

measured as W4. After that, the sample was taken out from curing pond and kept in bucket and water was filled to top. The weight was measured as W3. The sample was then left outside for 24 hours. After 24 hours, the air-dried sample was kept in the bucket and again the weight was measured as W2. The weight of displaced water was calculated using following equation:

$$\text{Weight of Displaced Water} = ((W4 - W1) - (W3 - W2)) \quad \text{Eq. 3.0.1}$$

The volume of displaced water is equals to the volume of sample solid, which is subtracted from the total volume of the sample to obtain the volume of voids. Porosity is calculated as the ratio of volume of voids to the total volume of sample, and expressed in percentage.

3.3.2 Permeability Test

The permeability of the sample was calculated using falling head method. In this method, the sample is subjected an initial water head and time taken to reach final water is recorded. The apparatus was prepared as shown in the figure below.



Figure 0.1 Falling Head Permeameter

The sample was prepared by wrapping it in thin shrink wrap plastic sheet and covered by rubber tightly to prevent any leakage from the side of the sample. A graduated tube was placed above the sample. The height of the exit pipe was fixed above the top level of the sample.

First the water was filled from exit pipe. This helps in removing the air trapped inside the sample. After that, the exit hole was covered and water was completely filled inside the graduated cylinder. The water was allowed to settle for a while and cover placed at exit hole was removed. The time taken (t) for water level to fall from initial height (h1) to final height (h2) was calculated by reviewing the video recorded during the testing process. The permeability of sample was calculated using following equation:

$$\text{Permeability (k)} = 2.303(aL/At)\log (h1/h2) \text{ cm/sec} \quad \text{Eq. 3.2}$$

Where, A= Cross-sectional area of sample, a = cross-sectional area of graduated stand pipe.

3.3.3 Compressive Strength Test

The compressive strength of the samples were carried out following the procedures mentioned in IS 516 (1959). As there was no use of fine aggregates, the top and bottom surface of the sample cylinders were rough, so it was capped using cement as per the code. Since the PC is weaker than conventional concrete, lower loading rate of 100kg/sq cm/min was applied.

4. RESULTS AND DISCUSSIONS

4.1 Aggregates Properties

The test results of the aggregates are summarized on the table below.

Table 0.1 Physical Properties of Aggregates

Physical Properties	Aggregate Size	
	9-16mm	5-9mm
Coefficient of Uniformity (Cu)	1.67	1.59
Coefficient of Curvature (Cc)	1.07	0.96
Flakiness Index (%)	8.13	6.91
Elongation Index (%)	9.95	9.57
Water absorption (%)	0.67	0.24
Apparent Specific Gravity	2.715	2.712

The Coefficient of Uniformity (Cu) and Coefficient of Curvature (Cc) value for both aggregate sizes are near to one indicating the aggregates as single sized or narrow graded aggregates. The flakiness and elongation index for aggregate size 9-16mm were found out to be 8.13% and 9.95% respectively. The flakiness and elongation index for 5-9mm size aggregate

were found out to be 6.91% and 9.57% respectively. Water absorption for aggregate size 9-16mm and 5-9mm were 0.67% and 0.24% respectively. Apparent Specific Gravity were 2.715 and 2.712 for aggregate size 9-16mm and 5-9mm respectively.

4.2 Density

The average dry density of the samples is listed on the table below. It can be seen that samples A, C and E have more density compared to samples B, D and E with same aggregate size used. This is because former group of samples were mixed with cement aggregate ratio of 1:3 compared to 1:4 for later. Because of this, more cement was available to mix with aggregate resulting in denser concrete compared to samples B, D and F with cement aggregate ratio of 1:4. Samples E and F have maximum density in their respective mix category because of the use of both size of aggregate. This has resulted in a densely packed structure with smaller aggregate occupying the spaces between the larger aggregate thus increasing dry density of PC.

