Pervious Concrete Incorporating Manufacturing Sand as a Partial Replacement for Coarse Aggregate

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Abstract - Pervious concrete has recently acquired popularity as a low-impact development strategy in pavements due to its structural, economic, and road-user benefits. The use of a single cement replacement material improved the performance of pervious concrete compared to replacing cement with fly ash or using cement alone. The most effective way for increasing the mechanical, hydraulic, and durability performance of pervious concrete was to replace both cement and aggregates with fly ash and produced sand. Replacement of 25% FA with cement was considered viable for cement replacement, while replacement of coarse aggregate with M-sand by 5%, 10%, or 15% was considered practical for aggregate replacement. The PC specimen had a cube size of 150mm x 150mm x 150mm and was cured in water for 7, 14, 28 days. The compressive strength test is performed in a laboratory after curing. The compressive strength of the pervious concrete is then compared to that of the M15 grade of concrete. The PC specimens had cylinder dimensions of 150mm dia by 300mm height and were cured in water for 28 days. Permeability testing is performed in a laboratory after curing.

***Key Words*:** Pervious Concrete (PC), Fly ash (FA), Manufacturing sand (M- Sand), Compressive strength, Permeability.

1. INTRODUCTION

Pervious concrete, also known as permeable concrete, is a type of concrete that allows water to pass through it, lowering stormwater runoff and filtering contaminants. It is formed from a unique combination of cement, water, and aggregate, resulting in a porous structure that allows water to travel through. Fly ash is obtained by burning coal in a thermal power plant, which is abundant and has characteristics similar to cement. Replacing cement with fly ash (10-30%) when constructing pervious concrete is more cost effective than using cement alone and adding manufacturing sand (up to 5%) to increase strength and aesthetic appearance. By releasing stream and thermal energy from the surface, pervious concrete pavement can balance outdoor thermal heat. This is because the underlying strata of the pavement are affected when the surface is covered with undrainable pavement.

Researchers from around the world are very interested in exploring the idea of using pozzolanic materials, particularly FA, as a partial substitute for cement, given the numerous economic and environmental drawbacks of using cement in the production of PC. The use of fly ash to partially substitute cement in the creation of pervious concrete has not yet been thoroughly examined, though. Thus, the purpose of this review study was to talk about previous research on using FA to partially replace cement in the production of PC. The method used in this publication is a thorough review of the results of earlier research, followed by a clear presentation of the data and analysis for future researchers.

1.2. OBJECTIVE OF INVESTIGATION

Investigating the impacts of partially substituting M-Sand for coarse aggregates and FA for cement is our main objective in this study. The permeability and compressive strength of regular M15 grade concrete are measured. Comparable outcomes were obtained for the 25% substitution of FA for cement and the 5%, 10%, and 15% substitution of M-Sand for coarse aggregate in terms of permeability and compressive strength. At 0.36, the water-to-cement ratio did not change during the course of the project's inquiry.

- To evaluate the combined impact of fly ash and manufactured sand in proposed pervious concrete.
- To check the compressive strength of proposed pervious concrete.
- To check the permeability of the proposed pervious concrete.
- To check the workability of the proposed pervious concrete.

2. LITERATURE REVIEW

Cement, coarse aggregate, and water are the ingredients of pervious concrete. These days, the construction sector prefers special concrete. Due to the lack of fine aggregate, pervious concrete is also known as porous concrete or no fine concrete. A novel substance, pervious concrete is made up of cement, water, coarse aggregate, and little to no sand. This cutting-edge substance is also known as "No Fines Concrete." Without sand or fine aggregate, properly constructed pervious concrete can contain between 15 and 30 percent void space. Its pores can be between 0.08 and 0.32 inches (2 and 8 mm), allowing water to flow through it without harming the porous concrete matrix. For flatwork applications, pervious concrete is a unique high porosity concrete that lets water from precipitation and other sources flow through, lowering runoff from a site and replenishing ground water levels 5,7. Porous concrete is sometimes referred to as permeable concrete, porous pavement, or pervious concrete.

Ch. Hari Sai Priyanka [2017]; Experimental Analysis on High Strength Pervious Concrete.

High strength pervious concrete was experimentally analyzed in 2017 by the authors, Ch. Hari Sai Priyanka. Pervious concrete's growing popularity in recent years is mostly due to its standing as a sustainable and eco-friendly building material. Through a battery of strength tests, the strength characteristics of pervious concrete are evaluated in this study, and the results are compared with those of samples of regular concrete. To ascertain the material's characteristics, the primary goals were to do tests for split tensile strength and compressive strength. For these tests, cubes of 150 x 150 x 150 mm were employed.

