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RESEARCH ARTICLE

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A STUDY ON RELATIONSHIP BETWEEN POROSITY AND PERMEABILITY COEFFICIENT FOR PERVIOUS CONCRETE PAVEMENT BY STATISTICAL MODELLING

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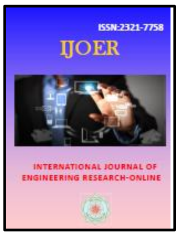


ABSTRACT

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.

Keywords—Pervious concrete, permeability, porosity, compressive strength, FPC, NPC, Laboratory Tests, etc.

I. INTRODUCTION

Pervious concrete has been produced in numerous nations with a specific end goal to meet Environmental Protection Agency (EPA) storm water control prerequisites. The American Society for Testing and Materials (ASTM) Concrete Committee (C09) has centered on this concrete and framed a subcommittee to bargain only with pervious concrete production, properties and use [3]. European nations have created pervious concrete, for water penetrability as well as for sound assimilation. In Japan, pervious concrete has been examined for the utilization in not just for street surfaces but also to help vegetation along waterway banks [5,6].

In Australia, pervious concrete has been created for enter execution in connection to Water Sensitive Urban Design (WSUD) which looks to enhance required water quality and amount in urban zone. Pervious concrete squares have been utilized as one of the porous asphalt frameworks. Figure 1.2 demonstrates a case of pervious concrete square used to meet WSUD necessities.

The most populous countries on the earth, namely China and India, produced 41.9% and 5.2% respectively of the world's cement output. As the demand for concrete increases, current Portland cement production will be substantially increased. Since one tone of cement production releases 0.93 tonnes of CO_2 into the atmosphere, cement production contributes significantly to global warming which leads to undesirable climate change. Thus it is basic for the concrete business to know about the results of using ecologically disagreeable bond. Each exertion ought to be made to limit the utilization of Portland bond in concrete blends. In concrete blends, Portland bond ought to be mostly supplanted with an assortment of demonstrated supplementary cementitious materials, for example, characteristic pozzolans, fly powder and ground-granulated impact heater slag. Considerable utilization of these cementitious materials will help to produce environmentally agreeable concrete blends.

II. BACKGROUND

Regular typical weight Portland bond concrete is for the most part utilized for asphalt development. The impenetrable idea of the solid asphalts adds to the expanded water overflow into the seepage framework, over-loading the foundation and causing exorbitant flooding in developed regions. Pervious cement has turned out to be essentially prevalent amid ongoing decades, on account of its potential commitment in unraveling ecological issues. Pervious cement is a kind of cement with altogether high-water porousness contrasted with ordinary weight concrete. It has been primarily developed for emptying water out of the ground surface, with the goal that tempest water overflow is diminished and the groundwater is revived.

III. NEEDS AND ADVANTAGES

The importance of strength for pervious concrete design is still undecided, so the primary

Applications of pervious concrete have been limited to walkways, sidewalks, bike lanes and parking lots.In these applications the pervious concrete is usually subjected to relatively light and low frequency loading. Although pervious concrete has been used for some low-traffic roads and shoulders, it is not widely used as a street paving material. This could be due to its decrease in strength from traditional concrete, concerns over surface durability, or simply because pervious concrete is a relatively new product and has not yet had time to prove itself. ACI Committee 522 states that "Little field data exists on the long-term durability of pervious concrete in northern climates." For expanded applications, additional research and testing must be done to determine how to incorporate the different strength and durability aspects of pervious concrete into successful pavement designs. There is currently no accepted thickness design method for pervious concrete. Without an accepted thickness design method, engineers may be hesitant to design pervious concrete pavements for road applications. This could be limiting its uses.

Even though pervious concrete is not a common road paving material, it is being used around the world as a top layer on roads. In Europe, it is used as a top layer to reduce traffic noise, increase skid resistance, and prevent water pooling on the surface of the road. However, in this application freeze-thaw damage is a large concern because of the higher likelihood that the pervious top layer will remain saturated (Van Gemert et al., 2003).

