Penetration and Strength Analysis of Pervious Concrete

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Abstract. Porous concrete is an amalgamation of coarse aggregate, Portland cement, and water, which permits rainfall water to permeate through the surface and into the ground before it runs off. Porous concrete encompasses little or no fine aggregates and adequate cementitious fixative to coat the coarse aggregate while keeping the voids interconnected. IRC 44-2017 states that range of permeability for pervious concrete should be from 0.135 cm/second to 1.22 cm/second and array of compressive strength should be 5MPa - 25MPa. In this experimental study, two properties of no fine concrete namely compressive strength and Infiltration tests were conducted on the pervious concrete of grade M10 and M15 by keeping variation of fine aggregates of 0\% - 5\%. We observed that fines aggregate help to rise the compressive strength of porous concrete but decrease the permeability. Thus, by careful optimization of the mix, pervious concrete can be obtained for suitable use in low strength load.

Key words: Infiltration, Pervious, Permeability, Concrete, Compressive strength

1. Introduction

The infrastructure of every country has a significant influence on its overall development that has resulted in continuous requirement for concrete, the most cherished building material [1]. With increasing demand of construction materials and concern of durability and sustainability Each year, nearly 25 billion tons of concrete are generated around the worldwide to remain in the race, infrastructure construction that is environmentally conscious is crucial [2]. Construction productivity opportunities, such as 13 \% construction expenses, account for the world's GDP. The sector's annual growth rate has increased from 1 \% to 20 \%, with a $1.6 trillion (USD) global opportunity to boost construction sector productivity [3]. Construction productivity prospects, such as the 13 percent of global GDP invested on construction, are enormous. The sector's annual evolution has increase to 1 \% to 20 \% and 1.6 trillion (USD) year global opportunity to boost the construction sector productivity. In the today's developing world is facing rapid industrialization and accordingly availability of resources having good quality is critical. It is now time to embrace environmentally friendly, long-term development methods which are sustainable also [4]. Porous concrete, as well recognised as pervious or no fine concrete, is comprised entirely of uninterrupted lacuna that are purposefully integrated into the concrete. It pertains to a specific entity than traditional concrete, and its physical properties are radically different as a result. It casted using large aggregates with little to no fine aggregates. The concrete fixative then coats the aggregates and consents water to pass through the concrete [5].

Pervious concrete is a high-porosity sort of concrete used for concrete flatwork applications that allows overflowing water to pass through directly, lowering runoff and enabling groundwater
replenishment [6]. Despite ordinary concrete having void ratio of 3-5 percent, no fine concrete can have void ratios ranging from 15 to 40%, liable on the Practice. Porous concrete has a bottom compressive strength, improved permeability, and a lower unit weight than regular concrete, generally by 70% [7]. Adamu et al used response methodology to study the effect of waste materials on strength and durability of pervious concrete. Compressive strength was found to be strongly influenced by the water cement ratio, aggregate cement ratio, aggregate size, compaction, and curing [8]. Xu et al. stated that compressive quality of porous concrete is influenced by the water solid extent, the total solid extent, compaction, and voids. It consequently stretches a blueprint that juxtaposes the effects of altering the total solid extent and compaction imperativeness on compressive quality and perviousness [9]. Bittencourt et al. established a correlation among the voids and water infiltration by recycling pavement aggregates and varying aggregate, cement ratio and aggregate size. It was found that addition of these aggregates can increase the infiltration rate but not necessarily maximize the compressive strength [10]. Liu et al. stated that irrespective of nature of permeable concrete or aggregate size, the outcomes present a nearly linear connection between compressive strength and total void ratio, as well as between coefficient of permeability and total void ratio within a range of 15–30 percent of total void ratio [11]. Huang et al. found that even if the apparent density of additives is nearly the same, the use results in varying compressive strength and porosity of the matrix [12]. Singh and Singh concluded that a combination of 25% recycled concrete aggregates and 5% metakaolin is found to be optimal for usage in porous concrete as low-cost strength enhancing materials results in increase of strength [13]. Chen et al. reported that a drop in porosity of previous concrete mixtures was found to increase compressive energy absorbed. Tensile strength values were found to be lower for low fixative content mixtures when compared to high fixative content mixtures of comparable strengths. There was also a decrease in compressive energy [14]. Kim et al. stated that no fine concrete systems have many potential benefits, such as reduced runoff, groundwater recharge, water savings through recycling, and pollution prevention. When opposed to older drainage systems, storm water retention and infiltration is a sustainable and cost-effective process that is ideal for urban environments [15].

