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An Experimental Investigation on Porosity and Permeability Co-efficent for Pervious Concrete Pavement by Statistical Modelling

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Abstract: Pervious concrete has varieties of names such as porous concrete, permeable concrete, no fines concrete and porous pavement. It is a special type of concrete with high permeability rate with porosity used for roadways applications that allows water from precipitation and other sources to pass directly through thereby reducing the runoff from a site and allowing recharge. The present research concentrates about bringing out the most efficient porous concrete by varying water cement ratios and size of aggregate. The main properties studied include porosity, compressive strength and water permeability. These properties were compared with those for conventional concrete. Although water permeability is the most important characteristic of the pervious concrete, there is no well-established method for its quantification. Therefore, an experimental procedure to assess the water permeability of pervious concrete is developed. Fine Pervious concrete is considered as FPC, Coarse Pervious concrete is considered as CPC, Nominal Pervious concrete is considered as NPC. Water cement ratios used are 0.28, 0.30, 0.32 and 0.34. It is observed that out of all varying water cement ratios from 0.28 to 0.34, FPC 3 got the highest compressive strength and later it decreased. CPC 2 got the highest compressive strength and later it decreased. NPC 1 got the highest compressive strength and later it decreased. However there is a lot of deviation in compressive strengths from grade of concrete since it is pervious concrete. It looks clear that with increase in water cement ratio there is decrease in Porosity percentage and permeability.

I. INTRODUCTION

Conventional normal weight Portland cement concrete is generally used for pavement construction. The impervious nature of the concrete pavements contributes to the increased water runoff into the drainage system, over-burdening the infrastructure and causing excessive flooding in built-up areas. Pervious concrete has become significantly popular during recent decades, because of its potential contribution in solving environmental issues. Pervious concrete is a type of concrete with significantly high-water permeability compared to normal weight concrete. It has been mainly developed for draining water from the ground surface, so that storm water runoff is reduced and the groundwater is recharged. Pervious concrete has been developed in many countries in order to meet Environmental Protection Agency (EPA) storm water regulation requirements. The American Society for Testing and Materials (ASTM) Concrete Committee has focused on this concrete and formed a subcommittee to deal exclusively with pervious concrete production, properties and usage. European countries have developed pervious concrete, not only for water permeability but also for sound absorption. In Japan, pervious concrete has been researched for the usage in not only for road surfaces but also to support vegetation along river banks.Pervious concrete is a relatively new paving material valued for its use as a storm water best management practice. It has environmental benefits such as water pollution removal and maintaining ground water levels. According to Tennis et al. (2004), pervious concrete collects automobile fluids such as oil and anti-freeze and prevents them from being washed into nearby streams or lakes during arain storm. Tennis et al. (2004) also presents the results of two studies that showed very high water pollutant removal rates for pervious concrete. The tests performed showed 82 and 95% total suspended solids removal for pervious concrete, respectively. Pervious concrete also has other benefits. It may increase driver safety by preventing standing water on road surfaces which will decrease hydroplaning and glare (Wanielista & Chopra, 2007).Pervious concrete may also improve land utilization by decreasing the need for detention basins. Some cities are now charging property owners impact fees based on the amount of impervious surface area on their property. Pervious concrete may help property owners avoid theseimpact fees (Tennis et al., 2004). According to Hendrickx (1998) pervious concrete also reduces road noise. This is because the pore structure allows the air between the tire and the pavement to escape, producing a lower frequency road noise. The results of an experiment conducted in Belgium, taken directly from Hendrickx (1998), are depicted in here shows that pervious concrete produced the lowest decibel levels of all the pavements at all four traffic speeds tested.

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II. MATERIALS

The materials used in the experimental investigation include:
1) Ordinary Portland Cement (OPC)
2) Coarse Aggregate
3) Water

A. Cement

Ordinary Portland Cement (OPC) of 53 grade of Cement conforming to IS: 12269 standards has been procured and various tests have been carried out according IS: 8112-1989 from them it is found that
1) Specific Gravity of Cement is 3.15
2) Initial and Final setting times of Cement are 50min and 480 min respectively
3) Fineness of cement is 6.0%

B. Coarse Aggregate

Machine Crushed granite aggregate confirming to IS 383-1970 consisting 20 mm maximum size of aggregates has been obtained from the local quarry. It has been tested for Physical and Mechanical Properties such as Specific Gravity, Sieve Analysis, and the results are as follows.
1) Specific Gravity coarse aggregate is
2) Fineness Modulus of Coarse Aggregate

C. Water

Local Drinking water free flow impurities has been used in this experimental program for mixing and curing.

III. CONCRETE MIX DESIGN

Concrete is a composite material with heterogeneous properties that are vitally dependent on the amount and properties of the constituents. The Concrete mix design is an essential tool in all aspects of concrete technology and its prime objective is to achieve the required compressive strength and workability. Well-developed mix design methods are thus prime tools in securing sustainable industrial concrete construction techniques.

IV. IS METHOD

The IS method recommended the correction factors for different w/c ratios, workability and for shape coarse aggregate. The quantities of fine and coarse aggregate are calculated with help of equations, which are based on specific gravities of the ingredients. Thus plastic density of concrete calculated from yield equation is generally expected to be closer to actual plastic density obtained in laboratory. Thus actual cement consumption will be close to that targeted in the first trial mix itself.

The mix ratio for pervious concrete is maintained as 1:6 and size of aggregate is varied to check the variation in compression, porosity and permeability. As the grade of concrete is M30 it is maintained that 350 kg/m^3 was kept constant varying size of aggregate and water cement ratio.

A. Mix Design for M30 Grade of Concrete

Grade Designation	M30
Type of Cement	OPC 53 Grade
Maximum Nominal size of Aggregate	20 mm
Minimum content of Cement	350 Kg/m^3
Maximum Water Cement ratio	0.28
Specific Gravity of Cement	3.15
Specific Gravity of Coarse Aggregate	2.62

Mix Design of M30 Grade

B. *Calculations of Cement Content*

Water Cement Ratio : 0.28
Water Content : 0.28×350
= 98Litres

C. *Mix Calculations*

- Volume of Concrete = $1\ m^3$
- Volume of Cement = $\frac{\text{Mass of Cement}}{\text{Specific Gravity of Cement}} \times \frac{1}{1000}$
  = $(350 / 3.15) \times (1/1000) = 0.111 m^3$
- Volume of Water = $\frac{\text{Mass of Water}}{\text{Specific Gravity of Water}} \times \frac{1}{1000}$
  = $(98 / 1.0) \times (1/1000) = 0.098\ m^3$
- Volume of All in Aggregates = $1 - [0.111 + 0.098]$
  = $0.791\ m^3$
- Mass of Coarse Aggregate = $0.791 \times 1 \times 2.62 \times 1000$
  = 2072.42 kg

