Mix Design and Factors Affecting Strength of Pervious Concrete

Bishnu Kant Shukla and Aakash Gupta

Abstract Pervious concrete is a sure sort of concrete with a high porosity utilized for concrete flatwork applications that will permit the water from precipitation and different sources to go straightforwardly through, along these lines diminishes the overflow from a site and permitting groundwater to revive. The concrete glue at that point coats the totals and enables water to go through the concrete piece. With interconnected void content, we can achieve high porosity. Water-to-cementitious material ratio is 0.40–0.50. Designs were made at different water–cement ratios, and these ratios show the different exposure conditions. In this paper, specific gravity of cement, coarse aggregate and fine aggregate were selected as 3.15, 2.68, 2.65 respectively. Cement used in this project was OPC-43. Coarse aggregate were used at different proportions. The present examination tended to the strength and seepage parts of pervious concrete mix and furthermore the impact of CS as FA. A point-by-point contemplate is required to know the impacts of total degree with different kinds of total. In this undertaking, the mechanical properties of pervious concrete have been used to plan road pavements. The properties of PCC blend to be examined are compressive strenth and flexural strength. An optimum percentage has been determined which shows the concrete is permeable and having good compressive and flexural strength. In this research paper, the mechanical properties of pervious concrete have been used to design road pavements. Main focus of the paper is to determine and improve compressive strength, and flexural strength.

Keywords Pervious concrete · OPC · NFC · FA · CA · River sand · Crushed stone

B. K. Shukla
Lovely Professional University, Phagwara, India
e-mail: bishnukantshukla@gmail.com

A. Gupta (✉)
Jaypee University of Information Technology, Waknaghat, India
e-mail: aakash1991gupta@gmail.com

S. Adhikari et al. (eds.), *Advances in Structural Engineering and Rehabilitation*, Lecture Notes in Civil Engineering 38,
https://doi.org/10.1007/978-981-13-7615-3_11

1 Introduction

Porous concrete is a blend of shake or stone, bond, water and alongside zero FA which influences an open cell for structure which further then empowers water and air to experience it. According to the environmental protection agency (EPA), storm water flood can send as much of 90% toxic substance, for instance, oil and other hydrocarbons. The limit of porous concrete to empower water to travel through itself resuscitates and after that groundwater restricts the level of defilement and whirlwind water overflow. Porous cement is used to allow storm water to attack through the black-top and diminish or shed the necessity for the additional control structures, for instance, support lakes.

The pervious solid black-top has various ideal conditions that can improve the city condition as takes after:

1. The water can quickly channel into the ground, so the groundwater resources can re-establish in time as the black-top is air permeable, water vulnerable and the soil underneath can be kept wet.
2. The porous solid black-top can hold the commotion of vehicles, which influences peaceful and pleasant to condition.
3. In tempestuous days, the pervious solid black-top has no plash at first look and does not flash around night time. This will improve the comfort and prosperity of the drivers.
4. The pervious solid black-top materials have openings that can cumulate warm.

