AN EXPERIMENTAL INVESTIGATION ON THE PROPERTIES OF PERVIOUS CONCRETE WITH VARIOUS COMBINATIONS OF COARSE AGGREGATE

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ABSTRACT

Presently we observe growth in urban population and that growth requires the raise in concrete jungles where almost all parts of the city are covered with impermeable concrete. In addition, the environment we live in is far from natural. This increases the problem in recharge of ground water and even it creates nuisance during monsoons. In the recent past we have observed the destruction caused by the nature to a renowned city Chennai. The answer to the above situations is PERVIOUS CONCRETE (PC). PC is a zero-slump; open graded, light weight and is a mixture of cement, aggregate & water that provide a level of porosity which allows water to percolate through it. There is typically single size aggregate in PC which provides larger air void than conventional concrete to increase the rate of infiltration. The PC is recognized by Environmental Protection Agency (EPA) as green building material for providing pollution control, storm management and sustainable development. The aim of this project is to propose a mix proportion and study the effects of aggregate gradations on the permeability and mechanical properties of PC. PC with three aggregate gradations was characterized through laboratory tests to evaluate the mechanical and permeability properties of the concrete mixtures. The results from this study indicated that aggregate gradations have significant influence on both strength and permeability properties of PC.

Key words: Chennai, permeability, pervious concrete, porosity, void content.

I.PERVIOUS CONCRETE

Pervious concrete (also called porous concrete, permeable concrete, no fines concrete and porous pavement) is a special type of concrete with a high porosity used for concrete flat applications allows water from precipitation and other sources to pass through directly , thereby reducing the runoff from a site and allowing groundwater recharge. PC is made using large aggregates with little to no fine aggregates. The concrete paste then coats the aggregates and allows water to pass through the concrete slab. The size of the connected pores in PC ranges from 2 to 8mm in diameter with void content between 15 to 35% **[01]**. PC can be used in numerous applications such as permeable concrete for pavement, base course, concrete bed for vegetation or living organism, noise absorbing concrete, thermal insulated concrete and other civil engineering and architectural applications. Porous concrete is made of attached single-size aggregate by Portland cement.

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Aggregate is the main part of the concrete volume. Chemical properties of PC are similar to the conventional concrete.

Fig.1: Representative pictures of Pervious Concrete

1.1 Water purifying performance

Pollution of urban lakes, rivers and wet lands and enclosed coastal waters near large citied has been serious in recent years due to runoff containing waste water from houses and plants, posing problems of environmental disruption. Water purification by PC is a sort of inter- gravel contact oxidation, in which the biota formed on the internal surfaces of continuous voids provides an additional bio-purification function. It is therefore anticipate that the porous concrete applied to revetment and coastal areas would contribute to water purification by the biota consisting of various organisms including microbes **[02, 03 & 04]**.

1.2 Pervious concrete – problem reduction

Trees are great tools in fighting greenhouse effect. Unlike impervious pavements, PC lets water and oxygen and enters the soil below. This allows tree roots to perform their tasks efficiently. Those tasks include cooling the surrounding air by the evaporation of the captured ground water. This helps reduce air conditioning cost. The light color of concrete pavements absorbs less heat from solar radiation than darker pavements, and the relatively open pore structure of PC stores less heat, helping to lower heat island effects in urban areas. The PC pavement also allows for increased skid resistance when compared to traditional concrete. Rougher surface and the presence of pores to remove stormwater during the summer and melt water during the winter were found to create drier surfaces resulting in better grip between tires and the pavement surface **[04]**.

1.3 Advantages of pervious concrete

Light weight concrete; Recharge of local aquifer; Water budget retention and pollution removal; less need for storm sewer; Green building alternative; suitable for many applications; Natural run-off allows rainwater to drain directly to sub-base; Reduced construction requirements for drainage structures; Reduced pollution; prevents environmental damage; Protects streams and lakes and allows local vegetation to thrive.