The strength and cohesive properties of High-Performance Pervious Concrete are superior. It demonstrated resistance to segregation, ease of compaction, and adequate strength. Zhong and Wille studied the design and effect of cohesive ingredients on a High-Performance Pervious Concrete that can reduce the total void ratio and porousness while increasing compressive strength and elastic modulus significantly [16]. Tang et al. found the perviousness of High-Performance Pervious Concrete without inclusion of silica as satisfactory. However, when High-Performance Pervious Concrete was made with diverse aggregates the permeability values ranged. The strength of High-Performance Pervious Concrete was found to increase as the total void ratio decreases [17]. Vieira et al found that the addition of a thickening agent affects the porosity or total void ratio; however, the improvement in strength is due to a strong bond between the cement fixative and the aggregate produced by the thickening agent [18]. Chen et al. investigated the affiliation between air content and compressive strength. As anticipated, a rise in air content jeopardizes concrete's compressive strength. This happens for the reason that aggregate filled space that used to be occupied by aggregate is here and now filled with air, reducing the structural stuff in the concrete [19]. Muthaiyan and Thirumalai investigated properties such as consistency, material proportion, specific weight, as well as curing in an effort to enhance perviousness in no fine concrete. It was signified that the compressive strength was affected by the water/cement ratio and the aggregate/cement ratio when different aggregate/cement ratios and size distribution of the aggregates was considered [20]. With these considerations, an attempt has been made to prepare pervious concrete of M10 and M15 grade and their properties has been explored for further applicability.

2. Materials and methods
IS 12269 – 1887 conforming Ordinary Portland Cement (OPC) of grade -43 (Table1) was used. Natural Fine aggregate used for study as following the guidelines to zone II of IS: 383-1987. Natural
Fine aggregate size of less than 4.75 mm. Natural coarse aggregate with a maximum size of 20 mm and a minimum size of 10 mm is used for research in accordance with IS: 383-1970 (Table 2). For compressive strength, 150 mm x 150 mm x 150 mm cubes specimens (Table 3) were prepared. For the Infiltration exam, 100 x 200 mm cylinders were cast. All test specimens were kept at room temperature for 24 hours after casting before being demoulded. Afterward, they were placed in the water tank to cure. Compressive Strength test (Figure 1) and for Infiltration test on specimens were performed at 7 and 28 days in conformity with provision of IS: 516- 1959 & IRC 44-2017 respectively [6].

| Parameter             | Value        |
|-----------------------|--------------|
| Fineness              | 4%           |
| Standard consistency  | 32%          |
| Initial setting time  | 155 min.     |
| Final setting time    | 210 min.     |
| Soundness             | 10 mm        |
| Specific gravity      | 3.10         |

Table 1. Characteristics of cement

Table 1. Properties of Aggregates

| Properties             | Fine aggregates | Coarse aggregates |
|------------------------|-----------------|-------------------|
| Specific Gravity       | 2.58            | 2.67              |
| Grading                | Zone II         | 10 mm             |
| Water absorption       | -               | 0.88%             |
| Fineness modulus       | 2.50            | 7.01              |

Table 2. Mix quantity for batches (1cu.m)

| Parameters                              | M10 with no fine aggregates (A) | M10 with 5% fine aggregates (B) | M15 with no fine aggregates (C) | M15 with 5% Fine aggregates (D) |
|-----------------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Mix Ratio                               | 1:0:6.04                        | 1:0:3.671                       | 1:0:4.4                         | 1:0.21:4.30                     |
| Target strength (N/mm²)                 | 14.13                           | 14.13                           | 19.95                           | 19.95                           |
| Water/cement                            | 0.38                            | 0.38                            | 0.38                            | 0.38                            |
| Void content                            | 24%                             | 24%                             | 15%                             | 15%                             |
| Fixative volume (% void content)        | 18%                             | 10%                             | 25%                             | 24.5%                           |
| Cement content (kg/m³)                  | 259                             | 252                             | 367.64                          | 360.29                          |
| Water content                           | 98 kg/m³                        | 96 kg/m³                        | 140 kg/m³                       | 137 kg/m³                       |
| Mass of Coarse aggregates               | 1566 kg/m³                     | 1693 kg/m³                     | 1620 kg/m³                      | 1552 kg/m³                      |
| Mass of fine aggregates                 | ----                            | 77 kg/m³                       | ---                             | 79.255 kg/m³                    |