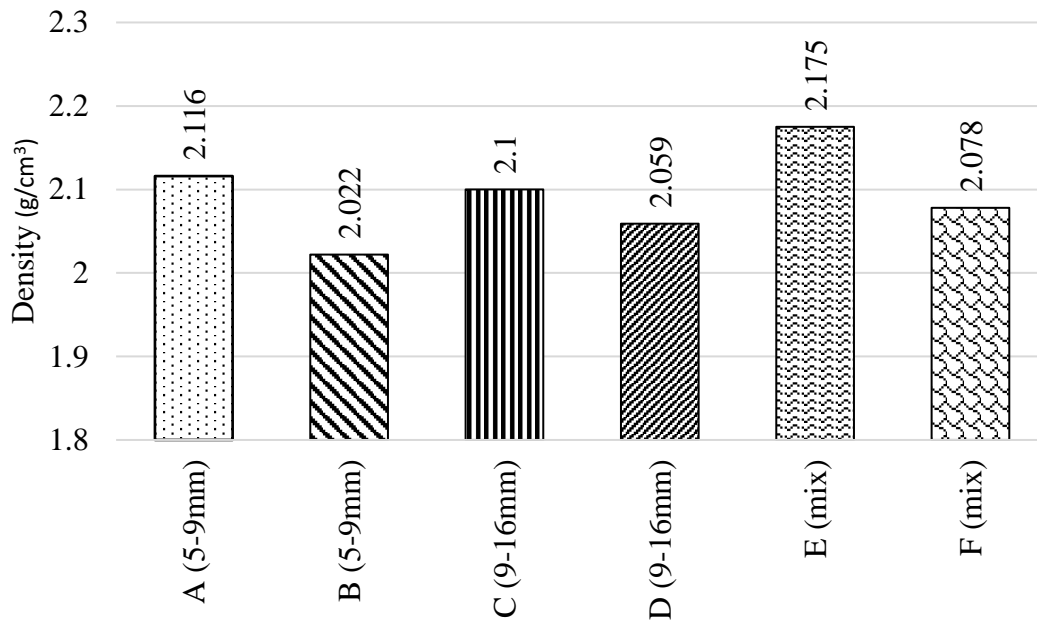


Figure 0.1 Average Density of Samples

4.3 Porosity

The graph plotted for the average porosity of different samples as calculated is shown below.

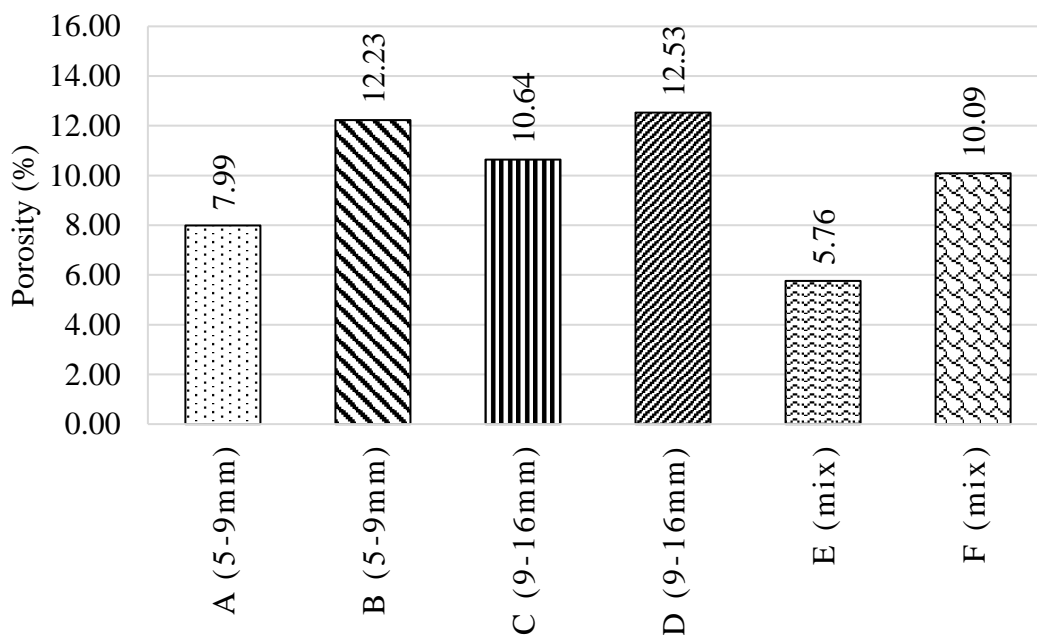


Figure 0.2 Average Porosity of Samples

The porosity of samples A, C and E are lesser compared to samples B, D and F for same aggregate size. On comparing samples, A and C, which were mixed with cement aggregate ratio of 1:3, sample C has better porosity. This is due to the larger aggregate size use in sample C. Similar results can be seen between sample B and D with porosity value of sample D slightly larger than sample B. But for samples E and F, the porosity values are lesser because of the use of mixed aggregate size. The overall porosity of all samples has a smaller value with a maximum value of only 12.53%. The use of flaky and elongated aggregate may be the reason for this as these types of aggregates forms a well packed concrete resulting in less porous structure. Better porosity can be achieved by using less flaky and elongated aggregates.