Such black-top can change the temperature and suddenness' of the earth's surface and gets rid of the wonder of hot island in urban zones. An achieved installer is irreplaceable to the accomplishment of pervious solid black-tops as with any solid black-top, fitting subgrade status is crucial [1]. The subgrade should be properly compacted for reason that it will give a uniform and stable surface. Right when pervious black-top is set direct on the sandy soil, then it is recommended to moderate the subgrade from 92 to 96% of the most extraordinary thickness. With the silty or clayey soils, the level of compaction will tons of black-top arrangement and a layer open assessed stone may must be put over soil. The voids can go from 18 to 35% with compressive strength of 10–30 MPa. The invasion rate of pervious cementitious materials, coarse totals, water with practically no fine aggregates and admixtures. The expansion of little measures of fine totals will continuously lessen the void space and increment the strength, which might be attractive in specific circumstances. This material is touchy to change in water content, so field modification of crisp blend is typically important. The right amount of water in the solid is basic. An excess of water will cause isolation, and too little water will prompt balling in the blender and moderate blender emptying. The W/C and C/A proportions are regularly varied from 0.25 to 0.45 and 1:3.5 to 1:6. To make a porous solid structure with ideal porousness and compressive strength, the measure of water, measure of bond, sort and size of aggregate, and compaction should all be considered. A colossal number of examinations have been now driven all through the past couple of decades by an assortment of specialists contrasting a few or these components. In his paper [2], V. M. Malhotra discussed pervious concrete as it relates to applications and properties. He gave purposes of enthusiasm on the properties such as consistency, extents of materials, unit weight, comparability and curing endeavouring to open up penetrability in the porous cement. Malhotra also drove various investigations on different test chambers endeavouring to find a connection between strength like compressive strength and any of the material's properties. He gathered for the compressive nature of pervious cement was reliant on the water bond proportion and the total concrete ratio. Attractive vibration is essential for nature of customary cement. The use of porous cement is one of a kind and is a self-pressing item. It was recommended by several researchers [2–6] that the use of mechanical vibrators and smashing is not proposed with porous cement. A light rodding should be attractive and used to ensure that the solid accomplishes all regions of the formwork. This is not an issue with customary cement, since it has more prominent stream capacity than penetrable cement. The light rodding ensures that the solid entered every region obstructed by fortifying steel. Malhotra [2] stressed that in circumstances where common conditions are not refined amid arrangement and curing, the formwork ought not to be expelled following 24 h as with normal cement. Permeable cement has low cohesiveness and formwork ought to stay until the point that the bond glue has solidified adequately to hold the total particles together. Be that as it may, this is to a greater degree a thought in low temperature conditions and when utilized as a part of non-asphalt applications where the concrete is not adequately upheld by the ground or different means.

Another recent work on Portland cement concrete pavement permeability execution [7] expresses test ponders on transport properties of concrete are controlled by the attributes of its pore arrange. Add up to porosity, pore size, pore connectivity, and pore saturation, all impact the deliberate transport coefficients [7]. Water-absorbing concrete was first utilized as a part of the 1800s in Europe as pavement surfacing and load-bearing walls. Cost-effectiveness was the principle thought process because of a diminished measure of cement. It ended up prominent again in the 1920s for two story homes in Scotland and England. It turned out to be progressively suitable in Europe after WWII because of the shortage of cement. It did not move towards becoming as well known in the USA until the 1970s. In India, it ended up well known in 2000. The first water-absorbing placement in the Indian metro area was in Sugar Creek, MO in November 2005. Since that time, around 30+ pavements have been put and numerous lessons found out about what makes water-absorbing concrete 'great'. Here in, are the present rules that have been educated and adjusted. Shah et al. [8], in his work on water-absorbing concrete examined on utilizing pervious concrete as street development material generally new idea for provincial street pavement, with expanding issue in country zones identified with low groundwater level, farming issue. His report centres around pavement utilization of concrete which additionally has been referred on pervious concrete, penetrable concrete, no fine concrete, hole-reviewed concrete and upgraded porosity concrete.

As a result of work on water-absorbing concrete, Eathakoti et al. [1] developed an innovative model that can transport water go into the pavement has been proposed towards this path. Diverse mixes of cement, water and coarse aggregate with various greatest size and gradation were adopted for mixing procedure to make roughly at M20 grade concrete. M20 grade concrete is accomplished with a w/c proportion of 0.4–0.45, coarse aggregate of nominal size 20 mm and with cement to coarse aggregate proportion of 1:4. Its density and flexural strength quality were seen to be 21 kN/m^3 and 35 kg/cm^2 individually. A pavement piece appropriate for low activity volume streets is planned according to IRC SP62: 2004 which permits stockpiling of water up to 125 L/m^3 of concrete pavement giving time for invasion in this way diminishing the runoff and reviving the groundwater or adequate time for transport of it. A perforated pipe can be given at focus of the pavement above sub-base with the end goal that it gathers the water put away in concrete and depletes it to the required treatment plant or a fill pit [9, 10]. This, however, needs to encourage examination and trials before practical implementation [11]. Aims and objectives of the present work are:

1. The principle target of this examination is to build up a solid and tough pervious bond concrete (PCC) blend utilizing distinctive kinds of FA with changing the amount of FA. Moreover, it is likewise expected to think about the properties of these PCC blends.
2. The level of fine aggregates to be utilized as a part of PCC blend is set to 30% max.
3. The properties of PCC mixes to be looked into are compressive quality and flexural quality.

2 Methodology

After distinguishing proof of issue and setting the targets of the research, the research methodology has been carefully designed to accomplish these destinations.

1. Accumulation and investigation of writing relating to the exposition work.
2. Decide the building properties of porous concrete and compare them with ordinary concrete. Cast different trial blends with changing rates of porous concrete and analyse for the compressive strength.
3. Get-ready test tests with the rate esteem and tests the examples for the different properties.
4. To remark on the reasonableness and confinements of porous concrete with traditional concrete.

2.1 Planning Schedule

Collections of material were carried out as per the following schedule:

1. Collection of OPC Cement
2. Preparation of mould for casting of cubes and beams

3. Collection of CA and FA.

Commercially available CA and FA were collected, and suitable percentages of both the aggregates were fixed. For example, NFA, 4:1, 3:2. Mixes were created by varying cement content from 350 to 480 kg/m^3. Sets of three cubes were casted having different mix proportions. After 24 h of casting, cubes were demoulded and water cured for several days. Each set of cubes were tested for mechanical properties at the end of 3, 7 and 28 days.

2.2 Casting and Testing

After making the mix design at three different cement contents, i.e. 479, 446, 384 kg/m^3 and without taking fine aggregates, with coarse aggregate to fine aggregate ratio as 5:0, the mix design with lowest concrete density has been selected. The cement content of 384 kg/m^3 has the lowest concrete density; therefore, further two more mix proportions prepared using ratio 4:1 and 3:2 of coarse aggregate and fine aggregate. Mix proportions for casting of cubes and beams have been shown in Tables 1, 2, 3, 4, 5 and 6.

Table 1 Mix proportion for cube using no fine aggregate at cement content 384 kg/m^3 (w/c = 0.50) (CA:FA = 5:0)

S. No.	Material	Quantity per m^3 (kg)	Quantity for casting one cube (150 * 150 * 150 mm) (kg/mm^3)
1	Cement	384	1.296
2	Water	191.6	0.6466
3	CA	1839.82	6.2093
4	FA	Nil	Nil
5	Yield	2415.42	8.1519

Table 2 Mix proportion for cube using fine aggregate at cement content 384 kg/m^3 (w/c = 0.50) (CA:FA = 4:1)

S. No.	Material	Quantity per m^3 (kg)	Quantity for casting one cube (150 * 150 * 150 mm) (kg/mm^3)
1	Cement	384	1.296
2	Water	191.6	0.6466
3	CA	1471.856	4.967
4	FA	363.845	1.2279
5	Yield	2411.3	8.1375

Table 3 Mix proportion for cube using fine aggregate at cement content 384 kg/m^3 (w/c = 0.50) (CA:FA = 3:2)

S. No.	Material	Quantity per m^3 (kg)	Quantity for casting one cube (150 * 150 * 150 mm) (kg/mm^3)
1	Cement	384	1.296
2	Water	191.6	0.6466
3	CA	1103.89	3.7256
4	FA	727.69	2.4559
5	Yield	2407.18	8.1241

Table 4 Mix proportion for beam using no fine aggregate at cement content 384 kg/m^3 (w/c = 0.50) (CA:FA = 5:0)

