AN EXPERIMENTAL STUDY ON PROPERTIES OF PERVIOUS CONCRETE (NO FINE CONCRETE)

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ABSTRACT: *Pervious concrete is also classified as No-fines, gap graded or porous concrete. This concrete is a mixture of Cement, Corse Aggregate and with or without sand. Pervious concrete has an unified pore structure that allows the passage of water freely to flow through. This concrete is also use as paving material to solve or reduce the storm water runoff to the drainage system and to minimize water logging problems. Pervious concrete is usually used in parking areas, areas with light traffic, pedestrian walkways, and greenhouses. Pervious Concrete is an important application for sustainable construction. The pervious concrete system and its corresponding strength are as important as its permeability characteristics. The strength of the system not only relies on the compressive strength of the pervious concrete but also on the strength of the soil beneath it for support. The present study covers some of the main characteristics and major uses of pervious concrete and its eco-friendly benefits. This concrete proves to be very beneficial if it utilize to its full extent in various flat work applications in India. In this study, an experimental investigation on physical, mechanical and hydraulic properties of pervious concrete by replacing the coarse aggregate with sea shell powder and steel slag aggregates with known percentages of 5%, 10% and 15% and cement replaced with titanium dioxide by known percentages of 3%, 5% and 7% with M20 concrete mix having water/cement ratio 0.34. In this investigation to find the influence of sea shell powder, titanium dioxide powder and steel slag aggregate on strength of pervious concrete without major affecting the permeability of the pervious concrete is carried out.*

Key Words: Cement, Sand, coarse aggregates, titanium dioxide powder, sea shell powder, steel slag aggregate.

1. INTRODUCTION

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. The pervious concrete is also called as No-fine concrete or porous concrete or gap-graded 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. The ability of pervious concrete to allow water to flow through itself and recharges ground water and minimizes the extent of pollution and storm water runoff. Pervious concrete has been developed in the USA in order to meet US Environmental Protection Agency storm water regulation requirements. The American Society for Testing and Materials (ASTM) Concrete Committee has focused on this concrete and formed a sub-committee 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. In Australia, pervious concrete has been developed for key performance in relation to Water

Sensitive Urban Design (WSUD) which seeks to improve required water quality and quantity in urban area. Pervious concrete blocks have been used as one of the permeable pavement systems.

Pervious or gap- graded concrete was mostly used in construction housing applications. Many new houses were built using pervious concrete in the United Kingdom, Germany, Holland, France, Belgium, Scotland, Spain, Hungary, Venezuela, West Africa, the Middle East, Australia, and Russia.

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Therefore, the temperature and humidity of the Earth's surface in large cities cannot be adjusted. This brings the phenomenon of hot island in city. At the same time, the plash on the road during a rainy day reduces the safety of traffic of vehicle and foot passenger. Hence we must use the type of concrete which reduces the amount of heat and energy releasing values to the environment. Here, we use the pervious concrete or No-fine concrete in place of Portland concrete for construction works especially for the pavements, parking-slots, etc.

The Pervious concrete mixture is composed of cementations materials, course aggregates, water with little or no fine aggregate and admixtures. Addition of small amounts of fine aggregates will gradually reduces the void content and increase the strength, which may be desirable in certain situations. This material is sensitive to changes in water content, so field adjustment of fresh mixture is usually necessary. The Optimum quantity of water in the concrete is critical. Too much of water cause segregation, and too little water will lead to balling in the mixer and very slow mixer unloading. The Water/Cement and Cement/Aggregate ratios are normally ranges from

0.25 to 0.45 and 1:3.5 to 1:6. The fine aggregates are not added in this pervious concrete mixture so that there are voids left in the coarse aggregate. The coarse aggregates may be any of the usual type or the light weight aggregates. The coarse aggregates are used should be finer than 20 mm size and not more than 10% should pass the 10 mm sieve. The usual proportion of cement to aggregate is 1:10 in case of heavy aggregate and 1:6 in case of light aggregate. The amount of water should be just sufficient to give a coating of cement paste on all particles.

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Pervious Concrete not only collects storm water but also filters and cools it economically with local materials. Low Impact Developments (LIDs) are encouraged to save space, save natural resources and promote sustainable communities. This mean the developments are encouraged to build up rather than out. With a pervious concrete parking lot or pavement the detention pond could be eliminated completely, thus conserving green space.