Nitin M N, Gururaj Acharya, Shaik Kabeer Ahmed (2016); Experimental Study on Implementation of Pervious Concrete in Pavements.

An experimental investigation on the use of pervious concrete in pavements was carried out in 2016 by the authors Nitin M. N., Gururaj Acharya, and Shaik Kabeer Ahmed. This study's main goal was to evaluate and improve pervious concrete's abrasion value, porosity, flexural strength, and compressive strength. The goal of the study was to determine the requirements for reaching particular objectives for strength, permeability, and porosity in porous concrete mixtures. Concrete cubes were cast and inspected at 7, 14, and 28 days of cure in order to perform these experiments. The study's key finding is that, at 7, 14, and 28 days of age, using 0% fine aggregates consistently resulted in the lowest compressive strength.

Elnaz Khankhaje, Taehoon Kim, Hyounseung Jang, Chang-Soo Kim (2023); Properties of pervious concrete incorporating fly ash as partial replacement of cement.

The properties of pervious concrete with fly ash used as a partial cement substitute were experimentally studied in 2023 by Elnaz Khankhaje, Taehoon Kim, Hyounseung Jang, and Chang-Soo Kim. The use of fly ash (FA) in place of cement in pervious concrete (PC) has been the subject of numerous studies. Reviewing the effects of partially substituting FA for cement in PC was the goal of this work. It was determined that 10–30% cement substitution with FA was the ideal level. But when the amount of replacement increases, the hydration process is impacted, leading to a decrease in strength. In comparison to regular PC, PC incorporating FA demonstrated reduced drying shrinkage and increased abrasion resistance. It can be concluded that using FA as partial substitution of cement would be environmentally friendly in association with more sustainable PC.

3. MATERIALS USED

3.1. Cement

High-rise buildings, bridges, and industrial structures that need quick early strength are among the projects that use OPC 53 grade cement, an ordinary Portland cement with a high strength. It has a quick initial setup, high fineness for improved particle distribution, and a compressive strength of 53 MPa after 28 days. It offers exceptional durability and resistance to chemical attacks, making it perfect for heavy-duty concrete projects.

Fig.1-Cement

3.2 Fly Ash

Burning pulverized coal in power plants produces fly ash, a fine, powdery byproduct. It is frequently used as an additional cementitious material in concrete and is mainly made up of silica, alumina, and iron. Fly ash makes concrete more environmentally friendly by increasing its strength, durability, and workability while using less cement. In mass concrete constructions, it lowers permeability, increases resistance to chemical attacks, and aids in regulating the heat of hydration.

Fig.2- Fly Ash

3.3 M-Sand

M-sand, also known as manufactured sand, is a kind of fine aggregate made by breaking down hard rocks, like granite, into particles the size of sand. In building, it replaces natural river sand, especially for making mortar and concrete. Compared to natural sand, M-sand has a number of benefits, such as constant quality, controlled gradation, and less contaminants like silt or clay.

Concrete's strength and endurance are increased by its angular shape, which strengthens the bond with cement paste.

Fig.3- M-Sand

3.4 Aggregate

20mm coarse aggregate is a common material in construction, especially for road construction and concrete manufacture. These aggregates, which are usually made of crushed stone or gravel, give the concrete mix strength and mass while assisting in load distribution and minimizing shrinkage. For the majority of structural concrete projects, such as beams, columns, and slabs, the 20 mm size is ideal because it strikes a reasonable compromise between strength and workability. Its angular design improves the cement paste connection, creating a strong and long-lasting concrete mixture. Maintaining consistent quality in construction requires proper aggregate grading and hygiene.

Fig.4- Coarse Aggregate

4. METHODOLOGY

To achieve the best results, a systematic strategy is used when adding M-sand and fly ash to concrete as partial substitutes for cement and coarse aggregate. Materials including fly ash, cement, coarse aggregate, and fine aggregate (M-sand) are first chosen and described. M-sand, which is made by crushing rocks, is used in place of natural sand, and fly ash, a byproduct of burning coal, is used to partially replace cement. A control mix and trial mixes with different ratios of fly ash (e.g., 25%) and M-sand (e.g., 5%, 10%, 15%) are then created using concrete mix design, frequently in accordance with IS: 10262 or ACI 211 criteria. The components are then precisely batch-baked and mixed to create these experimental mixes, guaranteeing that fly ash and M-sand are distributed evenly.