In summary, the testing of various PC batches with admixtures to achieve an ideal design mix is actively ongoing. Researchers continue to adjust design mixes to improve void ratios, infiltration rates, porosity and strength of the concrete. The ideal mix design would be based on the jurisdictions that need to accommodate weather, traffic volumes and environmental impacts of stormwater runoff. Current permeable field tests were limited to alleys and parking lots. The outcome of tests on design mixes, maintenance methodologies, and lifecycle of the mix designs would require an extended period of time. Typical infiltration rates of PC have been documented in several field tests which vary based on the underlying soil characteristics and/or jurisdiction. Several studies indicated that PC allows water to infiltrate at very high rates, typically between 15 m/hr – 40 m/hr, with void content of 15% – 35% and compressive strength range between 3.5 MPa – 27.5 MPa.

II.MATERIALS

Ordinary Portland cement of 43 Grade was used for casting all the Specimens which was obtained from a local dealer. It was tested for its properties in accordance with Indian Standard specifications. Coarse aggregate is the main ingredient which gives strength to the concrete. In this study of PC the coarse aggregate plays a vital role in determining the Porosity, Void ratio & Permeability of PC. Locally available single sized aggregates of sizes 12.5 mm and 20 mm were used for casting all specimens. The use of larger aggregate sizes up to 20 mm maximum size has been recommended for PC since they result in large sized pores in the material as well as reduced clogging **[05]**. Also the aggregate sizes for PC should be between 9.5 mm and 19 mm, and that no fine aggregates should be used **[06]**. Casting and curing of PC specimens were done with potable water available at nearby premises which was confirming to Indian Standards.

III.PERVIOUS CONCRETE MIX DESIGN

The mix design obtained from conventional method of concrete mix design was not applicable for designing the PC since mixes were assumed with zero fines. So the design of pervious mix was adopted as per the ACI 552.1 – 08 codes in which the quantities of PC (optimum) were mentioned. The optimum values from codes were tabulated table 1.

Table 1: Optimum values from codes

MATERIAL	QUANTITY
Cement	224 – 388 Kgs
Coarse Aggregate	1131 – 1670 Kgs
W/C Ratio	0.27 – 0.38
Void Ratio	13 – 30%
Infiltration rate	11.4 – 30.3 lit/hr

In accordance with the above optimum quantities of materials, in this project two mix proportions were used as primary mixes. They are C: C.A: W = 1:5:0.35 and 1:6:0.35.

IV.EXPERIMENTAL INVESTIGATION

4.1 General

The experimental investigations were carried out to obtain Mechanical and Permeability properties of PC. The Mechanical properties are namely Compressive strength, Split tensile strength, Flexural strength and Durability strength of PC. The Permeability properties were namely Porosity, Void ratio and Permeability (Infiltration rate). In the present investigation, Concrete specimens were prepared with various aggregate and mix proportion combinations. Two major mix proportions were considered and with the involvement of three aggregate combinations totally six different mix combinations were obtained. Conventional mix (MC) was used for the comparison. The Mix combinations considered in this thesis were tabulated in table 2.

Table 2: Mix Proportions

S.No	Mix (C:C.A)	Proportions
1	M1 (**1:6**)	C.A 100% (>16mm & ≤20mm)
2	M2 (**1:6**)	C.A 100% (>10mm & ≤12.5mm)
3	M3 (**1:6**)	C.A 60% (>16mm & ≤20mm) & 40% (>10mm & ≤12.5mm)
4	M4 (**1:5**)	C.A 100% (>16mm & ≤20mm)
5	M5 (**1:5**)	C.A 100% (>10mm & ≤12.5mm)
6	M6 (**1:5**)	C.A 60% (>16mm & ≤20mm) & 40% (>10mm & ≤12.5mm)
7	MC (**M20**)	C:F.A:C.A = **1:1.5:3**

4.2 Concrete mixing, casting & curing

The fresh concrete obtained was placed in the standard metallic moulds in three layers and was compacted each time by tamping rod. Before placing the concrete inner faces of the moulds were coated with the machine oil for easy removal of test specimens. Cubes, cylinders and prisms of standard sizes were cast as test specimens. Also PC specimens of known sizes were cast for the determination of porosity & void ratio. After the casting, the specimens were kept at room temperature for one day and they were covered with wet mats for atleast two more days so that the specimens attain the minimum bond strength. After acquiring the initial bond strength the specimens were demoulded and markings were made on them for identification. To maintain the constant moisture on the surface of the specimens, they were covered with wet mats till the desired age of testing.

