B. TECH. PROJECT REPORT

On

Development of A Functionally Graded Porous Concrete Paver Block (FGPCPB)

BY

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DISCIPLINE OF MECHANICAL ENGINEERING
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Development of A Functionally Graded Porous Concrete Paver Block (PCPB)

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degrees ***of***
BACHELOR OF TECHNOLOGY
in
CIVIL ENGINEERING

Submitted by:
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Guided by:
Dr. Sandeep Chaudhary

INDIAN INSTITUTE OF TECHNOLOGY INDORE

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CANDIDATE'S DECLARATION

I hereby declare that the project entitled **"Development of A Functionally Graded Porous Concrete Paver Block"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'Civil Engineering' completed under the supervision of **Dr. Sandeep Chaudhary, Professor, IIT Indore** is an authentic work.

Further, I declare that I have not submitted this work for the award of any other degree elsewhere.

Sumit Meena (160004039) **Date-**

CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the student is correct to the best of my knowledge.

Signature
Dr. Sandeep Chaudhary
Professor,
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Preface

This report on "Development of A Functionally Graded Porous Concrete Paver Block(PCPB)" is prepared under the guidance of Dr. Sandeep Chaudhary.

An experimental work done on development of functionally graded porous concrete paver block. The different experiments conducted to find the changes in various properties such as surface abrasion, permeability and compressive strength of functionally graded PCPB with compare to normal PCPB.

The results obtained from the present experimental study are presented in the tabular and graphical form.

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First and foremost, I would like to thank our supervisor Dr. Sandeep Chaudhary for guiding me thoughtfully and efficiently throughout this project, giving me an opportunity to work at our own pace while providing me with useful directions whenever necessary. I would like to thank Mr. Sanchit Gupta (PhD scholar) for his constant support and contribution throughout the project. I would also like to thank Mr. Akshay Anil Thakare, Mr. Vivek Gupta and Mr. Sapan Gaur for their invaluable support and guidance. I would also like to express gratitude towards the entire civil engineering materials lab staff and lab members for helping me whole heartedly along the way.

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I would like to take this opportunity to thank our fellow batch mates for being great sources of motivation and for providing encouragement throughout the length of this project.

Finally, I offer our sincere thanks to all other persons who knowingly or unknowingly helped me in completing this project.

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Abstract

Growth of a society is often associated with the amount of construction that has taken place. This constructed space, within the cities, constitute of impermeable surfaces like roads and buildings. These impervious surfaces prevent natural groundwater percolation and result in issues like water ponding. A more environment-friendly solution to this problem is the use of porous concrete in pavement and other similar structures. Porous concrete paver blocks (PCPB) provide groundwater percolation, but are limited in their application due to reduced mechanical and durability characteristics. A more sustainable solution to these issues can be the use of functionally graded porous concrete paver blocks (FGPCPB), which has been developed as a part of this study. The core concept of FGPCPB is the fact that different layers of concrete have different performance requirement. As the top layer experiences maximum stress and abrasion, providing porosity at the top will significantly reduce the performance of concrete as in the case of PCPB. However, lower layers serve the purpose of stress transfer and can be utilized for providing permeability to the concrete paver blocks. Different FGPCPB has been successfully developed as a part of this project based on increasing porosity as a function from top to bottom. A comparison between FGPCPB and PCPB of its corresponding layers show that FGPCB can be a viable and sustainable alternative for addressing the issues arising from lack of water percolation in built-up space.

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Chapter-1

Introduction

1.1 General Background-

In the arena of development most of the surface area in cities is covered by impermeable surfaces like roads, buildings etc. This tends to be a crucial issue because environmental problems are starting to arise because of the impervious area covered by roads around the world, since about 3% of the total surface of the planet is already paved [1]. Because of that, the surface area for infiltration of water is decreasing. So, the water does not find sufficient space for penetration into the ground. And because of that, water ponding occurs on roadways and parking lots. Ponding is the unwanted pooling of water, typically on a flat roof or pavement. The deterioration of many materials hastens due to ponding water. Most of the impermeable roads are made of concrete and asphalt.


Source:https://dynamicmedia.zuza.com/zz/m/original_/b/0/b010 9387-7a2d-44ee-a4fb-561b427a358f/flood_Super_Portrait.jpg


Source: http://redwiretimes.com/wp-content/uploads/2018/12/redwire-singapore-flooding-x7812.png

Figure 1. Water ponding on roads

At the time of the rainy season when the rainwater falling in an area is usually stored in the ground, in canals or lakes, or is drained away, or pumped out. But due to having less surface area for infiltration into the field, if more Rainwater falls or heavy rain is happens then the chances of water ponding is increased. Then because of the low area for infiltration, water cannot be infiltrated into the ground and it can increase the chances of flooding during a rainfall event.

To reduce the problems like water ponding on roads, flooding etc., a permeable(porous) concrete (PC) presented in which some connected voids are existing. It can replace impervious surfaces or roads. From these existing voids in permeable concrete water can pass through it and penetrate in the ground. The porous concrete has been known as one of the best solutions to reduce both air and water environmental impacts due to its multi-functional nature. But porous concrete has some problems like low compressive strength and high surface abrasion that is not good. Porous concrete also has a problem of clogging of voids with time. Because of the clogging of voids, passing of water through it decreases with time.

Concrete is widely used for producing pre-cast paver blocks. Block paving, or paver blocks commonly used for constructing pavements, patios, driveways, and so on. It is used due to its decorative aesthetic, ease of installation, and the fact that the bricks or blocks allow for easy remedial work by removing and replacing those that are necessary. Paver blocks can be used as foundations in ornamentation of roads and parking lots at the industrial and domestic places. The demand for concrete paver blocks is reported to be very high in developing countries for hastily growing their infrastructural facilities.

So, paver block is made of porous concrete to use the qualities of both paver block and porous concrete at the same time that's called as porous concrete paver block(PCPB). But they also have the problems of low compressive strength, high surface abrasion and clogging of pores with time.

The minimum required compressive strength of paver blocks is 30 MPa at 28 days from IS 15658 [2], and porous concrete has the compressive strength in the range between 5 MPa to 25 MPa with 15 to 35 % voids content based upon the IRC 44 [3]. To achieve minimum 30 MPa compressive strength with porous concrete is the main problem of PCPB. After that we can use the porous concrete paver block as pavements.

For solving the problems of PCPB, we try to give a solution by making a functionally graded porous concrete paver block (FGPCPB). Functionally graded PCPB is a concrete block in a layered form more than or equal to two layers.

1.2 Design and Concept of Functionally graded porous concrete paver block-

Functionally graded is the variation in any property of concrete with the change in any material, changes in mix proportion of concrete throughout any direction. Properties like compressive strength, permeability varies like a function of void content (pores) or depth. We make a functionally graded concrete based upon the stress distribution.

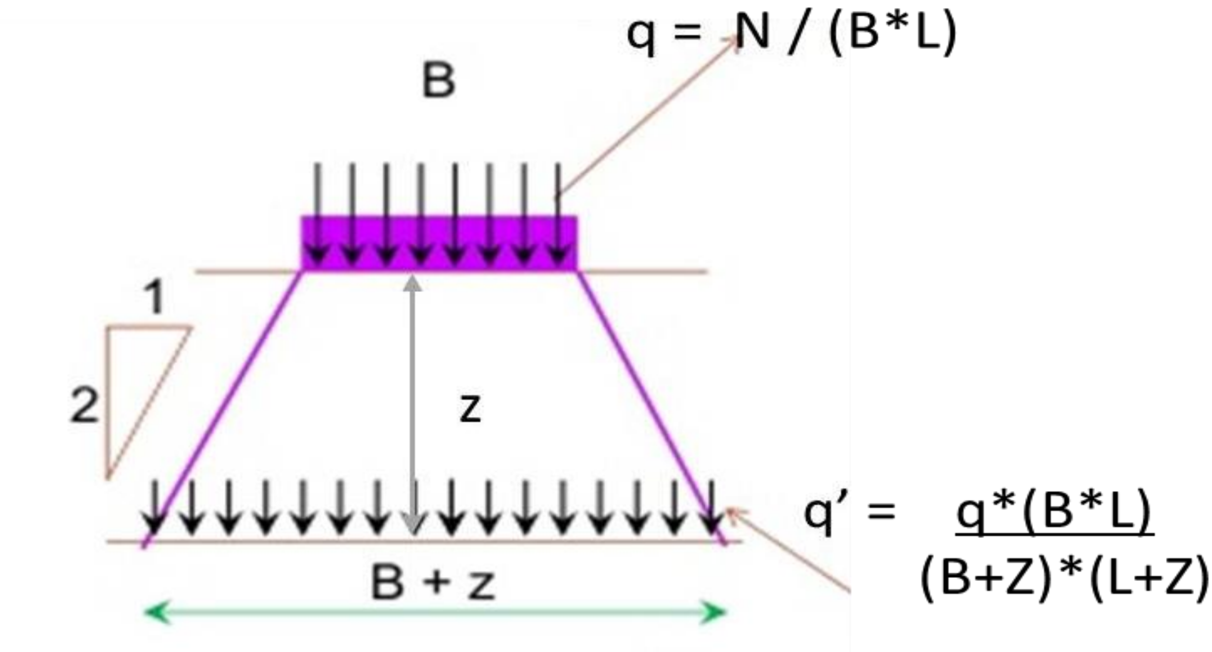


Figure 2. A typical stress distribution diagram

As we see in Figure 1, when the load is applied on the top surface, then the maximum stress will come on the top surface, and as the depth increases, the stress is decreasing because of the increase in load taking area. Based upon this, we found that stress is high on the top surface, and with the increase in depth, the stress decreases. So, we can make a functionally graded PCPB in three-layer, as shown in Figure 2.

