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EXPERIMENTAL STUDY OF THE EFFECT OF FINE AGGREGATE IN PERVIOUS CONCRETE

EKSPERIMENTALNA ŠTUDIJA VPLIVA DODATKA FINEGA AGREGATA NA PROPUSTNOST BETONA

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Pervious concrete is categorized as porous concrete due to its pore structure and high permeability. The permeability coefficient generally increases with porosity. A 4.75–12.5 mm coarse aggregate is used to make pervious concrete. An experimental study on the impact of a fine aggregate in pervious concrete is conducted in our investigation. The research mix design is done in accordance with American Concrete Institute 522R-10 and Indian Standard 10262. The proportion of water to cement is kept constant. Also, fine aggregates are added to the mix in increments of 2 %, ranging from 0 to 10 %. After adding a fine aggregate, the measured permeability yields various findings. The permeability of pervious concrete diminishes as fine aggregate is added. Also, various parameters such as compressive strength, porosity, split tensile strength, flexural strength and density are computed and analysed. American Concrete Institute 522R-10 states that designs should not include fine aggregate additions greater than 10 % of pervious concrete mixes. Beyond this point, strength is reduced. The flexural strength, compressive strength and splitting tensile strength of pervious concrete mixtures are all increased at an 8 % sand content.

Keywords: compressive strength, mix ratios, pervious concrete, porosity, split tensile strength, void ratio

Propustni beton je vrsta betona, ki ima specifično strukturo por in veliko permeabilnost. Koeficient permeabilnosti te vrste betona narašča v sozvočju z negovo poroznostjo. V glavnem se za to vrsto betona uporablja dodatek grobega agregata (zdrobljeno kamenje, pesek, plavžna žlindra, apnenec itd.) velikosti med 4,75 mm in 12,5 mm. Avtorji tega članka predstavljajo eksperimentalno študijo vpliva dodatka finega agregata na propustnost betona. Preiskovane mešanice so bile izdelane v skladu z ameriškim standardom American Conrete Institute 522 R-10 in kodo indijskega standarda Indian Standard 10262. Razmerje med deležem vode in cementa v mešanicah so obdržali konstantno. Prav tako je v izdelanih betonskih mešanicah dodatek finega agregata naraščal v korakih po 2 % v območju med 0 % in 10 %. Dodatek finega agregata betonskim mešanicam je povzročil spremembo permeabilnosti in drugih lastnosti betona. Permabilnost betona se je zmanjševala z naraščanjem dodatka finega agregata. Izvedene analize in izračuni so prav tako pokazali, da so se spremenile lastnosti betona; kot so poroznost, tlačna in cepilna trdnost ter gostota betona. Ameriški standard za propustni beton (American Concrete Institute 522 R-10) določa, da vsebnost finega agregata v betonski mešanici ne sme biti večja od 10 %. Nad to točko se trdnost prepustnega betona preveč zmanjša. Rezultati raziskave so pokazali, da sta se pri izdelanem betonu, ki je vseboval 8 % finega agregata, najbolj zvišali vrednosti za upogibno in cepilno trdnost.

Ključne besede: tlačna trdnost, sestave mešanic, propustni beton, poroznost, cepilna in natezna trdnost, razmerje in velikost praznin

1 INTRODUCTION

Pervious concrete (PC) has a large porosity and is easily permeable to water. Therefore, it can only be used in situations when it is necessary to drain water through precipitation or other sources. This significant porosity is caused by the absence of tiny particles. PC is also known as "no-fines concrete" as it is very important in creating a sustainable environment and it is a high-porosity form of concrete commonly utilized for concrete flatwork applications. It is also a subject of extensive research around the world. PC reduces site runoff and allows groundwater recharging.[1] There is a chance that PC can lessen flood flows. Porous PC may collect surface water and afterwards allow it to seep further towards groundwater and subgrade level, which is one of the greatest stormwater treatment solutions.[2] A PC paving material is made of cement, uniformly sized coarse aggregate, water and lesser, or no, fine aggregate. Constructions that use only coarse aggregate in the concrete mix have high porosity and permeability. Quick drainage of stormwater is accomplished by utilizing PC pavements. In addition to acting as a sound barrier, PC also lessens any urban heat island.[3,4]