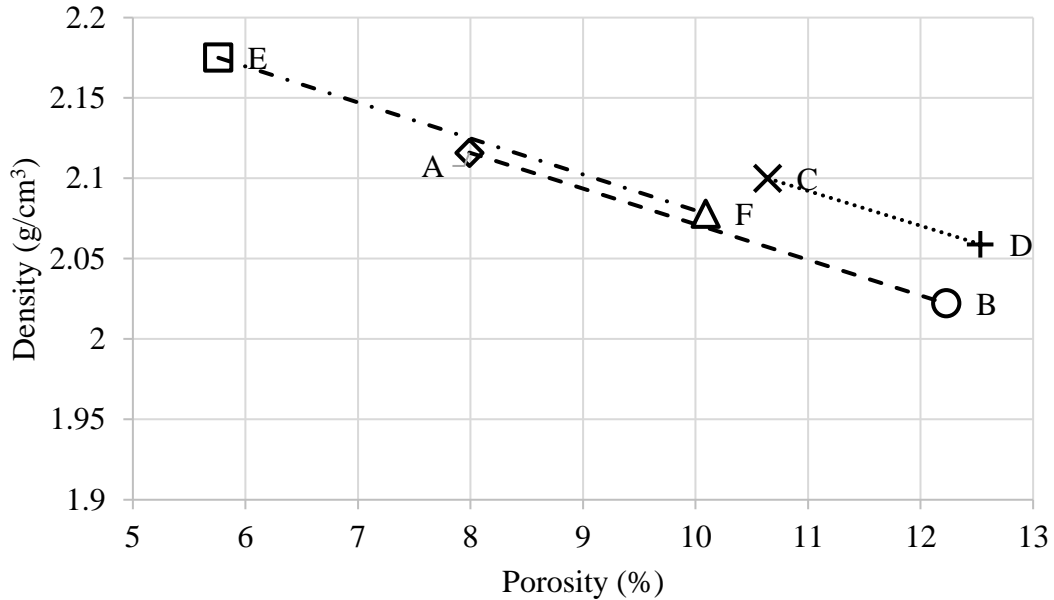


Figure 0.3 Comparison between Density and Porosity of samples

The graph between the density and porosity of samples shows that the increase in porosity has resulted in decrease in density. Samples E, A, F, and B have their porosity value in increasing order with their density in decreasing order. These samples have larger difference in porosity and density with change in cement to aggregate ratio from 1:3 to 1:4. For samples C and D, with application of larger aggregate size of 9-16mm, their porosity and density values are higher and the difference in their porosity and density values are smaller with change in cement to aggregate ratio from 1:3 to 1:4. The role of cement paste in deciding the porosity and density of PC is critical for small sized aggregates.