Where, top layer plays a role of high compressive strength and low surface abrasion and the

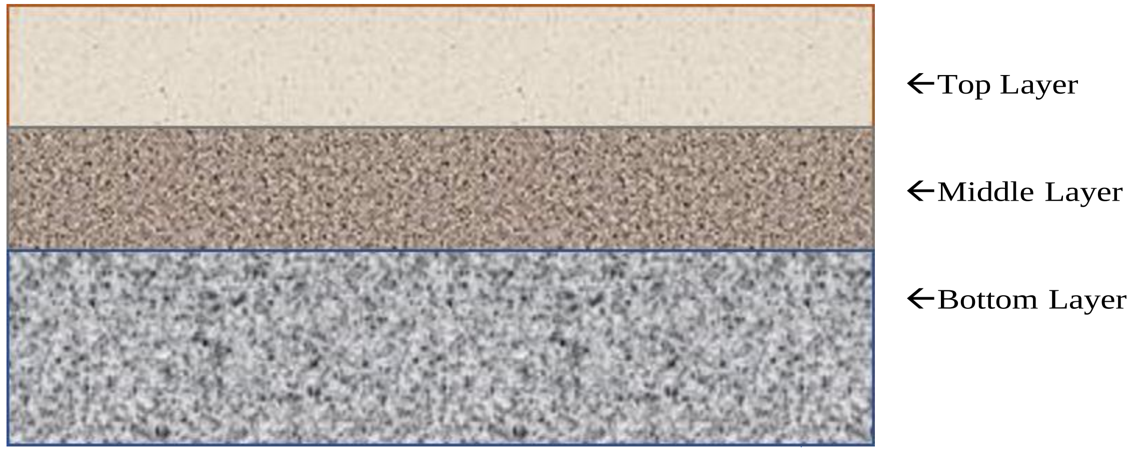


Figure 3. Functionally graded PCPB model

middle layer plays a role of supporting the stress distribution. The bottom layer role is to provide sufficient permeability with comparatively lower strength in comparison to the top layer.

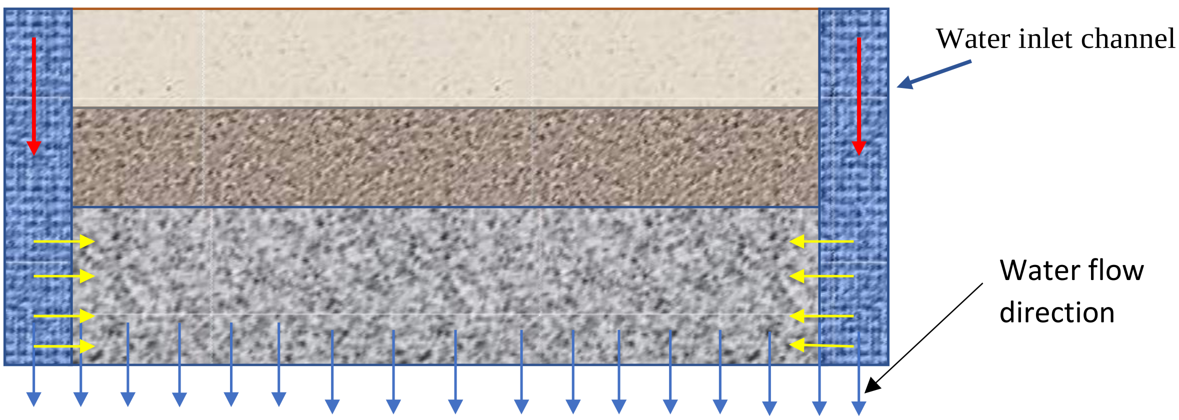


Figure 4. Functionally graded PCPB model with water inlet

For allowing water into pores for percolation, a side-channel was provided shown in Figure 4 with a sufficient infiltration rate, and a suitable filter may be installed from which only water can percolate and clogging of functionally graded PCPB is prevented. If the side channel (filter) is clogged with time, then we can remove it, clean it and again placed it.

1.3 Review of literature-

To enhance the performance of porous concrete paver block(PCPB), it is necessary to have profound knowledge about the properties and behaviour of the PCPB. To improve the features of PCPB, several studies have been carried out. In the recent past studies on porous concrete and paver blocks, many efforts have been done to improve the compressive strength, surface abrasion and permeability of PCPB experimentally and analytically.

Recently, Hidayah et al. [4] carried out a detailed experimental investigation on physical properties of porous concrete paving blocks with different sizes of coarse aggregate. In this, it is clearly shown that the compressive strength of porous concrete is decreasing with the increase in the size of coarse aggregate. It has also been started that the use of open-graded in pervious concrete, increase its void content and the porosity.

However, in another study, Zaetang et al. [5] investigated the properties of porous concrete containing the recycled concrete aggregate, and it is found that the porosity of pervious concrete increased and compressive strength had the low value in case of using recycled aggregate.

Xu et al. [6] carried out an investigation on properties of porous concrete as road base materials and observed that effective porosity has a relation with total porosity linearly. The compressive strength was found inferior to the other road base materials.

In a research article by Chopda and Chattani [7], study was done on the mechanical properties of porous concrete. In this, it was seen that compressive strength varies with the porosity of concrete. It found that the use of fly ash in pervious concrete increase the compressive strength but did not affect the permeability.

In a study, on porous concrete, Lian et al. [8] found out the relationship between the porosity and the compressive strength of pervious concrete on the different percentage use of fine aggregate and for the different values of water-cement ratio with different type of aggregates. They anticipated a model that has a relationship between the porosity and compressive strength.

Bhutta et al. [9] studied the properties like void content, compressive strength and porosity value of porous concrete with the use of recycled waste crushed aggregate. They found that the porous concrete with recycled aggregate has a higher porosity than the porous concrete with normal aggregates and for water permeability, porous concrete with recycled aggregate have enough permeability that required for drainage.

Recently, Joshi and Dave [10] evaluated permeability, compressive strength and void ratio of pervious concrete with changing the aggregate size and water-cement ratio. They noticed that with the increase in density, the compressive strength tend to increase. It was also found that bigger size aggregate reduces the compressive strength and mix of different sized aggregate increases the strength because in mix aggregates, smaller aggregate fills the gaps and that will cause an increase in compressive strength.

In a study done by Sonebi et al. [11] on the mix design and application of pervious concrete, it was found that in porous concrete the interconnected voids are present with the range between 15 to 35% by volume, and it was seen that it might reduce the flooding risk, recharge groundwater, reduce stormwater runoff, decrease noise when in contact with vehicle tires and skidding during rainy season by allowing water to pass easily through its pores. It was also observed that the surface abrasion is increased as we used permeable concrete instead of standard concrete.

Based upon IRC44 [3] the Indian standard code on guidelines for cement concrete mix design for pavements, it is shown in IS 15658 [2] that the previous concrete has the zero slump mix of open-graded material consisting of coarse aggregate, Portland cement, admixture and water with low or no little fine aggregates. The void content range varies from 15 to 35% with the compressive strength of 5 to 25 MPa. And the drainage rate should be in the range of 0.135 to 1.22 cm/sec.

Hernandez et al. [12] carried out investigation on the problems of rainwater and successive infiltration into the ground and they observed that porous concrete is one of the best solutions for reducing water and air environmental influences due to its multifunctional nature. PC also capture the rainwater and increase the infiltration into ground and minimise the stormwater runoff event by rapid drainage of water as well as reducing the on-site noise level [13].

In a recent study by Pennarasi et al. [14] based upon the IS 15658 [2]on paver blocks it has been observed that for the paver block the nominal maximum size of coarse aggregate shall be 12 mm, and the minimum required strength for paver block should be 30 MPa to use paver block in non-traffic areas. The thickness of the paver block should be in the range of 50 to 120 mm. In this study, coconut was used as coarse aggregate, and they found that surface abrasion is more in case of coconut shell as compared to conventional concrete.

Marios et al. [15] did an investigation on the effects of creation pattern and the unit interlock of different block pavements. In this study they observed that the concrete is widely used for producing pre-cast paver blocks because of the wide-ranging uses of these concrete foundations seen for decoration of roads and parking slots at domestic and industrial places. In this study, it was observed that different patterns would affect in terms of varying surface abrasion and the placing of paver blocks. The demand is increasing for the concrete paver blocks in developing countries for fastening growing their infrastructural facilities [15].

Recently Qin et al. [16] carried out a study on a water-retaining paver block for reducing runoff and cooling of paver blocks and Bao et al. [17] carried out studies on a drainable water-retaining paver block for evaporation cooling. In these studies, it was observed that drainable paver have sufficient permeability from the tubes used in the paver block to some height. And because of some water is retained in these paver blocks and when the water evaporates, it will result in the evaporation cooling of paver blocks. In these type of paver blocks, water can store up to a certain height, and above that height, water can infiltrate through the tubes filled with pervious concrete. That is considered as increasing infiltration rate of the drainable paver block.

In this experiments, we took the help of Qin et al. [16] and Bao et al. [17] in which they mainly focused on making of drainable water retaining paver blocks and that blocks can be used for cooling. From these papers, we got the idea for water inlet as side-channel in case of functionally graded PCPB.

In this experimental work, we try to develop a functionally graded porous concrete paver block to solve the problems of PCPB like low compressive strength, high surface abrasion resistance and the clogging of pores. For reducing these problems, we made the functionally graded PCPB in three layers based upon the 2:1 stress distribution concept. Because of that, we used high strength material in the top layer and middle layer for stress distribution and the bottom layer having sufficient permeability with low compressive strength compared to the top layer. After the development of functionally graded PCPB, we compared the properties of functionally graded PCPB with the normal PCPB.

Chapter-2

Experiment

2.1 Material properties-

In this experiment, different materials is used for functionally graded porous concrete mixes. In the mixtures, the coarse aggregates is used of 10 mm standard size range and the river sand used as fine aggregate of zone 2 based upon the sieve size distribution as per IS 383 [18].

Figure 5. Samples of 10mm aggregate and sand

Ordinary Portland cement (43 grade) of specific gravity 3.08 used for the concrete mixes in this study. Specific gravity is 2.64 of fine aggregates (natural sand) and 2.91 of coarse aggregate. Water absorption is 0.83 of fine aggregate and 1.51 of coarse aggregate. Physical and mechanical properties of cement and aggregates have shown in Table 1 and particle size distribution of the fine aggregate (sand), and coarse aggregate has shown in Figure 6.