S. No.	Material	Quantity per m^3 (kg)	Quantity for casting one beam (100 * 100 * 500 mm) (kg/mm^3)
1	Cement	384	1.92
2	Water	191.6	0.958
3	CA	1839.82	9.1991
4	FA	Nil	Nil
5	Yield	2415.42	12.077

Table 5 Mix proportion for beam using fine aggregate at cement content 384 kg/m^3 (w/c = 0.50) (CA:FA = 4:1)

S. No.	Material	Quantity per m^3 (kg)	Quantity for casting one beam (100 * 100 * 500 mm) (kg/mm^3)
1	Cement	384	1.92
2	Water	191.6	0.958
3	CA	1471.856	7.359
4	FA	363.845	1.8192
5	Yield	2411.3	12.056

Table 6 Mix proportion for beam using fine aggregate at cement content 384 kg/m^3 (w/c = 0.50) (CA:FA = 3:2)

S. No.	Material	Quantity per m^3 (kg)	Quantity for casting one beam (100 * 100 * 500 mm) (kg/mm^3)
1	Cement	384	1.92
2	Water	191.6	0.958
3	CA	1103.89	5.519
4	FA	727.69	3.638
5	Yield	2407.18	12.035

Fig. 1 Surface cleaned and oiled moulds

2.3 Size of Test Specimens

Test specimens cubical in shape was 15 cm × 15 cm × 15 cm. If the largest nominal size of the aggregate does not exceed 2 cm, 10-cm cubes may be used as an alternative. Similarly for beams, the size of moulds used was 50 cm × 10 cm × 10 cm. Cubes were casted to perform check on compressive strength of pervious concrete while beams were casted to check the flexural strength of pervious concrete.

2.4 Preparation of Moulds

Prior to mixing and casting of specimen, one of the most important and time-consuming works is the preparation of moulds [12]. Moulds were prepared such that all surfaces of moulds were cleaned and oiled properly, and all the bolts were tightened so that it did not allow any leakage of mortar (Fig. 1).

Special care was taken while applying oil. Excessive amount of oil can lead to the presence of bug holes on the surface of concrete after demoulding. A suitable brush or cloth was used while applying oil on the surface of moulds. Also, type of oil used is very important as the purpose of oil is to provide necessary lubrication so that concrete may not stick to the surface of moulds and it should be easy to demould the specimen. If suitable oil is not used, then it may break your specimens and whole procedure is to be repeated again. The oil used in this study was waste black oil easily available at any workshop at no cost or very minimal charges.

Fig. 2 Homogeneous dry mix

Fig. 3 Homogeneous wet mix after adding water

2.5 Mixing

All of the mixing of concrete was done by hand mixing only. All of the ingredients of pervious concrete like cement, coarse aggregate and fine aggregate were first weighed as per mix design proportion and then mixed on floor which was prepared for saturated surface dry condition so that floor shall not absorb any water from the mix neither shall it release more water into the mix. All three ingredients of pervious concrete were first mixed in dry condition (Fig. 2) so that all aggregates were properly mixed with cement in order to have homogeneous mixture (Fig. 3).

After the mixing of concrete, well-cleaned and oiled moulds were filled with concrete and hand compacted. Here, table vibrator is not recommended as it was noted that under effect of vibration cement slurry settles down and makes the concrete impervious. Each mould was filled in three layers and hand compacted after each layer with the help of tamping road.

Fig. 4 Specimen kept for 24 h prior to demoulding

Again, after the moulds were filled with concrete and leveled, the specimens were left for 24 h before demoulding (Fig. 4) so that concrete achieves its hardening. After 24 h of casting, the cubes were demoulded on very next day without any delay.

2.6 Testing of Specimens

The entire specimens were tested as per directions given in IS 516 (1959). To check compressive strength of concrete using pervious concrete cubes, compression testing machine was used, whereas to perform check on flexural strength of beams, flexural testing machine was used. The load for compression testing machine was set as specified in IS 516, i.e. 140 kg/cm^2/min. The load shall be applied slowly without shock and increased continuously until the resistance of specimen (concrete cube) to increasing load breaks.

