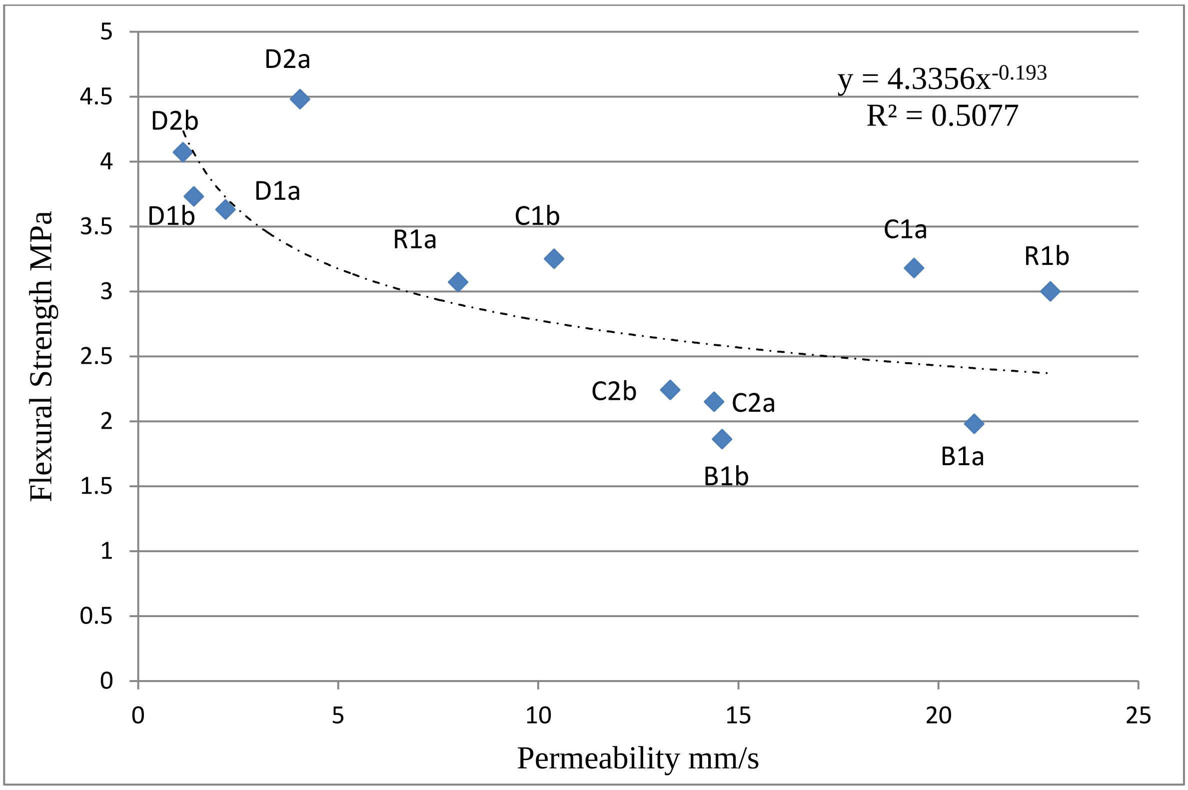


Figure 9. Compressive strength [MPa] versus permeability [mm/s].

4. CONCLUSION

Tests were carried out to investigate the effect of mix proportion on the properties of pervious concrete. To achieve a highly permeable and porous pavement without compromising on the compressive and flexural strength, the CA/C ratio should be in the region of 4.25 and the w/c ratio of around 0.3. Use of comb polymer superplasticier helped in achieving the desired permeability and strength.

5. REFERENCES

ACI committee 522 (2010), *Report on previous concrete, ACI 522R-10*, American Concrete Institute, Farmington Hills, Michigan, USA, 1 -38.

Bhutta, M.A.R., Tsuruta, K., Mirza, J. (2012) *Evaluation of high-performance porous concrete properties*. Construction and Building Materials 31, 67–73.

C, Lian., Y, Zhuge., S, Beecham. (2011) *The relationship between porosity and strength for porous concrete*, Construction and Building materials 25, 4294-4298.

Huang, B., Wu, H., Shu, X., Burdette, E.G. (2010) *Laboratory evaluation of permeability and strength of polymer-modified pervious concrete*, Construction and Building Materials 24, 818–823.

Kajio, S,, Tanaka, S., Tomita, R., Noda, E., Hashimoto, S. (1998) *Properties of porous concrete with high strength*. Proceedings 8th international symposium on concrete roads, Lisbon, 171–177.

Kevern JT. (2008) *Advancement of pervious concrete durability*. Ph.D. Dissertation, Iowa State University, Ames (IA), 1-118.

Meininger, R.C. (1988) *No-Fines pervious concrete for paving*. Concrete International, V.10, Aug, 20-27.

Neithalath, N. (2004) *Development and characterization of acoustically efficient cementitious materials*. PhD thesis, Purdue University, West Lafayette, IN, 269pp.

Onstenk, E., Aguado, A,, Eickschen, E., Josa, A. (1993) *Laboratory study of porous concrete for its use as a top layer of concrete pavements*. Proceedings of the fifth international conference on concrete pavement and rehabilitation, Purdue University, IN, V.2, 125-129.

Report on Key Conclusions and Recommendations of the Expert Panel on Drainage Design and Flood Protection Measures. (2012), January, 52pp.

Schaefer, V. R., Wang, K., Suleiman, M.T., Kevernm J.T. (2006) *Mix design development for pervious concrete in cold weather climates*. Final Report, National Concrete Pavement Technology Center, Iowa State University, Ames, IA.

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

Youngs, A. (2005) *Pervious concrete it's for real*. Presentation at pervious concrete and parking area design workshop, Omaha.