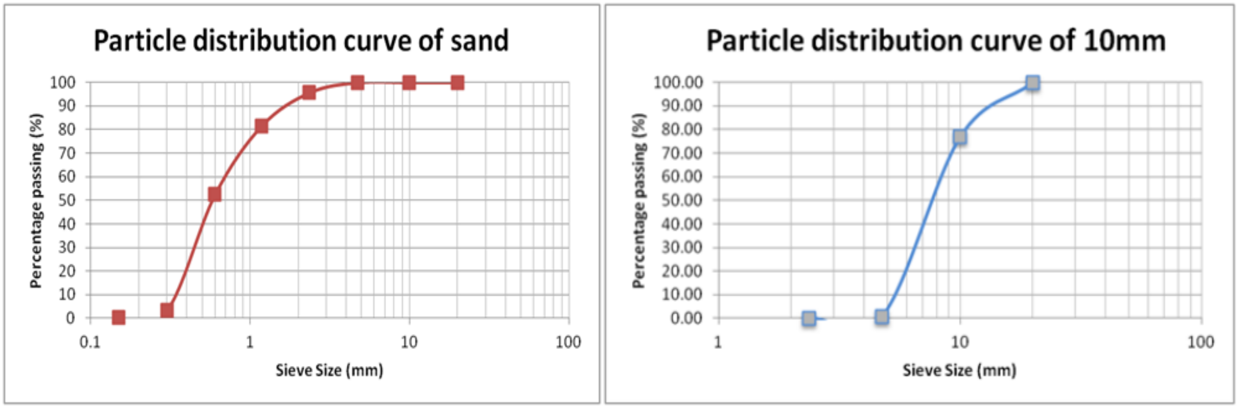


Figure 6. Particle size distribution curve of sand and 10mm aggregate

The values of water absorption, specific gravity, consistency and settling time of materials are coming by tests conducted on cement and aggregates like specific gravity test, consistency test of cement, initial and final setting time test.

Table 1. Physical and mechanical properties of cement and aggregates.

Component	Type of material	Specific gravity	Water absorption %
Coarse aggregate	10 mm single sized aggregate	2.91	1.51
Fine aggregate	River sand	2.64	0.83
cement	OPC grade 43	3.08	-

2.2 Material mixes-

Different concrete mixes are cast with varying percentages of fine aggregates and different cement content for 0.35 and 0.47 w/c ratios. Workability, compressive strength, permeability, stress distribution, surface abrasion resistance and porosity of these specimen determined as per codes guidelines.

At first, An initial mix is prepared for compressive strength more than 30 MPa. After that, a reduction of the % fine aggregate and cement content from the initial mix done to increase the number of voids that will increase the porosity of concrete and decrease the compressive strength of concrete.

A series of concrete from mixes M1 to M9 with different percentage of fine aggregates and different cement content are cast. In the series, the fine aggregate is reduced from all fine aggregate to 0% from the mixes with an decrement of 5%. In this series, the w/c ratio is 0.47 for 0% and 5% reduction of fine aggregate. For other mixes, the w/c ratio 0.35 selected. In concrete mixes, there are four mixes with zero amount of fine aggregate. In these four mixes, cement content is varying from 450 kg/m^3 to 300 kg/m^3 with an decrement of 50 kg/m^3.

Table 2. Concrete mix proportion with varying % fine aggregate, cement content and w/c ratio.

Mix no.	Mix name	Cement content (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water-cement ratio (w/c)	Water (kg/m^3)
M1	NC	442.55	865.83	906.18	0.47	228.59
M2	PC 05	442.55	865.83	775.27	0.47	227.51
M3	PC 10	442.86	984.73	674.27	0.35	175.47
M4	PC 20	442.86	984.73	412.44	0.35	173.29
M5	PC 30	442.85	984.73	150.61	0.35	171.12
M6	PCNF 450	442.85	984.73	0.00	0.35	169.87
M7	PCNF 400	400.00	1025.37	0.00	0.35	155.48
M8	PCNF 342	342.85	1079.56	0.00	0.35	136.30
M9	PCNF 300	300.00	1120.19	0.00	0.35	121.91

2.3 Sample preparation-

Different concrete mixes are prepared using varied percentage reduction of fine aggregate and different water-cement ratio and cement content. These mixes are first dry-mixed for 2–3 minutes in the pan mixer. And then water added to the dry-mix in pan mixer and doing mixing for 2-3 minutes for uniform mixing of aggregates, cement with water to get a good mix. The mixture is placed in 3 layers in moulds with 15 blows per layer with the tamping rod of 16 mm diameter and length of 60 cm. The specimen is covered with plastic sheets and stored at room temperature for

24 h before de-moulding. After de-moulding, sample specimens are placed into water for 28 day curing.

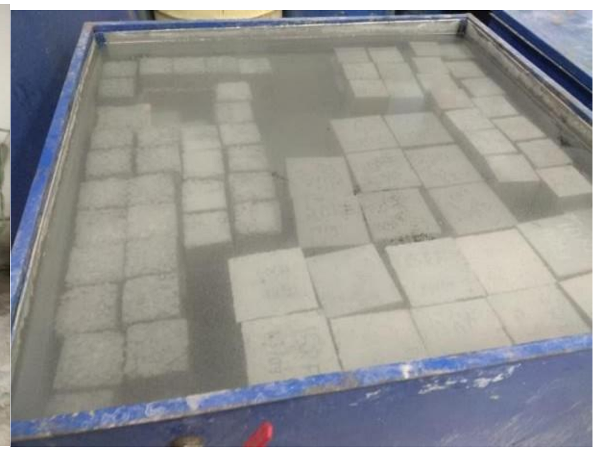


Figure 7. Pan mixer

Figure 8. Curing tank

Later on, based upon seven days compressive strength of nine mixes, three mixes are selected for the casting of functionally graded porous concrete of 100 mm cube size. Three different types of sample are prepared of 100 mm cube. In 1st and 2nd sample, samples are cast in 2 layers of 2 different mixes where each layer have the 50 mm depth of each mix. In the 1st sample, combinations is of M3 and M8. In the 2nd sample, mixes are M3 and M9. In the 3rd sample, samples cast in 3 layers of 3 different combinations where each layer have the 1/3rd (33.33 mm) depth of each mix. In 3rd sample, mixes are M3, M8 and M9. Where mix M8 placed between the mixes M3 and M9. The moulds filled with samples are covered with plastic sheets and stored at room temperature for 24 h before de-moulding. After de-moulding, samples are left for curing process into the curing tank for 28 days.

2.4 Testing programs-

2.4.1 Compressive strength test-

The compressive strength tests is performed following the Standard Test Method for Compressive Strength of 100 mm cube as per IS 156 [19]. Compressive strength tests are carried out on the porous concrete and functionally graded porous concrete of 100 mm cubic specimens. Compression test is done on the UTM(universal testing machine). All cubes are tested at a curing age of 7 days and 28 days respectively. Three replicates tested for each type of specimens. The sample specimens are placed in between compression plates of UTM and the stress is calculated based on the formula:

Figure 9. Universal testing machine (UTM)

$$\sigma = \frac{P}{A} \qquad \text{Equation 1}$$

Where:

σ = the ultimate stress in MPa

P = the ultimate load in newton as obtained from UTM

A = the area perpendicular to the applied load, in mm^2

The results of the compressive strength test based on the average of the three replicates.

2.4.2 Stress distribution test-

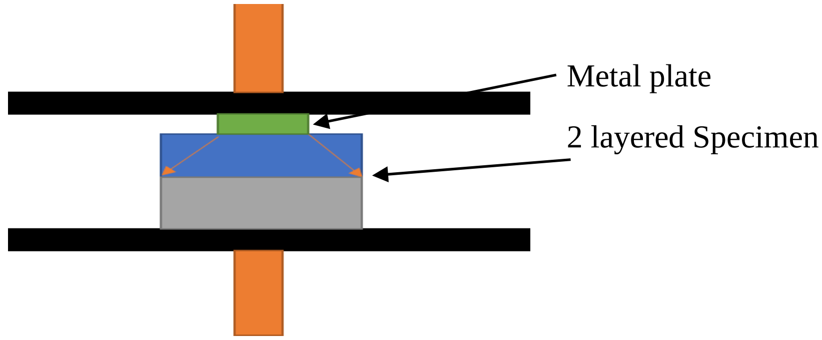


Figure 10. Setup for finding behaviour under stress distribution

A modified form of compressive strength test has been used for understanding the behavior of concrete cubes under stress distribution along the depth. For further references in this document this test has been termed as stress distribution test. For this, a metal plate of 10 mm thickness is placed between compression plate and top surface of the testing cube specimen. The area of metal plate is find out based upon the desired compressive strength ratio of top layer(surface) to bottom layer. In this experiment, the ratio of top to bottom layer are taken 4 and 2 for 100 mm cube. Based upon the ratio, the plate of size 50×100 mm used for desired strength ratio of 2 and 50×50 mm used for desired strength ratio of 4. Where area of metal plate is equal to $1/4^{th}$ of the testing cube area for desired compressive strength ratio of 4 and it is equal to $1/2^{nd}$ of the testing cube area for desired compressive strength ratio of 2.

2.4.3 Surface abrasion test-

Abrasion resistance determined on 28 days cured specimen [20]. The tile abrasion testing machine is seen in Figure 11 is used to measure the abrasion resistance of concrete, as recommended in IS1237 [26]. For this, three concrete samples with 100 × 100 × 100 mm dimensions used. Initial weight (w_1) of the specimen measured before testing and weight w_2 measured after testing. For each sample, 16 rounds are performed, Each round has 22 rotations of the wheel, and 20 gm abrasion sand used for each round. After each round, the sample is rotated clockwise by 90 degrees.

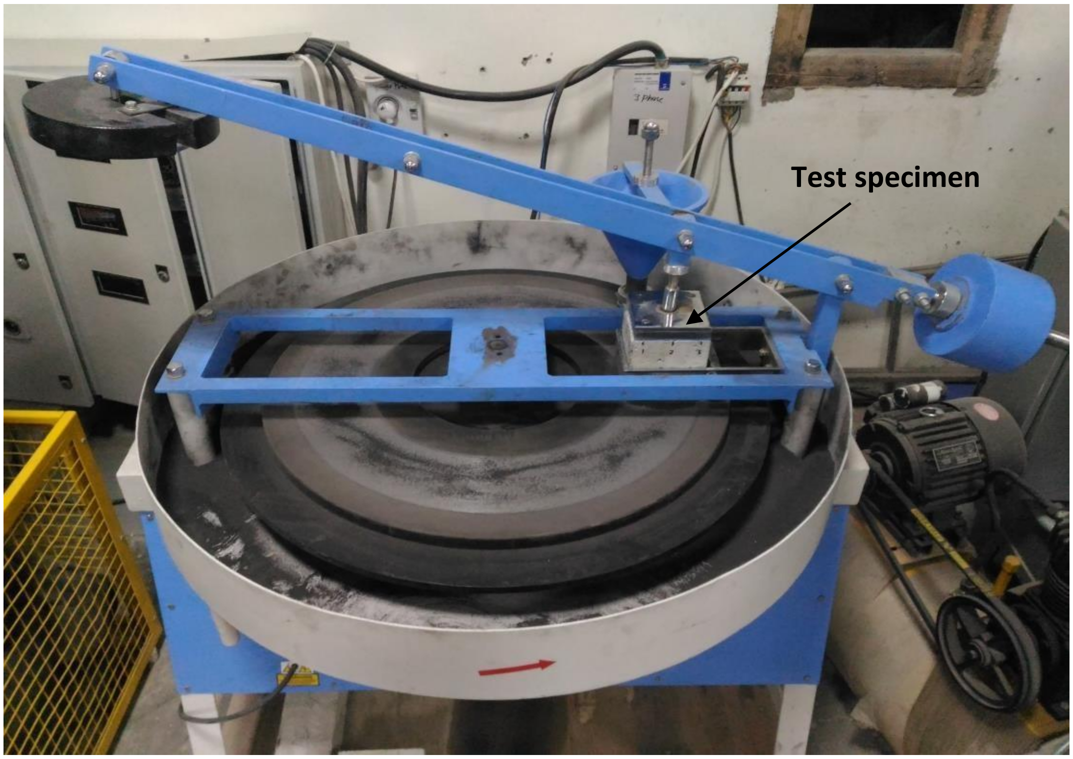


Figure 11. Tile abrasion testing machine

The abrasion resistance calculated in term of the depth of wear using the following relation:

$$Depth\ of\ wear = (w_1 - w_2) \times V_1 / (w_1 * A) \qquad \text{Equation 2}$$

where

V_1 = the initial volume of the specimen in mm^3

A = the surface area of the specimen in mm^2

2.4.4 Porosity test-

The functional properties of PC like compressive strength, durability etc. are strongly influenced by its porosity. Therefore, it is essential to obtain the porosity of all of the mixtures produced and compare it to the results of porosity of functionally graded mixtures. In this study, the procedure outlined in ASTM C1754 [21] used for the determination of porosity for each of the PC and FGPC samples.

Figure 12. Setup to find submerged weight

For the determination of porosity, the samples are kept submerged in water for 24 hr, and the weight underwater is measured. The submerged weight and the oven-dried weight of PC and FGPC samples are used in the relationship as given in ASTM C1754 [21] for calculating the porosity. calculate porosity using the following equation [22].

$$P = [1 - (\frac{w_2 - w_1}{\rho_w V})] \times 100(\%) \qquad \text{Equation 3}$$

where

P = Porosity, %.

w_1 = Weight under water, g.

w_2 = Oven-dried weight, g.

V = Volume of sample, cm^3.

ρ_w = Density of water at room temperature, g/cm3.

To guarantee accurate measurements, special care is taken to ensure the stable underwater weight of the specimens. Average 3 sample specimens taken for minimising the error. Each specimen is left to air dry for 24 h under laboratory conditions, and the exact dimensions of each cube are measured.

2.4.5 Permeability test-

The test method used to find the flow rate of porous concrete by using a constant head test method. In this experiment, The side permeability measurement to be determined of the specimens, Which is conducted for the first time. For that, A new experiment is designed for the measurement of permeability from sides to bottom or from top to sides of the specimen of porous concrete. A new test designed because No specified test intended for the measurement of side permeability till now.

Permeability is measured in terms of flow rate. For flow rate measurements, A setup made as permeability box that shown in Figure 13. Sample specimen for testing of flow rate placed between the top of the lower plastic jar and the water inlet tube of diameter 4 cm and for that bottom open area for water flow is 46.93 cm^2. The testing specimen placed in a position like that Bottom most layer comes on top. For the test, Water entering from side and leaving from bottom has been replicated by reverse to find the flow rate, by water flowing from bottom and leaving from sides. After that, The water inlet tube is fixed on top surface using m-seal for preventing the leakage of water from the top surface as shown in Figure 13.

Then, water can pass only from the sides of the sample specimen, and the water collected in the bottom plastic jar. In the plastic pot, the water level drawn for every one litre increase. The measurements of flow rate done in terms of time taken (in seconds) to collect the one litre water passing from the sample specimens. Flow rate can be proportionated to the permeability of the sample. The water head difference is about 30 cm between the top surface of the sample and the highest water level of inlet jar. The width and length of the specimen are 100 mm, and the height is 100 mm. The average of three samples taken for the value of permeability.

To calculate the water flow rate following formula is used:

$$q = \frac{Q}{T} \qquad \text{Equation 4}$$

where

q is the water flow rate in l/s or cm^3/s;

Q is the water output (litre or cm^3) in T time

T is the test time(sec).

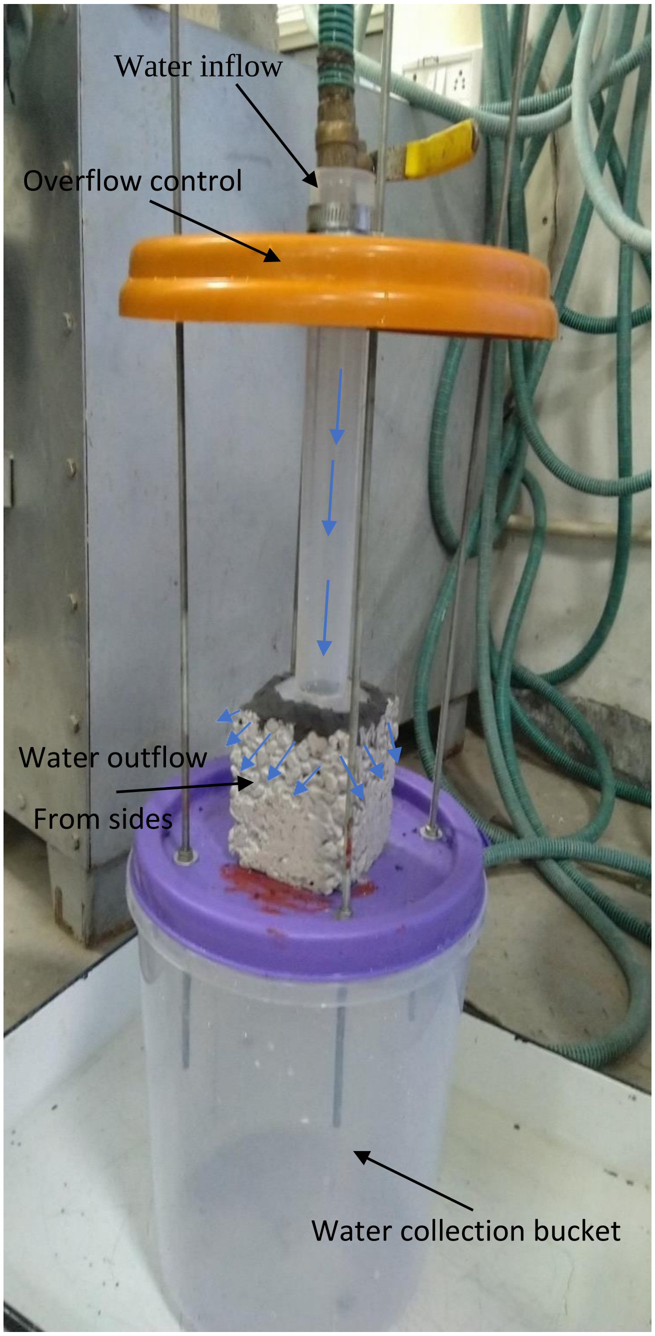


Figure 13. Permeability box for finding flow rate

Chapter-3

Results and discussion

3.1 Compressive strength-

The test results are presented of 7 day and 28 day compressive strength of the specimens of different mixes are shown below in Table 3 and Figure 14. Based upon the 7 day compressive strength, the expected 28 day compressive strength is find by 1.5 times 7 day strength for comparing with actual 28 day compressive strength. In the results, it is observed that compressive strength is decreasing with the increase of percentage fine reduction. Compressive strength is decreasing because the number of pores and voids present in the specimen are increasing. In the mix one and mix two the w/c ratio is very high, because of that the compressive strength of mix 1 & 2 are found low compare to other combinations with 0.35 w/c ratio and low % fine reduction.

When the present fine aggregate is reduced by full % to zero % from the mix with an decrement of 5 %. In initial fine aggregate reduction, the compressive strength is decreasing slowly, and after that, the decrease in compressive strength is high with an increment of % fine reduction. It is found because initially when some % of fine aggregate reduced, then some voids are formed but these voids filled by extra cement paste present in the mixes. Because of that, the change in compressive strength is very low. But when the % fine aggregate reduction is high, then the number of voids formed in high amounts and all of them not filled by extra cement paste present in the mix. So voids increase continuously, and because of that the sufficient decrease is noticed in compressive strength.

Table 3. 7 day and 28 day expected and actual compressive strength of the specimens of different mixes

Mix No.	Mix name	7 day compressive strength(MPa)	Expected 28 day compressive strength(MPa)	Actual 28 day compressive strength(MPa)
M1	NC	18.96	28.43	32.13
M2	PC 05	15.71	23.57	31.69

M3	PC 10	30.96	46.45	45.19
M4	PC 20	30.52	45.77	44.86
M5	PC 30	28.30	42.44	42.73
M6	PCNF 450	23.52	35.28	35.76
M7	PCNF 400	23.36	35.04	34.52
M8	PCNF 342	18.20	27.30	25.09
M9	PCNF 300	11.31	16.97	18.19