IV. LITERATURE REVIEW

Ibrahim H.A and Razak H.A (2016) have examined the expansion of palm oil clinker on properties of pervious concrete. In this examination, Palm oil clinker is taken as the coarse aggregate in the creation of pervious concrete. Crude materials like Portland bond Type I,10mmsize coarse total and settled water-concrete proportion of 0.3 are utilized. Here, Palm oil clinker extending from 0-100% replaces characteristic total. The test outcomes demonstrated that substitution with POC diminishes the quality of the material yet porosity and permeability increases. The compressive quality of the material lies between 3.43-9.52 MPa. It is noted that misfortune in quality was around 65% is watched full substitution. Be that as it may, substitution of Palm oil clinker at 25% shows better execution among all. Thusly, it has been identified as the best blend for ideal execution of the POCPC.

Yeih W et al. (2015) have considered the designing properties of pervious concrete made with air-cooling electric circular segment heater slag as totals. It is seen from the analysis that porous concrete arranged from EAFS totals have better mechanical quality and water penetrability than that made with characteristic stream rock. Aside from this permeable concrete made with EAFS totals had a lower weight reduction than that made with common stream rock for the soundness tests. It is discovered that EAFS based pervious concrete has a higher water permeability and higher compressive quality than that made with rock. The compressive strength is higher than 21 MPa and water porousness is 0.01 cm/s.

Zaetang Y et al. (2015) have considered the use of coal slag to be geo-polymer fastener to frame coarse total in pervious concrete. This examination clarifies the utilization of Fly Ash (FA) as a geo-polymeric folio alongside coarser total to produce pervious concrete. During the think about properties, for example, impact of grouping of NaOH, substitution of fly fiery debris with ordinary Portland bond (OPC) and the effect of curing temperature pervious geopolymeric concrete (PGC) were broke down . The outcomes inferred that the qualities of geopolymeric concrete expanded alongside centralization of NaOH and substitution percentage of OPC. It is presumed that PGC containing BA had the warm conductivity of 0.30– 0.33W/mK, compressive quality of 5.7– 8.6 MPa with thickness of 1466– 1502 kg/m3 and it is suitable as an eco-accommodating concrete.

Jang J.G et al. (2015) have examined a novel eco-accommodating permeable concrete manufactured with coal ash and geo polymeric fastener: Heavy metal filtering attributes and compressive quality. Here, coal base fiery debris is taken as coarse total and geo-polymer as folio. The test results demonstrated the convergences of substantial metals which filtered from the base fiery debris in porous concrete were underneath the chosen criteria, and the qualities of geo-polymer dominantly influence the dispersion of overwhelming metals from base cinder. It is reasoned that the porous concrete created in this examination can viably immobilize overwhelming metals as solidified/balanced out item.

V. METHODOLOGY

The methodology adopted to achieve the required objectives is presented below. In the present work the methodology adopted is as follows:

A. Characterization of materials
B. Scheme of experiments
C. Experimental procedure

A. Characterization of materials

The main constituents of the present investigation are Cement, Coarse aggregate, Water, are procured from various places. Coarse aggregate is procured from quarry (machine crushed). Local drinking water is used for mixing and curing.

Characteristics of Cement

Ultratech 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

a) Specific Gravity of Cement is 3.15
b) Initial and Final setting times of Cement are 50min and 480 min respectively
c) Fineness of cement is 6.0%

Characteristics of Coarse Aggregate

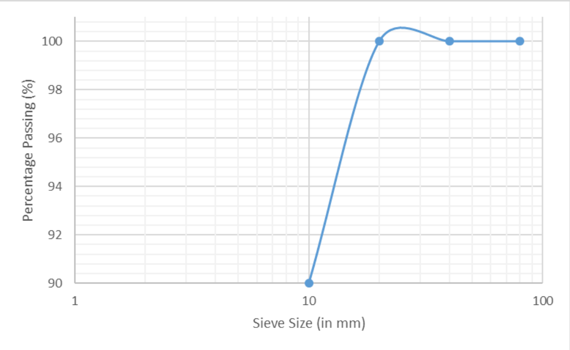
Machine Crushed rock total affirming to IS 383-1970 comprising 20 mm greatest size of totals has been gotten from the nearby quarry. It has been tried for Physical and Mechanical Properties, for example, Specific Gravity, Sieve Analysis, and the outcomes.

a) Specific Gravity coarse aggregate is
b) Fineness Modulus of Coarse Aggregate

The particle size distributions of coarse aggregate were determined and the results are tabulated in Table 1 and Fig. 1 shows the grading curve for coarse aggregate used for Concrete preparation.