2. MATERIALS

2.1 Cement: Ordinary Portland cement is used for general constructions. The raw materials required for manufacture of Portland cement are calcareous materials, such as limestone or chalk and argillaceous materials such as shale or clay. The manufacture of cement consists of grinding the raw materials, mixing them intimately in certain proportions depending upon their purity and composition and burning them in a kiln at a temperature of about 1300^{0}C to 1500^{0}C at which temperature, the material sinters and partially fuses to form nodular shaped clinker. The clinker is cooled and ground to a fine powder with addition of about 2 to 3% of gypsum. The product formed by using the procedure is a "Portland cement".

Table 1 Physical Properties of Cement

S. No	Property	Test results
1	Fineness of cement	4.7%
2	Specific gravity	3.12
3	Normal consistency	29%
4	Initial setting time	91 minutes
5	Final setting time	195 minutes
6	Compressive strength at 3days 7days 28days	 34.57 N/mm^2 44.78 N/mm^2 54.48 N/mm^2

2.2 Fine aggregate (sand): The size of the fine aggregate is below 4.75mm.Fine aggregates can be natural or manufactured. The grade must be throughout the work. The moisture content or absorption characteristics must be closely monitored.

2.3 Coarse Aggregate: The material whose particles are of size are retained on IS sieve of size 4.75mm is termed as coarse aggregate and containing only so much finer material as is permitted for the various types described in IS: 383-1970 is considered as coarse aggregate.

Aggregates are the major ingredients of concrete. They constitute 70-80% of the total volume, provide a rigid skeleton structure for concrete, and act as economical space fillers. Because at least three-quarters of the volume of the concrete is occupied by aggregate, it is not surprising that its quality is of considerable importance. The properties of aggregate greatly affect the durability and structural performance of concrete. Aggregate was originally viewed as an inert material dispersed throughout the cement paste largely for economic reasons. It is possible, however, to take an opposite view and to look on aggregate as a building material connected in to a cohesive whole by means of the cement paste, in a manner similar to masonry construction.

In fact, aggregate is not truly inert and its physical, thermal and sometimes also chemical properties influence the performance of concrete. Aggregate is cheaper than cement and it is, therefore, economical to put in to the mix as much of the former and as little of the later possible. But economy is not only the reason for using aggregate, it confers considerable technical advantages on concrete, which has a higher volume stability and better durability than hydrated cement paste alone.

Aggregates should be of uniform quality with respect to shape and grading. The size of coarse aggregated depends upon the nature of the work. The coarse aggregate used in this experimental investigation is 20mm and 10mm size, crushed and angular in shape. The aggregates are free from dust before used in the concrete.

Table 2. Physical properties of coarse aggregate

S. No	Property	Value
1	Specific gravity	2.78
2	Fineness modulus	6.835
3	Bulk density Loose Compacted	 14 kN/m^3 16 kN/m^3
4	Nominal maximum size	20 mm

2.4 Sea shell powder: Seashell powder is a waste obtained near the seashore area as the result of disintegration of dead animals. Seashell consists of three layers outer, intermediate and inner layer .Outer layer is made up of calcite material whereas inner layer is otherwise known as nacre which is made up of calcium carbonate. Since 95% of calcium carbonate present in seashell, it has the strength nearly equal to coarse aggregate. Specific gravity of seashell is 2.65 and the values are tabulated in table 3.

Table 3 Chemical composition of Sea shell powder

S. No	Oxide	Percentage (%)
1	SiO_2	1.60
2	Al_2O_3	0.92
3	CaO	51.56
4	MgO	1.43
5	Na_2O	0.08
6	K_2O	0.06
7	H_2O	0.31

2.5 Titanium dioxide (TiO_2): Titanium dioxide also known as titanium oxide or Titania is the naturally occurring oxide of titanium, chemical formula TiO_2. It is mainly sourced from Ilmenite ore. This is the most widespread form of titanium dioxide-bearing ore around the world. When used as a pigment, it is called titanium white. TiO_2 is a white, highly stable and unreactive metal oxide, present in nature in three different polymorphs: anatase, rutile and brookite. Rutile and anatase have been used since the 1920‟s in many different industrial fields as white pigments due to their high pigmentation power and high stability whereas brookite is not commonly used. The beneficial effects of the photo-catalytic activity of titanium dioxide have been applied to various materials. The physical and chemical properties of Titanium dioxide are tabulated in table 4.