S.No.	Mix Designation	Cement (Kg/m^3)	FPC (Kg/m^3)	CPC (Kg/m^3)	NPC (Kg/m^3)		Water (in Lit)
					> 20 mm	> 10 mm	
1	FPC 1	350	2073	-	-	-	98
2	FPC 2	350	2054	-	-	-	105
3	FPC 3	350	2036	-	-	-	112
4	FPC 4	350	2018	-	-	-	119
5	CPC 1	350	-	2073	-	-	98
6	CPC 2	350	-	2054	-	-	105
7	CPC 3	350	-	2036	-	-	112
8	CPC 4	350	-	2018	-	-	119
9	NPC 1	350	-	-	1244	829	98
10	NPC 2	350	-	-	1232	822	105
11	NPC 3	350	-	-	1222	814	112
12	NPC 4	350	-	-	1211	807	119

Mix Proportions for $1\ m^3$ of Concrete

V. EXPERIMENTAL PROGRAMME

A. *Compressive Strength Test*

Compressive strength of pervious concrete is usually found to be lower than conventional concrete due to its high porosity. Compressive strengths are in the range of 500 psi to 4000 psi (3.5- 28 MPa).For each series of tests, a set of standard size cube were made. The size of cube 150×150×150 mm was made for compressive strength measurement as shown in Figure. The cube were tested in different curing days (3, 14, 28& 56 -days) in accordance with the test procedures given in the Indian Standard IS: 516-1959.

For the experiment purpose the compressive testing machine of 2000KN capacity (CTM Digital) in the concrete laboratory at the loading rate of 0.2-0.4 N/mm^2s. The compressive strength of the concrete specimens are calculated as follows.

$$\text{Compressive strength } (kg/mm^2) = W_f / A_p$$

Where W_f = Maximum applied load just before load (kg)

A_p = Plan area of the cube mould (mm^2)

B. Water Permeability Test

The permeability is defined simply as the measure of the ease with which any fluid can pass through the voids present in a porous media. The interconnected voids present in a previous concrete specimen are responsible for the permeability of the specimen, which is directly dependent on the porosity, pore sizes, and pore roughness. Permeability as a unique ability for water to penetrate through porous concrete was expressed in millimeter per second (mm/s). The permeability is one of the most crucial characteristics to qualify pervious concrete. Because of the lack of standardized permeability test method, falling-head apparatus is adopted to determine permeability of Pervious concrete. The test apparatus shown in Figure. In this test each specimen is sealed with petroleum jelly and put in to a latex membrane to prevent leakage along their sides during testing. The sealed sample was placed into the specimen holder at the bottom of the standing pipe. Samples were then saturated with water to a level above the concrete specimen sample. Water was allowed to flow through the specimen by opening the bottom valve. Initial head was fixed at 305 mm above the specimen and the time needed to reach a final head of 50 mm was recorded. The measurement is repeated three times for each sample to determine a mean value.

The hydraulic conductivity k is then calculated according to the equation

$$K=(a\,L / A\,t)\ \mathrm{In}\ (h_2 / h_1)$$

Where,

a =Cross section of the graduated standing pipe above the sample in mm^2,

L = Length of the sample in mm

A= Cross section of the sample mm^2

t= Time for head drop from h0 to h1 in sec

h1= Initial head of 305 mm

h2=Final head of 50 mm above the sample.

k = Hydraulic conductivity coefficient in mm/s

The hydraulic conductivity can be related to intrinsic permeability by using the relation

$$K = k\,\rho\,g / \mu$$

Where ρ is the density of the fluid, g is the acceleration due to gravity and μ is the dynamic Viscosity of the fluid. When water is used as the permeating fluid, the Equation 3.3 can be Simplified as

$$k\ (m^2) = K\ (m/s) \times 10^{-7}$$

C. Porosity Test

Porosity is regarded as one of the most important pore structure features of pervious concretes that dictate several of its mechanical and functional properties. Porosity or void content of a porous material is expressed as a percentage value and is defined as the volume of pores in the material to the total volume of the material. The porosity test was carried out at 28 days of age. A value of less than 15% is considered as low porosity while 30% is a high value of porosity for pervious concretes. A reasonable average value for preliminary structural and hydrological design is 20% .The total porosity in pervious concrete includes disconnected porosity and connected porosity, which is the primary influencing factor o fwater permeability

The equation for connected porosity $P1$ is as follows

$$P_{1}= \frac{[1-(W_2-W_1)]}{V_1 \times vol} \times 100(\%)$$

A caliper was used to measure and calculate specimen volume $V1$ the specimen was immersed in water until it is filled with water before its weight in water $W1$ is measured. Subsequently, the specimen was taken out of water and dried, and then its weight in air $W2$ when its weight is stable was measured which was produced from coarse aggregate. Mixture FPC4 has the lowest permeability coefficient

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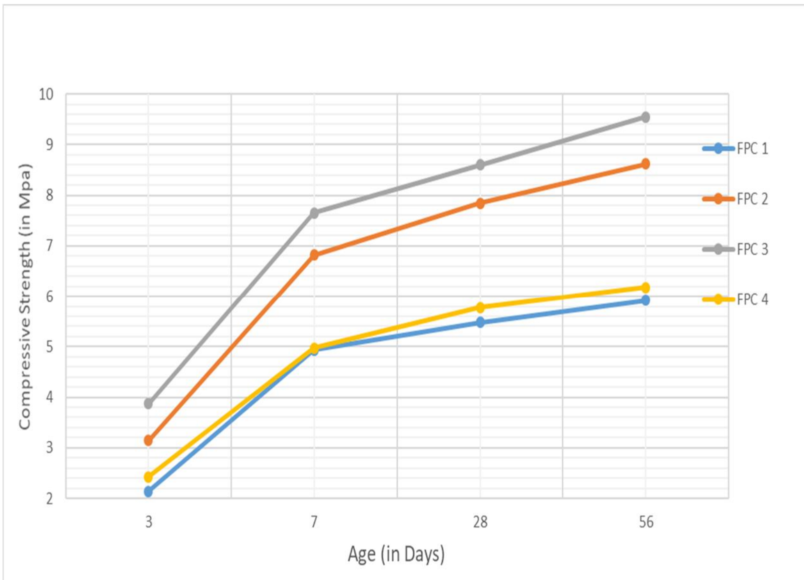
VI. RESULTS ANS DISCUSSIONS

