Hardened properties of pervious concrete using mixed aggregate blended with admixtures

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Abstract: In the present study, a new combination of materials for making pervious concrete have been obtained based on compressive strength and permeability. The investigation is done for finding hardened properties and its main aim is to know the improvement in compressive strength and permeability by different combinations of materials. Also, different tests for void ratio, porosity and water absorption are conducted. The different sizes of aggregate used are 20mm, 12.5mm and 10mm with cement replacement with fly-ash 10%, 20%, 25% and 30% and with maximum cement content 450kg/m³, 500kg/m³ of 53 grade. It is observed that the strength and other properties are highly fluctuating. The maximum compressive strength obtained is 21.3MPa with 450kg/m³ cement content of aggregate combination 60-20-20 with 30% of fly ash. The maximum permeability obtained is 2.87 cm/sec with 450kg/m³ cement content of aggregate combination 20-40-40 with 20% fly-ash. The maximum water absorption obtained is 4.087% with 500kg/m³ of aggregate combination 50-20-30 with 30% fly-ash. The maximum void ratio obtained is 37.545% with 500kg/m³ cement content of aggregate combination 40-30-30 with 25% fly-ash. The maximum porosity obtained is 68.912% with 500kg/m³ cement content of aggregate combination 40-30-30 with 25% fly-ash.

Keywords: Pervious concrete, Compressive strength, Permeability, Water absorption, Porosity, Void ratio

1. Introduction

“Pervious concrete” it is a special type of concrete in which fine aggregate is not used, it consists of a high volume of voids, it is divided into interconnected pores, capillary pores, dead-end pores, which will increase porosity from, permeability. It is mainly used to improve groundwater recharge by the action of percolation. Pervious concrete is used for the development of transportation infrastructure, to avoid water pollution, waterlogging, to control flood run-off and also to improve the skid resistance of roads in rainy seasons. Advantages of pervious concrete are low expansive, low density, it will have good isolating properties. Pervious concrete is made by using ordinary Portland cement which is designed for various applications as per requirements. However, it is used in several parts around the world but still, it is not practised in some countries may be due to some technical issues, material preparation etc. Maintenance of pervious concrete is somewhat difficult due to clogging problems. Research is going on to improve compressive strength, the effect of water to cement ratio, aggregate to cement ratio, aggregate sizes, binding material type, its quantity on strength of pervious concrete and use of recycled aggregate in pervious concrete, use of cement replacing materials like fly-ash, silica fume, GGBFS.
Omkar Deo et al. (2010) [1] studied the improvement of permeability which is reduced due to clogging effect. To avoid this clogging several experiments and models are done with different proportions of aggregate to improve pore structure. Permeability generally is reduced when fine sand is used as clogging material. Here the volumetric porosity, porosity is resolved by image analysis and hydraulic conductivity by permeability cell. Modelling has been done for clogging behaviour. Here the modelling approach is based on the geometrical model and probabilistic particle which was captured in pores. And then by all these modellings and testing the clogging is reduced up to some extent. Lian et al. (2011) [2] developed a mathematical model to characterize the relationship between compressive strength and porosity for porous concrete by analysing empirical results and theoretical derivations. The suitability of existing equations for porous concrete is assessed and a new model is then proposed. Bradley and Andrew (2011) [3] found different techniques for preparation test specimen of pervious concrete. As that specimen should be similar to the pervious pavement which is compared to each other by taking cores from pavements. This comparison is based on porosity, infiltration capacity etc. For this, cylinders of 150mm dia and 300mm height and slabs of 150mm thickness with three different sizes are cast. Correlation between porosity and infiltration is done. The flow chart of the experimental approach is clearly given for 3 cylinders, pavements, and slabs for determining the best specimen. Rasiasriravindra rajah et. al. (2012) [4] prepared a mix design for pervious concrete which is made of recycled aggregate and to replace the cement 70% of its weight with Ground Granulated Blast Furnace Slag (GGBS). Here the relationship developed between permeability, porosity and compressive strength. Based on this the mix design was prepared. The compressive strength relies on type, size, shape of materials and porosity. As the porosity decrease, the strength will be increased. By using this recycled aggregate strength was reduced and porosity improved and there is no change in permeability. The empirical equations for compressive strength and porosity were given for recycled aggregate. Daniel and Jorge (2014) [6] observed that stormwater management can be done by proper drainage systems by involving Sustainable urban drainage systems which impact on the economy, environment, and society. Pervious concrete pavements are the solution for managing urban stormwater runoff. The authors further opined that there are many possibilities based on integrated value models to facilitate the proper selection. For this accurate information is given to know the alternatives. Here a series of variables are modelled by stochastic simulations based on Monte Carlo methods and opinions of experts related to water management about selected criteria comparing with Analytical Hierarchy Process (AHP). Three types of pervious pavement are figured to determine the favourable model.