Because of the rapid population growth, it is essential to concentrate on sustainable construction. Also, urbanization requires more pervious surfaces, including sidewalks, road infrastructure, build-up spaces for parking lots and so on. These amenities have an immediate impact on the ecosystem. For instance, effective stormwater runoff control can result in a more effective water management.[5] The volume of impermeable areas increases

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along with the global population. As a result, problems like flood catastrophes or urban heat islands get worse. PC, which has a porous surface, emerged as a possible substitute used to decrease impervious surface adverse effects. PC has not been used much on busy roads because of its weakness due to its high porosity.[6] To enhance PC's mechanical strength, numerous experiments have been conducted. There are only two ways to make PC stronger. One of them is to increase the area of the binder and the other is to strengthen the cement paste.[7] By expanding the binder area, small-sized aggregates are used to strengthen PC and it is found that this enhances its mechanical strength. The goal is to enhance the contact area by employing small aggregates, which can increase the mechanical strength. A larger aggregate, on the other hand, provides more PC strength. Increasing the aggregate size enhances the hardness of PC at the same void ratio. This improvement occurs due the formation of a thick outer paste, which facilitates the interaction between large aggregate particles when appropriate compaction and surface vibration are applied.[8] PC is not being widely used notwithstanding its many advantages, including lowering noise pollution, recharging groundwater and decreasing the urban heat island effect.[9] This is because of its restricted strength attributes and the lack of regulations for its use on high-traffic roads.

Portland cement, chemical admixtures, water and coarse aggregate are the main ingredients of PC. Due to higher voids caused by the absence of fine aggregate, liquid flows through it and attains the ground level. Its strict consistency sets rules for how it must be treated and used.[9] Permeable pavements may reduce any potentially hazardous elements as well as screen out contaminants that lead to water contamination.[10] Porous concrete should have the required strength, dynamic stability, permeability, volume stability and scouring resistance to be employed as the base layer of a road as well as in the coarse overlay. As a result, PC seems to be an effective remedy for several problems. Based on environmental advantages like reducing tire-pavement interaction disturbance, regulating storm water runoff and restricting pollutants invading groundwater, an aggregate holding bed would minimize the storm water runoff volume, velocity and contaminants appropriately.[11]

After including fine aggregate in the mix, the ratio was increased from 0 % to 100 % for seven days and twenty eight days and then compressive strength was evaluated. The 28-day infiltration rate shows a clear correlation between the largest rate of infiltration of 273 % when sand gets eliminated from the mix ratio, and sand reductions of much more than 40 %.[12] The aim is to study the effects of fine aggregates on crucial engineering parameters for PC. The following characteristics were determined: density, split tensile strength (STS), permeability, porosity, flexural and compressive strength.

2 EXPERIMENTAL PART

The appropriate ratios for a mix of PC that might produce the best results were determined through a mix design. Cement, water, coarse aggregate, admixtures and an amount of fine aggregate were some of the components employed in this experiment.

2.1 Materials

The most popular kind of cement, ordinary Portland cement (OPC) was employed in this research. OPC cement having a grade of 53 was utilized throughout this experiment. The experiment used common Portland cement which complied with the IS 12269-1989[19] standards. Crushed aggregates with a size of less than 12.5 mm were obtained from local crushing plants. The aggregates that only passed through a 12.5 mm sieve were chosen. In line with IS: 2386-1963, physical characteristics of the aggregates, including gradation, specific gravity, bulk density and fineness modulus, were examined.[12] To achieve the appropriately combined grading, separate aggregates were blended. The experiment employed M sand that was readily available in the market. In compliance with IS: 2386-1963,[15] the aggregate was evaluated for physical specifications such as gradation, fineness modulus and specific gravity. Before using the sand, it was thoroughly dried on the surface. Concrete had be made with potable water that was safe to drink and had a pH value of 6.5. Auramix 200 was added to the mix as an admixture. Auramix 200 is a high-performance superplasticizer for low and high-grade concrete. It is designed for applications that require a lot of water reduction and long workability retention. In this study, the method for the PC mixture percentage design was established based on IS 10262.2009. In these tests, fine aggregate ranging from 0 to 10 % was added at a rate of 2 % intervals. In this experiment, the binder-water ratio in all cases was 0.33. This investigation was conducted not only following IS 10262.2009[14] but also ACI