V. MECHANICAL PROPERTIES

5.1 Compressive strength of pervious concrete

The compressive strength test was conducted on specimens on specified ages as per IS 516 (1959). The dimensions of pervious concrete cubes used in this thesis were of 150 mm X 150 mm X 150 mm and the ages of testing are 3, 7, 28 days. The obtained values are tabulated in the above table 3. Bond strength is the major contributor in the compressive strength of PC. Based on the results regarding compressive strength of various mixes of PC it can be inferred that one particular mix named M6 is nearly equal to MC. This is because of the highest packing of the solids in the concrete compared to all other pervious mixes. Also M5 & M6 are in the

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satisfying range of compressive strength as per **[01]**. And all the pervious mixes are in the satisfying range of compressive strength as per **[04]**. Graphical representation is made in fig 2.

5.2 Split tensile strength of pervious concrete

Split Tensile Strength test was conducted on the specimens at 28days as per IS 5816-1999. Three cylindrical specimens of size 150 mm × 300 mm were cast. The load was applied gradually till the failure of the specimen occurs. The maximum load applied was then noted. The splitting tensile strength (F_t) was calculated. The obtained values are tabulated in the above table 3. Based on the results regarding split tensile strength of various mixes of PC it can be inferred that one particular mix named M6 is nearly equal to MC. And all the pervious mixes are in the satisfying range of tensile strength as per **[04]**. Graphical representation is made in fig 2.

5.3 Flexural strength of pervious concrete

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam to resist failure in bending. The flexural strength can be determined by Standard test method as per IS 516 (1959). In this study, three beams of size 100 mm × 100 mm × 500 mm were used for each mix to find flexural strength. The test values are shown below in the table 3. Based on the results regarding the flexural strength of various mixes of PC it can be inferred that one particular mix named M6 is nearly equal to MC. And all the pervious mixes are in the satisfying range of tensile strength as per **[04]**. Graphical representation is made in fig 2.

Table 3: Mechanical Properties

S.No	Mix	Compressive Strength (MPa) days			Split Tensile Strength (MPa) 28-days	Flexural Strength (MPa) 28-days
		3	7	28		
1	M1	4.88	7.55	9.85	1.50	1.65
2	M2	4.29	7.26	9.48	2.36	2.51
3	M3	5.63	7.41	9.74	2.22	2.47
4	M4	8.59	11.85	14.52	2.25	2.25
5	M5	11.41	11.26	17.63	2.40	2.28
6	M6	12.74	12.29	22.37	2.50	2.67
7	MC	14.22	16.44	25.78	2.88	2.98