Calculation of Load:

Load as per IS Code = 140 kg/cm^2/min
1 kg = 9.81 N
1000 N = 1 kN
1 min = 60 s

But load specified in IS 516 is in kg/cm^2/min
= (1.373 × 15 × 15)/60
= **5.148 kN/s**

Similarly, for flexural strength test, load specified in IS 516 = 180 kg/min for 10-cm beams that comes out to be 29.42 N/s.

3 Results and Discussion

The results of the study have been presented under the following heads.

3.1 Compressive Strength Results

Compressive strength results were determined after 3, 7 and 28 days of curing and presented in Tables 7, 8 and 9.

Table 7 Compressive strength of cubes using no fine aggregates (CA:FA = 5:0)

S. No.	Age of cube (days)	Compressive strength of cube (MPa)
1	3	6.9
2	3	7.6
3	3	7.4
4	7	8.2
5	7	8.8
6	7	9.4
7	28	10.55
8	28	11.3
9	28	11.9

Table 8 Compressive strength of cube using fine aggregates (CA:FA = 4:1)

S. No.	Age of cube (days)	Compressive strength of cube (MPa)
1	3	8.53
2	3	8.88
3	3	8.1
4	7	11.87
5	7	11.82
6	7	12.88
7	28	13.55
8	28	15.7
9	28	16.66

Table 9 Compressive strength of cube using fine aggregates (CA:FA = 3:2)

S. No.	Age of cube (days)	Compressive strength of cube (MPa)
1	3	18
2	3	17.82
3	3	18.1
4	7	33.64
5	7	32.26
6	7	33.82
7	28	42.04
8	28	41.91
9	28	41.56

Table 10 Flexural strength of beams using no fine aggregates (CA:FA = 5:0)

S. No.	Age of beam (days)	Compressive strength of beam (MPa)
1	7	2.76
2	7	2.73
3	7	3
4	28	2.99
5	28	3.26
6	28	3.5

Table 11 Flexural strength of beams using fine aggregates (CA:FA = 4:1)

S. No.	Age of beam (days)	Compressive strength of beam (MPa)
1	7	4
2	7	3.25
3	7	3
4	28	4.2
5	28	4.3
6	28	3.9

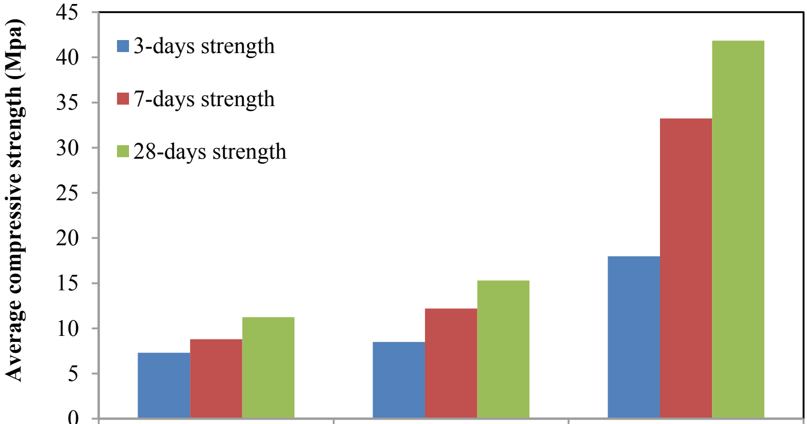
3.2 Flexural Strength Results

Flexural strength results were determined after 7 and 28 days of curing and presented in Tables 10, 11 and 12.