Table 1: Pervious concrete mix design ratios

Ingredients (g/cm^3)	Mix 1 (M1)	Mix 2 (M2)	Mix 3 (M3)	Mix 4 (M4)	Mix 5 (M5)	Mix 6 (M6)
Cement	0.440	0.440	0.440	0.440	0.440	0.440
Coarse aggregate	1.260	1.260	1.260	1.260	1.260	1.260
Fine aggregate	0	0.0252	0.0504	0.0756	0.1008	0.126
Water	0.13504	0.13504	0.13504	0.13504	0.13504	0.13504
Admixture	8.18×10^{-3}	8.18×10^{-3}	8.18×10^{-3}	8.18×10^{-3}	8.18×10^{-3}	8.18×10^{-3}

522R-10.[13] The mix design ratios for PC are given in **Table 1**.

2.2 Methodology

In this work, the experimental method was applied. There were five different fine aggregate percentages used: (0, 2, 4, 6, 8 and 10) %. Six different types of mixed PC emerged from these changes. In addition to permeability and porosity tests, solid concrete tests after seven days and twenty eight days comprised flexural strength (FS), CS and splitting tensile strength. The initial stage of determining the mixed proportions of the PC formulation was to gather data from many journals, including ACI 522R-10, IS 12727[16] and 10262.2009.[14] Based on the outcomes of lab testing, the components of the mixture used were selected. W/C had to be considered in conjunction with the ACI standard, which was 0.33, as the initial stage in creating the mix design. The moisture content could be lowered by up to 20 % or more when a superplasticizer was applied. Using the superplasticizer, it was possible to reduce the water content by 27.4 % according to the tests. Next, we calculated the quantity of concrete necessary to attain the compressive strength using the 440 kg/m^3 w/c ratio. The number of aggregates could indeed be obtained based on the amounts of water, superplasticizer and cement. As per the ACI standard, experiment results varying between 0 % and 10 % by mass of coarse aggregate at a 2 % increment were used to estimate the composition of the said fine aggregate. In this experiment, OPC cement, coarse aggregate having a size of 4.5–12.5 mm, fine aggregate having a size of less than 4.5 mm, superplasticizer and water were used. **Figure 1** depicts the mix proportions and testing methods involved in this research.

2.3 Compressive strength of concrete

Each set includes eight cubes, four cylinders and four beams. In total, 48 cubes, 24 cylinders and 24 beams were produced. After concrete was mixed, it was poured into a cube mould. Compression testing was performed using a (15 × 15 × 15) cm cube mould. The cube was made in accordance with IS code 516-1959.[13] Concrete was poured into the mould in three stages. Each layer was compacted with a standard tamping bar. The bar's strokes had to be equally distributed across the mould's cross-section. A rodding rod was used to smash each layer of samples 35 times to condense them. After all samples were compacted, the pervious composite samples were left in the mould for over 24 h. After 24 h, the scaffolding was removed and the sample of PC was labelled and treated using water ponding. A compressive strength analysis was conducted using a specialised instrument on samples aged 7 d and 28 d.

2.4 Tensile strength analysis

A splitting tensile strength analysis conducted on a concrete cylinder helped us to determine the concrete's tensile strength. IS 5816:1999[17] was employed. The splitting tensile strength was tested using a cylinder mould with a 150 mm diameter and a length of 300 mm. After the mixture was produced, it was poured into the greased mould, forming 5 cm layers. After that, each layer was manually compacted. To condense it properly, the bar strokes were evenly distributed. Each layer was compacted with 30 strokes of a tamping bar. The formwork was taken off the PC sample, which was then marked and cured by water ponding after 24 h. A compressive strength analysis device was adopted for conducting a splitting strength tensile test on the material after 7 d and 28 d.