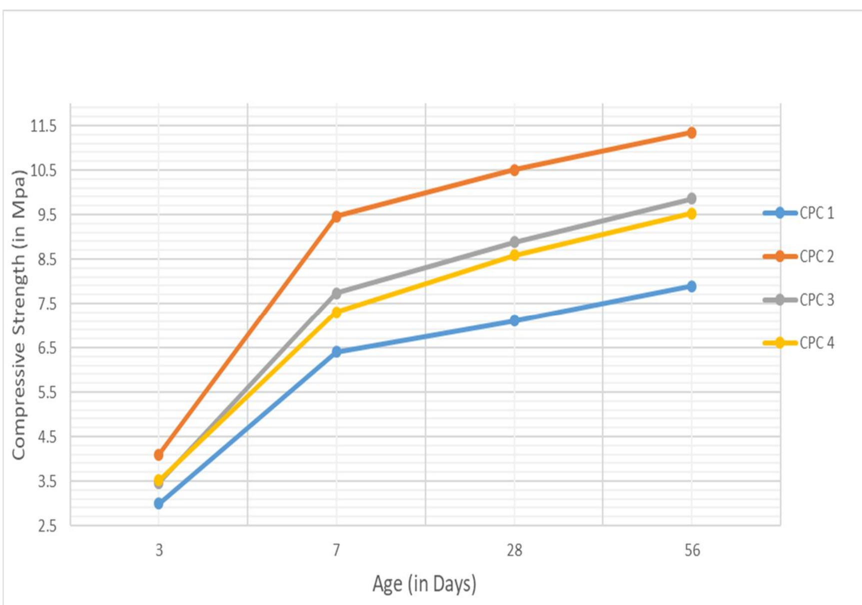
The results of the experimental investigation are presented in this chapter. This chapter provides the results of pervious concrete without fine aggregate and the conventional concrete. The relationships among density, porosity, compressive strength and water permeability of all pervious concrete are discussed.

A. Compressive Strength

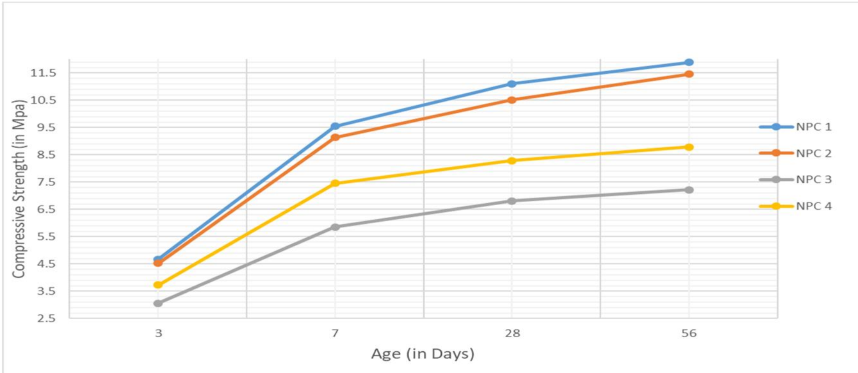
The compressive strengths of each specimen. The specimens were tested at the age of 3, 14, 28 and 56 days for water cured conventional concrete and pervious concrete. The compressive strengths develop with age for conventional concrete and pervious concrete. The cube compressive strength indicates the average of three test results. The Graphical Representations of the above results are shown below with various Combinations.



Variation of Compressive Strength of Fine Pervious Concrete (FPC)

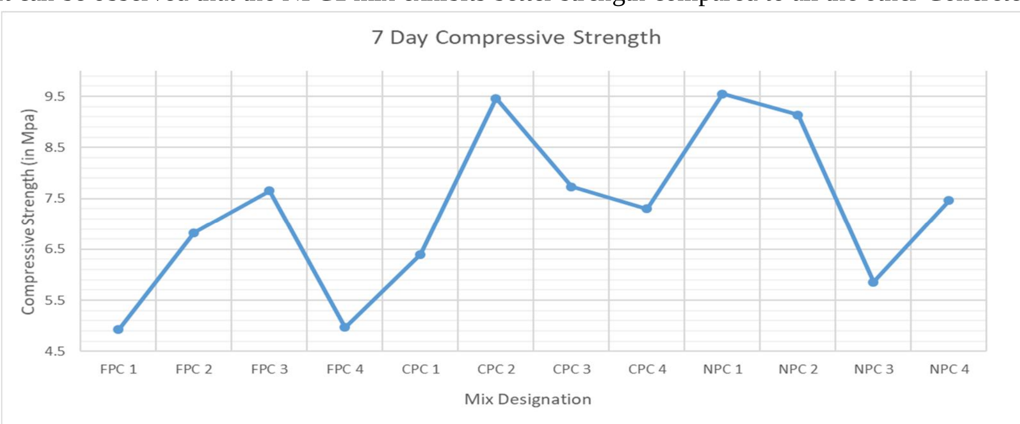


Variation of Compressive Strength of Coarse Pervious Concrete (CPC)

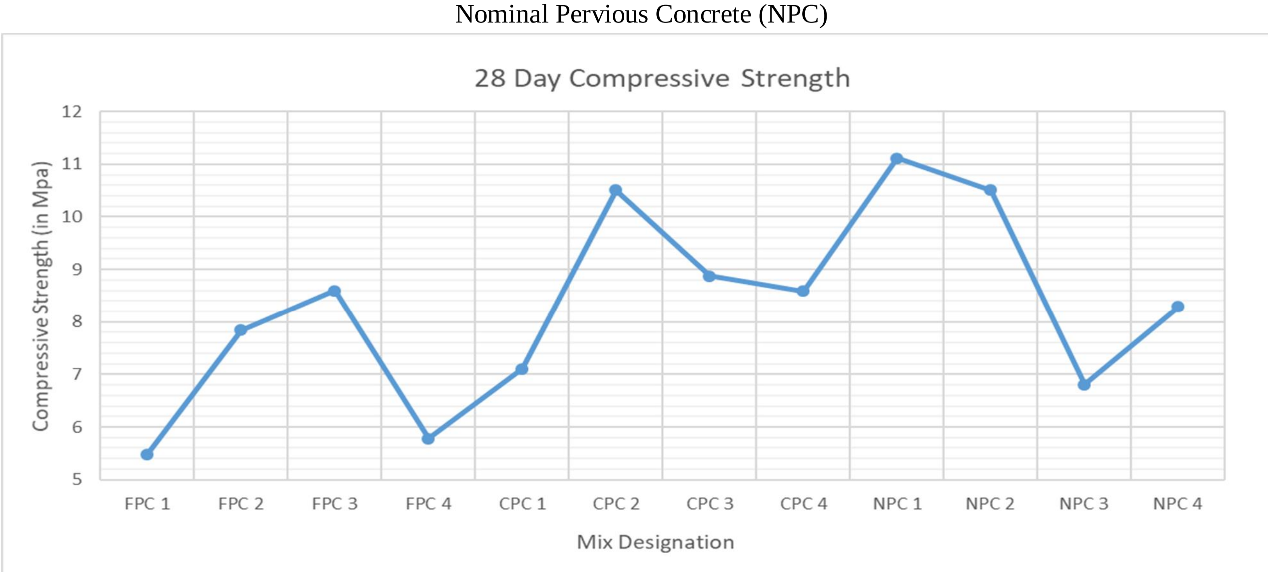


Variation of Compressive Strength of Nominal Pervious Concrete (NPC)