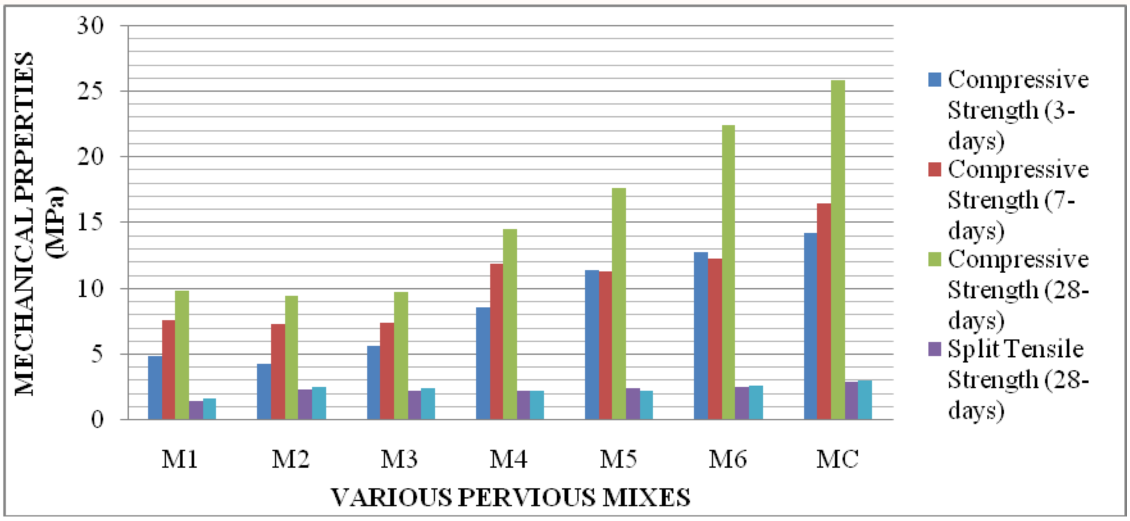

Fig 2: Graph representing Mechanical properties of various pervious mixes

5.4 Durability test on pervious concrete

Durability of PC is the ability of the concrete to serve its intended purpose for its design life period. In the PC, the main durability criterion is its bond strength. The bond strength of concrete is adversely affected by the action of salts as per the previous studies. In cold climates, road salts are used to melt snow and ice on pavements. The commonly used salts are sodium chloride and calcium chloride. Salt exposure in concrete can lead salt crystals to form in the pores, and at high concentrations can change the chemical composition in the cement paste **[07]**. The chemical reaction causes the cement paste to lose its structure, and the bonds can be destroyed **[08 & 09]**.

Studies have shown that a 2-4% solution of salt causes maximum scaling (cement paste to be dislodged) in saturated conditions and for the percentages above & below this range less scaling is expected **[10 & 11]**. Conversely, for the wetting-drying condition, the amount of damage increases as the concentration of salt increases **[08]**. Freeze-thaw testing conducted with a 3% sodium chloride solution also showed that as the solution freezes, the concentration of the unfrozen solution can rise to nearly 4 times the original concentration **[12]**. The effect, known as freeze concentration, is believed to aid in the process of supercooling. Supercooling occurs when the freezing point of the solution is depressed because of the salt concentrations, until the point where the phase shift in the water does occur, and at much larger pore pressures **[13]**. The application of deicing salts allows the degree of saturation in conventional concrete to exceed the amount normally attainable with pure water. Additionally salt crystallization is identified as a source of pressure in the large pores in concrete, by both physical forces and hydraulic pressures, as it draws water out of the smaller pores **[13]**.

Hence on the basis of previous studies 5% salt solution (NaCl) was taken as the water solution for curing purpose. In this test, the concrete cube specimens were tested for compressive strength comparison with the normally cured specimens. As the action of salt on the concrete is such that it reduces the bond strength which results in reduction of strength of such salt solution cured specimens. 150 mm cube specimens were used for the

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test and were tested at 90 days of salt solution curing. The cube specimens when cured in salt solution formed a white layer (scaling) due to the action of slats on cement bonding which is shown in the fig. 3.

Fig 3: Pervious concrete cube specimens in salt solution

Table 4: Compressive Strength values regarding durability at 90 Days

S.No	Mix	f^1 – 90-days (MPa)	f_{ck} – 28-days (MPa)	Decrease in Strength (%)
1	M1	6.44	9.85	34.62
2	M2	7.21	9.48	23.95
3	M3	6.42	9.74	34.09
4	M4	11.30	14.52	22.17
5	M5	14.79	17.63	16.10
6	M6	17.08	22.37	23.65
7	MC	24.38	25.78	05.43

The obtained values are tabulated in the above table 4. Based on the results regarding durability test of various mixes of PC it can be inferred that there is downward trend in the values of compressive strength as the age of the salt cured specimens increased. This might be due to the action of salt on the bonding in PC. Since the bonding strength is the major contributor for compressive strength of PC, salts act on the bonds resulting in the decrement of strength parameters of PC. This concludes that the bond strength of the PC is weakened by the action of salt. The percentage decrease in strength regarding durability of PC is calculated and tabulated below in table 4.