Table 4. Physical and chemical properties of Titanium dioxide

S. No	Property	Units	Value
1	Specific surface area	m^2/g	50 ± 15
2	Average primary particle size	Nm	21
3	Moisture (2hrs at 105°c)	wt.%	1.5
4	Ignition loss (2hrs at 1000°c)	wt.%	2.0
5	pH (in 4% dispersion)	wt.%	4.5
6	TiO_2	wt.%	99.50
7	$Al2O_3$	wt.%	0.300
8	SiO_2	wt.%	0.200
9	$Fe2O_3$	wt.%	0.010
10	Sieve residue (45 μm)	wt.%	0.050
11	Density	Kg/m^3	130

2.6 Steel slag aggregates: Steel slag is a by-product of steel making, and a kind of solid waste produced during the separation of the molten steel from impurities in steel-making furnaces. Due to their high heat capacity, steel slag aggregates have been observed to retain heat considerably longer than conventional natural aggregates. Steel slag has high bulk specific gravity and less than 3% water absorption. Steel slag aggregates have high density, but apart from this feature most of the physical properties of steel slag are better than hard traditional rock aggregates. They have high resistance to abrasion and impact. Specific gravity of steel slag aggregate values tabulated in table 5.

Table 5. Physical Properties of Replacing Materials

S.no	Specific Gravity	Fineness Modulus	Water absorption
Sea shell Powder	2.65	1.96	1.3
Titanium dioxide powder	3.77	---	1.1
Steel slag Aggregates	3.45	8.12	1.2

3. MIX PROPORTION

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of ingredients of concrete is governed by the required performance of concrete in two states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance.

The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depending upon many factors, e.g. w/c ratio quality and quantity of cement, water, aggregate, batching, placing, compaction and curing. The cost of concrete is made up of the cost of material, plant and labour. The variation in the cost of material arise from the fact that the cement is several times costly than the aggregates, thus the aim is to produce as lean a mix as possible.

The actual cost of concrete is related to the cost of materials required for producing a minimum mean strength called characteristic strength that is specified by the designer of the structure. This depends on the quality control measures, but there is no doubt that the quality control adds to the cost of concrete. The cost of labour depends on the workability of mix.

4 RESULTS AND DISCUSTIONS

4.1 compressive strength: The compressive strength values obtained by testing standard cubes of size 150mm x

150mm x 150 mm made with different PCC mixes with different proportions of sea shell powder and steel slag aggregates of 5%, 10% and 15% and titanium dioxide powder of 3%, 5% and 7% at 7, 28 and 56 days and results are tabulated in table 6.

Table 6. Compressive strength test results

S. NO	Concrete Mix Designation	Compressive Strength (N/mm²)					
		7 Days	% Increase or Decrease	28 Days	% Increase or Decrease	56 Days	% Increase or Decrease
1	PCC	6.50	---	9.89	---	12.00	---
2	PCCS5	7.20	+10.76	15.18	+53.48	13.30	+10.83
3	PCCS10	9.89	+52.15	15.77	+59.45	14.50	+20.83
4	PCCS15	8.14	+25.35 -17.61	14.19	+43.47 -10.00	12.86	+7.16 -11.31
5	PCCT3	6.60	+1.53	14.70	+48.63	15.50	+29.16
6	PCCT5	6.87	+5.60	15.10	+52.67	16.58	+38.16
7	PCCT7	6.90	+6.15	16.40	+65.82	17.60	+46.66
8	PCCST5	8.50	+30.76	14.90	+50.65	15.10	+25.83
9	PCCST10	8.60	+32.30	14.91	+50.75	15.20	+26.66
10	PCCST15	9.33	+43.53	15.70	+58.74	16.00	+33.33