Ahmed et al. (2014) [7] developed a linear regression relationship to establish relationships between density and porosity, compressive strength and permeability, tensile strength and permeability, and compressive strength and porosity. The results showed that properties such as permeability, porosity, are significantly affected by using either one or two coarse aggregate sizes in all concrete mixtures. Furthermore, density can be an effective factor for predicting compressive strength, and porosity. In this study, the maximum compressive strength was 6.95 MPa, which obtained by using one aggregate size of 9.5 mm with 250 kg/m³ cement content. Ruizhong and Kay (2015) [8] developed an ultra-high-performance cement-based matrix with compressive strengths over 150 MPa and high durability properties are designed and applied to the mixture design concept of pervious concrete. The research results show that compressive strength and elastic modulus increase by up to 150% and 100%, respectively, without sacrificing the hydraulic conductivity of the concrete. Furthermore, freeze-thaw tests have been carried out to compare the durability performance of conventional pervious concrete with high-performance pervious concrete.

Hariyadi and Hiroki (2015) [9] observed the relationship between mechanical properties of concrete with volcanic pumice explored and compared them with those of other researchers’ works and ACI standard. They concluded that utilizing volcanic pumice on porous concrete mixtures resulting in a high porosity (void content) and a low modulus of elasticity of porous concrete. Moreover, by using volcanic pumice a higher tensile strength (flexural strength) than that of ACI standard can be obtained. This volcanic pumice porous concrete is potential for future structure with adequate strength and good impact energy-absorbing. Anush and Krishna (2016) [10] observed that the water to cement ratio is a very
important variable and is lower compared to those used in the conventional concrete mix and has been historically varied over the range of 0.28 to 0.4 with the main intention to provide sufficient cement coating for the aggregates. Tejas Joshi and Urmil Dave (2016) [11] studied the effect of different aggregate size and water-cement ratio on pervious concrete. The experiments are done for determining void ratio, permeability, strength and density. As the strength increased the density also increased was noticed. Rui Zhong and Kay Wille (2015) [12] observed that pervious concrete has remarkable potential to counteract the adverse impacts on the environment while providing necessary structural integrity, thus supporting continued urbanization. Broader application of pervious concrete could be achieved through increased ravelling resistance and enhanced durability performance. This research emphasizes the development and characterization of high-performance pervious concrete aiming at improved mechanical resistance and advanced durability properties. Jiusu et al. (2017) [13] aimed at a solution towards the current deficient strength, durability and inconvenient maintenance in pervious concrete. Substantial performance evaluation indicated that HSPC possesses ideal compressive and flexural strength while maintaining excellent water permeability. Furthermore, an efficient drainage system and clogging-preventing paths from bottom to top were combined in the precast concrete pavement systems to overcome other technical bottlenecks in current pervious concrete technology.

In the present study, an attempt has been made to find out the hardened properties of pervious concrete such as compressive strength, permeability, water absorption, voids ratio and porosity made with different combinations of materials. Also, to know the improvement in compressive strength and permeability by using different combinations of materials.

2. Materials and Methods

2.1 Mix design:
The practice of mix design of pervious concrete is similar to traditional concrete. In our country, there is no suitable or perfect mix design for pervious concrete. As we know IS 12727 1989 [14] it is the code of practice for no fines concrete. This code gives us various proportions of materials which are used in pervious concrete. But this code is not in practice because the maximum compressive strength by using this code is 10MPa. So, to improve the compressive strength based on both codes IS 456 2000 [15] and IS 10262 2009 [16] the mix design of pervious concrete is followed by neglecting fine aggregate. The mix proportions of materials used are shown in tables 1 to 3.

| Mix | Cement / fly ash (kg/m$^3$) | Coarse aggregate (kg/m$^3$) | Water (kg) | Proportion Cement: CA | W/binder ratio |
|-----|-----------------------------|-------------------------------|------------|------------------------|----------------|
| 1   | 450                         | 1861.75                       | 180        | 1: 4.15                | 0.4            |
| 2   | 500                         | 1828.96                       | 197.16     | 1: 3.65                | 0.4            |

