Mix design challenges of porous concrete pavements modified with mineral admixtures

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Abstract: Pervious concrete has been gaining importance in pavement constructions and low volume road applications. It has applications in parking lots, footpaths and can be used with other materials to prevent erosion. The main problem of porous concrete pavement is its strength. This mainly depends on its pore structure, cement matrix, aggregate gradation, cement content, admixtures and water/cement ratio. The research aims at determining the compressive strength and permeability of pervious concrete with W/C of 0.34. Variations in aggregate sizes is considered and admixtures like fly ash, micro silica, nano silica and superplasticizer are used. The test results show significant difference in compressive strength with variations in admixtures addition. The results were in good agreement in the case of mixtures with W/C of 0.34 and 3% nano silica with respect to compressive strengths and permeability.

Keywords: pervious concrete, porous concrete, permeability.

1. Introduction

In recent years, porous concrete has its wide application in pavement construction as an effective stormwater management tool. With rapid growth in population and continuous urbanization, the percolation of rainfall through the ground has decreased. Porous concrete pavements have become a tool in conservation of water resources. The conventional concrete cannot capture rain water and does not support in percolating into the ground. Moreover, normal concrete in pavement construction utilizes more land for retention ponds and other stormwater management techniques. The major advantage of pervious concrete over conventional concrete is the presence of voids which allows the water to percolate. Pervious concrete also has structural, economic and road - user benefits in pavement systems[1],[2]. However, there is a gap in research and use of pervious concrete as a pavement material. One of the major reasons being lack of standardized technique for material preparation and testing [3],[4]. Various studies have been carried out on various parameters like aggregate grading, type of aggregate, cement paste content, water-binder ratios etc [3]. The mechanical properties such as compressive strength, permeability and void content have been studies through these parameters [3], [5],[6],[7],[8],[9],[10],[11].

Few researchers have emphasized on partial replacement of Cement with rice husk ash (RHA) for testing the properties of pervious concrete [3] [12] and further the strength and abrasion.
characteristics have been improved by addition of super plasticizer, silica fume and polymers [13],[14],[15],[16]. Kevern et al used fibers to improve the freeze and thaw action [17]. Few researchers have introduced rubber in pervious concrete [18]. Recycled aggregates and municipal solid waste incinerated bottom ash have also been introduced into pervious concrete as aggregates [7], [19], [11],[20],[21],[22].

The minimum cementitious material used per volume of pervious concrete varies for about 350 kg/m$^3$ and permeability ranges from 100 to 900 L/min/ m$^2$ of surface [23],[27]. The literature on pervious concrete confirms that the void content and the water percolation rate are directly related. The target compressive strength achieved by most researchers varied between 3.5 to 28 MPa [27]. The selection of superplasticizer should be such that it allows high reduction of water content without disturbing the consistency of the mix [27]. Also, improvement in the mechanical properties such as compressive and flexural strength can be achieved by adding mineral admixtures. The w/c ratio used is around 0.35 to 0.45 with a void content of 15 to 25% [27]

2. Materials and Methods
The work was carried out to find compressive strength, split tensile strength and permeability of pervious concrete by using locally available materials which are given below

2.1 Cement
The cement used was 53 grade Ordinary Portland Cement (Ultra Tech) confirming to properties like specific gravity, initial and final setting time and fineness.

2.2 Fine Aggregates
Natural river sand is used as fine aggregate in the study. The sand is tested for various properties like specific gravity, bulk density and water absorption. In this present study coarse aggregate is partially replaced with 0% , 5 % and 10% fine aggregates.

2.3 Coarse Aggregates
Crushed granite of 10 mm and 20 mm nominal size are used as coarse aggregate. A different proportion of (20 mm: 10 mm) in ratios of 50:50 was used.

2.4 Water
Locally available water has been used for mixing and curing which is potable and free from impurities like oils, salts, sugar, organic materials etc.

2.5 Admixtures
Commercially available fly ash, micro silica and nano silica are used as admixtures . The fly ash used was class F from Hyderabad industries Ltd., Its specific gravity is 1.97. Micro silica used in this work was obtained from Oriental Texvim Pvt ltd). Its specific gravity is 2.2. Nano silica used was from Elkem industries, with its specific gravity as 2.12 and particle size of 17nm.

Figure 1 (a)Fly ash (b) Micro silica (c) Nano silica
Conplast SP 430—superplasticizer is used in this research. It is mixed with 0.7% by the weight of cement and then mixed with water.