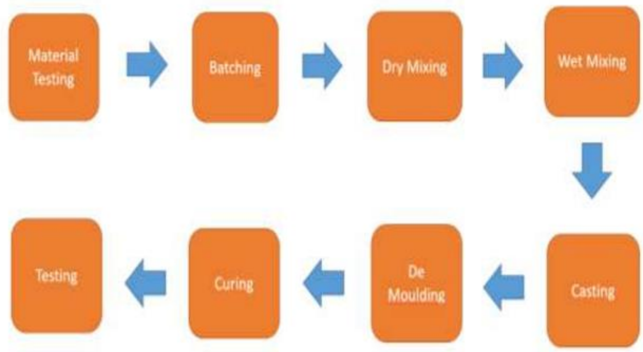

Fig.5 Work flow pattern

5. TESTING OF CONSTITUENT MATERIALS

5.1 Cement

All concrete mixtures contained Dalmia Cement Limited's Ordinary Portland Cement of Grade 53 (OPC 53). The methods outlined in Indian Standard standards are used to assess the physical characteristics of cement, such as its fineness, standard consistency, initial setting time, and specific gravity. Cement's fineness was assessed using the method outlined in IS 4031(Part 1):1996.

Table No. 1 Summary of test result for cement

Sr. No.	Properties	Result
1	Colour	Grey
2	Fineness	1.55
3	Specific Gravity	3.15
4	Standard consistency	31%
5	Initial setting time	35 min

5.2 Fine Aggregate

In the project activity, manufactured sand is utilized as fine aggregate. Using the pycnometer bottle method, the specific gravity of M-sand was determined in accordance with IS 4031(Part 11):1988.

Table No 2. Summary of test result for Manufacturing Sand

Sr. No.	Properties	Result
1	Type	Artificial
2	Partical shape	Rounded
3	Grading zone	Zone II
4	Specific Gravity	Zone II

5.3 Coarse Aggregate

In this experimental program, coarse aggregate with a nominal size of 20 mm is utilized. The methods outlined in Indian Standard standards are used to assess the physical characteristics of coarse aggregate, such as sieve analysis and specific gravity. In accordance with IS 2386(Part 1):1988, aggregates were sieved through a series of sieves to provide sieve analysis, which was then compared to IS 383:1970 standards.

Table No. 3 Summary of test result for Coarse Aggregate

Sr. No.	Properties	Result
1	Type	Natural
2	Partical shape and size	Angular & 20mm
3	Specific Gravity	2.70

6. MIX DESIGN

- Grade Designation – M15
- Type of cement- OPC 53 Grade
- Maximum Nominal Size Aggregate- 20mm

6.1 Target Strength

f'ck = fck + 1.65*s (as per IRC 44-2017)
Where,
f'ck = target mean compressive strength at 28 days, N/mm2
fck = characteristic compressive strength at 28 days,N/mm2
S = standard deviation of compressive strength, N/mm2

Standard Deviation:- the value of standard deviation given in Table 18 for mix designs based on compressive strength may be assumed for proportioning of mix.

IRC: 44-2017 (Table no.18) Assumed Standard Deviation Values for mix design based on compressive strength (considering good quality control)
From Table 18, standard deviation, S = 3 N/mm2, Therefore, target strength,
f'ck = 15+1.65×3
f'ck = 19.95 N/mm2

6.2 Water-Cement Ratio

Assume w/c = 0.36 (As per IRC 44-2017, CL.6.3.3)

6.3 Void content

Void content = 25% for percolation rate of 350 mm/min (As per IRC : 44-2017 Table no 19)
IRC: 44-2017 (Table no.19) Estimation of Approximate void content for Different Rates of percolation (Percolation Rate as Measured by Permeability Test Method given in Annexure-A)

6.4 Estimation of Paste Volume (Vp), cement (Wc) and Water content(W)

Paste volume = 17% for 25% of void content (for lightly compacted)
(As per IRC 44-2017, Table No- 21)

Paste Volume
Vp = Cement Volume + Water Volume
0.17 = Wc/3.15*1000 + (0.36*Wc/3.15*1000)
Wc = 393.75 kg/m3

Water Content
W = 0.36*393.75
= 141.75 kg/m3

Volume of Coarse Aggregate = 1- (Void Content + Paste Volume)
= 1 - (0.25 + 0.17) = 0.58 m3