Table 1. Sieve Analysis of Coarse Aggregate (FPC)

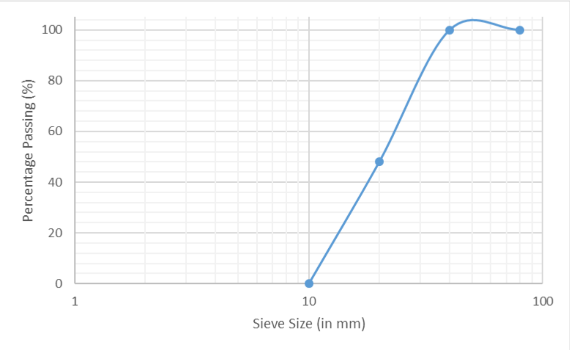
Sieve Size	Weight Retained(kg)	Cumulative % Retained	Cumulative % Passing
80 mm	0	0	100
40 mm	0	0	100
20 mm	0	0	100
10 mm	10	10	90
Pan	0	100	0



Graph 1. Particle Size Distribution of Aggregate used for Fine Pervious Concrete (FPC)

Table 2. Sieve Analysis of Coarse Aggregate (NPC)

Sieve Size	Weight Retained(kg)	Cumulative % Retained	Cumulative % Passing
80 mm	0	0	100
40 mm	0	0	100
20 mm	5.2	52	48
10 mm	4.8	100	0
Pan	0	100	0



Graph 2.Particle Size Distribution of Aggregate used for Nominal Pervious Concrete (NPC)

Characteristics of Water: Local Drinking water free flow impurities have been used in this experimental program for mixing and curing.

B. Scheme of experiments: The detailed scheme of experiments, formulated to meet the objectives stated in the Chapter-1 is presented in this section

C. Experimental Procedure

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 ofcube 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 thetest procedures given in the Indian Standard IS: 516-1959.

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 into 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.

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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 of water permeability.

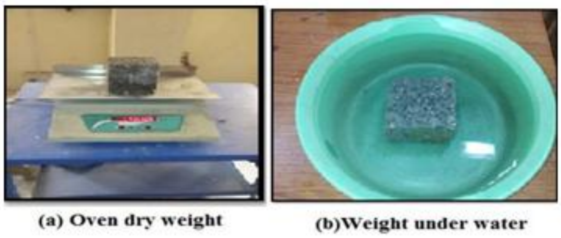


Fig 1.Porosity test

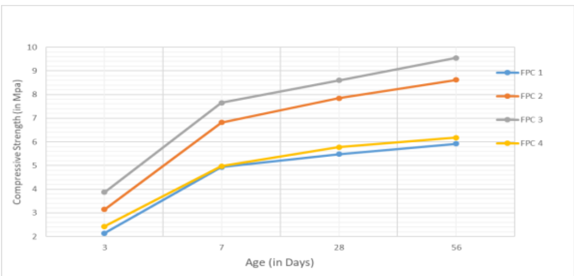
VI. RESULTS AND DISCUSSIONS

Compressive strength

Table 3 summarizes 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.

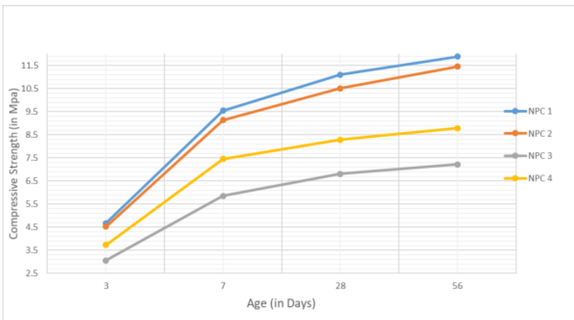
Table 3 Compressive Strength

S.No	Mix Designation	Compressive Strength (in Mpa)			
1	FPC 1	2.14	4.93	5.48	5.92
2	FPC 2	3.14	6.82	7.84	8.62
3	FPC 3	3.87	7.65	8.6	9.55
4	FPC 4	2.43	4.97	5.78	6.18
6	NPC 1	4.67	9.55	11.11	11.89
7	NPC 2	4.52	9.14	10.51	11.46
8	NPC 3	3.06	5.86	6.81	7.22
9	NPC 4	3.73	7.46	8.29	8.79



Graph 3.Figure showing the Variation of Compressive Strength of Fine Pervious Concrete (FPC)

Graph 3& 4 represents the 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).