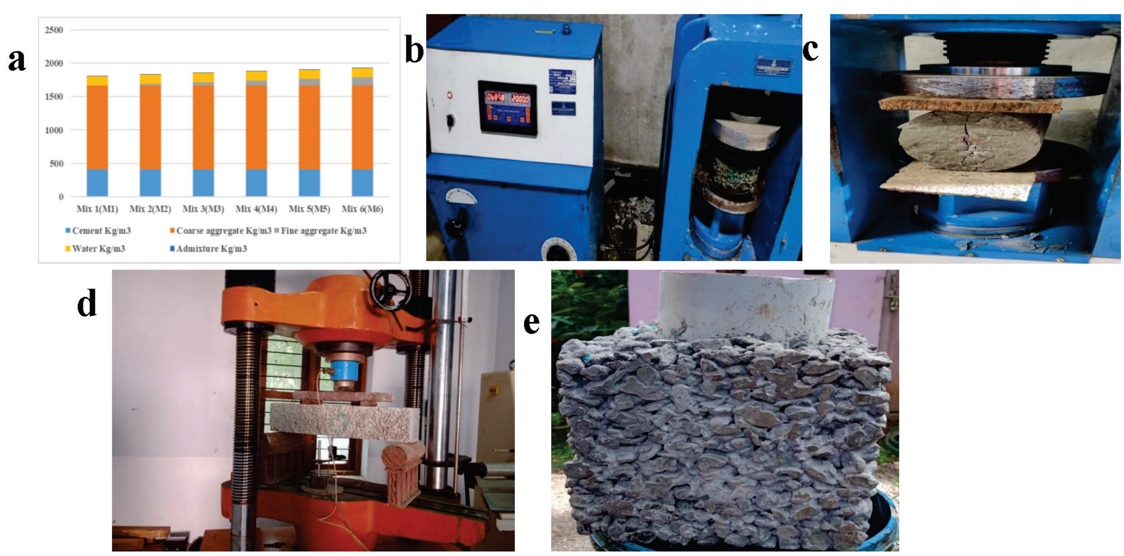

Figure 1: a) Mix design ratios of pervious concrete, b) compressive strength test set-up, c) splitting tensile strength test set-up, d) flexural strength test set-up, e) permeability sample

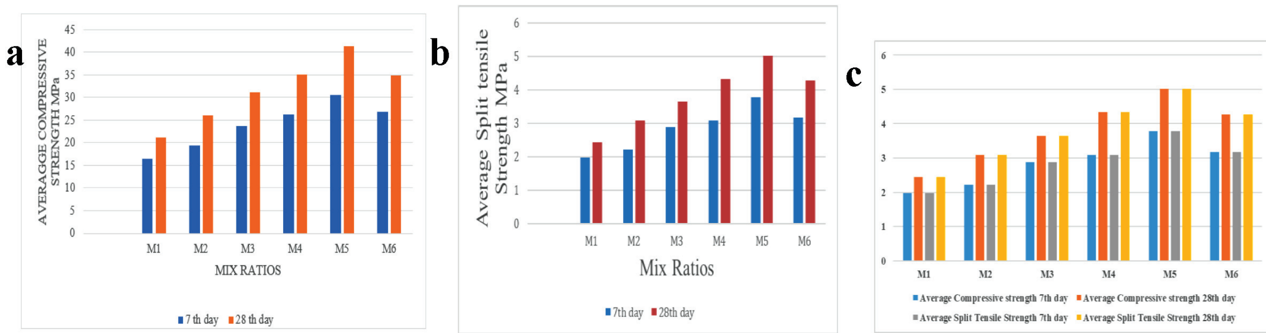

Figure 2: a) Average compressive strength of PC with various percentage of fine aggregate mix ratios, b) average split tensile strength with various fine aggregate mix ratios in PC, c) comparison of compressive strengths and split tensile strengths

2.5 Flexural strength of concrete

A (15 × 15 × 70) cm beam mould was used to test the flexural strength. The mould was filled with three layers of concrete. Each layer was compacted with the standard tamping bar. The bar's strokes were equally distributed across the mould's cross-section. To condense the samples, each layer was tamped 35 times using the rodding rod. The pervious composite samples were placed inside the mould approximately 24 h after most of the samples had been compacted. The formwork was taken off the PC sample, which was then marked and cured by water ponding after 24 h. Whenever a test object was aged for 7 d and 28 d, a flexural strength experiment was performed using the method outlined in IS code 516-1959[13].