Table 1. Mix proportions for 450 kg/m$^3$ and 500 kg/m$^3$

| Sl. No | Mixed Proportions | Aggregate sizes | W/C ratio |
|--------|-------------------|-----------------|-----------|
|        |                   | 10mm 12.5mm 20mm|           |
| 1      | A1                | 50% 20% 30%     | 0.4       |
| 2      | A2                | 60% 20% 20%     | 0.4       |
| 3      | A3                | 40% 30% 30%     | 0.4       |
| 4      | A4                | 20% 40% 40%     | 0.4       |

Table 2. Details of aggregate proportions
Table 3. Percentages of fly-ash and cement

| Designation | Cement (%) | Fly-ash (%) |
|-------------|------------|-------------|
| MFC1        | 90         | 10          |
| MFC2        | 80         | 20          |
| MFC3        | 75         | 25          |
| MFC4        | 70         | 30          |

2.2 Experimental Program
With the above mix proportions, the cubes and cylinders are cast and shown in figure 1.

2.2.1 Compressive strength test
Tested as per IS 516 1958 [17], IS 456 2000 [15] after 28 days curing of the cube (15 cm × 15 cm × 15 cm)

2.2.2 Water absorption test
The water absorption of pervious concrete samples was evaluated by calculating the difference between the dry weight of the cylinder and the saturated weight of the cylinder. By using the equation.

\[
W\% = \left( \frac{w1 - w2}{w1} \right) \times 100
\]

Where,

- w1 is the wet weight of cylinder in kg
- w2 is the dry weight of cylinder in kg

2.2.3 Falling head permeability test to find out permeability

Figure 1. Casted cubes and cylinders

Figure 2. Falling head permeability apparatus
This is one of the methods to find out permeability. The following formula is adopted in the present study for falling head permeability test to calculate permeability.

$$K = \frac{a \times L}{A \times T} \log \left( \frac{h_0}{h_1} \right)$$

Where,

- $K$ : coefficient of permeability (cm/sec)
- $a$ : Cross-sectional area of pipe (cm$^2$)
- $L$ : Length of the cylinder (cm)
- $A$ : is the cross-sectional area of the cylinder (cm$^2$)
- $T$ : Time taken for head to fall from $h_0$ to $h_1$
- $h_0$ : Initial water head (cm)
- $h_1$ : Final water head (cm)

2.2.4 Void ratio

The void ratio of the cylinder is calculated according to ASTM C1688 [18]. Void ratio is explained as the total percentage of voids present divided by the volume of the specimen. The equation is given below.

$$\text{Void ratio } \% = \frac{T - D}{T} \times 100$$

Where,

- $D = (M_c - M_m)/V_m$ (Density)
- $M_c$ = Mass of measure filled with concrete
- $M_m$ = Net mass of concrete by subtracting the mass of measure
- $V_m$ = Volume of measure
- $T = M_s/V_s$ (Theoretical Density)
- $M_s$ = Total mass of materials batched
- $V_s$ = Total absolute volume of materials

2.2.5 Porosity

The total porosity was calculated by measuring the difference between the weight of the dry cylinder and weight of the submerged cylinder and dividing with the volume of the cylinder. Using formula

$$P = 1 - \left( \frac{W_1 - W_2}{\rho_w V} \right) \times 100$$

Where,

- $W_1$ = Weight of dry cylinder in (kgs)
- $W_2$ = Weight of submerged cylinder (kgs)
- $\rho_w$ = Density of water (kg/m$^3$)
- $V$ = Volume of cylinder (m$^3$)

3. Results and Discussions

With the proportions of the materials as obtained in materials and methods section, the cubes of 15 cm $\times$ 15 cm $\times$ 15 cm are cast in the laboratory and tested for their 28-days compressive strength with 450 kg/m$^3$ and 500 kg/m$^3$ as maximum cement content. The various results such as compressive strength, permeability, porosity, voids ratio and water absorption obtained are presented graphically and then discussed. The strength and permeability characteristics of various combinations of aggregate with the weight of cement 450 kg/m$^3$ and 500 kg/m$^3$ are shown graphically in figures 3 to 6.