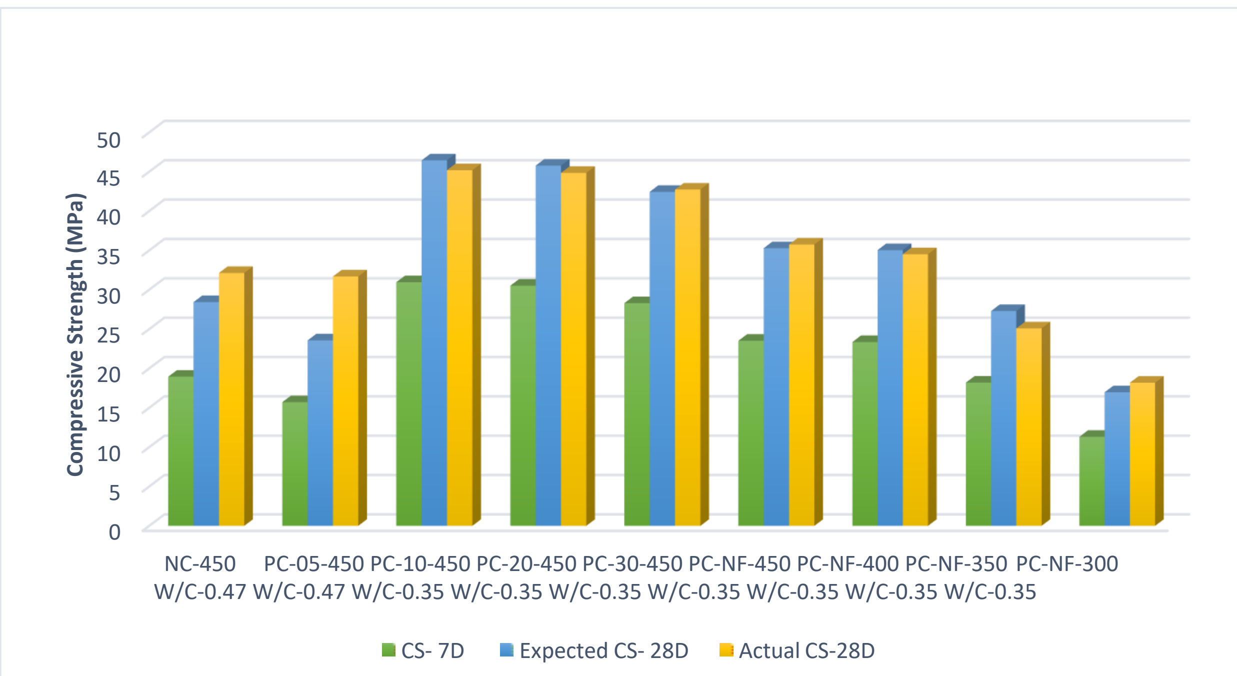


Figure 14. Graphical comparison of compressive strength of different mixes

After the compressive strength tests of different mixes, Functionally graded sample cubes are tested. In this test, it is verified that the weak layer of functionally graded samples takes how much strength because the failure should occur on the weak layer. The results of 7 day and 28 day compressive strength of the specimens of different functionally graded mixes are shown below in Table 4 and Figure 15 with the 28 day compressive strength of mixes M3, M8 and M9.

Table 4. 7 day and 28 day compressive strength comparison of functionally graded with their single layered mix

Sample name	M3 PC 10	M8 PCNF 342	M9 PCNF 300	FG10+342 2 Layer	FG10+300 2 Layer	FG10+342+300 3 Layer
7 Day compressive strength	30.96	18.20	11.31	13.28	11.71	11.17
28 Day compressive strength	45.19	25.09	18.19	27.76	21.82	20.13

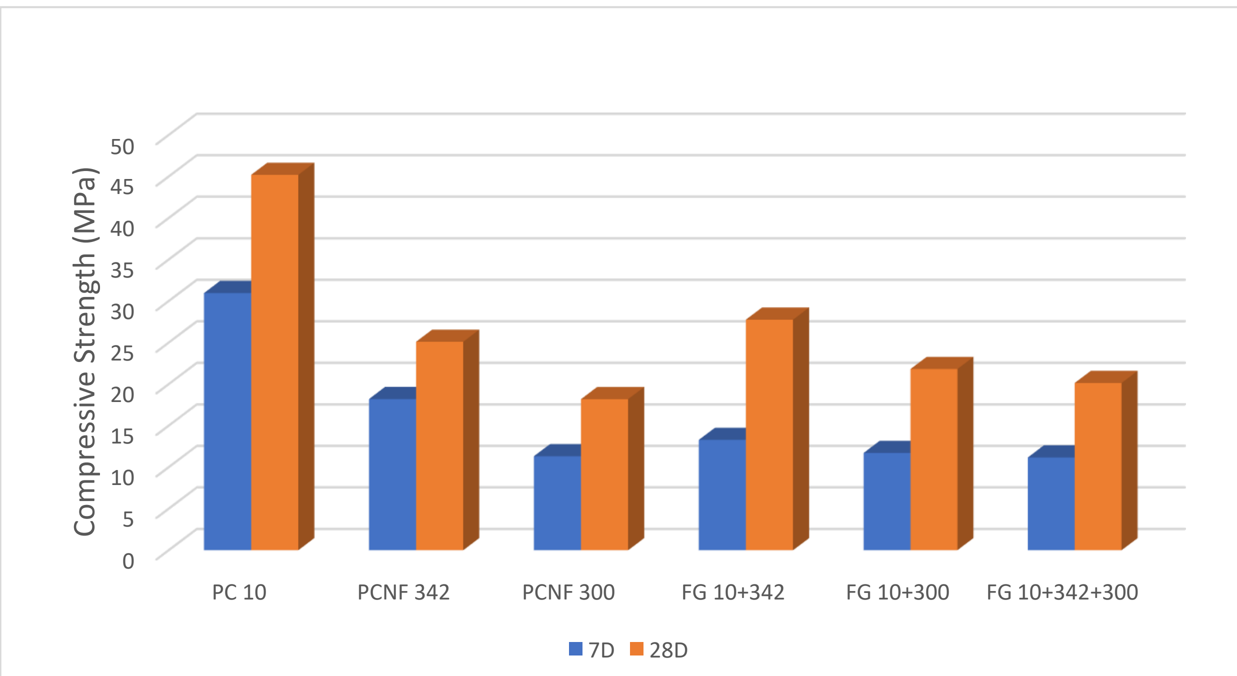


Figure 15. 7 day vs 28 day compressive strength comparison plots of functionally graded with their single layered mix

In this test, it observed that the 28 day compressive strength of functionally graded specimens found more than their specimens of the bottom layer mix.

Main reason for increasing some compressive strength may be the change of failure pattern because of different layers. Second reason is that compressive strength can be increase because in the casting of functionally graded, which is done in different layers of different mixes. In that phase of compaction, when one layer is filled by tamping then the second layer filled by tamping. At the time of tamping of second layer, some mix of layer1 is combine or mixed with layer2 till some length because of the compaction by tamping. It is happened because in the mix of layer2, Voids are presented and in these voids, some cement paste or mix of layer1 can go inside them and filled them.

Figure 16. (a) Failure of normal concrete cube (b). Failure of functionally graded concrete cube

Some different failure patterns of compressive strength of specimens of different normal mixes and functionally graded mixes are shown above in Figure 16.

3.2 Stress distribution-

For stress distribution test, The standard compressive strength test method is used with some changes. A metal plate placed between the compression plate and top surface of the 100 mm cubic specimen. The metal plate of 5×10 mm^2 and 5×5 mm^2 is used for 1:2 and 1:4 stress distribution for the ratio of the bottom layer to the top layer. For 1:1 stress distribution, Normal compressive strength test is done without any metal plate.

The test results of 28 day stress distribution test of the specimens of different mixes and different functionally graded mixes are shown below in Table 5, Figure 17 and Figure 18.

Table 5. 28 day load and stress distribution comparison of functionally graded with their single layered mix

S. No.	Stress distribution type		PC 10	PCNF 342	PCNF 300	FG10+ 342	FG10+ 300	FG10+342 + 300
1	1:1	Load (KN)	45.19	25.09	18.18	27.75	21.81	20.13
		Stress(MPa)	45.19	25.09	18.18	27.75	21.81	20.13
2	1:2	Load (KN)	27.91	14.81	10.36	14.32	13.41	9.70
		Stress(MPa)	55.83	29.62	20.73	28.64	26.83	19.41
3	1:4	Load (KN)	15.43	11.02	7.57	8.43	7.92	6.67
		Stress(MPa)	61.74	44.10	30.31	33.72	31.71	26.68