2.6 Permeability

The permeability/infiltration was measured in mm/s, showing that porous concrete exhibited a significantly greater permeability than conventional dense concrete. The permeability analysis procedure for determining the infiltration rate of PC replacement is sufficient as per IS 3085-1959.[18] To measure the infiltration rate, each cylindrical PC sample was covered with plastic. The rate of infiltration was estimated with the help of Equation (1) shown below:

$$I = \frac{M \cdot K}{D^2 \cdot t} \tag{1}$$

where I indicates the rate of infiltration at the surface (mm/min), K is Darcy's coefficient of permeability, M indicates the infiltrated water mass (kg), D indicates the rings inside the diameter (mm) and t indicates the time (s).

2.7 Porosity

To measure the porosity of the cylindrical specimens, they were weighed under two different conditions: completely submerged and after being dried for 24 h in air. Additionally, the samples' volume was determined and Equation (2) was used to calculate their porosity.

$$P = \left[1 - \frac{(W_2 - W_1) \cdot 100}{V \cdot \rho} \right] \tag{2}$$

Here, p indicates porosity in %, W_2 stands for the sample weight (air drying – 24 h, kg), W_1 is the sample weight (when immersed in water), V denotes the sample volume and ρ represents the water density.

3 RESULTS

The results of our experiments are described below.

3.1 Compressive strength and tensile strength

Compressive strength results were acquired by testing a total of 36 specimens after 7 d and 28 d. The average split tensile strength values were acquired by testing a total of 24 specimens after 7 d and 28 d and averaging the outcomes. **Figure 2** shows the average compressive strength of PC with various fine aggregate mix ratios, average split tensile strength with various fine aggregate mix ratios in PC and a comparison of compressive strengths and split tensile strengths.

The compressive strength analysis was done after 7 d and 28 d. The PC compressive strength study considered six sand quantities, using six specimens for each quantity. The PC compacted using the rodding technique exhibited the lowest compressive strength, found to be 16.4 N/mm^2 after 7 d and 21.20 N/mm^2 after 28 d. This concrete contained 0 % sand, with no variation in its composition. The greatest compressive strength was found in the PC including an 8 % sand variability, 30.65 N/mm^2 after 7 d and 41.26 N/mm^2 after 28 d. The compressive strength of the PC with a 10 % sand variability was found to be 26.85 N/mm^2 after 7 d and 34.92 N/mm^2 after 28 d. These results show how the compressive strength increases until the optimal quantity of sand is added to the PC mix. The IS12727-1989 standard was complied with during each compressive strength analysis included in this research.

According to the results, the PC splitting strength ranges from 1.98 MPa to 3.17 MPa after 7 d and 2.44 MPa to 4.27 MPa after 28 d. The M1 mixture's lowest value was 1.98 MPa after 7 d and 2.44 MPa after

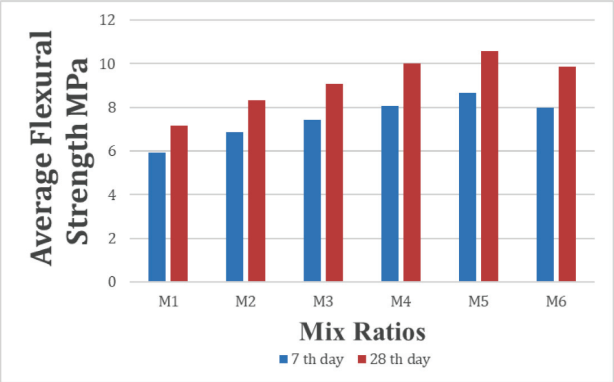

Figure 3: Flexural strength of pervious concrete with various fine aggregate ratios

28 d. The highest results for M5 were 3.78 MPa (7 d) and 5.02 MPa (28 d). The optimum result was 1.75 times the lowest value after 28 d and 1.6 times the lowest value after 7 d. Whenever the void content reached the optimum level and the coarse aggregate's particle size stayed constant, the splitting strength increased.

3.2 Flexural strength

These results were acquired by testing a total of 24 specimens after 7 d and 28 d and averaging the outcomes as shown in the table below. The analysis results for the flexural strength after 7 d and 28 d and graphically represented in **Figure 3**.