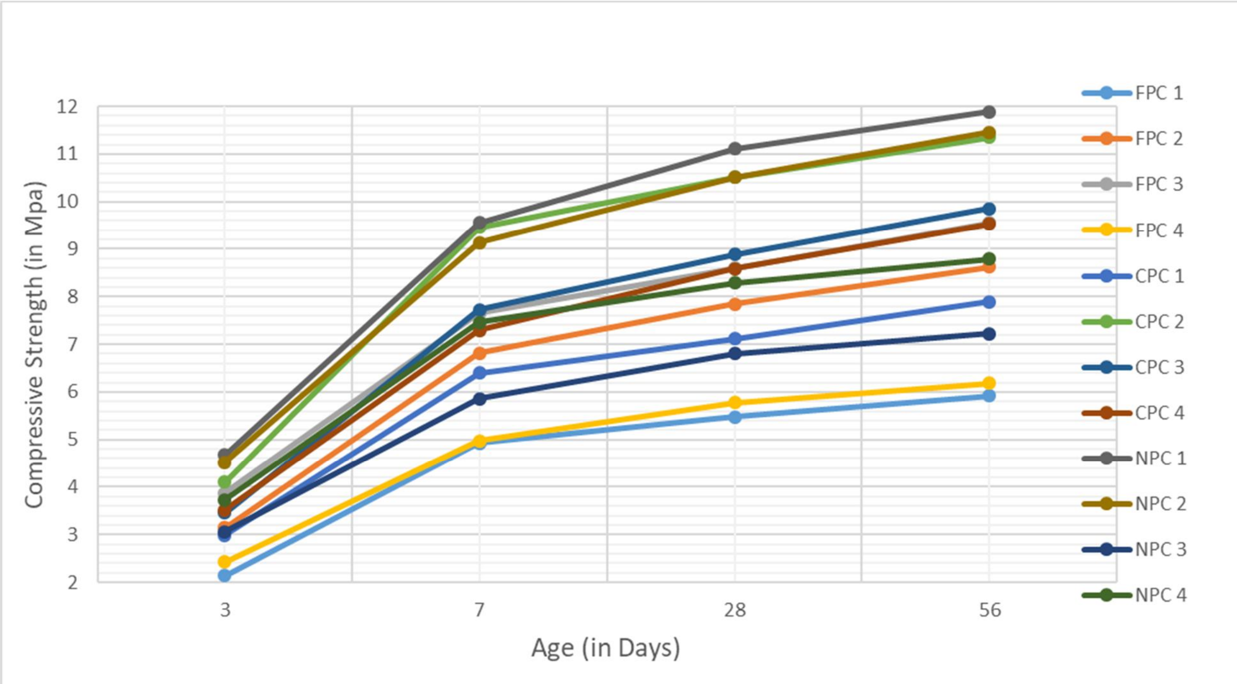
Variation of Compressive Strength with Age (3, 7, 28 & 56 Days). From the above Graphical representations, It can be concluded that FPC3 Mix exhibits higher compressive Strength in case of Fine Pervious Concrete (FPC). Mixes of CPC 2 and NPC 1 exhibited improved strength characteristics in case of Coarse Pervious Concrete and Nominal Pervious Concrete respectively. The 7 – Days & 28 Days Compressive Strength of all Mixes of Fine Pervious Concrete (FPC), Coarse Pervious Concrete and Nominal Pervious Concrete (NPC). It can be observed that the NPC1 mix exhibits better strength compared to all the other Concrete Mixes.



Variation of 7 – Day Compressive Strength of different mixes of Fine Pervious Concrete (FPC), Coarse Pervious Concrete and Nominal Pervious Concrete (NPC)



Variation of 7 – Day Compressive Strength of different mixes of Fine Pervious Concrete (FPC), Coarse Pervious Concrete and Nominal Pervious Concrete (NPC)

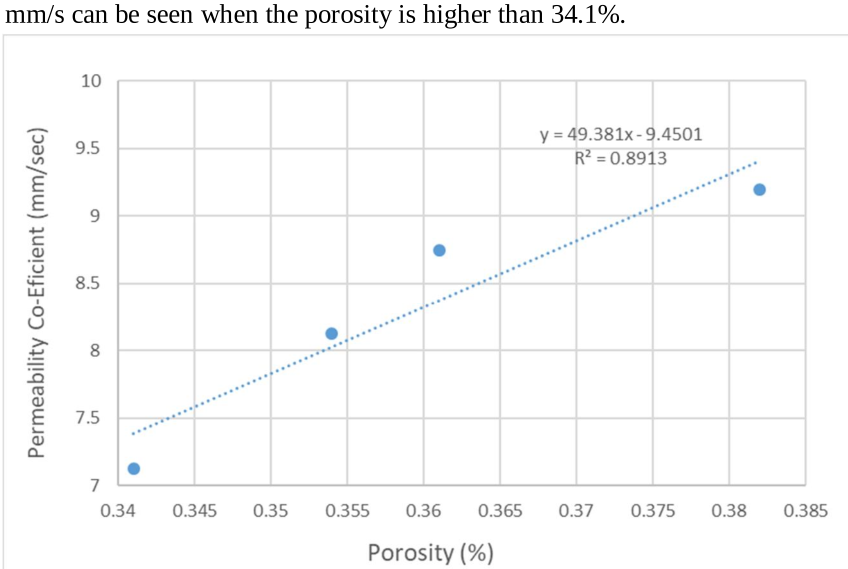


Variation of 3, 7, 28 & 56 Days of Compressive Strength of different mixes of Fine Pervious Concrete (FPC), Coarse Pervious Concrete and Nominal Pervious Concrete (NPC)

B. Porosity and Permeability Coefficient

The measured properties of all PC mixes, including permeability coefficient and porosity. Average results from the experimental research were summarized. The tests yielded a range of values from about 7 mm/s to 10 mm/s for permeability coefficient. It can be seen from that the highest permeability coefficient achieved in this study is 10.1 mm/s for mixture CPC1of 8 mm/s, which was produced from fine aggregate.

The density of PC is approximately 1800 kg/m^3.Graphical Representations shown below illustrate the effect of porosity on permeability coefficient for CPC. Although there is a not ables catter in the plotted data, the permeability coefficient generally increases when the porosity increases. Figure 4illustrate the effect of porosity on permeability coefficient for FPC. The highest permeability coefficient of around 10.1 mm/s can be seen when the porosity is higher than 40.2%.The smallest permeability coefficient of around 7.13 mm/s can be seen when the porosity is higher than 34.1%.



