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A Study on Properties and Use of Environmental Friendly Pervious Concrete

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Abstract

Pervious concrete is an open graded material specially engineered to have high porosity to allow water from precipitation and other sources to pass through besides of retaining sufficient strength allowing its use to perform various structural functions. Due to larger porosity in the pervious concrete mass, its strength is lower when compared with conventional concrete, even; pervious concrete of sufficient strength has been prepared using different combinations of ingredients so that it can find enough application areas. Recently it is predominantly being used for pavement applications in light traffic density areas like parking lots, side walks, service lanes etc.Now-a-days our modernized cities are covered with air-water proof building material. It obstructs the lack of air permeability and water permeability common concrete pavement so that the rain water is not filtered underground. A large amount of rain water ends up falling on impervious surface such as parking lots, drive ways, sidewalks and streets rather than soaking into soil. This creates a natural imbalance in the ecosystem and leads to various problems like soil erosion, floods, ground water depletion. A simple solution is to be avoiding these problems to stop construction impervious surface and switch to pervious concrete. Working on rain-drain concept, porous concrete allows large amount of water in the body system resulted ground water rechargement and control storm water management. Pervious concrete pavement is the best solution for protecting trees in a impervious surface. Many plants have faced difficulty growing in impervious because air and water can't touch to the roots. Porous concrete helps the adjacent trees to receive more water and air from the soil. Pervious concrete creates opportunity for lands caper and architects who wish to use greenery in parking lots and paved urban areas. Pervious concrete pavement systems (PCPS) has emerged as a unique and effective means to address site development related environmental issues and to support sustainable growth by capturing stormwater and allowing it to infiltrate into the underlying soil thereby recharging ground water levels, reducing quantity of storm water and its pollution level, reduce occurrence and intensity of flash flooding, etc. As it is evident that more porosity in concrete causes reduction in its strength. This study is carried out to investigate the effect of aggregates engineering properties and variation of mix proportions on strength and permeability of pervious concrete and also to develop recommendations about the certain minimum quality parameters of the aggregate and about the mix proportions to develop a required target compressive strength and porosity.. Inspired by the pervious concrete technology and the fact that fly ash is a waste material abundantly available, the research Group at KIIT University, India commenced a comprehensive research program on fabrication of Fly ash based pervious Material [FPC] from fly ash. The compressive strength of the material falls on the range of 3-28 MPa , porosity 15 - 35 % with permeability 8 - 20 mm/s. This material has potential

application such as ground water rechargement, storm water management, noise reduction, control surface run-off, temperature behavior and pollution retention sinks. The research mainly focuses on the manufacture of fly ash-based pervious material for ground water rechargement and large amount of utilization fly ash.

Keywords: Pervious, Concrete, Fly Ash, Strength, Permeability, Porosity

Unlike conventional concrete, Pervious Concrete(PC) possess an open graded structure due to the fact that it contains no or very less amount of fine aggregates. This open structure of PC helps in water infiltration. Increasing concretization in urban areas has resulted in formation of impermeable surface everywhere. All the storm water is forced into the drain whose size is insufficient to accommodate them. This has resulted in urban flooding. Also due to absence of infiltration, ground water level is diminishing

1 LITERATURE REVIEW

Pervious concrete has been referred to as no-fine concrete, lightweight concrete, gapgraded concrete, porous concrete, permeable concrete and enhanced-porosity concrete in literature **(Chopra et al. 2007A; Obla 2007**). It has been employed in European countries since the nineteenth century in various ways and applications including cast in place load bearing walls, pavement around trees, domestic car parks, prefabricated panels, steam cured blocks, etc. **(ACI 522R-06). Its first use is reported in 1852 in United Kingdom for construction of houses using gravel and concrete (Ghafoori et al. 1995; ACI 522R-06). Chopra et al. (2007 B)** reports that pervious concrete has been in existence in the United States for nearly 50 years in applications such as parking lots, low-volume roadways and pedestrian walkways.