4.4 Permeability

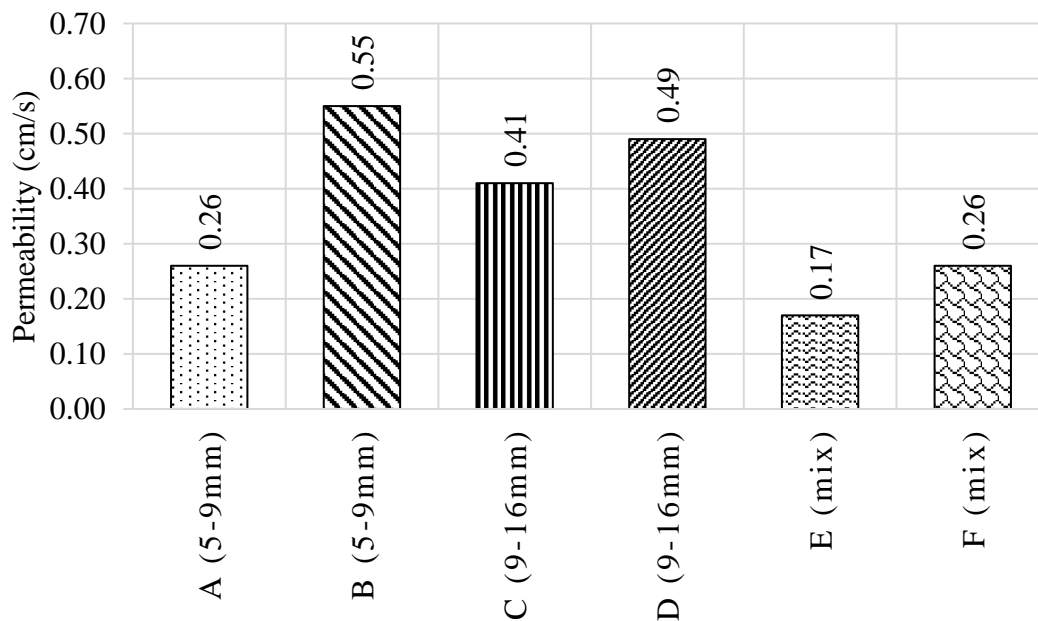


Figure 0.4 Average Permeability of Samples

The above graph shows the permeability values for different samples. Samples A, B, C and D prepared using narrow graded aggregate shows better permeability properties compared to samples E and F. This is because of the formation of interconnected voids, which is possible in concrete prepared using narrow graded aggregates. For same aggregate size, the permeability value has increased with change in cement to aggregate ratio from 1:3 to 1:4. The quantity of excess cement after coating of aggregate is decreased when more amount of aggregate is used in samples B, D and F, compared to samples A, C and E. this has resulted in increased permeability on the former group of samples.

Similarly, from the comparison graph between porosity and permeability, as shown below, we can that porosity and permeability are directly related as an increment in the value of one result in an increment in another. For samples A and B, with aggregate sizes 5-9 mm, the difference in porosity and permeability is large compared to other samples with a similar change in cement to aggregate ratio from 1:3 to 1:4. Samples E and F have lesser values for porosity and permeability because of the use of the different size of coarse aggregates.