Effect of porosity on permeability coefficient for FPC

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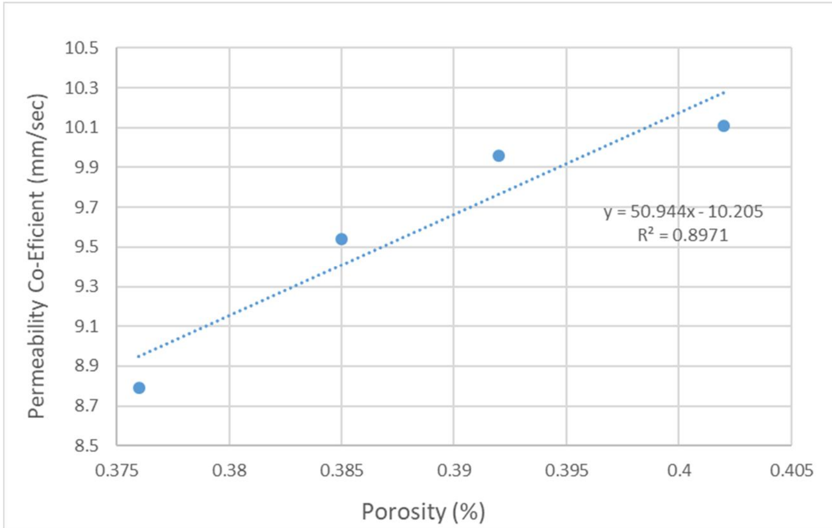
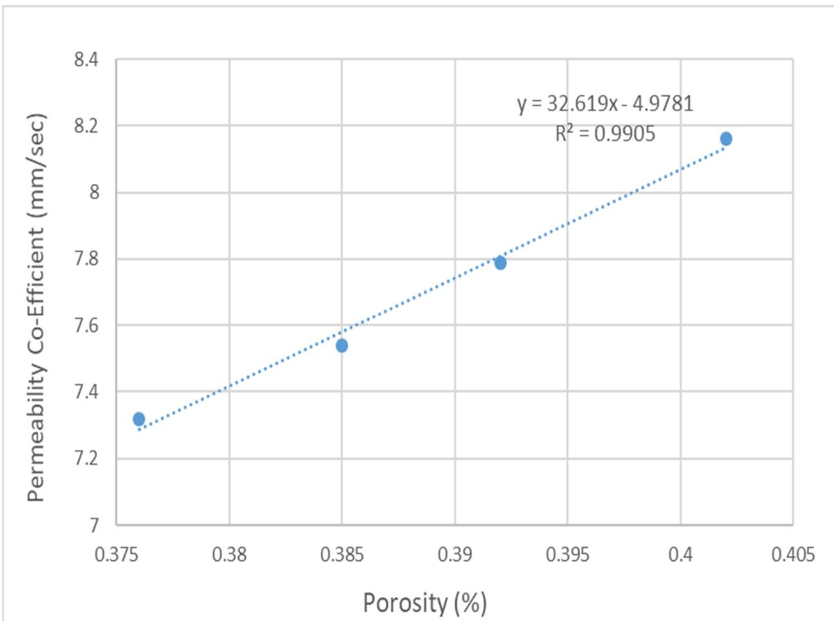


Effect of porosity on permeability coefficient for CPC



Effect of porosity on permeability coefficient for NPC

These Figures show that porosity played an important role in the PC specimen permeability coefficient. These changes can be mainly attributed to the decrease in workability of the mix designs as the W/C is adjusted. Traditional methods of measuring the workability of a PC mix are not effective for mixes, as they generally have negligible slump even when the W/C is below the optimal level. With increased workability, greater densification occurs even when and porosity decreased. This greater densification led to decrease in permeability that was observed for the various mix designs.

C. Effect of Water Cement Ratio on Permeability

The effect of W/C on permeability coefficient for FPC, CPC and NPC. The highest permeability coefficient achieved in this study is 10.1 mm/s for mixture CPC1. Mixture FPC4 has the lowest permeability coefficient of 7.13 mm/s. Results indicated that reduction in permeability coefficient caused by size of aggregate was more than that by W/C. Results show good relationship between permeability coefficient and W/C, supporting the conclusion that greater workability leads to a denser specimen with smaller permeability coefficient. Lab mixes had the highest permeability coefficient, had the lowest W/C.

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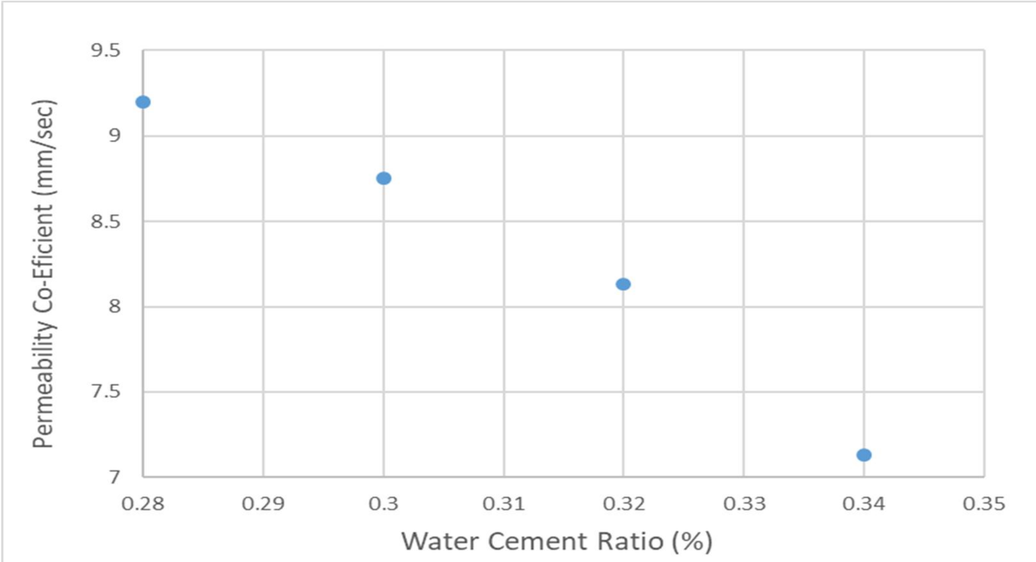
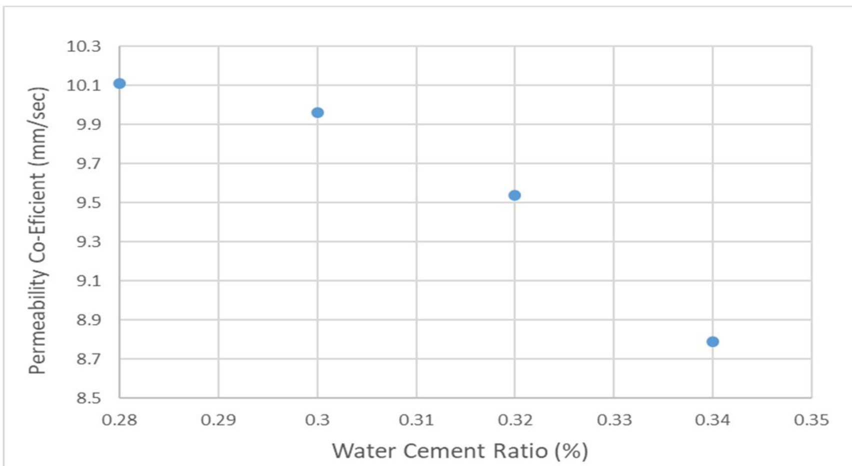
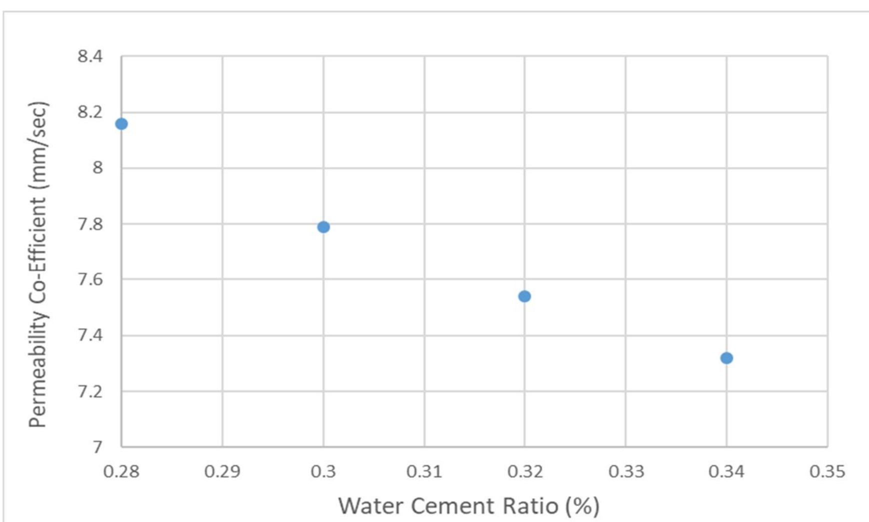