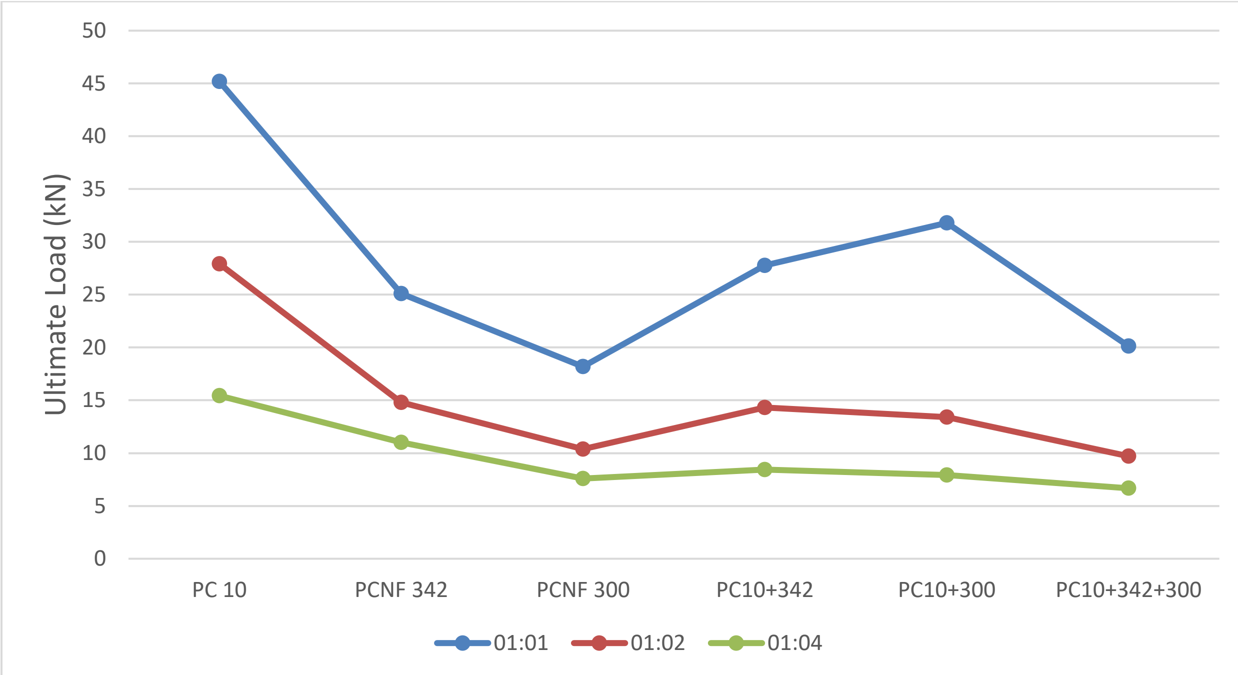


Figure 17. Ultimate Load comparison plots in compression with change in area

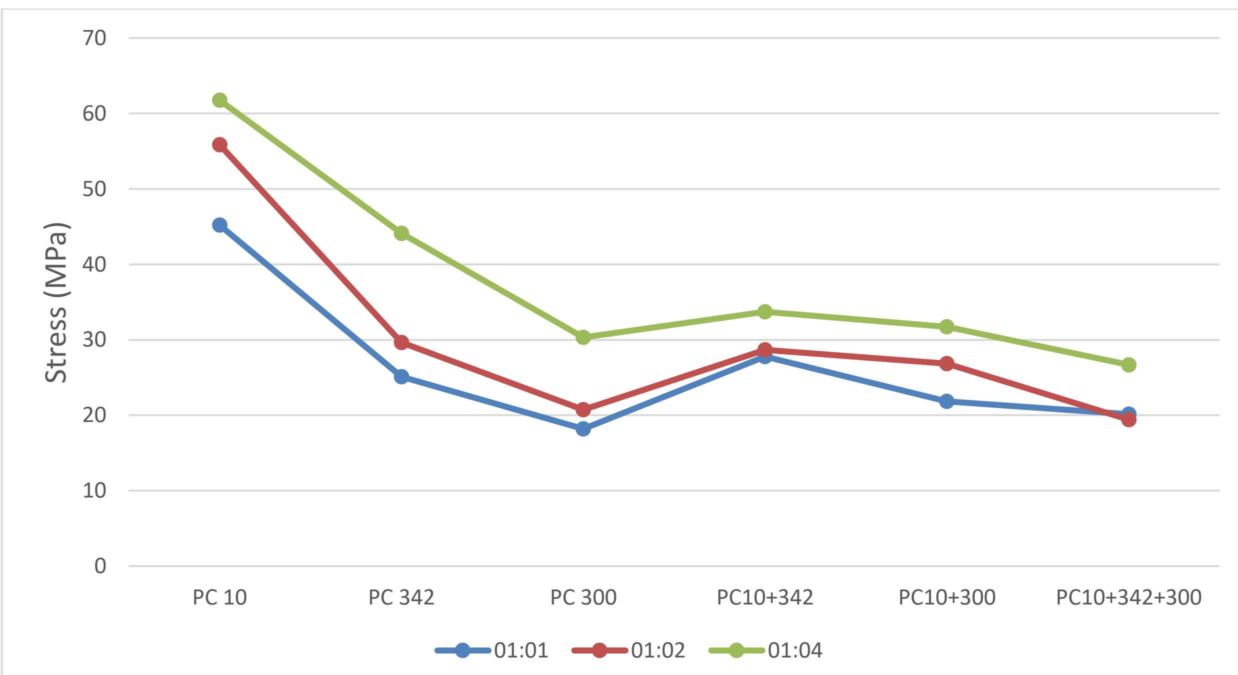
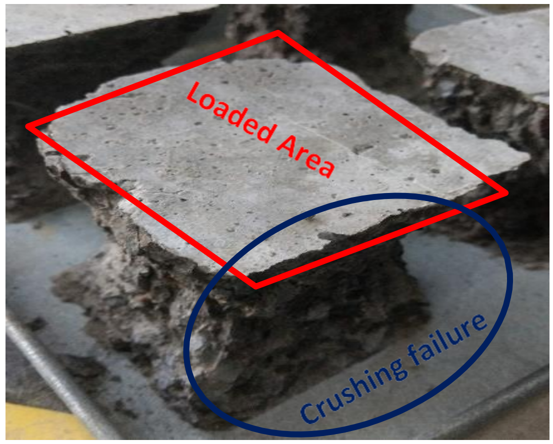


Figure 18. Stress comparison plots in compression with change in area

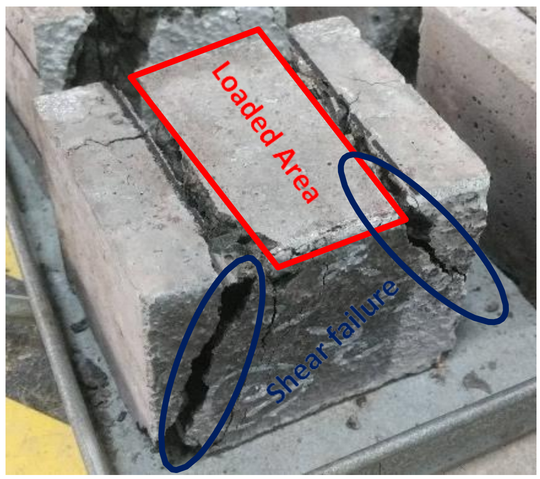
In above Table 5 and Figure 17 and Figure 18, the results of the stress distribution of different type of samples are shown. The results clearly show that the compressive strength of functionally graded samples found more than their respective single-layered sample in 1:1 condition. The compressive strength of FG10+342 was found more than separate sample of PCNF 342 based upon the bottom layer of the functionally graded sample. Compressive strength of FG10+300 was found more than PCNF 300, FG10+342+300 was found more than PCNF 300 and less than PCNF 342.

In stress distribution test results, it is observed that when the ratio of the type of stress distribution is increasing from 1:1 to 1:2 to 1:4. then the value of compressive strength is increasing for all type of different functionally graded and single-layered sample specimens. The value of the ultimate load of all different samples is decreasing as it goes from 1:1 stress distribution to 1:4 stress distribution and because load is not distributed in ratios properly. Thus, it is giving the higher stress values.

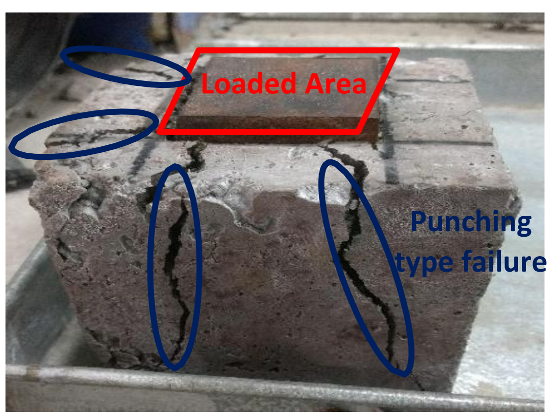
The different failure patterns of sample specimen in 1:1, 1:2 and 1:4 stress distribution condition are shown below in Figure 19 to Figure 23.



(a) 1:1

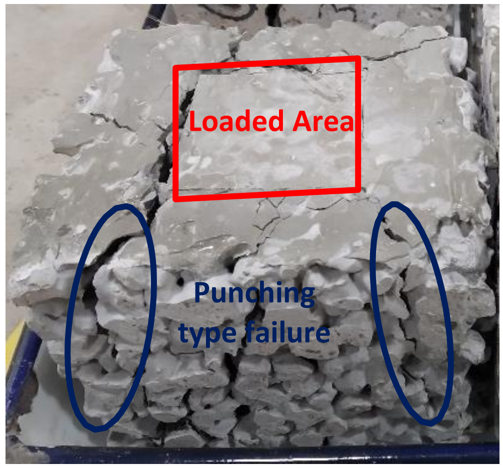


(b) 1:2



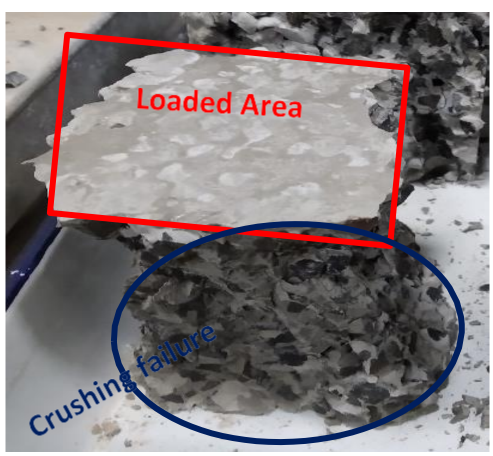
(c) 1:4

Figure 19. 1:1, 1:2, 1:4 Stress distribution test specimen failures of PC 10



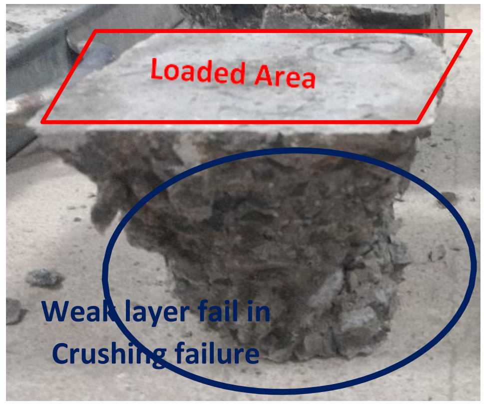
(a) 1:4

(b) 1:2

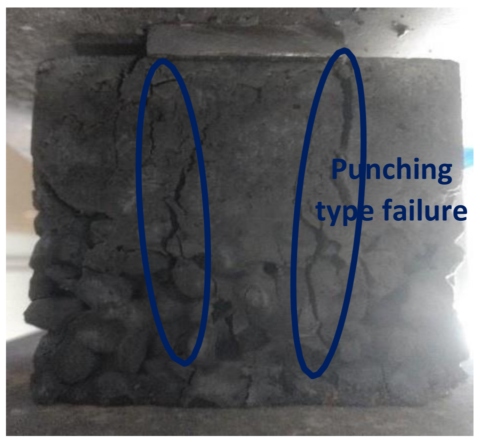


(c) 1:1

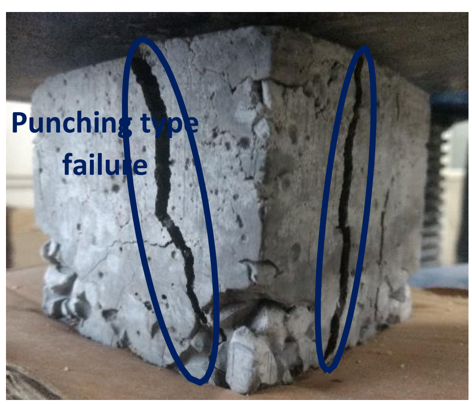
Figure 20. 1:4, 1:2, 1:1 Stress distribution test specimen failures of PCNF 300