2.6 Mixture Proportion
In each of the control mixes, 30% (by weight) of cement was partially replaced by fly ash, 10% by micro silica and 3% by nano silica. The coarse aggregates were partially replaced by fine aggregates by 10% (by weight). About 50% of the total coarse aggregates were taken in size range of 19–9.5 mm and 50% in the size range of 9.5–4.75 mm were used. Based on trails conducted, the desired dosage of plasticizer of about 0.7% by weight of cement was taken. A constant water-binder (w/b) ratio of 0.34 was taken for all mixes. The mixes were designed according to ACI 522 R-10. The mechanical properties such as compressive strength, permeability and void characteristics of pervious concrete have been studied. The details of various mixes used are given in Table 1.

Table 1: Pervious concrete mix designations with quantities of ingredients used in mixtures

| S.No | Mix Designation | Cement Kg/m³ | Sand Kg/m³ | Coarse aggregate Kg/m³ | Water Kg/m³ | Fly ash Kg/m³ | Micro silica Kg/m³ | Nano silica Kg/m³ |
|------|----------------|--------------|------------|------------------------|-------------|--------------|-------------------|-------------------|
| 1.   | PCF0           | 350          | 0          | 1698                   | 119         | 0            | 0                 | 0                 |
| 2    | PCF5           | 350          | 85         | 1613                   | 119         | 0            | 0                 | 0                 |
| 3    | PCF10          | 350          | 169        | 1529                   | 119         | 0            | 0                 | 0                 |
| 4    | FPCF0          | 266          | 0          | 1843                   | 129         | 114          | 0                 | 0                 |
| 5    | FPCF5          | 266          | 92         | 1751                   | 129         | 114          | 0                 | 0                 |
| 6    | FPCF10         | 266          | 184        | 1659                   | 129         | 114          | 0                 | 0                 |
| 7    | MPCF0          | 342          | 0          | 1843                   | 129         | 0            | 38                | 0                 |
| 8    | MPCF5          | 342          | 92         | 1751                   | 129         | 0            | 38                | 0                 |
| 9    | MPCF10         | 342          | 184        | 1659                   | 129         | 0            | 38                | 0                 |
| 10   | NPCF0          | 388          | 0          | 1940                   | 136         | 0            | 0                 | 12                |
| 11   | NPCF5          | 388          | 97         | 1843                   | 136         | 0            | 0                 | 12                |
| 12   | NPCF10         | 388          | 194        | 1746                   | 136         | 0            | 0                 | 12                |

2.7 Casting of pervious concrete
Casting process of pervious concrete is as follows.
1. The materials are tested initially and weighed properly as per the mix design.
2. First aggregates and admixture including cement are mixed for 1 min. Then 50% water is added to the mix.
3. Remaining water with superplasticizer is then added to mix and mixed for 2 min.
4. It is then compacted with tamping rod.
5. The curing is done at a temperature of 20 ± 1 °C, and relative humidity of 95%. After one day, the specimen is removed from the mould and kept into a curing tank for specific age [28].

Figure 2. (a) casting of pervious concrete
3. Testing of specimens

3.1. Compressive strength

Standard cubes of size $150 \times 150 \times 150$ mm were casted for each mix and curing was done. Compressive strength was tested at 7, 28 and 56 days in accordance with the Indian standard IS:516-1959 [3].

3.2. Split tensile strength

Standard cylindrical specimens of size $150$ mm diameter and $300$ mm height were casted for each mix and curing was done. Split tensile strength was tested at 7, 28, and 56 days in accordance with the Indian standard IS:5816-1999 [3].

3.3. Permeability

In order to check the permeability of porous concrete, a special experimental setup has been fabricated based on falling head permeability method (figure 2). This was initiated by Neithalath, Weiss and Olek [24]. Specimens of dimensions $100$ mm dia and $200$ mm height were casted and checked for permeability after 28 days of curing [3].

3.4. Porosity

Pervious Concrete is related to porosity and permeability. The porosity was measured for cylinder specimens based on ASTM C1754 guidelines. The equation for calculating it is as follows:

$$P = (1 - (W_2 - W_1)/pw \cdot V) \cdot 100\%$$

Where $P$ = Porosity, %

$W_1$ = Weight under water, Kg

$W_2$ = Air dried weight, Kg

$V$ = Volume of sample, m$^3$

$pw$ = Density of water, Kg/m$^3$ [29].