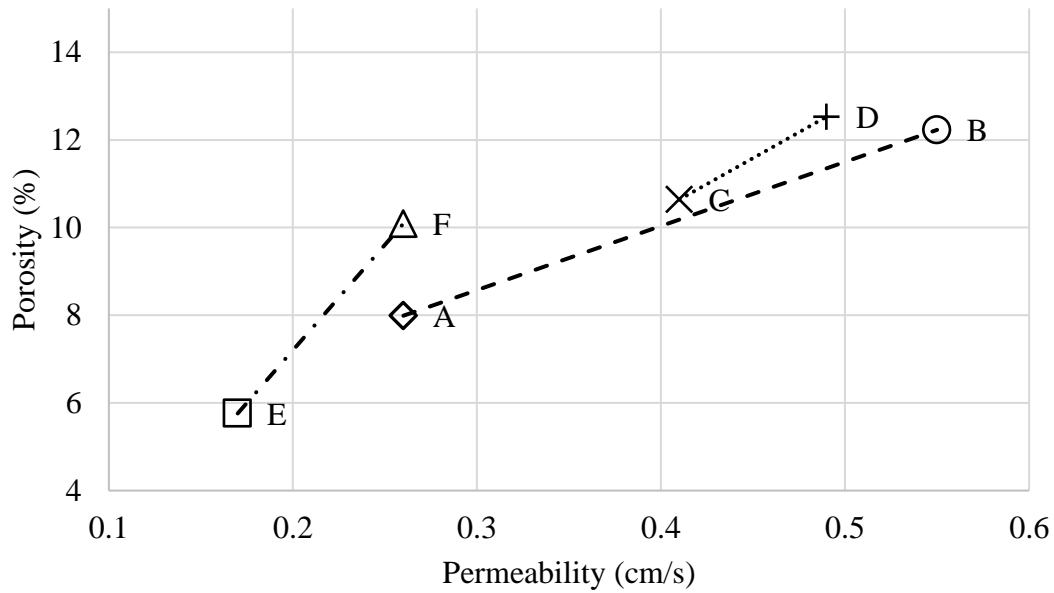


Figure 0.5 Comparison between Porosity and Permeability of Samples

4.5 Compressive Strength

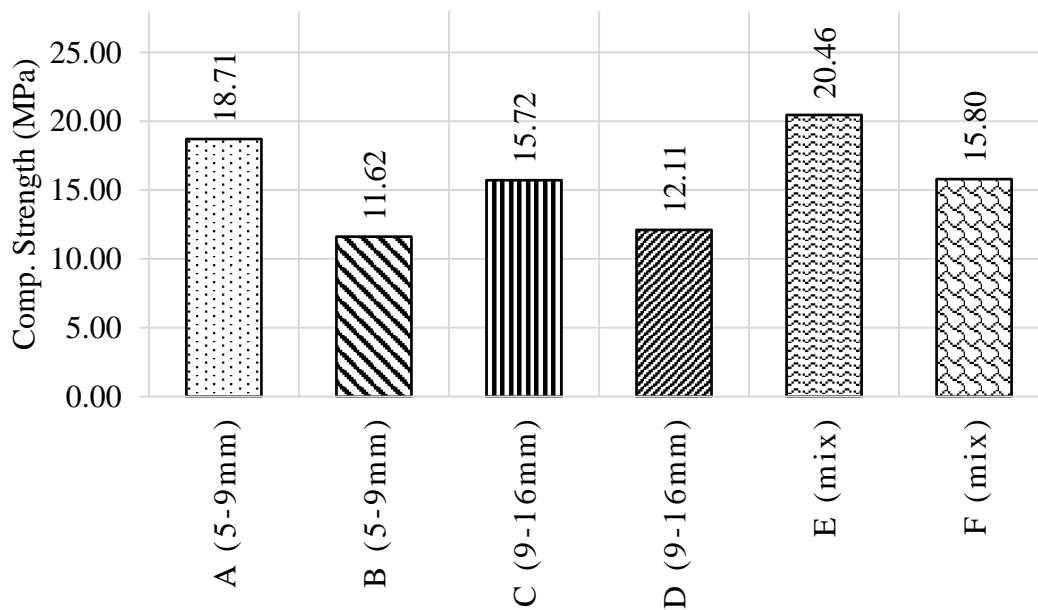


Figure 0.6 Average Compressive Strength of Samples

The above figure shows the compressive strength of different PC samples. Samples A and E prepared using cement to aggregate ratio of 1:3 i.e. M20 mix ratio have higher compressive strength with values nearer to 20 MPa whereas sample C

with similar ratio has only compressive strength of 15.72 Mpa. This is because samples A and E were prepared using small sized aggregate of 5-9 mm, with sample A consisting of 5-9 mm aggregate and sample E with mixture of 5-9 mm and 9-16 mm aggregate. Due to the use of small size aggregate in sample A, they are densely packed with enough cement paste for bond resulting in larger value of compressive strength. Similarly, for sample E, use of both size of aggregate has resulted in a uniform structure with small sized aggregates occupying the voids created by large sized aggregates forming a dense structure resulting in larger compressive strength value. Samples C and D have lesser strength value as they were prepared using large sized aggregate 9-16 mm, which formed larger voids resulting in weaker concrete.