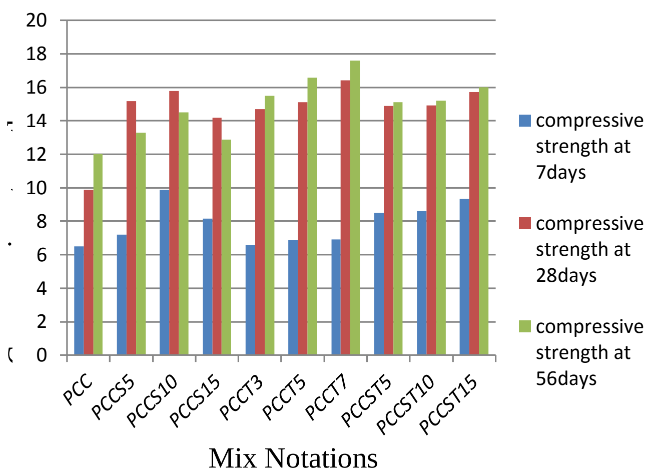

Figure 1.Compressive strength result

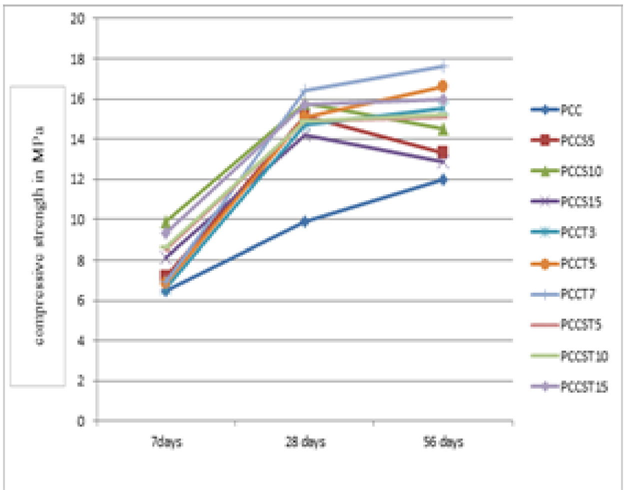

Figure 2. Compressive strength result graph

4.2 SPLIT TENSILE STRENGTH: The indirect tensile strength was measured on 150 x 300 mm cylinders and the results were shown below table 7. A total of 90 cylinders were cast for the ten mixes. Three specimens were tested each time and the average value at the particular age was reported as the tensile strength of the concrete.

Table 7. Split tensile strength test results

S.No.	Concrete Mix Designation	Split Tensile Strength(N/mm²)					
		7 Days	% Increase Or Decrease	28 Days	% Increase Or Decrease	56 Days	% Increase Or Decrease
1	PCC	0.87	---	1.21	---	1.47	---
2	PCCS5	1.27	+45.98	1.73	+42.82	1.89	+28.33
3	PCCS10	1.35	+55.75	1.83	+51.15	1.97	+34.10
4	PCCS15	1.44	+66.09	2.01	+66.00	2.20	+49.50
5	PCCT3	1.13	+30.00	1.98	+63.36	2.41	+63.52
6	PCCT5	1.27	+45.98	2.14	+76.56	2.76	+87.11
7	PCCT7	1.31	+51.38	2.30	+89.76	2.91	+97.28
8	PCCST5	1.20	+38.16	1.90	+57.24	2.16	+46.85
9	PCCST10	1.31	+51.38	2.14	+77.07	2.18	+47.93
10	PCCST15	1.39	+60.23	2.29	+89.72	2.81	+90.51