Figure 5 shows a comparative study of compressive strengths after 3, 7 and 28 days for sample 1, sample 2 and sample 3. It was noticed that compressive strength increases from sample 1 to sample 3 with sample 3 showing highest compressive strength and sample 1 showing lowest compressive strength as compared to other

Table 12 Flexural strength of beams using fine aggregates (CA:FA = 3:2)

S. No.	Age of beam (days)	Compressive strength of beam (MPa)
1	7	4.6
2	7	4.5
3	7	4
4	28	6
5	28	5.75
6	28	5

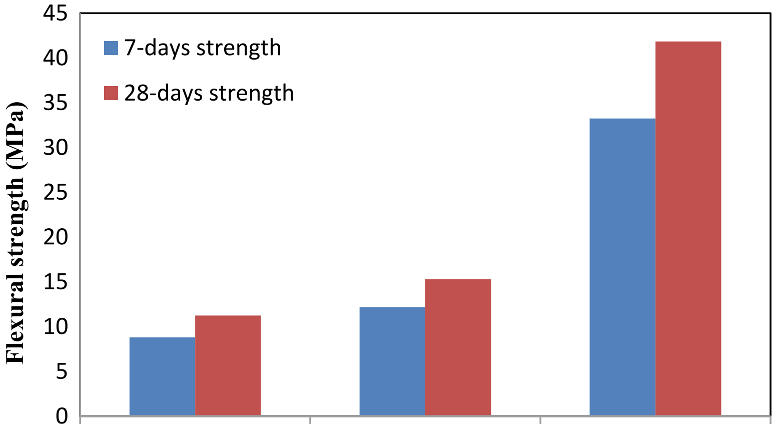


	Sample1(CA:FA=5:0)	Sample2(CA:FA=4:1)	Sample3(CA:FA=3:2)
3-days strength	7.3	8.5	17.97
7-days strength	8.8	12.19	33.24
28-days strength	11.25	15.3	41.84

Fig. 5 Comparison of average compressive strength of cubes with different CA:FA ratios

two samples, but sample 2 having higher compressive strength than sample 1 and lower compressive strength than sample 3.

Figure 6 shows a comparative study of flexural strengths after 7 and 28 days for sample 1, sample 2 and sample 3 which shows that flexural strength increases from sample 1 to sample 3. Sample 3 demonstrated higher flexural strength as compared to the other two samples while sample 1 showing the lowest flexural strength .



	Sample1(CA:FA=5:0)	Sample2(CA:FA=4:1)	Sample3(CA:FA=3:2)
7-days strength	8.8	12.19	33.24
28-days strength	11.25	15.3	41.84

Fig. 6 Comparison of average flexural strengths of beams with different CA:FA ratios

3.3 Discussion of Results

Compressive Strength:

It was established as a result of experimental observations that the 3-day strength of specimen increases in the compressive strength of M20 grade (from ratio 5:0 to 3:2 of CA:FA) of pervious concrete by 13.8%, whereas an increase in the compressive strength of M20 grade (from ratio 5:0 to 3:2 of CA:FA) of pervious concrete was seen by 25.9% in case of 7-day strength. On the other hand, the rise in 28-day compressive strength was observed to be 54.8% From the results, it was concluded that compressive strength increases from ratio 5:0 to 3:2 of coarse aggregate and fine aggregate. Compressive strength of pervious concrete is lower than of conventional concrete. At the CA:FA ratio 4:1, sample shows very good porosity and good compressive strength. Strength also increases from 3 days to 28 days. It means strength is directly proportional to time.

Flexural Strength:

As a result of experimental observations, an increase of 10.7% was observed in the 7-day flexural strength of M20 grade (from ratio 5:0 to 3:2 of CA:FA), whereas the increase in 28-day flexural strength of the sample was found to be 21.4%. From the flexural strength results, it was concluded that flexural strength increases from ratio 5:0 to 3:2 of coarse aggregate and fine aggregate. Flexural strength of pervious concrete is lower than of conventional concrete. At ratio 4:1, sample shows the porosity and good flexural strength. Strength also increases from 3 days to 28 days, which means that flexural strength increases with time.