This material was proved advantageous where manpower was scarce or expensive. Over the years, the pervious concrete were used in the production of new houses in the United Kingdom, Germany, Holland, France, Belgium, Scotland, Spain, Hungary, Venezuela, West Africa, the Middle East, Australia, and Russia. By 1942 over 900 houses were built using pervious concrete most of them were in the United Kingdom **(ACI 522R-06; Schaefer et al. 2006).**

Amendments to the Clean Water Act (US EPA 1999), which requires both mitigation of the quantity of stormwater runoff and maintenance of water quality, has been instrumental for the use of Pervious Concrete Pavement Systems (PCPS). It rapidly gained popularity with designers, owners, developers, and permitting agencies in US. It demonstrated potential to fulfill both of the above mentioned requirements of amended Act.
The high flow rate of water through a pervious concrete pavement allows rainfall to be captured and to percolate into the ground, reducing stormwater runoff, recharging groundwater, supporting sustainable construction, providing a solution for construction that is sensitive to environmental concerns, and helping owners comply with EPA stormwater regulations. This unique ability of pervious concrete offers advantages to the environment, public agencies, and building owners by controlling rainwater on-site and addressing stormwater runoff issues. This can be of particular interest in urban areas **(Malhotra 1976, Tennis et al. 2004, Chopra et al. 2007 A).**

The common approaches to stormwater management focus primarily on detainingand retaining excess runoff on the site (Ghafoori et al. 1995). Another alternative approach is to reduce the amount of impervious surfaces added to a site and, by doing so, reduce the generation of excess runoff. The installation of porous concrete in parking or low traffic roadways is one of the techniques utilizing the mixed approach i.e. the non-generation approach as well as detaining and retaining of the excess stormwater. Today, probably the most extensive use of this type of stormwater management has been in Tokyo, where it is estimated that some 494,000 m2 of porous pavement have been constructed since **1984 (Pratt 1997; Chopra et al. 2007 A).**

Other applications that take advantage of the high flow rate through pervious concrete include drainage media for hydraulic structures, parking lots, tennis courts, greenhouses, and pervious base layers under heavy-duty pavements. Its high porosity also gives it other useful characteristics for example it is thermally insulating and has good acoustical properties. These properties have encouraged its use for construction of

wall of buildings and as sound barrier walls. In United States, pavements are the dominant application of pervious concrete. Other common applications using pervious concrete are patios, swimming pool decks, shoulders, zoo areas, artificial reefs, sidewalks, pathways, pavement edge drains, slop stabilization, low-water crossings, residential roads, alleys, driveways, sewage treatment plant sludge beds, beach structures, seawalls, bridge embankments, rigid drainage layers under exterior mall areas, solar energy storage systems, wall lining for drilled water wells **(Schaefer et al. 2006; ACI 522** pervious concrete **2006; Tennis et al. 2004).**

2 INTRODUCTION

The urban areas, world over, are suffering with many environmental problems like increased quantity of stormwater, depletion of ground water table, deteriorating runoff quality, flash flooding, urban heat island effect etc. Indiscriminately ever increasing spread of impervious surfaces during land development is one among the major causes. With the increase in the quantity of stormwater, variety and amount of pollutants, which include, sediment; oil, grease and toxic chemicals from motor vehicles; pesticides and nutrients from lawns and gardens; viruses, bacteria and nutrients from pet waste and failing septic systems; heavy metals from roof surfaces, pavements, motor vehicles and other sources; thermal pollution from dark impervious surfaces etc., carried into streams, rivers and lakes, also increased. These pollutants can harm aquatic and wildlife populations, kill native vegetation, deteriorate drinking water supplies and make recreational areas unsafe and unpleasant.Certainly! Here's a revised version with the words changed but the meaning preserved:Concrete is a hardened, stone-like substance made from a uniform mixture of cement, fine aggregate, and coarse aggregate in the presence of water, and is widely used as a construction material today. **Pervious Concrete (PC)** is a unique form of concrete created by using little to no fine aggregates. According to ACI 522R (2010), PC is characterized as a near-zero slump, open-graded material made up of Portland Cement, coarse aggregates, minimal or no fine aggregates, admixtures, and water. In contrast to standard concrete, PC incorporates pores by removing fine aggregates, which normally fill the spaces between coarse aggregates. This process results in voids ranging from 2 to 8 mm, allowing water to flow through easily. The void content in PC varies from 15% to 35%, while its compressive strength falls between 2.8 and 28

MPa. Its permeability ranges from 0.14 to 1.22 cm/s, depending on the shape, size, grading, and density of the aggregates used. This hydraulic characteristic makes PC beneficial for use as pavement material.