In this study, the flexural strength was measured after 7 d and 28 d. Six sand quantity modifications, with six samples, were used for the flexural strength analysis of PC. The PC which had a 0 % sand variability and had been compacted using the rodding technique had the lowest flexural strength. After 7 d, it was 5.92 N/mm^2 and after 28 d, it was 7.17 N/mm^2. The maximum flexural strength was obtained by the PC including an 8 % sand variability, which was 8.65 N/mm^2 after 7 d and 10.586 N/mm^2 after 28 d. The flexural strength of the PC with a 10 % sand variability was 7.99 N/mm^2 after 7 d and 9.87 N/mm^2 after 28 d. These results also demonstrate that the flexural strength increased until the optimal quantity of sand was integrated into the pervious concrete mix. Every flexural strength analysis conducted during our research complied with the IS12727-1989 standards.

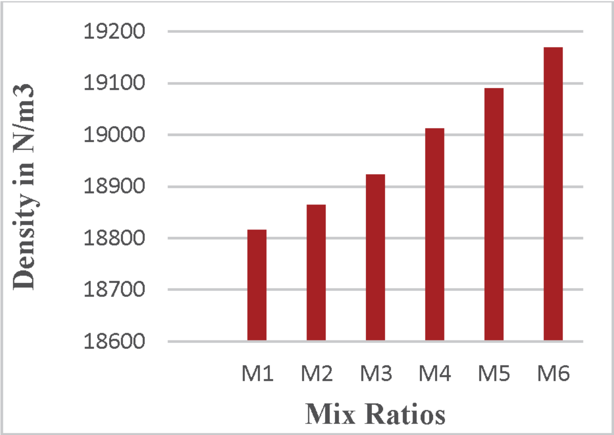

Figure 4: Density of pervious concrete with various percentages of fine aggregate

3.3 Density

The density of PC was calculated using six sand quantity adjustments. The lowest density was created using the rodding process when PC exhibited a 0 % sand variability. The minimum mean value was 18815.58 N/m^3. Furthermore, it was discovered that the mixture including 10 % of fine aggregate had a higher density. Its highest value was 19168.74 N/m^3. It was demonstrated that an addition of fine aggregate increased the density. The analysis of density after 7 d and 28 d is represented in **Figure 4**.

3.4 Permeability and porosity

This research determined the permeability using six different weights of fine aggregate. The maximum permeability was recorded when no fine material was included; it was 9.8 mm/s. When 10 % of fine aggregate was added, a minimum permeability of 4.2 mm/s was obtained. It was demonstrated that the integration of fine aggregate decreases the permeability of PC. Therefore, fine aggregate does have a big impact on the permeability of PC. The test findings showed that the mixture without fine aggregate exhibited a higher porosity. Its value was 28.12 %. When the porosity was 25.79 %, the permeability was at its weakest after the introduction of 10 % fine aggregate. It stands to reason that adding fine aggregate causes the porosity to decrease. PC was used to obtain permeability and porosity results, illustrated in **Figure 5**.

4 DISCUSSION

This study investigated the effects of adding fine sand to PC. The authors used materials such as cement, coarse aggregate, fine aggregate, water and admixture (Auramix 200). The mixture used was based on ACI 522R-10 and IS 10262.2009.[19] Several experiments were conducted.[20,21] The researchers used (0, 2, 4, 6, 8 and 10) %

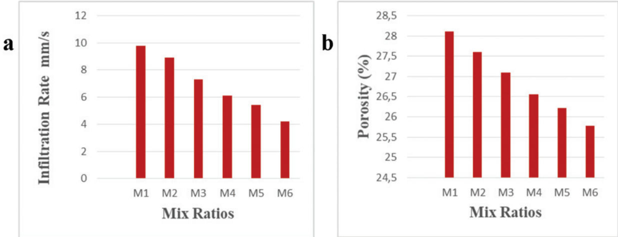

Figure 5: a) Infiltration rate and b) porosity of pervious concrete with various fine aggregate percentages