Graph 4.Figure showing the Variation of Compressive Strength of Nominal Pervious Concrete (NPC)

Graph 5&6 represents 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

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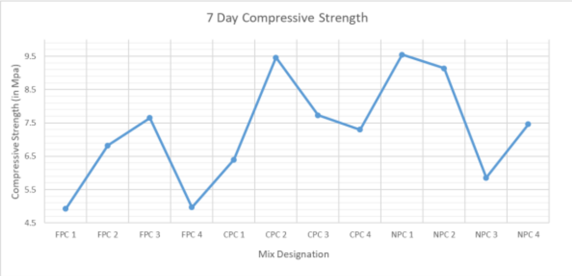
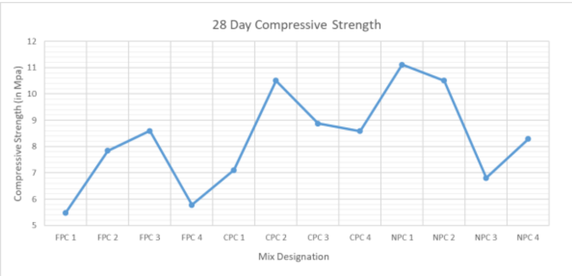
Vol.6., Issue.4, 2018
July-Aug.

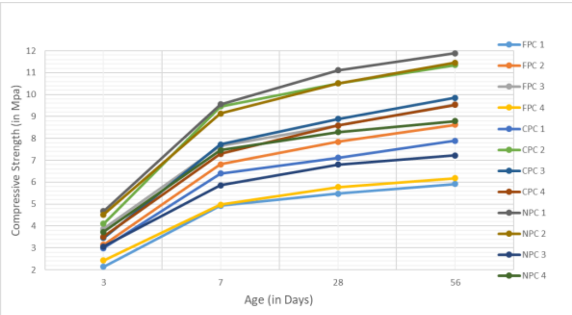
observed that the NPC1 mix exhibits better strength compared to all the other Concrete Mixes.



Graph 5.Variation of 7 – Day Compressive Strength of different mixes of Fine Pervious Concrete (FPC), Coarse Pervious Concrete and Nominal Pervious Concrete (NPC)



Graph 6.Variation of 7 – Day Compressive Strength of different mixes of Fine Pervious Concrete (FPC), Coarse Pervious Concrete and Nominal Pervious Concrete (NPC)



Graph 7. 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)

Porosity and Permeability Coefficient

Table 4. shows the measured properties of all PC mixes, including permeability coefficient and porosity. Average results from the experimental research were summarized in this table. The tests yielded a range of values from about 7 mm/s to 10 mm/s for permeability coefficient. It can be seen from Table 4. that the highest permeability coefficient achieved in this study is 10.1 mm/s for mixture FPC1, which was produced from coarse aggregate. Mixture CPC4 has the lowest permeability coefficient of 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 FPC. Although there is a notable scatter in the plotted data, the permeability coefficient generally increases when the porosity increases. Figure 4 illustrate 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%.