(a) 1:1



(b) 1:2

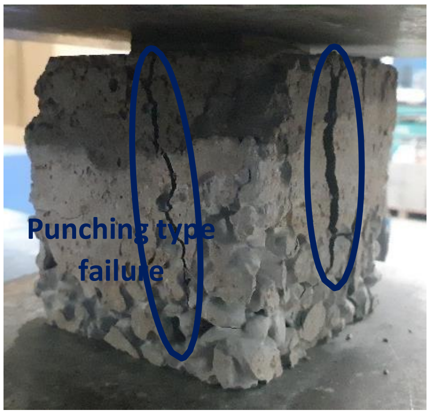


(c) 1:4

Figure 21. 1:1, 1:2, 1:4 Stress distribution test specimen failures of FG 10+342

(a) 1:1

(b) 1:2

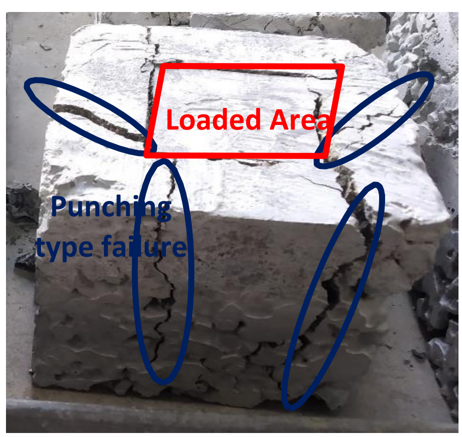


(c) 1:4

Figure 22. 1:1, 1:2, 1:4 Stress distribution test specimen failures of FG 10+300

(a) 1:1

(b) 1:2



(c) 1:4

Figure 23. 1:1, 1:2, 1:4 Stress distribution test specimen failures of FG 10+342+300

From these Figs., it is observed that in stress distribution test the failure comes of different types. Generally In 1:1 condition of stress distribution, more stress is coming on sides. So, the failure occurs as crushing failure of specimens. In 1:2 condition, stress distributed across perpendicular to the length of metal plate used for the stress distribution and the failure occurs as shear failure with sample specimen to some depth of the testing specimen and top surface fails in crushed And the shear failure is observed on two sides of the sample specimen in 1:2 condition. For 1:4 condition of stress distribution, it observed that failure occurs in the form of punching type failure. In this specimen getting cracks all around the metal plate, or we can say that stress distributed in all directions. In case of 1:2 distribution of FG10+300, The bottom layer reached its crushing strength and crushing failure occurs in bottom layer with shear failure occurs in top layer And it is also seen that failure affects the top layer of specimens, and the bottom layer did not fail. so we can say that stress distributed and the top layer with high strength take that stress, and because of that, the bottom layer that has low strength in case of functionally graded specimen did not affect that much. So, we can use the low and high compressive strength mixes in layers and always placed a mix having low compressive strength in the bottom layer and a mix having high compressive strength in top layer because we want the high compressive strength in the top layer.

3.3 Surface abrasion test-

The abrasion resistance of any paver block is the most crucial property since all the surface will interface to the tire and foot pressure directly. The rough surface of the porous concrete paver block is required to resist the skidding, sliding, and the breaking friction of the vehicles, so that the lower value of abrasion means preferable porous concrete. The abrasion of functionally graded porous concrete in terms of deep wear demonstrated in Figure 24, and the results of surface abrasion are shown below in Table 6.

Table 6. Surface abrasion

S. No.	Sample type	Initial weight before testing (w_1)	Final weight after testing (w_2)	Depth of wear in mm (Dow)
1	NC	2429.00	2396.50	13.56
2	PC 10	2462.50	2426.00	15.12
3	PCNF 342	2459.50	2392.50	27.62

4	PCNF 300	2214.50	2147.00	32.54
5	FG 10+342	2353.50	2322.50	13.17
6	FG 10+300	2473.50	2430.50	18.66
7	FG 10+342+300	2368.50	2324.00	19.13

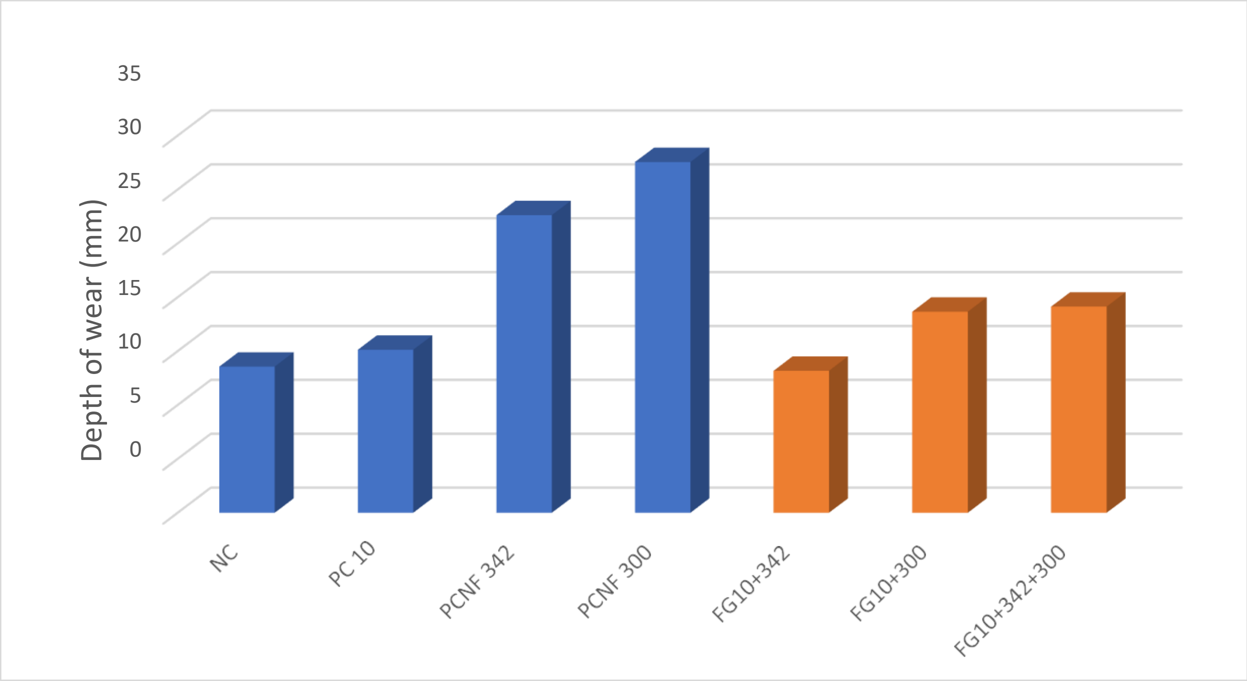


Figure 24. Surface abrasion plots

The results of surface abrasion show that depth of wear is increasing from sample type NC to PCNF 300. It is occurred due to the increase the number of pores from NC to PCNF 300. When sample specimen having more voids, due to this sample specimen have rough or more un-even surface. Because of that depth of wear is increased. In the case of functionally graded specimens, where only top layer is affected in the surface abrasion, and PC10 used as the top layer in all cases of functionally graded. The results of surface abrasion of functionally graded specimens show that the value of depth of wear of functionally graded samples is very low compared to their bottom layer mixes of PCNF 342 and PCNF 300. And a little bit higher compared to their top layer mix of PC10. From these results, it observed that the surface abrasion could be reduced by using different sample types in layered form as a functionally graded sample type.

Abrasion may be different due to change in mix proportion of layers due to casting. Although layers of functionally graded are expected to perform equivalent to PC 10 in abrasion but they have performed slightly lower in abrasion, probably due to intermixing during casting.

3.4 Porosity test-

The concrete is inherently porous, and The porosity of concrete influences the properties in many aspects. So, the porosity is essential for the permeability and compressive strength etc. The normal values of porosity for conventional concrete porosity typically range between 9 and 10%, so the value of porosity for porous concrete can be higher than 9-10%. The results of porosity calculated for each of the PC and FGPC samples. Porosity is calculated based upon the submerged weight, oven-dried weight and the volume of the specimen by equation 1. The value of density of water is 0.998 g/cm^3.

The test results of porosity test of the specimens of different mixes and different functionally graded mixes are shown below in Table 7 and Figure 25.

Table 7. Porosity of different mixes

S. No.	Sample name	Submerged weight (w_1)(g)	Oven-dried weight (w_2)(g)	Volume (cm^3)	Porosity (%)	Average porosity (%)
1	NC	1439.00	2348.50	1017.72	10.45	10.35
		1428.00	2335.50	1014.60	10.37	
		1428.00	2347.50	1026.48	10.24	
2	PC 10	1530.50	2400.50	1010.58	13.73	11.25
		1536.00	2450.50	1031.75	11.18	
		1504.50	2425.00	1011.77	8.83	
		1535.50	2431.00	1019.50	11.98	

3	PC 20	1557.00	2440.00	1019.28	13.19	11.61
		1567.50	2482.50	1014.92	9.66	
4	PC 30	1540.50	2433.50	1024.40	12.65	12.35
		1551.00	2441.50	1025.28	12.97	
		1550.50	2451.50	1019.32	11.43	
5	PCNF 342	1509.50	2369.00	1054.65	18.33	17.03
		1501.50	2364.50	1060.35	18.44	
		1503.50	2366.00	1008.55	14.31	
6	PCNF 300	1373.50	2184.00	1058.88	23.30	24.87
		1314.50	2067.50	1039.68	27.42	
		1312.00	2080.50	1011.78	23.89	
7	FG 10+342	1472.00	2323.50	1036.75	17.70	14.90
		1506.00	2388.50	1026.90	13.88	
		1521.50	2420.50	1037.02	13.13	
8	FG 10+300	1481.50	2335.00	1057.65	19.13	16.03
		1496.50	2358.50	1040.80	17.01	
		1536.00	2421.00	1007.15	11.95	
9	FG10+342+300	1409.50	2254.50	1048.02	19.20	18.49
		1427.00	2266.50	1025.68	17.98	
		1419.00	2260.00	1031.20	18.28	