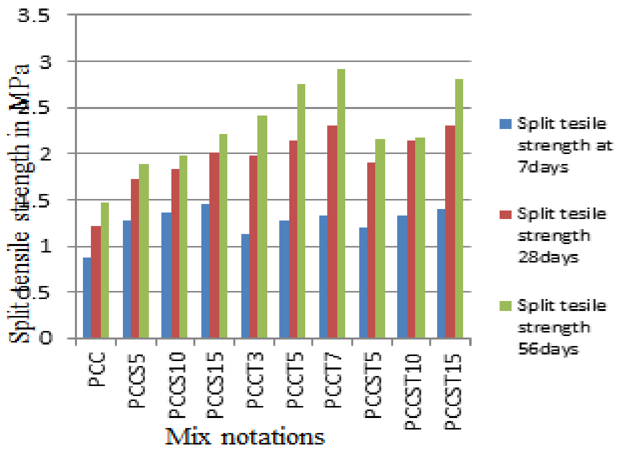

Figure 3. Split tensile strength results

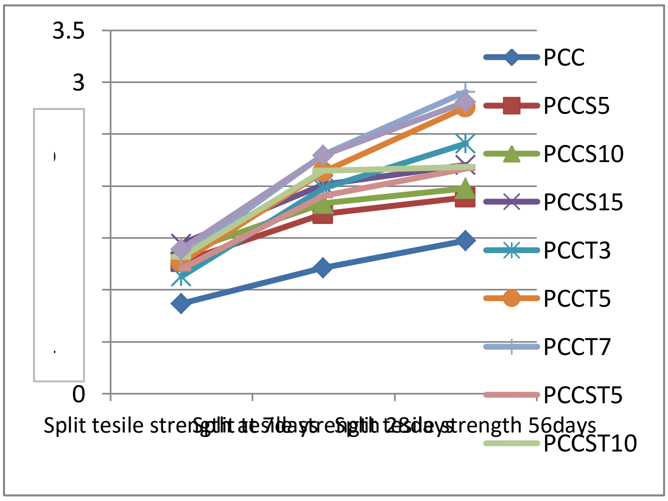

Figure 4. Split tensile strength results graph

4.3 FLEXURAL STRENGTH: Flexural strength of the concrete was determined from modulus of rupture test on beam specimens of 100 x 100 x 500 mm size. Here also, a total of 90 specimens were cast out of which three specimens were tested for each mix at 7days, 28 days and 56 days.

Table 8. Flexural strength test results

S. No.	Concrete Mix Designation	Flexural Strength(N/mm²)					
		7 Days	% Increase Or Decrease	28 Days	% Increase Or Decrease	56days	% Increase Or Decrease
1	PCC	1.17	---	1.785	---	1.970	---
2	PCCS5	1.5	+28.20	2.25	+26.05	2.7	+37.05
3	PCCS10	2.12	+81.19	2.8	+56.86	3.08	+56.34
4	PCCS15	2.22	+89.74	2.9	+62.46	3.78	+91.87
5	PCCT3	2.1	+79.48	2.72	+52.38	3.5	+77.66
6	PCCT5	2.21	+88.88	3.14	+75.91	3.54	+79.69
7	PCCT7	2.31	+97.43	3.55	+98.87	3.93	+99.49
8	PCCST5	2.09	+78.63	3	+68.06	3.25	+64.97
9	PCCST10	2.23	+90.59	3.42	+91.59	3.61	+83.24
10	PCCST15	2.32	+98.29	3.56	+99.43	3.91	+98.7