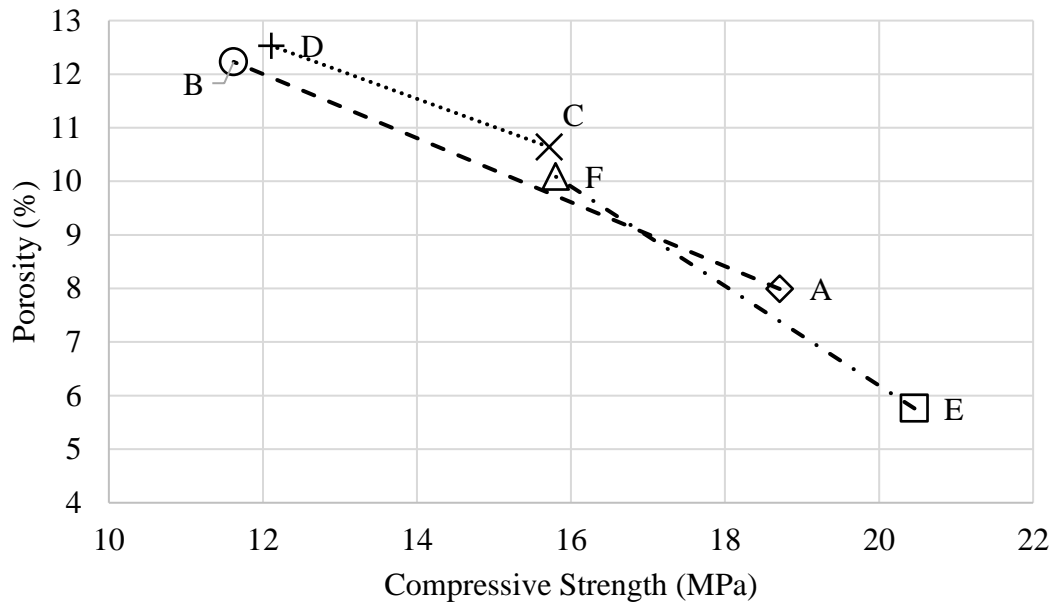


Figure 0.7 Comparison between Porosity and Compressive strength of Samples

From above comparison chart, we can see that the range of change in porosity and compressive strength from sample B with cement to aggregate ratio 1:4 to sample A with ratio 1:3 for same aggregate size of 5-9 mm is larger compared to other samples. The graph shows the inverse relationship between the porosity and compressive strength larger porosity value with lesser compressive strength and vice versa. The change in porosity and compressive strength from sample C to D is subtle. The line between sample E and F for its porosity and Compressive strength follows a steeper slope.

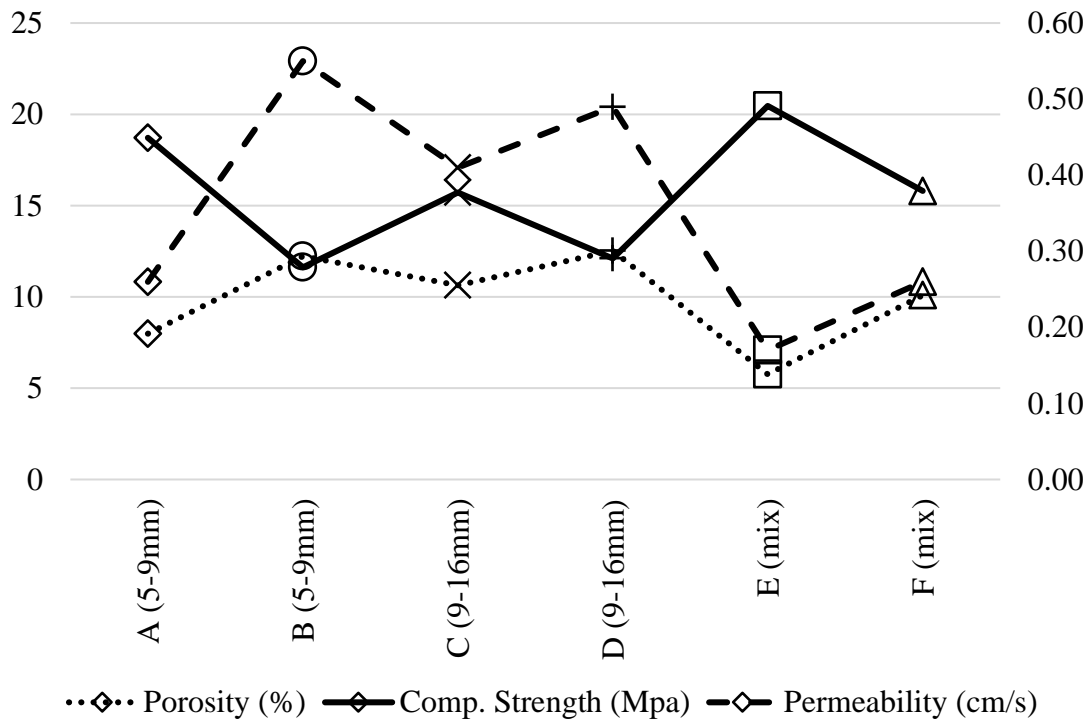


Figure 0.8 Comparison of Porosity, Permeability and Compressive strength

From above comparison graph for porosity, permeability and compressive strength, we can see that the slope for the porosity and permeability line are similar in nature, whereas the slope for compressive strength line is inverse in nature. Sample B has the highest value for permeability and higher porosity with lower value for compressive strength. Sample E has highest value for compressive strength with lowest value for porosity and permeability. The difference in properties for sample A to B and E to F are steeper in nature whereas the difference for sample C to D is of milder nature.