Table 2: Results for pervious concrete with various fine aggregate percentages

Mix ratios	Average compressive strength		Average split tensile strength		Average flexural strength		Density in N/m^3	Infiltration rate in mm/s	Porosity (%)
	7th day	28th day	7th day	28th day	7th day	28th day			
M1	16.4 MPa	21.2 MPa	1.98 MPa	2.44 MPa	5.92 MPa	7.17 MPa	18815.58	9.8	28.12
M2	19.33 MPa	26.13 MPa	2.21 MPa	3.08 MPa	6.85 MPa	8.32 MPa	18864.63	8.9	27.6
M3	23.75 MPa	31.12 MPa	2.88 MPa	3.65 MPa	7.43 MPa	9.09 MPa	18923.49	7.3	27.09
M4	26.23 MPa	35.1 MPa	3.09 MPa	4.33 MPa	8.05 MPa	10.02 MPa	19011.78	6.1	26.55
M5	30.65 MPa	41.26 MPa	3.78 MPa	5.02 MPa	8.65 MPa	10.58 MPa	19090.26	5.4	26.22
M6	26.85 MPa	34.92 MPa	3.17 MPa	4.27 MPa	7.99 MPa	9.87 MPa	19168.74	4.2	25.79

fine aggregate. The tests was done on samples aged 7 d and 28 d. The testing of compressive strength, flexural strength, splitting tensile strength, density, porousness and permeability was used to evaluate the materials. The results are given in **Table 2**.

5 CONCLUSIONS

An addition of 8 % sand improved the flexural strength, compressive strength and splitting tensile strength of PC mixtures. The mix with a 6 % sand addition showed better results. Adding sand to the mixture increased flexural strength, splitting tensile strength and compressive strength up to a certain degree. Afterwards, the strength was reduced. The mix with a 0 % sand addition had the highest infiltration rate, while the mix with a 10 % sand addition showed the lowest value. That is, as the proportion of fine aggregate in the mix increased, its permeability decreased. The addition of fine sand reduced the permeability of PC. In the case of density, the 0 % sand addition exhibited the lowest density, while the 10 % sand addition showed the highest value. It was found that the density of PC increased with the aggregate content in the mixture. The 0 % sand addition caused the highest percentage of porosity. As this ratio increased, the porosity decreased; the mix with the 10 % sand addition exhibited the lowest value, i.e., when fine aggregate was added, the porosity decreased. This was due to the fine sand filling in the pores of the PC. This research underscores the importance of the PC mix design optimization for achieving a balance between permeability and structural performance. The findings provide a basis for future studies of PC, specifically the role of fine aggregates and other admixtures in enhancing its properties. By advancing the knowledge on PC's material characteristics, this study contributes to sustainable engineering practices, promoting a wider utilisation of pervious concrete in infrastructure projects. This research has significant implications for the development and application of PC, particularly in areas requiring efficient stormwater management and sustainable construction practices. The implications of this study extend to sustainable urban planning and climate resilience. As cities face increased pressure related to stormwater management issues and demand for eco-friendly infrastructure, PC emerges as a viable solution for reducing urban flooding and minimizing environmental impact. By refining the mix design to incorporate the right proportion of fine aggregates, the material's durability and lifespan can be improved, making it more appealing for long-term infrastructure investments. Additionally, understanding the impact of fine aggregates on PC in accordance with material standards and construction guidelines contributes to more effective regulatory frameworks for sustainable construction materials.

6 REFERENCES

[1] A. Bonicelli, F. Giustozzi, M. Crispino, Experimental study on the effects of fine sand addition on differentially compacted pervious concrete, Constr. Build. Mater, 91 (**2015**), 102–110, doi:10.1016/j.conbuildmat.2015.05.012

[2] A. Ahmet, I. H Çağatay, Experimental investigation of the use of pervious concrete on high volume roads, Constr. Build. Mater, 279 (**2021**), 122430, doi:10.1016/j.conbuildmat.2021.122430

[3] T. Chockalingam, C. Vijayaprabha, J. L. Raj, Experimental study on size of aggregates, size and shape of specimens on strength characteristics of pervious concrete, Constr. Build. Mater, 385 (**2023**), 131320, doi:10.1016/j.conbuildmat.2023.131320

[4] O. B. Furkan, S. Sakall, Y. Şahin, The effects of aggregate and fiber characteristics on the properties of pervious concrete, Constr. Build. Mater, 356 (**2022**), 129294, doi:10.1016/j.conbuildmat.2022.129294

[5] Y. Demet, S. Yazici, Experimental study of aggregate size and gradation on pervious concretes' mechanic, hydraulic, and surface properties, Struct. Concr., 24 (**2023**), 5451–5464, doi:10.1002/suco.202200234