Mass of Coarse Aggregate = (Volume of CA * Sp.Gr. of CA * 1000)
= 0.58 * 2.7 *1000 = 1566 kg/m3

For 1m3 volume of Concrete contains
Cement = 393.75 kg
Water Content = 141.75 kg
Coarse Aggregate = 1566 kg
Ratio = 1:3.99

7. MIX PROPORTIONING

In Mix 1, we are substituting fly ash for 25% of the cement and M-sand for 5% of the coarse aggregate. In Mix 2, we are substituting fly ash for 25% of the cement and M-sand for 10% of the coarse aggregate. In Mix 3, we are substituting fly ash for 25% of the cement and M-sand for 15% of the coarse aggregate.

Table No.4 Summary of Mix Proportioning

Mix	W/C Ratio	Cement	Fly ash	Coarse Aggregate	M-sand
Mix-1	0.36	75%	25%	95%	5%
Mix-2	0.36	75%	25%	90%	10%
Mix-3	0.36	75%	25%	85%	15%

8. TEST METHODS

8.1 Workability

The IS 1199-1959 was followed for conducting the slump test.No-fine concrete exhibits poor workability since it belongs to the no-slump concrete category. However, there is no connection between the workability of the No-fine concrete and its slump.

Fig.6- Slump cone

8.2 Compressive Strength Test

ASTM C 39 was followed when performing the compressive strength test. For every mix, specimen cubes of 150 mm by 150 mm by 150 mm were made. The specimens were demolded after 24 hours and cured in water for 7, 14, and 28 days prior to testing. In order to reduce the impact of stress concentration, capping was applied to specimens with uneven surfaces. The average of three findings from three identical cubes is the reported compressive strength.

Fig.7- Compressive strength testing

Table No.5 Results of the compressive strength testing

Sr.No.	Mix	Age of cube	compressive strength (N/mm^2)
1	Mix-1	7 Days	9.07
		14 Days	11.02
		28 Days	15.21
2	Mix-2	7 Days	9.16
		14 Days	11.94
		28 Days	17.84
3	Mix-3	7 Days	14.18
		14 Days	19.39
		28 Days	35.72

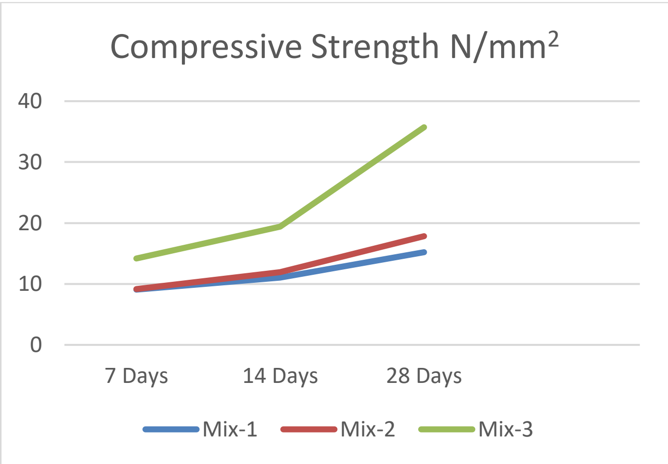

Fig.8- Graphical Representation of Compressive Strength

8.3 Water Permeability Test

The permeability coefficient of pervious concrete is determined by the water permeability test (WPT). Permeability is the most crucial functional performance of pervious concrete, which makes this test crucial. The ability of pervious concrete to drain ponding water from the concrete surface is indicated by its permeability or saturated hydraulic conductivity. It only depends on the properties of the porous medium and measures the medium's resistance to flow. Pervious concrete's permeability was examined using IRC 44-2017 protocol.