Table 0.2 Test results of the samples

Sample	w/c	C/A	Porosity (%)	Permeability (cm/s)	Comp. Strength (MPa)
A (5-9mm)	0.3	1:3	8.31	0.25	18.71
B (5-9mm)	0.3	1:4	12.23	0.54	11.62
C (9-16mm)	0.3	1:3	10.64	0.41	15.72
D (9-16mm)	0.3	1:4	12.63	0.52	12.11
E (mix)	0.3	1:3	6.08	0.15	20.46
F (mix)	0.3	1:4	10.36	0.29	15.14

The above table shows the summary of properties of PC. For two different size of narrow graded aggregated, with mix ratio of cement and aggregate in 1:3 and 1:4, six groups of sample mixes were prepared keeping water cement ratio as 0.3. Porosity in the range of 6.08% to 12.63% were achieved with its permeability value from 0.15 cm/s to 0.54 cm/s. the compressive strength of PC achieved ranges from 11.62 MPa to 20.46 MPa with most of the samples having compressive strength above 15 MPa. Aggregate size 5-9 mm had a greater range in change of properties. Its porosity varied from 8.31% to 12.23% with permeability varying from 0.25 cm/s to 0.54 cm/s. The change in compressive strength was observed ranging from 11.62 MPa to 18.71 MPa. Aggregate size 9-16 mm showed a small change in their properties when mix ratio was changed from 1:3 to 1:4. Samples mixed prepared by mixing both the aggregate sizes had a better strength property over with their value between 15.14 MPa for 1:4 mix ratio and 20.46 MPa for 1:3 mix ratio. But they showed significantly less hydraulic property with porosity ranging only between 0.15 cm/s to 0.29 cm/s.

5. CONCLUSIONS AND RECOMMENDATIONS

The study was carried out to prepare Pervious Concrete and study its properties. The size and grading of aggregates and mix properties were finalized after conducting literature review and following different codes and guidelines. Pervious Concrete was prepared by mixing Ordinary Portland Cement with natural riverbed aggregate of size 5-9 mm and 9-16 mm in proportion of 1:3 and 1:4 by weight, keeping the water cement ratio at 0.3. The PC prepared was tested for its physical properties in two categories as hydraulic property and mechanical property. For hydraulic property, porosity and permeability were measured and density and compressive strength were measured for mechanical property. The results obtained were in accordance to the criteria given by ACI 522R (2010). Compressive strength above 10 MPa was achieved for all samples with maximum value of 20.46 MPa which is suitable for application in light loading areas. Conclusions drawn from the study may be listed as:

1. The size of aggregate and its grading affected both hydraulic and mechanical property of PC with small sized narrow graded aggregate showing better result.
2. Porosity of all samples were relatively lesser compared to results obtained in different literatures. This may be due to the fact that aggregates with flakiness and elongation index of 6.9% to 9.95% were used and also the concrete was poured in the mould in three layers tamping each layer 25 times by tamping rod rendering the concrete dense. However, further study is necessary to validate this claim.
3. PC prepared with larger sized aggregate and narrow grading resulted in better hydraulic property for both mix proportions. However, they were accompanied with reduced strength.
4. PC prepared with aggregate of both sizes had higher compressive strength in both mix proportions but they had lesser hydraulic property.
5. The results obtained indicate that the prepared PC can be used in light-loading areas like parking lots, sidewalks, bicycle lanes, drains, greenhouses, and playgrounds.

To conclude, PC can be prepared using locally available materials with desirable properties. The application of PC primarily depends on its hydraulic performance. However, it is not sufficient condition as PC should possess enough strength for its application in different loading conditions. Nonetheless, for extensive use of PC, more studies are necessary. Some recommendations are:

1. The effect of freezing and thawing in cold climate.
2. Stresses on PC in hot areas.
3. Effect of vibration in PC due to dynamic loading.
4. Durability of the top surface of PC due to heavy loading.
5. The effect of flakiness and elongation index of aggregates on hydraulic performance of PC.
6. Study on clogging of PC on long term use.

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