When compared to traditional concrete pavements, **Pervious Concrete Pavements (PCP)**offer several benefits, especially in terms of reducing hydroplaning risks. They play a crucial role in managing stormwater pollution at the source, as well as in controlling runoff. They also help to reduce hydroplaning on road and highway surfaces. The noise generated by the interaction between tires and the pavement, as well as glare on wet road surfaces at night, is significantly minimized. Furthermore, PCP contributes to increasing parking spaces by eliminating the need for water retention areas and reducing the size of stormwater drainage systems. It also allows air and water to reach tree roots, even when pavement is laid within the tree's drip line.

However, there are certain challenges and limitations associated with PCP, particularly in areas subjected to heavy loads. Pervious concrete is sensitive to water content and requires longer curing times. This necessitates specialized construction techniques, particularly when applying PC in areas with high groundwater levels or in soil types that are prone to frost and expansion. The absence of standardized testing methods also poses a challenge in its application. PC is generally applied in pavement as a surface layer, permeable base, edge drains, and shoulders. Its use and thickness primarily depend on two factors: its hydraulic properties (porosity and permeability) and its mechanical properties (strength and stiffness).

Materials And Mix Proportion

The specimens are obtained by the mixture of cement, aggregates, little amount of sand or no sand, water and admixture. During the mixing process, extreme care was taken in order to maintain water content so that the pervious concrete can get better workability. Generally ,the mix design were produced with cement to aggregate ratio (C/A) of 1:3, 1:4,1:6 and water
cement (w/c) ratio of 0.30,0.35,0.40 respectively are summarized in Table. Additionally admixture 7-15 % of silicafume and 5-7 % of super plasticizer (weight of cement) were added to the mixture in order to get maximum strength.All the mix designs are prepared to achieve good permeability and porosity.The mix proportion of pervious concrete is shown in table 1.

Mix Proportion of Pervious Concrete	
Materials	Proportion
Cementious material	270 to415 Kg/m^3
Aggregates	1190to1480Kg/m^3
Water:Cementratio(bymass)	0.27to 0.40

Aggregate: Cementratio (bymass)	4to6:1
Ad mixture	5 -7%
Fine:Coarse aggregaterat io(bymass)	0to1:1

CHARACTERSTICS OF PERVIOUS CONCRETE

The properties of Pervious concrete (PC) such as compressive strength, split tensile strength, permeability, porosity, density, were foundvarysatisfactoryperformanceandthe test results are discussed below in table.2.

Table no.2

Properties of Pervious Concrete	
Density	1600to2000Kg/m3
Compressive Strength	3.5to28MPa
Flexural Strength	1to3.8MPa
Tensile Strength	1 to3MPa
Permeability	8-20 mm/s
Porosity	15 to35%
Slump	Zero

LIFECYCLE COST OF PERVIOUS CONCRETE

No-fine concrete is the ideal solution for light weight roadway such as pedestrian road, parking lots and residential street. As porous concrete is porous is nature, so its various mechanical properties are weaker than conventional concrete but it can solve many environmental issues such as storm water management and het island effect. The best way to compare this material with other is of its cost parameter and application. In the present there is no long studied has been conducted for its cost analysis. If available it is only suitable for local condition. Only few studied have been done on comparative analysis of cost construction between porous concrete and conventional concrete. The result reveals that the initial cost of porous concrete is high due to controlled design and to maintain proper void.If life cycle cost is determined than its overall benefits can be calculated. It is sometimes very difficult to determine the life cycle cost because of lack of large scale testing, performance analysis and maintenance cost. By determining the actual life cycle cost its cost would be reduced up to 30%.In another study it reveals that