Mix Design
- Method used = IRC 44-2017
- Grade of concrete = M10 and M15
- Type of cement = OPC grade 43
- Minimum permeability = 350mm/min
- Specific gravity of cement = 3.15
• Specific gravity of coarse aggregate = 2.7
• Water absorption = 0.5%

Figure 1. (a) Specimen under Compressive strength test (b) and (c) specimen after cracks

3. Results and discussion

3.1. Density
Figure 2 illustrates that the comparison of density of specimens without and fine inclusion of fine aggregates. It is evident that there is an enhancement in density values with increase in grade of pervious concrete due to presence of more quantity of cement. Similarly, it is clear that with inclusion of fine aggregates in M10 as well as M15 grade pervious concrete. The rise in density of pervious concrete specimen B and D as compared to A and C may be attributable to the inclusion of fine aggregates in the mix. The density of pervious concrete and porosity as well as infiltration rate are correlated and must be controlled to get better performance [21,22].

Figure 2. Variation of Density
3.2. Compressive strength
The compressive strength findings (Figure 3) indicate that grade M10 acquires only 64% of compressive strength at 7 days of curing, but achieves compressive strength that is greater than the IS code's goal compressive strength at 28 days of curing. Grade M15 with 5% fine aggregate able to achieve 83.9% of compressive strength at the curing of 7 days, on other hand compressive strength of M15 with no fine aggregate is 67.1% & days but at curing age of 28 days attain compressive strength which is in excess of target compressive strength as per the IS code. It is clear that fine aggregate in no fine concrete helps to enhance compressive strength [23]. The compressive strength of M10 in addition to 5% fine aggregate rises by 7.46%, and the compressive strength of M15 in addition to 5% fine aggregate boosts by 9.42%. For higher void ratio pervious concrete demands paste volume to maintain the bonds of aggregates. The H$_2$O - to - cement ratio, additive, and amalgamate duration all influence the properties of cement paste [18]. The use of a low H$_2$O / cement ratio results in a cement paste with a high viscosity and high flow, which really is excellent for creating porous concrete. Thus sample M10 with no fines aggregate and M15 with 5% fines aggregate show good compressive strength as well as adequate permeability which lies in the range as per IRC 44-2017. It states that "range of permeability for pervious concrete will be from 0.135 cm/second to 1.22 cm/second and range of compressive strength for porous concrete is 5MPa - 25MPa", our all-tested values within range [24].

![Figure 3. Variation of Compressive strength](image)

| Sample | Compressive strength (MPa) at 7 Days | Compressive strength (MPa) at 28 days |
|--------|-------------------------------------|-------------------------------------|
| A      | 9.05                                | 14.16                               |
| B      | 9.16                                | 15.09                               |
| C      | 13.39                               | 20.23                               |
| D      | 16.74                               | 21.83                               |

3.3. Infiltration rate
The findings of the infiltration test (Figure 4) clearly indicated that the higher permeability of 0.305 cm/sec is managed to achieve with no fine aggregate, followed by 0.289 with a concrete mix that also contains no fine aggregate. As per IRC 44-2017, the permeability range will be 0.135cm/sec to 1.22cm/sec [6]. All of the values fall in the range (Table 4). Fine particles lessened water intrusion in pervious concrete. Higher is the fine content lesser will be void contents and permeability. The concrete with low void contents is prone to clogging by water containing soil particles [18].
4. Conclusion

According to the findings, fines aggregates help to advance the compressive strength of no fine concrete while diminishing permeability. It has been identified that as the size of coarse aggregate dwindling, due to which contact area increases hence the compressive strength increases but on other hand, permeability decrease. Infiltration increases as the aggregate sizes increase; void ratio enhances which positively affect the permeability. The important conclusive points are as follows:

- The most important aspect that had to be preserved was the proper void ratio within the permeable concrete mixture.
- Giving up permeability to gain strength or durability was not considered a viable option.
- While conducting experiment it was noted that compressive strength depends upon various factors like sizes of coarse aggregate, quantity of fine aggregate. The infiltration rate obtained from variation in percentage of fine aggregate and size of coarse aggregate.
- For good quality pervious concrete, we need to find adequate balance between compressive strength and permeability. In future we can conduct studies regarding effect of varying the quantity of fines aggregates on permeability of pervious concrete and effect of sizes of coarse aggregate on both permeability or compressive strength of pervious concrete.

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