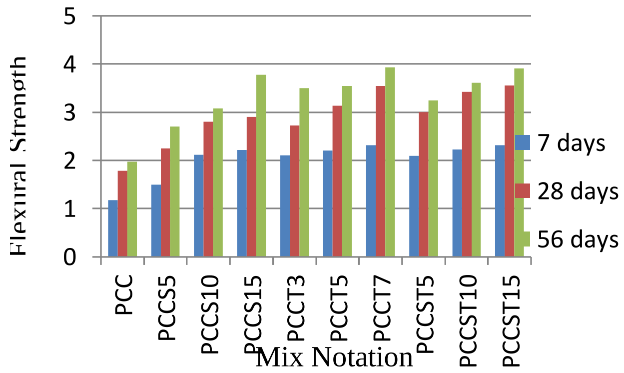

Figure 5.Flexural strength results

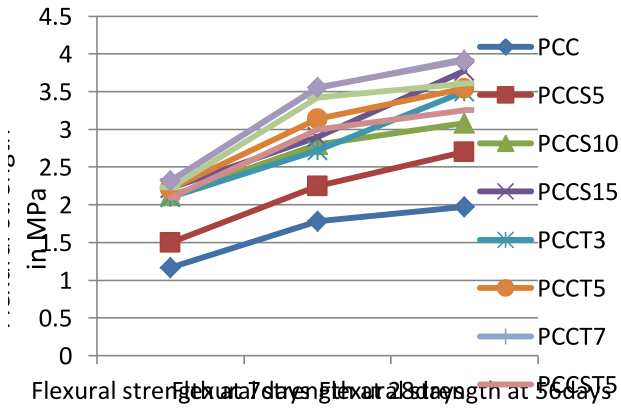

Figure 6.Flexural strength results graph

4.4 PERMEABILITY TEST: The coefficient of permeability values obtained by a cylindrical mould made with different PCC mixes with different proportions of sea shell powder, titanium dioxide powder and water is allowed through the specimen with the help of pump set of tri axial test under varying pressure head and values are tabulated in below table.

Table 9. Coefficient of Permeability of Pervious Concrete when pressure varying from 2kg/Cm²-0kg/Cm² and an average pressure of 1kg/Cm²

S. No.	Concrete Mix Designation	Coefficient Of Permeability cm/sec	% Increase or Decrease
1	PCC	0.98	---
2	PCCS5	0.91	-7.09
3	PCCS10	0.88	-10.20
4	PCCS15	0.84	-14.28
5	PCCT3	0.79	-19.38
6	PCCT5	0.70	-28.57
7	PCCT7	0.58	-40.81
8	PCCST5	0.95	-3.06
9	PCCST10	0.91	-7.142
10	PCCST15	0.66	-32.65

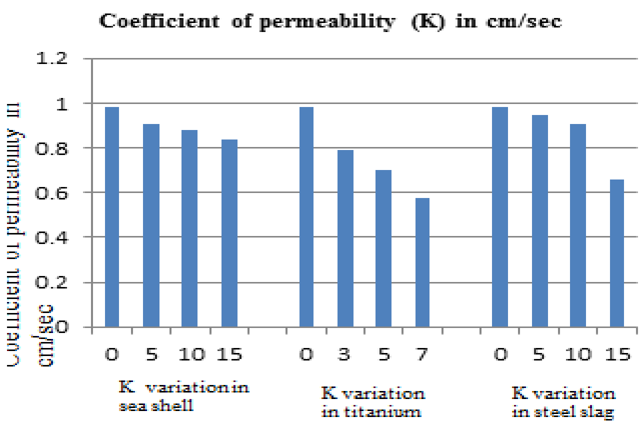

Figure 7. Coefficient of Permeability of Pervious Concrete

Table 10. Coefficient of Permeability of Pervious Concrete when pressure varying from 4kg/Cm2-0kg/Cm2 and an average pressure of 2kg/Cm2

S. No.	Concrete Mix Designation	Coefficient Of Permeability Cm/sec	% Increase or Decrease
1	PCC	0.49	---
2	PCCS5	0.45	-8.16
3	PCCS10	0.44	-10.20
4	PCCS15	0.42	-14.28
5	PCCT3	0.39	-20.48
6	PCCT5	0.35	-28.57
7	PCCT7	0.29	-40.81
8	PCCST5	0.47	-4.08
9	PCCST10	0.45	-8.16
10	PCCST15	0.33	-32.65

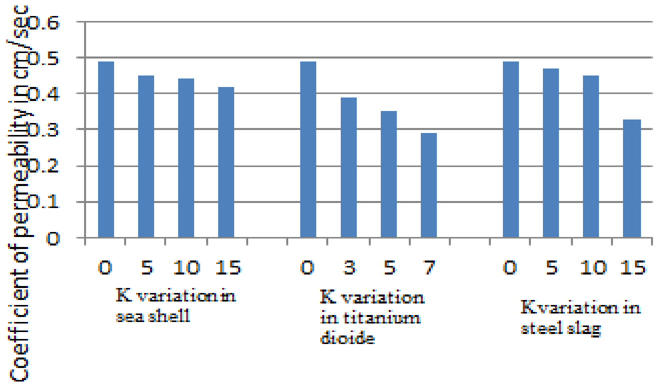

Figure 8. Coefficient of Permeability of Pervious Concrete

4.5 POROSITY TEST : The porosity values obtained by testing standard cubes made with different PCC mixes with different proportions of sea shell powder and steel slag aggregates of 5%, 10% and 15% and titanium dioxide powder of 3%, 5% and 7% at 28 days are tabulated in table 11.