by installation of pervious concrete it can save up to $64,649 for water treatment benefits and $3,788,856 for installation cost for more than 25 years as compared to conventional concrete. The reduction cost of pervious concrete can be increased because it doesn't require an drainage system. Since more pores present insidethebodysystemhelpstopercolatewater.AccordingtoFederalHighway Administration (FHWA) the cost of Pervious concrete is 15-20 % more than traditional concrete. It basically depends upon few factors such as material employed
and application method. In the present report the cost analysis of full, partial and no filtration pavement is studied. It is found from the literature only few work has been done on cost analysis of pervious concrete (PC).And the date available which shows that the construction cost of PC more expensive than other concrete. Due to non-availability of long term performance data. Most of the studied are conducted on storm water runoff but none one include the scope of taking UHI mitigation benefits. The author identify this is a potential area of research to study its various properties such as durability, construction cost, life cycle etc

3TESTING OF SAMPLE SPECIMEN

After 7 days, the samples were tested to calculate its dry density, porosity and permeability.

Porosity Test

The porosity of the sample was calculated using water displacement method. In water displacement method, weight of water displaced by the sample solid is calculated, which is equals to the volume of the sample solid. At first, an empty clean bucket was taken and its weight was measured as W1. The bucket was then filled with water to its top and its weight was 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:

$$\text{Weight of Displaced Water} = ((W4 - W1) - (W3 - W2)) \qquad \text{Eq 3.1}$$

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.

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 of Falling Head Parameter

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:

Permeability (k) = 2.303(aL/At)log (h1/h2) cm/sec Eq. 3.2

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

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

Aggregates Properties

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

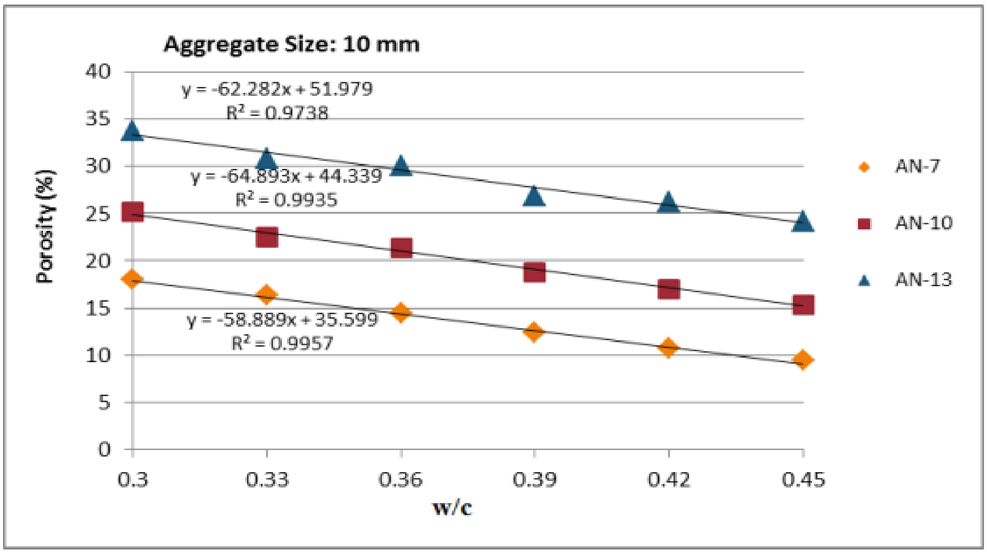
Table 0.1 Physical Properties of Aggregates

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.