Figure 3. (a) Porosity Test (b) Permeability Test
4. Results and Discussions

4.1 Influence on Compressive strength

The compressive strength of pervious concretes with different percentages of mineral admixtures (with 30% fly ash, 10% micro silica and 3% nano silica replacement of cement) are shown in figure 4 and figure 5. It is noticed that the compressive strength of pervious concrete increased with increase in percentages of fine aggregate. The compressive strength varied from 15.45 to 25.45 MPa (at 28 days). The addition of mineral admixtures has greatly influenced the strength of pervious concrete. The strength of pervious concrete along with admixture has been highest with 10% replacement of coarse aggregate with sand. This trend has been followed by all three mineral admixtures (with 30% fly ash, 10% micro silica and 3% nano silica replacement of cement) at 28 days of curing. The highest strength of 35.56 MPa for 28 days and 40.42 MPa for 56 days is obtained by 3% nano silica replacement of cement and 10% replacement of coarse aggregate with sand. According to Indian standards, the strength requirement for lean cement concrete (LCC) for sub base of flexible pavement should lie in the range of 3.7-7.2 MPa (28 days) and dry lean concrete (DLC) for sub base of rigid pavements should lie in the range of 7.8-10 MPa (28 days) [3]. The results obtained satisfy the Indian standards and hence can be recommended for the use as sub-base material in pavements.

Nano silica has shown a better performance in pervious concrete when compared with flyash and microsilica. Therefore nano silica is highly recommended as sub base in pavements. However different percentages of nano silica as replacement of cement should be checked in pervious concrete. A variation in percentages of flyash and microsilica should also be done to check the performance of pervious concrete.

![Graph representing compressive strengths with different admixtures and percentages of fine aggregates for 28 days curing](image)

**Figure 4.** Graph representing compressive strengths with different admixtures and percentages of fine aggregates for 28 days curing
Figure 5. Graph representing compressive strengths with different admixtures and percentages of fine aggregates for 56 days curing

4.2 Influence on split-tensile strength

The influence of different admixtures and varying percentages of fine aggregate in pervious concrete on split tensile strength is graphically represented in figure 6. It is observed that this graph also follows a similar pattern as that of compressive strength. A highest strength of 3.91 MPa is obtained for pervious concrete with nano silica as replacement of cement and 10% sand as replacement of coarse aggregate. There was a noticeable increase of 17% with fly ash and 10% fines when compared with without fash and fines. Similarly, an increase of 31% and 78% with the addition of micro silica and nano silica is seen.

Figure 6. Graph representing split tensile strength with different admixtures and percentages of fine aggregates for 28 days curing
4.3 Influence on Permeability

The effect of different admixtures along with different percentages of fine aggregate on permeability are graphically represented in figure 6. It is observed that the permeability decreases with addition of admixtures. The highest permeability of 1.48 cm/s is obtained with no admixture and no fines pervious concrete. When admixtures are added, the highest permeability of 0.956 cm/s is obtained with cement replaced with 30% flyash. Among all the mixes, the lowest value obtained is 0.401 cm/s for nanosilica with 10% sand. However, the results obtained fall in the range of 0.1 to 2 cm/s as reported by various researchers [25],[26].

![Image](Figure 6)

**Figure 6.** Graph representing permeability coefficients with different admixtures and percentages of fine aggregates for 28 days curing

4.4 Influence of voids on compressive strength characteristics

The voids percentage with no admixtures and different percentages of sand are in the range of 21.21 to 26.23%. Similarly, 17.34 to 23.24% (for 30% fly ash content), 16.43 to 21.63% (for 10% micro silica content) and 16.11 to 20.98% (for 3% nano silica content). The compressive strength ranges from 15.45 - 35.56 MPa from zero admixtures to 3% nano silica (Figure 7).

![Image](Figure 7)

**Figure 7.** Graph representing permeability coefficients with different admixtures and percentages of fine aggregates for 28 days curing
From the results, it is noticed that the voids percentage is less with nano silica when compared with flyash and micro silica. This is because of more fine particle size. This causes more filler effect and lesser is the void content. Hence the nano silica replacement has shown lesser void content when compared to fly ash and micro silica. The reduction in voids has lead to the compactness of the concrete and increased strength.

5. Conclusions

From the present study, the combined effect of different types of admixtures along with different percentages of fine aggregate on pervious concrete is studied. The compressive strength results obtained with various combinations of fine aggregate percentages along with admixtures recommend the use of admixture based pervious concrete as a sub base material in pavement constructions. Replacement of cement up to 3% by nano silica over 30 % fly ash and 10 % micro silica has significantly increased the compressive strength. However further variation in admixture percentages should be checked. The split tensile strength results follow the similar trend as that of the compressive strength results. The permeability values obtained through various combinations fall within the common range of 0.1 to 2 cm/s as obtained by many researchers. The voids content obtained are also in the permissible range. Finally, it can be concluded that the presence of mineral admixtures enhances the performance of pervious concrete. Among the three admixtures considered for the study, the performance of nanosilica was better. This is because of the filling effect caused by the increased surface area of nano silica particles. The addition of superplasticizer has improved the fluidity of the mix with suitable consistency. It has no specific change with respect to strength rather maintaining proper binding between all the powder content and the aggregates.

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