From figure 3, it is observed that the maximum compressive strength obtained for 450 kg/m$^3$ of cement content is 21.3 MPa for MFC4A2450. It is varying in the range of 7.8 to 21.3 MPa. Also, it is observed that the increasing trend of compressive strength from 10% to 30% fly-ash for all combinations of aggregates.
From figure 4, it is observed that the maximum permeability obtained for 450 kg/m$^3$ of cement content is 3.01 cm/sec for MFC4A4450. It is varying in the range of 3.01 to 1.51 cm/sec. Also, it is observed that the decreasing trend of permeability from 10% to 30% fly-ash for all combinations of aggregates.

Figure 3. % of Fly-ash Vs Compressive Strength for 450 kg/m$^3$ cement content

Figure 4. % of Fly-ash Vs Permeability for 450 kg/m$^3$ cement content

Figure 5. % of Fly-ash Vs Compressive Strength for 500 kg/m$^3$ cement content
From figure 6, it is observed that the maximum permeability obtained for 450 kg/m$^3$ of cement content is 2.49 cm/sec for MFC4A4450. It is varying in the range of 2.49 to 1.66 cm/sec. Also, it is observed that the decreasing trend of permeability from 10% to 30% fly-ash for all combinations of aggregates. The water absorption, porosity and void ratio characteristics of various combinations of aggregate with the weight of cement 450 kg/m$^3$ and 500 kg/m$^3$ are shown graphically in figures 7 to 12.

**Figure 6.** Variation of % of Fly-ash Vs Permeability for 500 kg/m$^3$ cement content

**Figure 7.** % of Fly-ash Vs Water absorption for 450 kg/m$^3$ cement content

**Figure 8.** % of Fly-ash Vs Porosity for 450 kg/m$^3$ cement content
From figure 7, 8 and 9, it is observed that for 450 kg/m³ cement content, the maximum values of water absorption, void ratio and porosity obtained are of aggregate combination 50-20-30 with fly-ash 10% is 1.83%, an aggregate combination of 60-20-20 with fly-ash 25% is 18.83% and aggregate combination of 60-20-20 with fly-ash 25% is 41.50% respectively.

Figure 9. % of Fly-ash Vs Void Ratio for 450 kg/m³ cement content

Figure 10. % of Fly-ash Vs Water absorption for 500 kg/m³ cement content

Figure 11. % of Fly-ash vs Porosity for 500 kg/m³ cement content
From figure 10, 11 and 12, it is observed that for 500kg/m³ cement content, the maximum values of water absorption, void ratio and porosity obtained are of aggregate combination 50-20-30 with fly-ash 30% is 4.087%, an aggregate combination of 60-20-20 with fly-ash 25% is 37.54% and aggregate combination 40-30-30 with fly-ash 25% is 68.91% respectively.

4. Conclusions
1. The maximum values of compressive strength and permeability for a combination of water-cement ratio 0.4 and cement content 450kg/m³ obtained are 10.43 MPa, at 30% fly-ash and 2.90 cm/sec at 10% fly-ash for 60-20-20 aggregate combination. For this combination of materials, the maximum values of water absorption, void ratio and porosity obtained are of aggregate combination 50-20-30 with fly-ash 10% is 1.83%, an aggregate combination of 60-20-20 with fly-ash 25% is 18.83% and aggregate combination of 60-20-20 with fly-ash 25% is 41.50% respectively.
2. The maximum values of compressive strength and permeability for the combination of water-cement ratio 0.4 and cement content 500kg/m³ obtained are 13.06 MPa at 30% fly-ash for 20-40-40 aggregate combination and 2.49cm/sec at 10% fly-ash for 60-20-20 aggregate combination. For this combination, the maximum values of water absorption, void ratio and porosity obtained are of aggregate combination 50-20-30 with fly-ash 30% is 4.087%, an aggregate combination of 60-20-20 with fly-ash 25% is 37.54% and aggregate combination 40-30-30 with fly-ash 25% is 68.91% respectively.
3. It is observed from the graph of % of fly ash vs compressive strength drawn for different combinations of aggregates, that, there is a rising trend of compressive strength with increase in fly ash up to 30%.
4. It is observed from the graph of % of fly ash vs permeability drawn for different combinations of aggregates, that, there is a decreasing trend of permeability with an increase in fly ash up to 30%.
5. It is observed from the graphs drawn for % of fly ash vs, water absorption, voids ratio and porosity that there is no specific trend either increasing or decreasing.

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