Generally compressive strength @ 28 days is considered as the characteristic compressive strength for any concrete. So 28 days compressive strength is taken as f_{ck}. Then for the durability, it was tested for 90-days (f^1) salt solution cured cube specimens and f^1 is considered as the worst case scenario in any kind of environment. So the values of f_{ck} & f^1 are compared and the decreases in the compressive strength values are noted in percentage. A particular trend was not observed in the decrement of the compressive strength of specimens cured in salt solution. But M1 is observed to have maximum decrement in strength when compared to all other mixes. This might be due to the highest porosity in M1 which means least in bond strength. This also concludes that PC cannot be used in extreme weather conditions. Also M5 showed the least decrement in strength which on the addition of some admixtures might be used at moderate weather conditions **[14 & 15]**.

VI.PERMEABILITY PROPERTIES

6.1 Porosity, void ratio and water absorption test

The void ratio of PC was determined by a procedure similar to the test procedure involving in the determination of Specific Gravity of Coarse Aggregate. To facilitate the movement of water, interconnected voids must be present in the hardened PC. Higher porosity generally produces lower strength due to its lower density and higher voids, while lower porosity mixes have higher strength due to its higher density and lower voids. Porosity is an indirect measure of permeability of the PC, if the porosity is more, permeability is more and vice-versa. The reason being for the same volume of concrete, when a lesser coarse aggregate mix proportion is taken it would have lesser mass to voids. So if the mix proportion increases then the porosity decreases and vice versa. The values from the test are tabulated in table 5.

Based on the test results regarding porosity and void ratio of various PC mixes it can be inferred that porosity and void ratio are directly proportional to each other. Also from the previous inferences it can be concluded that higher the porosity, lower will be the strength & vice versa. It is because of the voids the concrete will become lighter in density and acquires less strength. Also because of the higher porosity which leads to lower packing of the solids which in turn results in lower strength of that particular pervious mix and vice versa. The trend followed by the various mixes is shown in the Fig 4. The void ratios of all the mixes obtained ware in the satisfying range as per **[01, 06, 16 & 17]**.