Table No. 4. Porosity and Permeability

S. No	Mix Designation	Aggregate Size (in mm)	Water Cement Ratio (W/c)	Porosity	Permeability (in mm/sec)
1	FPC 1	Less than 10 mm	0.28	0.382	9.20
2	FPC 2	Less than 10 mm	0.30	0.361	8.75
3	FPC 3	Less than 10 mm	0.32	0.354	8.13
4	FPC 4	Less than 10 mm	0.34	0.341	7.13
5	NPC 1	B/w 10 mm- 20 mm	0.28	0.359	8.16
6	NPC 2	B/w 10 mm- 20 mm	0.30	0.342	7.79
7	NPC 3	B/w 10 mm- 20 mm	0.32	0.335	7.54
8	NPC 4	B/w 10 mm- 20 mm	0.34	0.312	7.32

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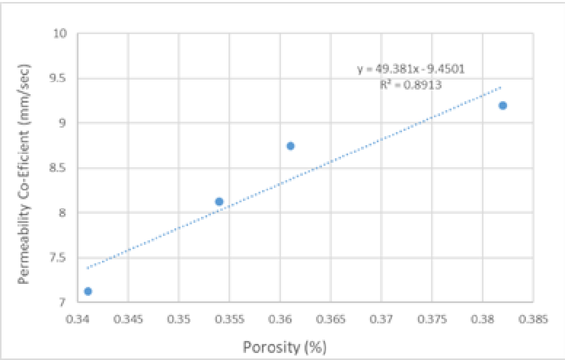
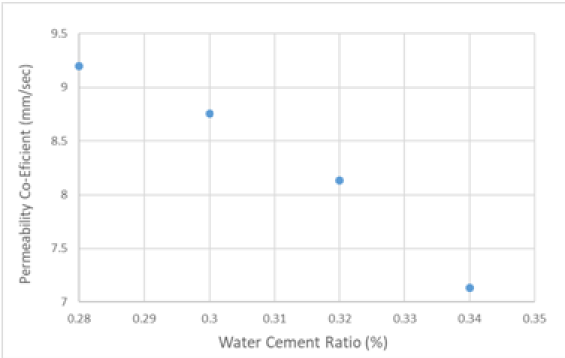
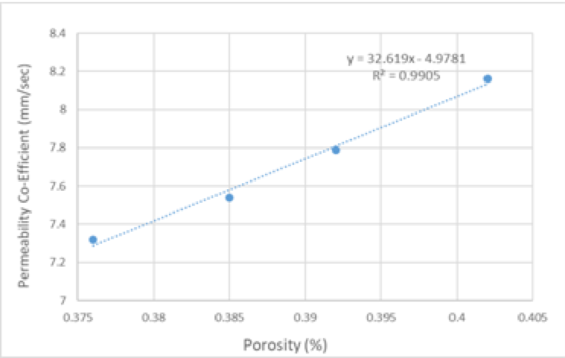


Graph 8. Effect of porosity on permeability coefficient for FPC



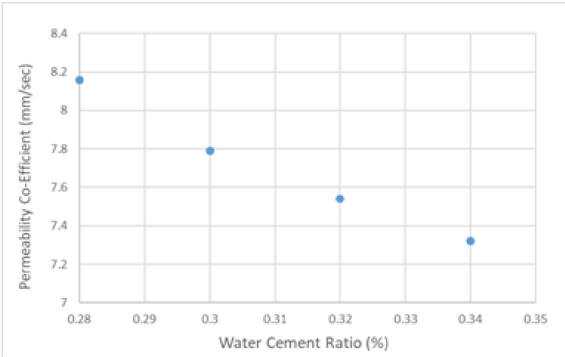
Graph 10. Effect of Water Cement Ratio on permeability coefficient for FPC



Graph 9. Effect of porosity on permeability coefficient for NPC

Effect of Water Cement Ratio on Permeability:

Graph10 & 11 show the effect of W/C on permeability coefficient for FPC and NPC. The highest permeability coefficient achieved in this study is 10.1 mm/s for mixture FPC1. Mixture NPC4 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.



Graph 11. Effect of Water Cement Ratio on permeability coefficient for NPC

Effect of Water Cement Ratio on Porosity:

Graph 12 & 13 show the effect of W/C on Porosity for FPC and NPC. The highest Porosity achieved in this study is 0.402% for mixture FPC1. Mixture NPC4 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.