Table 11. Porosity Test results

S. No	Concrete mix designation	Porosity In (%)
1	PCC	26.82
2	PCCS5	23.64
3	PCCS10	21.32
4	PCCS15	20
5	PCCT3	21.29
6	PCCST5	20.07
7	PCCST7	19.76
8	PCCST5	22.13
9	PCCST10	22.01
10	PCCST15	21

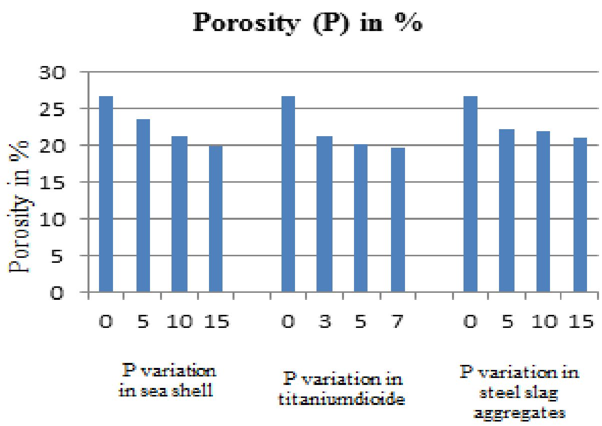

Figure 9. Porosity variations in pervious concrete

The relationship between porosity and compressive strength was given by park and Tia 2004 an empirical formula is used.

$$f_{ck} = 23.31 * e\text{^}(-0.045P)$$

Where, P= Porosity in (%)

Table 12. Relation between compressive strength and porosity

S. No	Concrete mix Designation	Porosity In (%)	Compressive strength (N/mm^2)
1	PCC	26.82	6.97
2	PCCS5	23.64	8.04
3	PCCS10	21.32	8.93
4	PCCS15	20	9.47
5	PCCT3	21.29	8.94
6	PCCT5	20.07	9.45
7	PCCT7	19	9.92
8	PCCST5	22.13	8.65
9	PCCST10	22.01	8.66
10	PCCST15	21	9.12

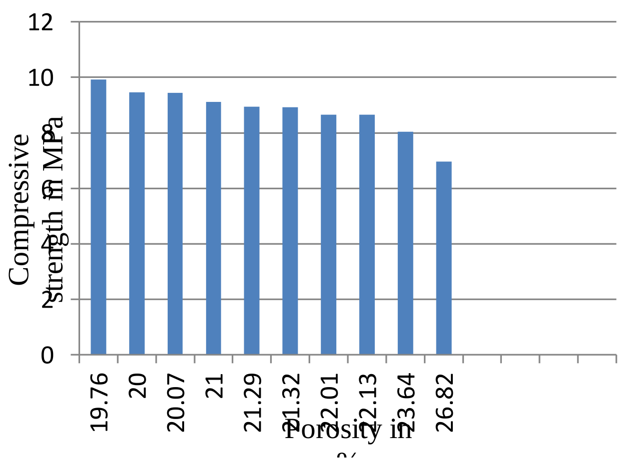

Figure 10.The Relation Between Compressive Strength And Porosity

5. CONCLUSIONS

1. Compressive strength increases with increase of % replacement of coarse aggregate with sea shell up to 10% and then decreases. However, there is no significant change in permeability.

2. Compressive strength increases with increase of % replacement of cement with Titanium Dioxide up to 7% and however, permeability decreases significantly.

3. Compressive strength increases with increase of % replacement of coarse aggregate with steel slag aggregate. However, permeability decreases significantly.

4. Flexural strength increases with % increase of replacement of coarse aggregate with sea shell, Titanium Oxide and Steel slag aggregate.

5. Split tensile strength increases with % increase of replacement of coarse aggregate with sea shell, Titanium Oxide and Steel slag aggregate.

6. Permeability values of all mixes range between 0.41 cm/sec to 1.258 cm/sec which is sufficient for a drainage layer of pavement in Indian road conditions.

7. Compressive strength of all mixes is inversely proportionate to the percentage of porosity of that mixes.

8. Overall it is observed that when void ratio and permeability decrease, flow of water through pervious pavement decreases and compressive strength increases and vice versa.

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