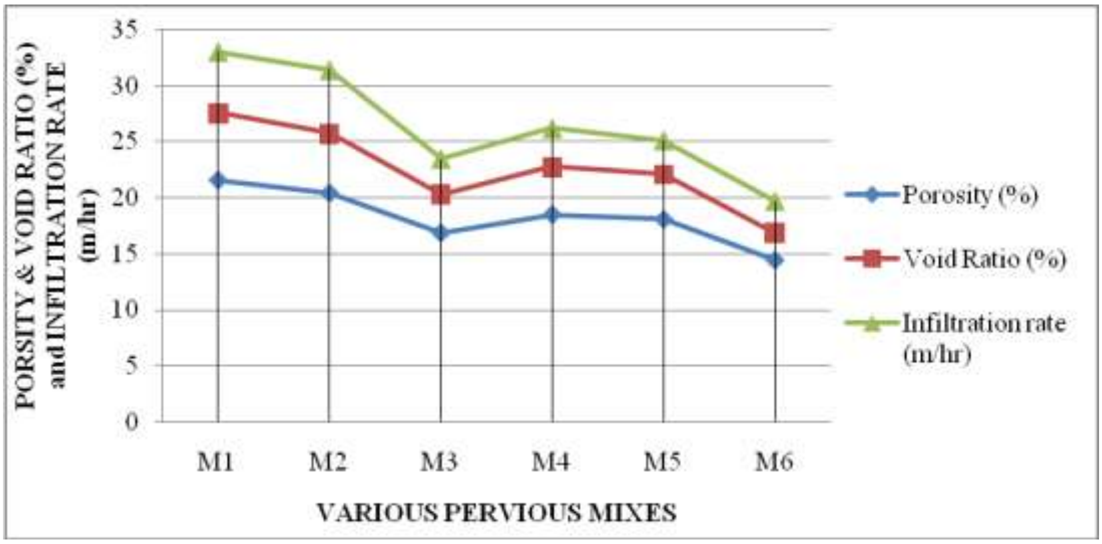

Fig 4: Graph representing trend followed by porosity and void ratio

Table 5: Permeability Properties

S.No	Mix	Porosity (%)	Void Ratio (%)	Water Absorption (%)	Infiltration Rate (m/hr)
1	M1	21.60	27.55	4.91	33.01
2	M2	20.44	25.69	3.55	31.38
3	M3	16.89	20.34	3.52	23.45
4	M4	18.53	22.74	3.00	26.17
5	M5	18.10	22.10	4.15	25.11
6	M6	14.45	16.89	4.25	19.67

6.2 Permeability test on pervious concrete

The ability of the concrete to drain runoff water is the key to the success of PC. Interconnected voids within the concrete allow the water to penetrate to the sub-base and remove trace contaminants **[04]**. While there is an inverse relationship between porosity and compressive strength, it is imperative that proper PC pavement designs allow for full saturation of the sub-base and not allow the runoff water to pond within the concrete layer or above the surface (NRMCA 2004).

While there is no set standard for testing the permeability of concrete, Flores, Martinez, and Uribe (2007) have devised a testing procedure that evaluates the filtration ability of PC cores. The test involves measuring the time it takes for a given amount of water to pass from the top of a 4 x 8 inch cylinder to the bottom. To account for bi-directional flow, the PC cylinder was wrapped in a waterproof, non-absorbent material **[18]**.

Another method developed to measure the permeability of PC has been the use of the falling head permeameter **[19]**. The PC cores are encased in an impermeable, non-absorbing membrane and connected to a vertical PVC pipe with open ends on each side, labeled upstream and downstream. To remove the air voids in the PC, water was filled in the downstream end up until water reached the top of the concrete core. Water was then filled on the upstream end. Equilibrium was allowed to be reached. Water was then added to the upstream side to a height of 12 in., and fall to about 4 in. The time for the water to drop a predetermined height was recorded.

In this project, the permeability of the PC was determined after the slab specimens were cured under mats for atleast 3 days. Using Infiltration rate test on slab specimens based on ASTM C–1701 permeability of PC mix was determined, in which the Infiltration rate was determined using a square test specimen of 1m side for each mix. The test setup is shown in fig 5.

(1): $I = (KM) / (D^2 * t)$

Where, I = Infiltration rate in mm/hr

M = Mass of water used (in any case 18.2 Kgs)

D = Diameter of the ring used (in any case 300 mm)

t = Time Elapsed in seconds (s)

K = Infiltration constant (in any case 4583666000 mm^3-s/kg-hr)

The values from the test are tabulated in table 5. Based on the results, it can be inferred that higher the porosity higher will be the infiltration rate. This is because of the interconnected voids and percentage of void content.

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Also the trend followed by various mixes regarding infiltration rate is shown in Fig 4. The Infiltration rates of all the mixes obtained are in the satisfying range as per **[01, 04 & 06]**.

VII.GRAPHICAL REPRESENTATION OF VARIOUS PROPERTIES OF PERVIOUS CONCRETE

7.1 Relationship between Void ratio, Compressive strength and Infiltration rate:

Based on all the above relationships a combined graph representing the different properties of PC can be presented in a single graph. This graph gives the overall representation of the every single detail of the PC characteristics. Also from the graph it can be concluded that, out of all mixes M1 has the highest Infiltration rate, highest Void ratio and least compressive strength. Similarly M6 has the least Infiltration rate, least Void ratio and highest compressive strength. Same is shown in the Fig 5.