Effect of Water Cement Ratio on permeability coefficient for FPC



Effect of Water Cement Ratio on permeability coefficient for CPC



Effect of Water Cement Ratio on permeability coefficient for NPC

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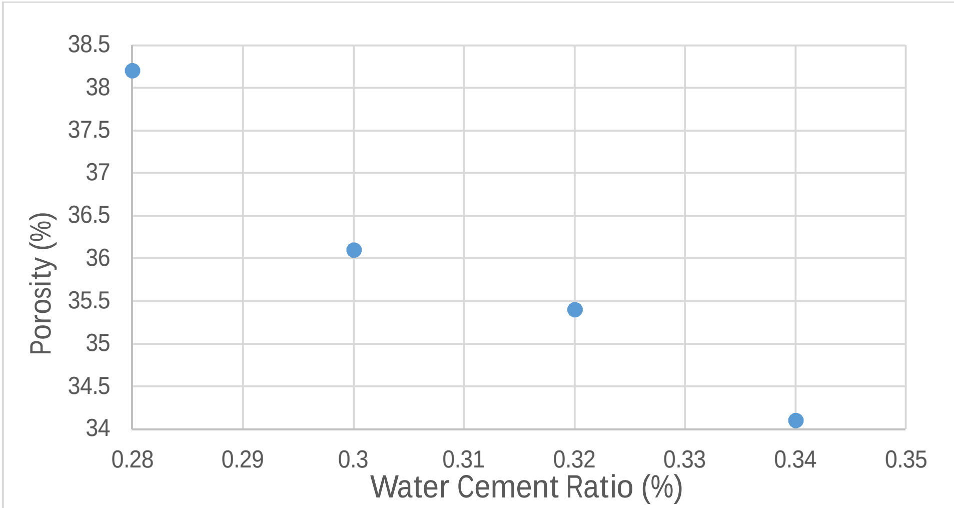
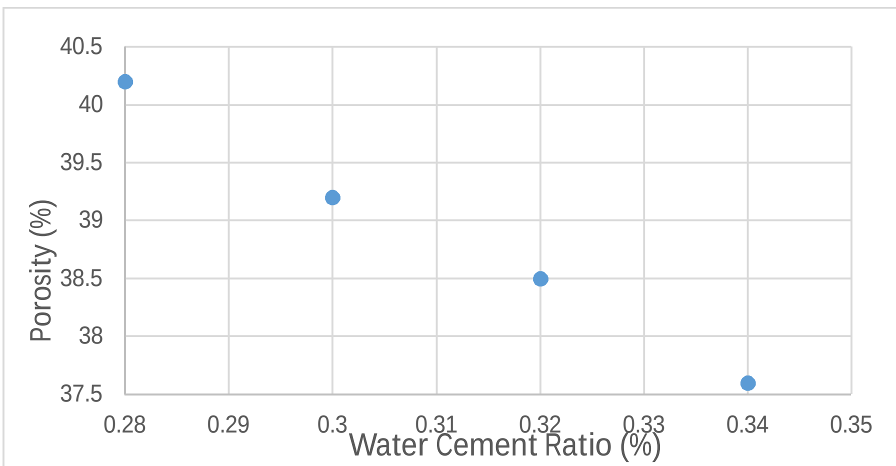
D. Effect of Water Cement Ratio on Porosity

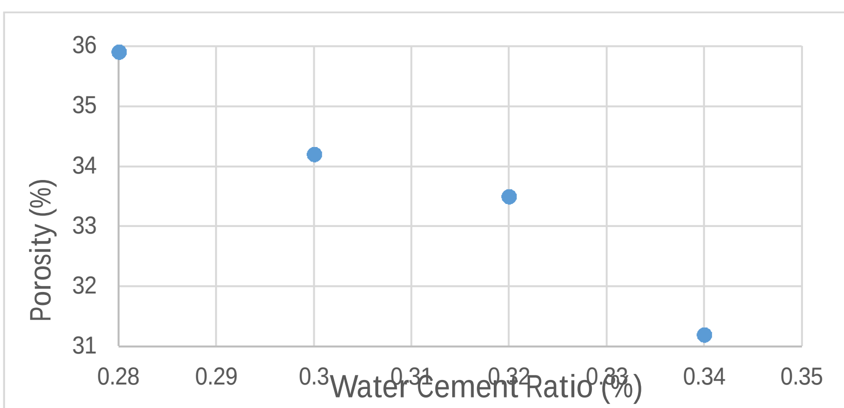
Figure 6.12, 6.13& 6.14 show the effect of W/C on Porosity for FPC, CPC and NPC. The highest Porosity achieved in this study is 0.402% for mixture CPC1. Mixture FPC4 has the lowest Porosity of 0.312 %. Results indicated that reduction in Porosity caused by size of aggregate was more than that by W/C. Results show good relationship between Porosity and W/C, supporting the conclusion that greater workability leads to a denser specimen with reduced porosity. Lab mixes had the highest Porosity, had the lowest W/C.