Porosity

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



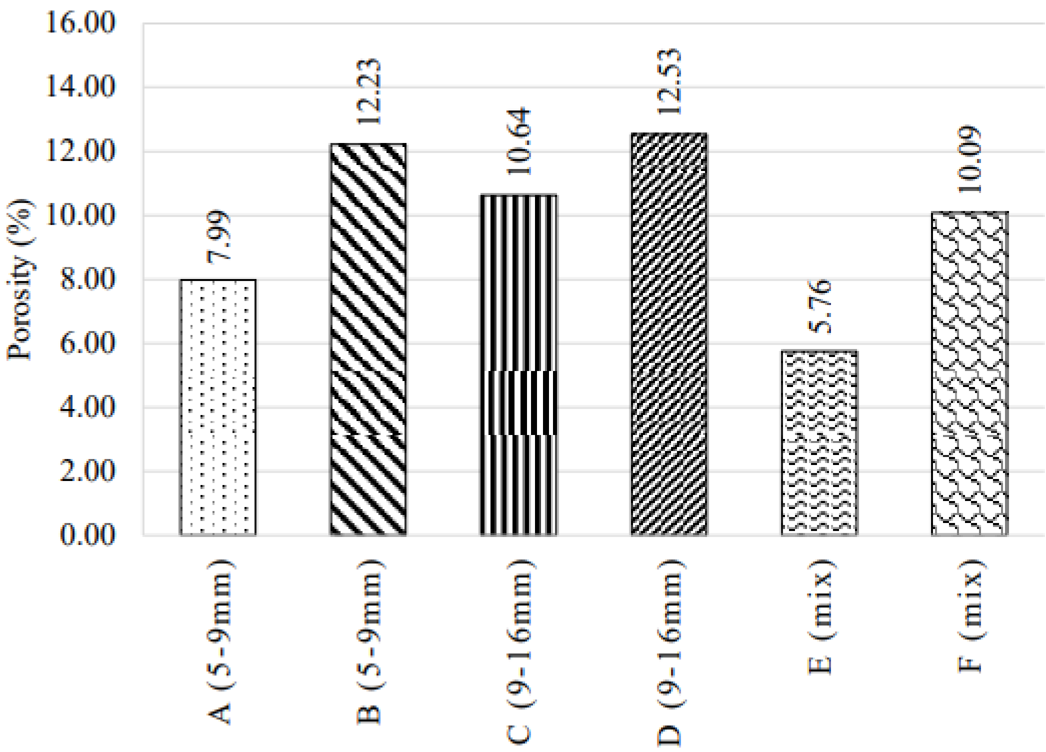
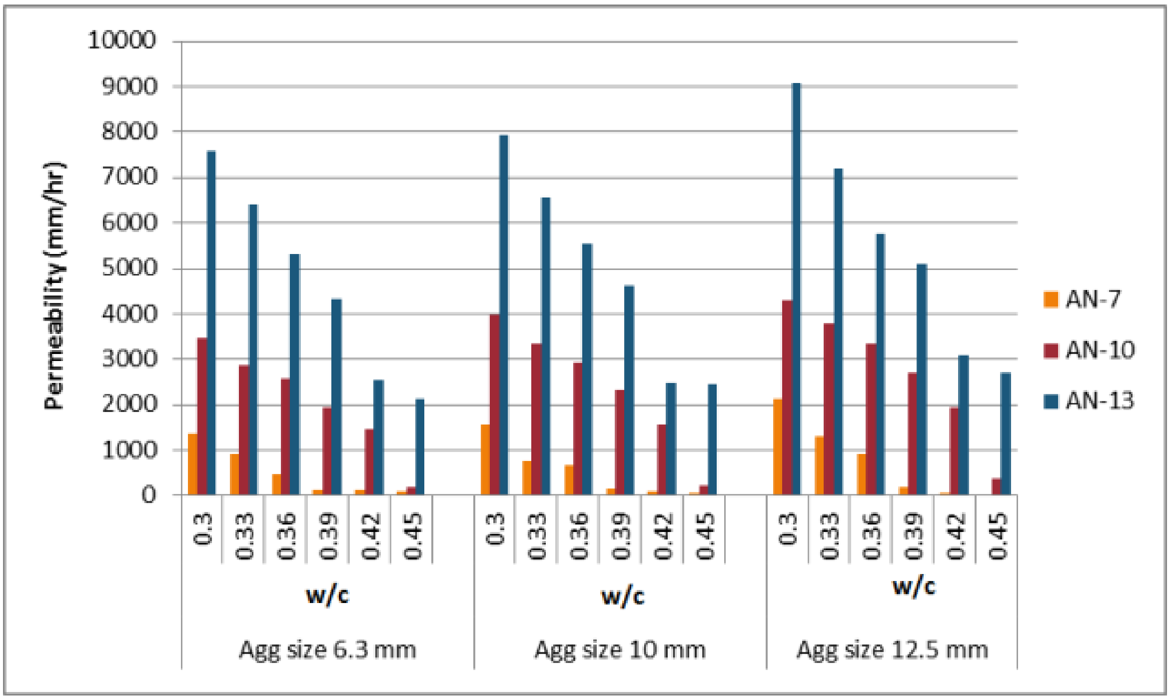