4 Conclusions

From this study, several conclusions were made to successfully develop pervious concrete of desired physical and mechanical properties

- Content of cement is a very important aspect to be considered while designing pervious concrete. Excessive amount of cement will form cement slurry when mixed with water and will settle down after the concrete has been placed into the moulds, thereby making the base of concrete impervious.
- It was also found that as the mixture is unable to retain/hold water while mixing therefore concrete mixer is recommended for heavy concreting. However for small scale work in laboratory, steel or iron mixing tray can be used in order to avoid loss of water.
- Table vibrator or any other vibratory compaction method shall not be used while compacting pervious concrete as vibration leads to gravitational settlement of cement slurry again making the base of specimen impervious. Only hand compaction is recommended as per this study.
- While oiling the cubes, excessive oil should be prevented on the surface of moulds as it leads to the formation of bug holes on the surface of concrete cubes. Type of oil used should be checked for its lubricating properties. Oil should not be sticky rather it should be oily. Motor vehicle black oil is recommended in this study.
- Out of three different mixes on different proportions of cement, i.e. 479, 446 and 384 kg/m^3 it was found that specimens having cement quantity as 384 kg/m^3 had greater permeability.
- Three different mixes were prepared having cement content as 384 kg/m^3 of cement—Mix 1 having 0% sand, Mix 2 having 15.02% sand and Mix 3 having 30.22% sand. It was found that the first two mixes had good permeability, while the third mix was impermeable. Out of the first two mixes, second mix is recommended as it had considerable permeability and good compressive strength as compared to Mix 1 specimens.
- Lastly, it was concluded that the proportion of fine aggregate can be used in development of pervious concrete not exceeding 15% in proportion of mix by weight.

References

1. Eathakoti S, Gundu N, Ponnada MR (2015) An innovative no-fines concrete pavement model. IOSR J Mech Civ Eng IOSR-JMCE 12(3):34–44
2. Malhotra VM (1976) No-fines concrete-its properties and applications. Can Mines Branch Inf Circ IC 313, vol 73(11), pp 628–644
3. Teware PR, Harle SM (2016) Mix proportion of cementitious material in pervious concrete. J Recent Act Archit Sci 1(3):1–13
4. Shah DS, Pitroda J, Bhavsar JJ (2013) Pervious concrete: new era for rural road pavement. Int J Eng Trends Technol 4(8):3495–3499
5. Nishikant K, Nachiket A, Avadhut I, Sangar A (2016) Manufacturing of concrete paving block by using waste glass material. Int J Sci Res Publ 6(6):61–77

6. Balaji MH, Amarnaath MR, Kavin RA, Jayapradeep S (2015) Design of eco friendly pervious concrete. Int J Civ Eng Technol IJCIET. ISSN 0976-6308
7. Castro J, Spragg R, Kompare P, Weiss WJ (2010) Portland cement concrete pavement permeability performance. Can Mines Branch Inf Circ IC 313, vol 73, pp 628–644
8. Pitroda J, Umrigar DF, Principal B, Anand GI (2013) Evaluation of sorptivity and water absorption of concrete with partial replacement of cement by thermal industry waste (Fly Ash). Int J Eng Innov Technol IJEIT 2(7):245–249
9. Mageswari M (2016) High strength permeable pavement using no fines concrete. Int J Civ Eng (SSRG-IJCE) 3(3):53–57
10. Patil VR, Gupta AK, Desai DB (2010) Use of pervious concrete in construction of pavement for improving their performance. IOSR J Mech Civ Eng (IOSR-JMCE) 54–56
11. Nataraja MC, Das L (2010) Concrete mix proportioning as per IS 10262: 2009—comparison with IS 10262: 1982 and ACI 211.1-91. Indian Concr J 64–70
12. Dierkes C, Kuhlmann L, Kandasamy J, Angelis G (2002) Pollution retention capability and maintenance of permeable pavements. In: The proceedings of global solutions for urban drainage, pp 1–13