[6] Z. Junyu, H. Sun, X. Shui, W. Chen, Experimental Investigation on the Properties of Sustainable Pervious Concrete with Different Aggregate Gradation, Int. J. Concr. Struct. Mater, 17 (**2023**) 64, doi:10.1186/s40069-023-00625-0

[7] F. Althoey, O. Zaid, A. A. ?. Zaid, , C. M. Grădinaru, Y. Sun, M. M. Arbili, A. M. Yosri, Properties of ultra-high-performance self-compacting fiber-reinforced concrete modified with nanomaterials, Nano Rev., 12 (**2023**), 20230118, doi:10.1515/ntrev-2023-0118

[8] M. S. Nawab, T. Ali, M. Z. Qureshi, O. Zaid, N. B. Kahla, Y. Sun, A. Ajwad, A study on improving the performance of cement-based mortar with silica fume, metakaolin, and coconut fibers, Case Stud. Constr. Mater., 19 (**2023**), 02480, doi:10.1016/j.cscm.2023.e02480

[9] L. Ming-Gin, Y. Wang, W. Wang, H. Chien, L. Cheng, Experimental Study on the Mechanical Properties of Reinforced Pervious Concrete, Build., 13 (**2023**), 2880, doi:10.3390/buildings13112880

[10] F. Kajo, V. S. Kumar, A. Romić, H. Gotovac, Effect of aggregate size and compaction on the strength and hydraulic properties of pervious concrete, Sustain., 15 (**2023**), 1146, doi:10.3390/su15021146

[11] A. S. Abdrahman, B. H. Saeed, S. N. Hussein, H. U. Ahmed, S. K. Rafiq, D. A. Ahmad, K.O. Fqi, Impact of substituting coarse aggregate with waste glass granules on the fresh and mechanical properties

of pervious concrete: an experimental study, J. Build. Pathol. Rehabil, 9 (**2024**) 29, doi:10.1007/s41024-024-00390-x

[12] W. S. Heshan, T. Shajeefpiranath, D. N. Subramaniam, N. Sathiparan, A mathematical model to predict the porosity and compressive strength of pervious concrete based on the aggregate size, aggregate-to-cement ratio and compaction effort, Asian J. Civ. Eng., 25 (**2024**) 67–79, doi:10.1007/s42107-023-00757-4

[13] S. Risson, D. B. Kathleen, F. B. G. Sandoval, F. S. C. Pinto, M. Camargo, A. C. de Moura, B. M. Toralles, Contribution to predicting laboratory pervious concrete behavior through density control and coarse aggregate granulometry, Case Stud. Constr. Mater., 20 (**2024**), e02837, doi:10.1016/j.cscm.2023.e02837

[14] Y. Ammar, K. D. Kabagire, New approach to proportion pervious concrete, Constr. Build. Mater., 62 (**2014**) 38–46, doi:10.1016/j.conbuildmat.2014.03.025

[15] S. S. Bright, M. Murugan, Effect of metakaolin on the properties of pervious concrete, Constr. Build. Mater., 346 (**2022**), 128476, doi:10.1016/j.conbuildmat.2022.128476

[16] BIS, Concrete mix proportioning – Guidelines (Standard No: IS 10262) (2009), retrieved from https://law.resource.org/pub/in/bis/S03/is. 10262.2009.pdf

[17] BIS, Methods of Test for Aggregates for Concrete, Part I – Guidelines (Standard No: IS 2386) (1963), retrieved from https://law.resource.org/pub/in/bis/S03/is.2386.1.1963.pdf

[18] BIS, Code of practice for no-fines cast in situ cement concrete – Guidelines (Standard No: IS 12727) (1989), retrieved from https://www.cracindia.in/admin/uploads/IS-12727.pdf

[19] BIS, Method of Test Splitting Tensile Strength of Concrete – Guidelines (Standard No: IS 5816) (1999), retrieved from https://law.resource.org/pub/in/bis/S03/is.5816.1999.pdf

[20] BIS, Method of Test for Permeability of Cement Mortar and Concrete Guidelines (Standard No: IS 3085) (1965), retrieved from https://www.cracindia.in/admin/uploads/IS-3085.pdf

[21] BIS, 53 grade ordinary Portland cement guidelines (Standard No: IS 12269) (1987), retrieved from https://law.resource.org/pub/in/bis/S03/is.8112.1989.pdf