Figure 0.2 Average Porosity of Samples The porosity of samples A, C and E are lesser compared to samples B, D and F for same aggregate size. On comparing samples, A and C, which were mixed with cement aggregate ratio of 1:3, sample C has better porosity. This is due to the larger aggregate size use in 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 cabe achieved by using less flaky and elongated aggregates.

Permeability

It may be observed that the pervious concrete mixes prepared using flaky aggregates demonstrated maximum permeability followed by the mixes with angular and irregular aggregates. This may be because the mixes prepared using irregular size of aggregates results in to least porosity Also the permeability through the mixes prepared using smaller size of aggregates for a given aggregate type and water to cement ratio (w/c) is lower than that of the mixes prepared using larger size of aggregates. This may be because the pore size of the mixes prepared using smaller size of aggregate will be smaller in comparison to that of the mixes prepared using larger size of aggregates. considering the results observed by Schaefer et al. (2006) where it as found that the average Portland Cement Pervious Concrete (PCPC) void ratios tend to increase as the aggregate size increases, where river gravel were used in the mix and it is a wellresearched fact that permeability through a mass is typically a function of total interconnected pores and size of the pores.



Compressive strength

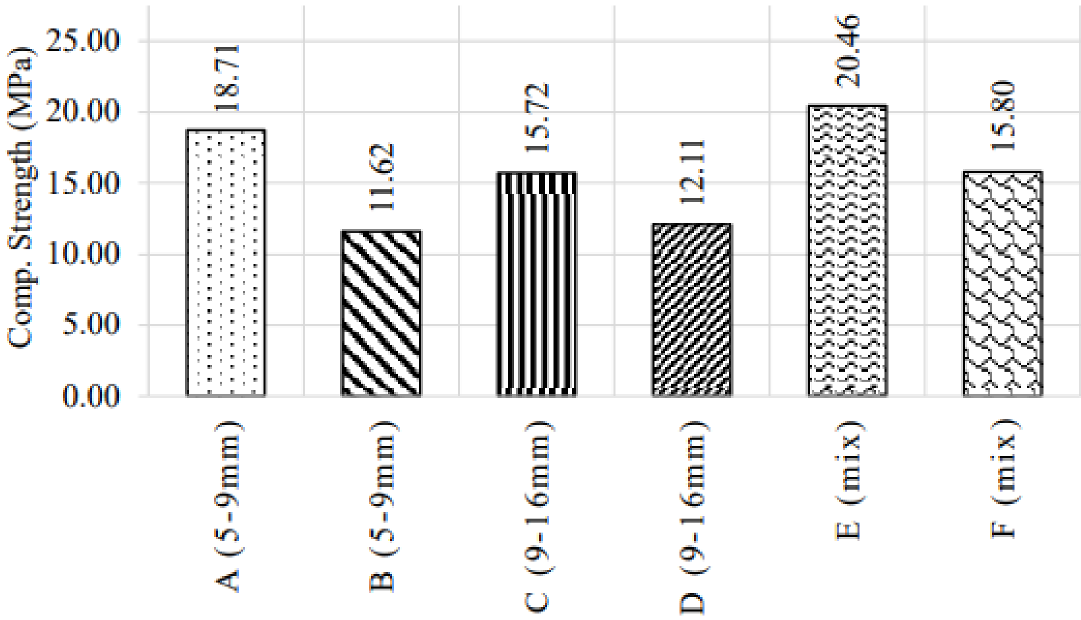


Figure 0.6 Average Compressive Strength of Samples The above figure shows the compressive strength of different PC samples. Samples A and E prepared using cement to aggregate ratio of 1:3 i.e. M20 mix ratio have higher compressive strength with values nearer to 20MPa whereas sample C with similar ratio has only compressive strength of 15.72Mpa. 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

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 ad 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 inn 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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