Effect of Water Cement Ratio on Porosity for FPC



Effect of Water Cement Ratio on Porosity for CPC



Effect of Water Cement Ratio on Porosity for NPC

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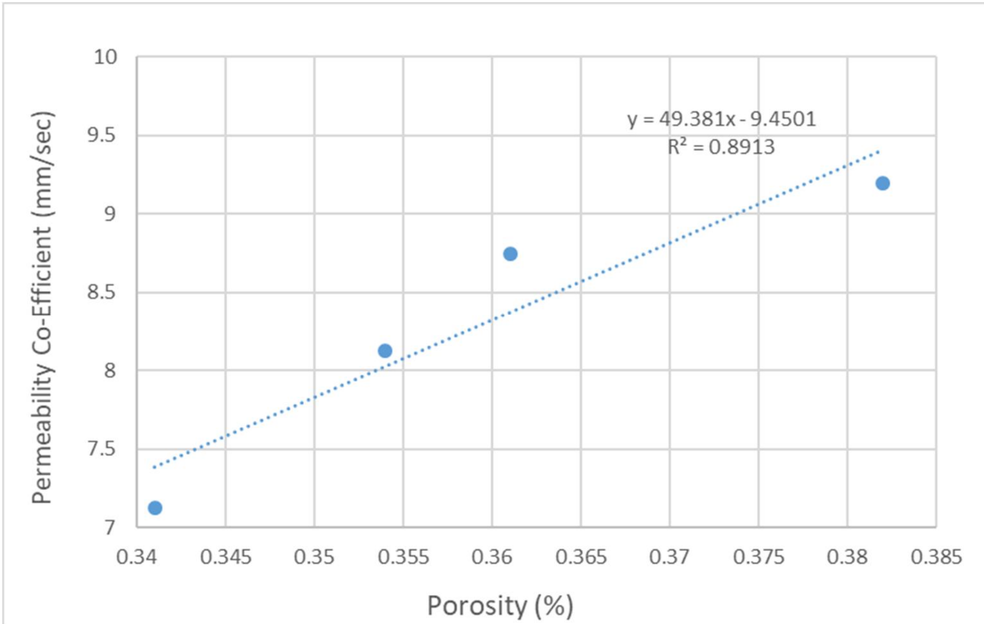
VII. STATISTICAL MODELLING

A. *Fine Pervious Concrete (FPC)*



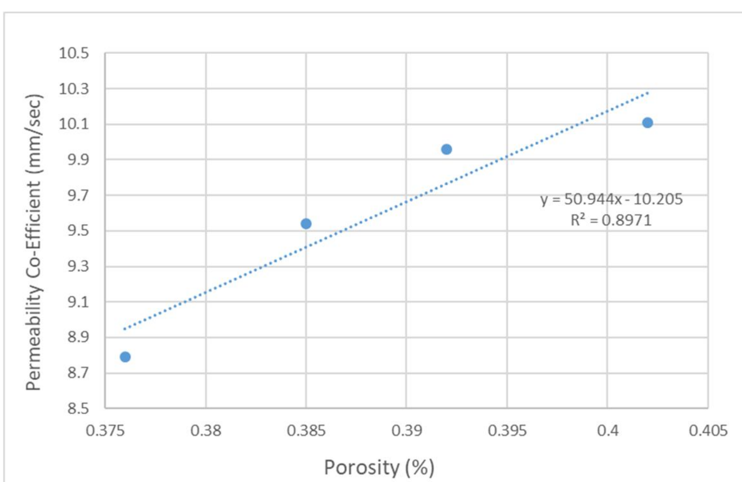
Effect of porosity on permeability coefficient for FPC

Regression Modelling parameters for Permeability Coefficient of FPC

Factor	Multiplier Estimate	Standard Error	T Test	R Squared
Constant	-9.45	4.39	-2.15	0.89
A	49.381	12.19	4.05	

The Regression Modelling indicates that for Permeability coefficient of FPC samples, the porosity is significant with R-Squared value of 89%.

B. *Coarse Pervious Concrete (CPC)*



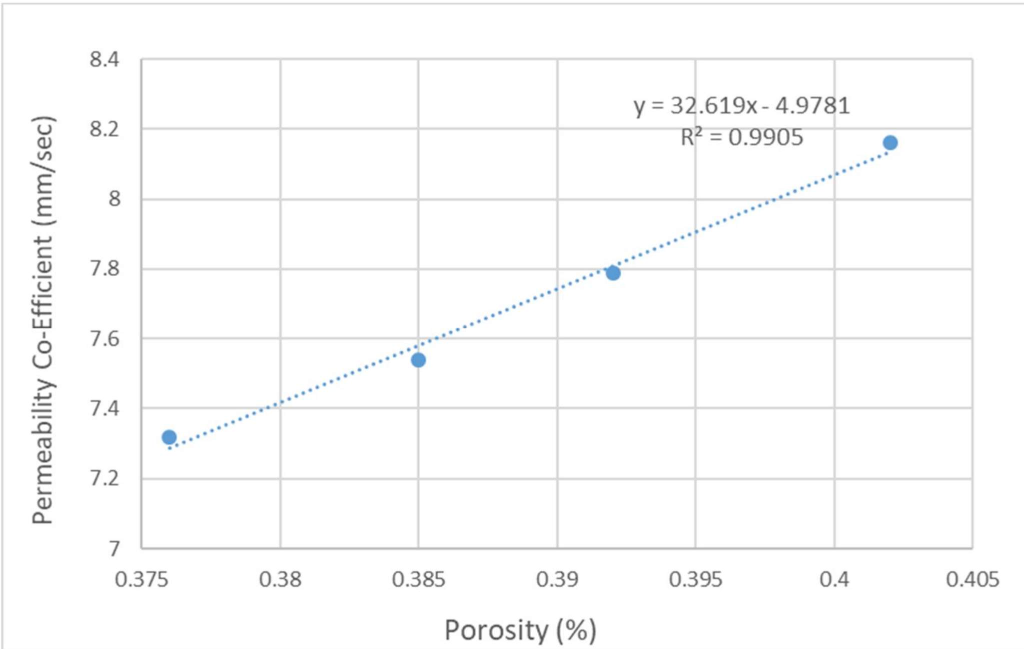
Effect of porosity on permeability coefficient for CPC

Regression Modelling parameters for Permeability Coefficient of CPC

Factor	Multiplier Estimate	Standard Error	T Test	R Squared
Constant	-10.21	4.74	-2.15	0.90
A	50.94	12.20	4.17	

The Regression Modelling indicates that for Permeability coefficient of CPC samples, the porosity is significant with R-Squared value of 90%.

C. Nominal Pervious Concrete (NPC)



Effect of porosity on permeability coefficient for NPC

Regression Modelling parameters for Permeability Coefficient of NPC

Factor	Multiplier Estimate	Standard Error	T Test	R Squared
Constant	-4.98	0.88	-5.66	0.99
A	32.62	2.26	14.42	

The Regression Modelling indicates that for Permeability coefficient of NPC samples, the porosity is significant with R-Squared value of 99%.