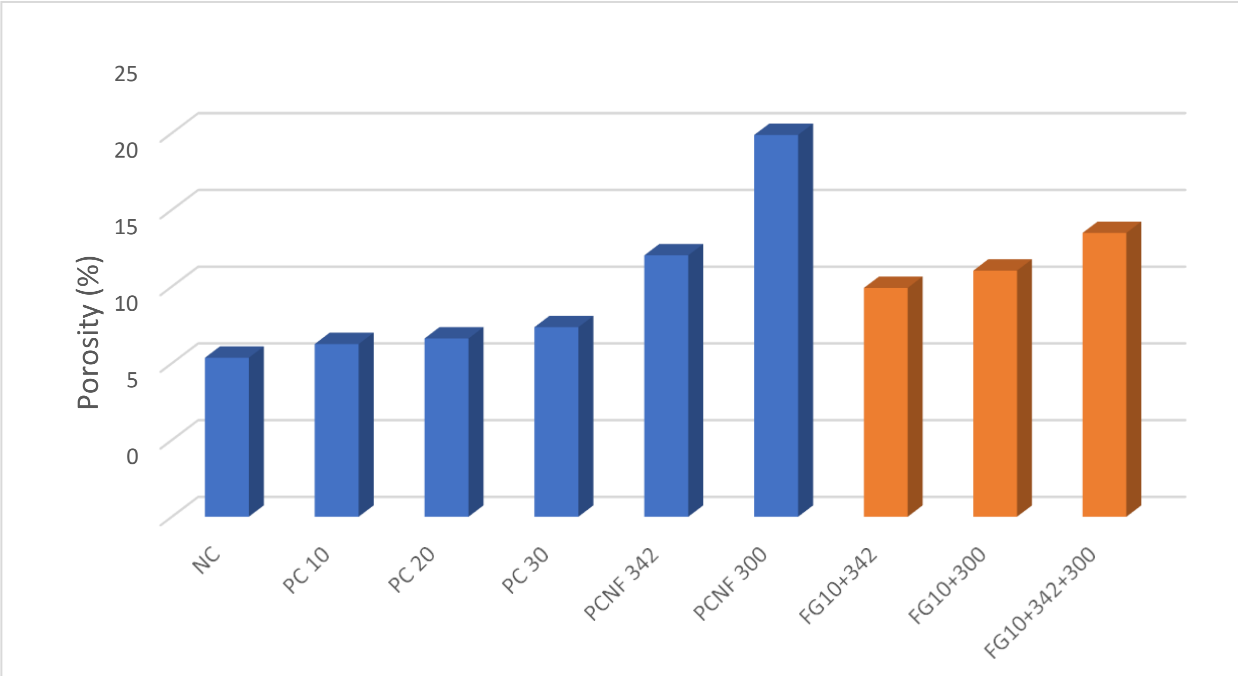


Figure 25. Porosity plot of different mixes

From the results of porosity, we observed that a minimum porosity is present in the first conventional mix of NC and found 10.36%, which is nearby the normal range of porosity in conventional concrete. After that, it is observed that with the increase in reduction of % fine aggregate, the porosity would increase and because of that porosity increased from 10.36 % to 24.87 % till mix of PCNF 300.

For the samples of functionally graded, which cast in layered form by using sample mixes of PC10, PCNF 342 and PCNF300. For FG10+342, the 50% depth filled by PC10 and other 50% depth filled by PCNF 342. For FG 10+300, the mix PC10 and PCNF 342 each had the 50% depth. And in FG10+342+300, each mix layer has a thickness of 33.33% or 1/3rd depth of sample specimen of 100 mm cube. Because of this layered casting, Each sample functionally graded have at least two different porosity type mixes.

The porosity of FG10+342 found 14.91 % that is greater than the porosity of PC10 and less than the porosity of PCNF 342. And for FG10+300 and FG10+342+300 the value of porosity is higher than the PC10 and less than PCNF 300. Also, the porosity of PCNF 342 was higher than FG10+300 and less than FG10+342+300. All this type of results found because in the functionally graded sample specimens, some volume of the sample have different porosity and other left volumes have other value of porosity of the same sample specimen because of different mixes used in different layers. so the resultant porosity of functionally graded samples is found between the porosity of different mixes used as different layers in a functionally graded sample. It observed that casting in the functionally graded gives a little increase in porosity of sample specimen.

3.5 Permeability test-

The test results of water flow rate test of the specimens of different mixes and different functionally graded mixes are shown below in Table 8 and Figure 26.

Table 8. Water flow rate of different mixes

S. No.	Sample name	Flow rate of sample 1 (cm^3/s)	Flow rate of sample 2 (cm^3/s)	Flow rate of sample 3 (cm^3/s)	Average Flow rate (cm^3/s)
1	PC 10	0	0	0	0
2	PCNF 342	17.08	16.18	17.10	16.78
3	PCNF 300	39.80	40.33	41.96	40.68
4	FG 10+342	11.15	11.48	12.06	11.55
5	FG 10+300	20.06	21.31	18.01	19.70
6	FG10+342+300	26.17	26.99	26.47	26.54

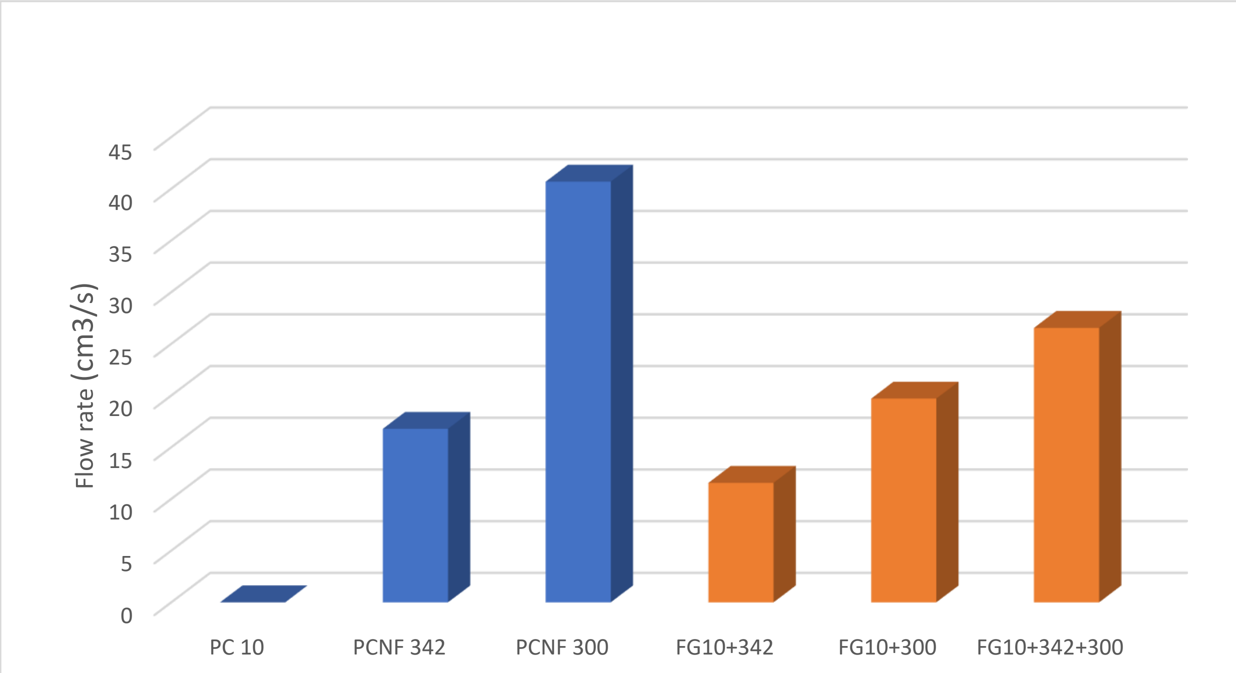


Figure 26. Flow rate plot of different mixes

In results, Water flow rate shows in terms of discharge per unit time. It is seen that flow rate depends upon the porosity and the layered form of the sample also. The value of flow rate of PC10 is found zero because there is plan surface exist with no voids on the surface from that water can pass from the sample. So the value of discharge from PC10 is found zero.

The flow rate is increasing with the increase in porosity of samples PCNF 342 and PCNF 300. In the test, maximum flow rate 40.68 cm^3/s is observed by the sample of PCNF 300. Because it has the highest value of porosity, compared to other mixes. The value of flow rate of functionally graded samples depended upon the layered mixes. The samples of FG10+300 and FG10+342+300 have values of average flow rate as 19.70 cm^3/s and 26.54 cm^3/s respectively, which were higher than the flow rate of PCNF 342 sample mix and less than the flow rate of PCNF 300 sample mix. It is found because, in the test procedure, water inlet from the top surface and water comes out from the sides of the sample specimen. In functionally graded samples, where at time of testing, the top layer has the high porosity mix layer and bottom layer of PC10. So, water inflow comes from top surface and outflow is done only from the sides of the top layers of PCNF 342 and PCNF 300. Thus, the value of flow rate of functionally graded is decreasing slightly compare to mix PCNF 300 because of the decrease in the area of outflow due to layered casting. But the flow rate increase of functionally graded in case of FG10+300 and FG10+342+300 was high in compare to mix PC10.

Chapter-4

Conclusion

4.1 Conclusions-

As an alternative solution to porous concrete paver blocks (PCPB), functionally graded porous concrete paver block (FGPCPB) has been developed and evaluated for different properties in comparison with conventional paver blocks.

Some key findings from this experimental analysis results are presented in details below

1. In FGPCPB, failure occur in the weakest layer. However, the value of compressive strength of FGPCPB was slightly higher than that of PCPB of weakest layer, showing a positive impact on compressive strength due to functional grading.
2. Stress capacity of concrete increased with reduction in loaded area, which can be attributed to stress distribution through shear forces in the periphery of loaded area and three distinct failure patterns can be observed: (i)crushing, when strength of weakest layer became a critical criterion: (ii) shear, when stresses cannot be fully transferred through shearing mechanism: (iii) punching, when crushing of the loaded area occurs due to excess stress development prior to its distribution.
3. Due to stress distribution effective compressive strength of FGPCPB was significantly higher as compared to the compressive strength of the weakest layer, showing the advantage of functional grading in effective strength. However, increase in number of layers reduced the performance of FGPCPB, highlighting the limitations of functional grading in terms of number of layers.
4. Abrasion occurs at the exposed surface, and the performance of FGPCPB was found comparable to the performance of exposed layer, highlighting the advantage of functional grading for tackling surface abrasion of PCPB.
5. Porosity of FGPCPB was found to be a cumulative of various adopted layers. This shows porosity is not affected by functional grading of concrete.
6. Permeability results show that the FGPCPB, despite having an impermeable top surface, have a sufficient flow rate that is required for the pervious concrete. This shows functional grading of concrete with use of lower layers for permeability is practically possible.
7. It can also be seen that permeability increases with increase in porosity of concrete, and

the surface abrasion also increases with the increase in porosity. Compressive strength decreases with an increase in porosity, which is in agreement with existing literatures.

In all, it can be concluded that, FGPCPB is a viable alternative to PCPB and can be used to improve the compressive strength and surface abrasion of PCPB while maintaining its permeability. The scopes of present experimental work was limited to development of FGPCPB as a concept for application in the construction industry, further experimentations are required for optimization of the mix of different layers, for obtaining maximum benefits from functional grading: for the application of demonstrated FGPCPB as a commercial paver block. Also, effect of height of layer has not been covered in the scope of this study, which can be included as additional parameters for optimization. Further more water inflow channels needs to be designed for the development of FGPCPB as a manufactured commercial product with direct application in the field.

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