Fig.9-Graphical Representation for Permeability tests

Table No. 6 Summary of water permeability test

Sr.No.	Mix	Age of specimen	Time (sec)	Percolation (cm/sec)
1	Mix-1	28 Days	11.56	0.049
2	Mix-2	28 Days	17.57	0.032
3	Mix-3	28 Days	28.03	0.02

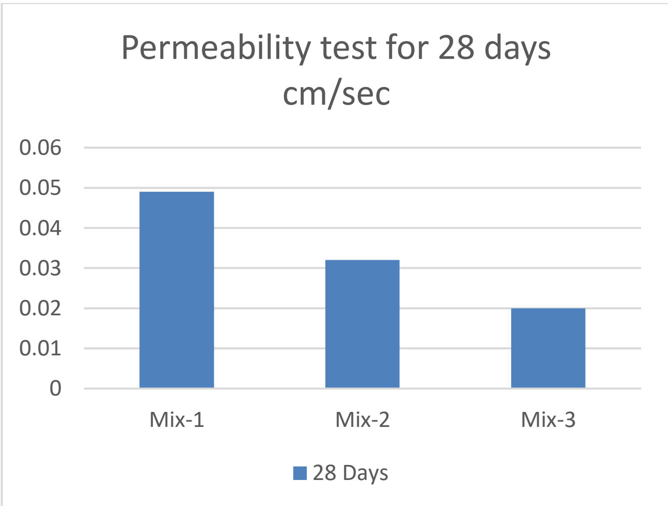

Fig.10- Graphical Representation for Permeability test

9. CONCLUSION

Overall, if mix design and material selection are carefully considered, adding fly ash as a partial substitute for cement and manufactured sand as a partial substitute for coarse aggregate can result in concrete with better qualities.

1. The permeability fluctuates as the aggregate size grows, but when some fines are added, it exhibits a declining pattern.
2. When the cone's frustum mold is raised vertically, the concrete entirely collapses, indicating that it has zero slump value. When tested after 28 days, similar differences in concrete strength were found.
3. The size of the coarse aggregate and the proportion of M sand in the concrete mix have a significant impact on the compressive strength of no-fine concrete.
4. For the 0% blend, a lower compressive strength and a higher permeability value were achieved. However, the addition of M sand produces low permeability but relatively strong strength.
5. We have determined that, for improved strength and permeability, a 10% substitution of M sand is appropriate out of 5%, 10%, and 15%.
6. The strength of concrete is increased by increasing the percentage of manufacturing sand in the suggested pervious concrete.
7. The suggested pervious concrete's permeability is decreased by increasing the percentage of manufacturing sand. 8. The suggested pervious concrete's zero workability and need for trained labor make its installation challenging.

10. REFERENCES

1. M. Dobiszewska, O. Bagcal, A. Beycioˇglu, D. Goulias, F. K¨oksal, B. Płomi´nski, H. Ürünveren U, Utilization of rock dust as cement replacement in cement composites: an alternative approach to sustainable mortar and concrete productions, J. Build. Eng., 69 2023.
2. Dr K N Sheth and Mittal Patel, "A Study on Pervious Concrete Using Construction and Fly Ash as Coarse Aggregate for Infrastructure Engineering", pp 1-9, 2015.
3. Karthik H Obla, " Pervious Concrete - An Overview" The Indian Concrete Journal, August , pp 9-18, 2010.
4. Darshana S Shah and Jayeshkumar Pitroda, " An Experimental Study on Durability and Water Absorption Properties of Pervious Concrete, pp 12-22, 2014.
5. N. Ghafoori and S. Dutta, "Development of No-Fines Concrete Pavement Applications, Journal of transportatioin Engineering, 121(3), pp 283-288, 1995.
6. Brown, Dan, " Pervious Concrete Pavement: A Win Win System, Concrete Technology Today, 24(2), pp 1-3, 2003.
7. Karthik H Obla, " Pervious Concrete for Sustainable Development", Recent Advances in Concrete Technology, pp 1-12, 2007.
8. Myers, D. G. (2007). Pervious concrete (1st Canadian ed.). Worth: New York.
9. M. S. Shetty Concrete Technology: Theory and Practice.
10. U.S.D. of The, U.S.G.S. Interior, U.S. Geological Survey, Cement – mineral commodity summaries, in: Cement Statistics and Information -, Annual Publications, 2020.
11. Perfect, T.J. and Schwartz, B. L. (Eds.) (2002). Structure of pervious concrete.
12. A. K. Chandrappa, K.P. Biligiri, Pervious concrete as a sustainable pavement material – research findings and future prospects: a state-of-the-art review ` 49 | Page
13. Biji.U.I[1], M.Rajeswari[2], Dhaarani.K.K[3], Karthikai Raja.k (2016)"pervious concrete for pavement:
14. International journal of Emerging Technology and Advanced Engineering (IJETAE)-Vol 6, Issue9.
15. 2. Darshan. S Shah[1], Prof. Jayeshkumar Pitroda[2] Prof. J.J.Bhavasar[3] (2013) "pervious Concrete