VIII. CONCLUSIONS

Pervious concrete has high water permeability due the presence of interconnected air voids. The presence of high porosity relative to conventional concrete makes the pervious concrete to become light weight concrete with limited compressive strength. However, pervious concrete has been significantly popular for a few decades due to itspotential to reduce the incidence of flooding, and to assist in recharging the groundwater level. This investigation was carried out on the effects of incorporating Fine (<10mm), Coarse (<20mm) & Nominal aggregate (10mm – 20mm), on the properties of pervious concretes. Thepervious concrete properties were compared.

A. Compressive Strength

1) *Fine Pervious Concrete (FPC):*It is observed that out of all varying water cement ratios from 0.28 to 0.34, FPC 3 got the highest compressive strength and later it decreased. Water cement ratio 0.32 got more strength around compared to other water cement ratios.

2) *Coarse Pervious Concrete (CPC):* It can be clearly stated that out of all varying water cement ratios from 0.28 to 0.34, CPC 2 got the highest compressive strength and later it decreased. Water cement ratio 0.30 got more strength around compared to other water cement ratios.
3) *Nominal Pervious Concrete (NPC):* It is observed that out of all varying water cement ratios from 0.28 to 0.34, NPC 1 got the highest compressive strength and later it decreased. Water cement ratio 0.28 got more strength around compared to other water cement ratios.

How ever there is a lot of deviation in compressive strengths from grade of concrete since it is pervious concrete.

B. Permeability Coefficient

1) *Fine Pervious Concrete (FPC):* It looks clear that with increase in water cement ratio there is decrease in permeability coefficient. FPC 1 is noted to be having greater permeability and there after it reduced with increase in water cement ratios.
2) *Coarse Pervious Concrete (CPC):* It looks clear that with increase in water cement ratio there is decrease in permeability coefficient. CPC 1 is noted to be having greater permeability and there after it reduced with increase in water cement ratios.
3) *Nominal Pervious Concrete (NPC):* Similar trend was observed in Nominal pervious concrete, decreasing of permeability coefficient with increase in W/C ratio.

But on a overall comparison between FPC, CPC and NPC, it was found that NPC is having lower permeability increasing durability to concrete.

C. Porosity

1) *Fine Pervious Concrete (FPC):* It looks clear that with increase in water cement ratio there is decrease in Porosity percentage. FPC 4 is noted to be having least porosity.
2) *Coarse Pervious Concrete (CPC):* It looks clear that with increase in water cement ratio there is decrease in Porosity percentage. CPC 4 got least porosity values compared to other coarse pervious concrete proportions.
3) *Nominal Pervious Concrete (NPC):* Similar trend was observed in Nominal pervious concrete, decreasing of Porosity percentage with increase in W/C ratio.

But on a overall comparison between FPC, CPC and NPC, it was found that NPC is having lower Porosity percentage increasing strength of concrete by reducing voids.

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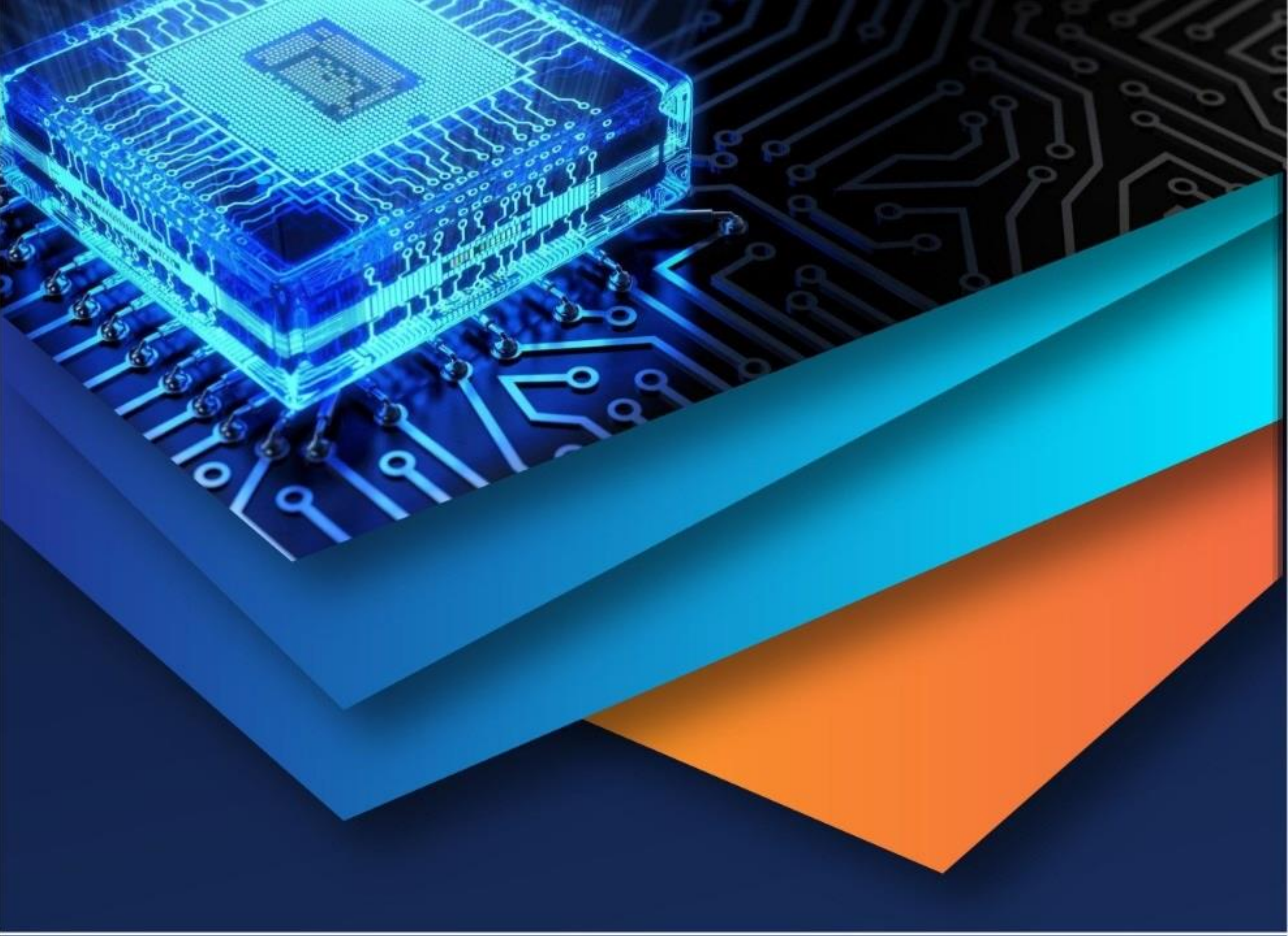

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