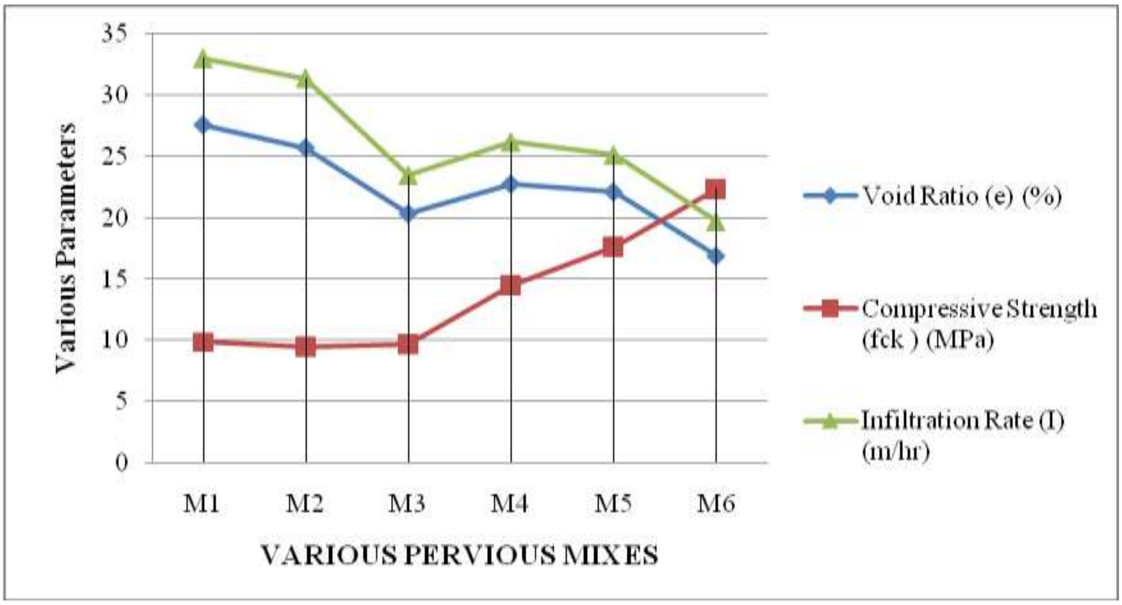

Fig 5: Graph representing relation b/w (e), (f_{ck}) & (I) of various pervious mixes

VIII.CONCLUSIONS

After conducting a detailed study on the effect of aggregate gradations on the strength and permeability characteristics of PC based on the limited laboratory and analytical results, the following can be concluded.

- ❖ All the pervious concrete mixes yielded zero or nearly zero slump. So the workability of all the pervious mixes is very low.
- ❖ The Mechanical properties of PC increases with decrease in Void ratio. Out of all mixes, M6 showed the values on par with MC.
- ❖ Durability of PC decreases with increase in Void ratio.
- ❖ The increasing order of Porosity & Void ratio of all the pervious mixes is M6, M3, M5, M4, M2 and M1. All the mixes satisfied the Void ratio parameters as per ACI 522.1 – 08.

- Porosity and Void ratio are inversely proportional to strength characteristic of the pervious concrete which means if Porosity & Void ratio of a particular mix is high then the strength characteristic of that mix is low and vice versa.
- Increasing order of Infiltration rates of all mixes is M6, M3, M5, M4, M2 and M1. All the mixes satisfied the Infiltration rate parameter as per ACI 522.1 – 08. Mix M1 has the highest infiltration rate among all the mixes.
- Among all the mixes considered, the mix named M6 proved to be practically applicable due to its satisfactory Strength and Permeability properties as per ACI 522.1 – 08.
- Finally it can be concluded that the mix with moderate strength, durability and permeability characteristics is suitable for almost all the applications of pervious concrete with a need for proper water drainage.

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