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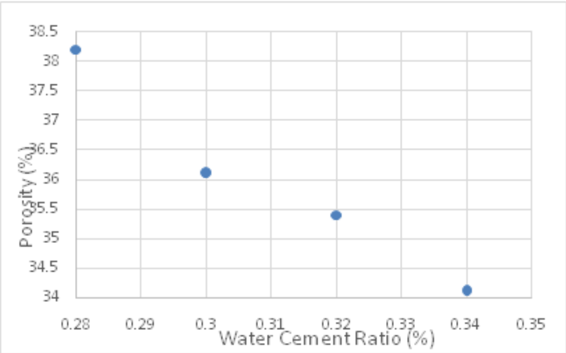
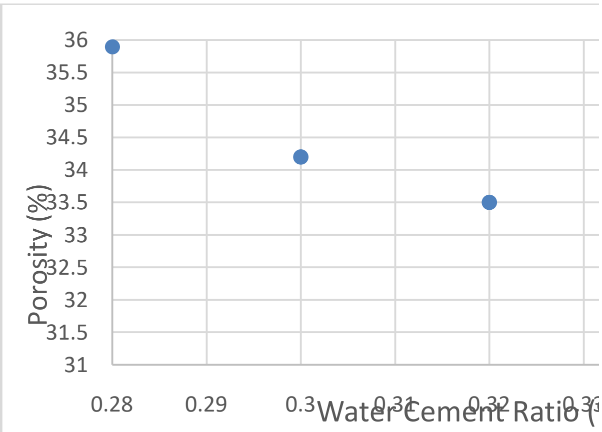
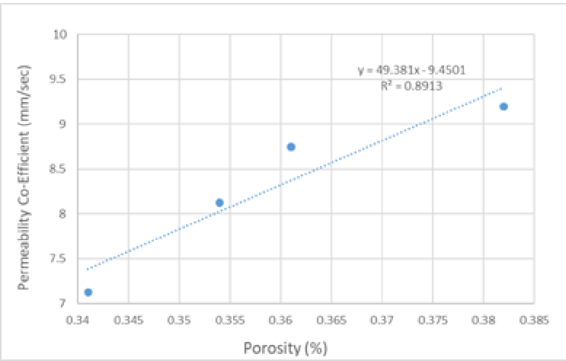


Graph 12 Effect of Water Cement Ratio on Porosityfor FPC



Graph 13. Effect of Water Cement Ratio on Porosity for NPC

STATISTICAL MODELLING



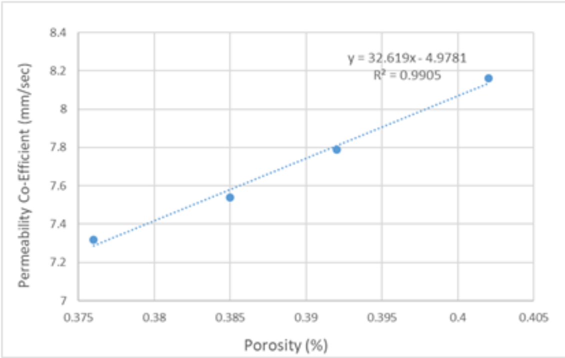
Graph 14. Effect of porosity on permeability coefficient for FPC

Table No. 5. Regression Modeling parameters for Permeability Coefficient of FPC

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

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

Nominal Pervious Concrete (NPC)



Graph 15. Effect of porosity on permeability coefficient for NPC

Table No.6.Regression Modeling parameters for Permeability Coefficient of NPC

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

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

VII. CONCLUSION

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 its potential 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. The pervious concrete properties were compared.

Compressive strength

(a) 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.

(b) 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.

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

Permeability Coefficient

(a) 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.

(b) 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 and NPC, it was found that NPC is having lower permeability increasing durability to concrete.

Porosity

(a) 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.

(b)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 and NPC, it was found that NPC is having lower Porosity percentage increasing strength of concrete by reducing voids.

Recommendations for further work

.Suggestions for future research work can be summarized as follows:

1) The effect of time on the properties of pervious concrete should be investigated
2) The pore structure should be investigated because of its effect on the water permeability of pervious concrete.
3) A clogging test for a combination of pervious concrete should be carried out to evaluate the long-term performance of pervious concrete under severe conditions.
4) A detailed study is needed to develop combined pervious concrete and pervious mortar for pavement application having adequate water permeability, strength, volume stability and durability.
5) A durability of pervious concrete, pervious mortar and combination of pervious concrete and mortar should be investigated to use the pavement structure.

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