Experimental Study of Pervious Concrete and Artificial Clogging

Kanish Kapoor, Mudasir Nazeer, Gowhar Afzal, and S. P. Singh

Abstract Pervious concrete is a form of lightweight porous concrete, obtained by eliminating or by minimizing the content of fines from the normal concrete mix. The special property of pervious concrete is 'adequate permeability' because of its high percentage of porosity (15–40%). However, with the passage of time, pores of pervious concrete get closed or blocked with sediments like sand, clay, or mud, etc. In the present study, to predict the life period in which the pervious concrete works with full efficiency, an artificial method, known as artificial clogging, is performed on pervious concrete to find the critical sediment and effect on the rate of infiltration. An investigation is performed on two mixes (M1 and M2) using sand, clay, and mixture of both as sediment of clog. A total of six cycles were repeated with an increment of 10 g per cycle and the infiltration rate was recorded after each cycle. It was observed that the decrease in infiltration rate was 30%, 50%, and 45% after the sixth cycle where sand, clay, and combination were used, respectively. Furthermore, compressive strength and permeability test were performed on six separate mixes of pervious concrete.

Keywords Pervious concrete · Artificial clogging · Permeability test

1 Introduction

Concrete, the most commonly used composite material composed of fine aggregates, coarse aggregates, cement, and water having relatively high compressive strength but low tensile strength. It is being estimated that the consumption of concrete is approximately 10 billion tons per year throughout the world. Such a tremendous impermeable building material which can be used to mold any shape and perform

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under all environmental conditions. Concrete is the most durable, fire-resistant, and energy-efficient material having 65–80% of aggregates that acquires the properties of the rock made with constituent particles having a very close bond together [1]. Pervious concrete is relatively a unique kind of concrete, gaining fast prominence in sustainable construction. It allows the flow of water through a concrete matrix, sometimes also referred to as porous concrete. The proportioning of this special concrete is done by gap grading the coarse aggregates and either eliminating or reducing the volume of fine aggregates to form a network of interconnected pores. Pervious concrete contains no or a small percentage of fine aggregates so also known as no-fines, gap-graded, zero-slump concrete. Pervious concrete is primarily used in pedestrian footpaths, car parks, and other low traffic areas [2]. Pervious concrete pavements are designed to minimize the stormwater runoff by allowing it to percolate into the ground instead of making it run over the surface or toward stormwater drains [3]. Pervious concrete has usually high porosity that ranges between 15 and 40%, thus provides good permeability, drainage, and high noise absorption characteristics [4]. The compressive strength of this concrete ranges up to 28 MPa at 28-day testing but can be increased to 46 MPa with the introduction of supplementary cementitious materials like silica fume, metakaolin, etc. [3, 5, 6]. Porous concrete retains suspended solid impurities like phosphorus, nitrogen, copper, and motor oil, improving groundwater quality [7]. It also improves skid resistance and heat island effects in cities [8].

Although porous concrete clearly has many benefits but is inevitably susceptible to clogging that leads to premature degradation and serviceability problems. Physical clogging is caused due to sediments of sand, clay, and debris built upon the surface. Algae, bacteria, and plant root penetration are responsible for biological clogging. This leads to the reduction in permeability which in turn leads to a susceptibility of inland flooding and freeze–thaw damage thus decrease the life span of pervious concrete pavements [9, 10]. The aim of this study was to check the serviceability of the pervious concrete, which was examined by doing artificial clogging due to sediments like sand and clay in different cycles. Compressive strength test and permeability tests were performed and ultimately the age of the pavement is defined.

2 Experimental Programme

2.1 Preparation of Specimens

To make the mix permeable and to maintain both permeable and strength properties, various trials of mixing are performed. A simple hand mixing procedure was adopted to avoid the chances of making slurry inside the pervious concrete. A cylinder of diameter 12 inches and height of 12 inches was cast for checking the infiltration rate of pervious concrete and, at the same time, cubes of size 150 mm were cast in order to check the compressive strength of the pervious concrete. And a total of six mixes

Table 1 Properties of cement

S. No.	Properties	Obtained value	IS Code recommendation
1	Specific gravity	3.15	3.10–3.15
2	Initial setting time(min)	49	30
3	Final setting time(min)	284	600
4	Consistency	27.7%	26–33%

were performed, starting with highly impermeable mix T1 in which cement content was in access and the size of aggregates were too large and, in the case of T2, T3, T4, T5, the cement quantity was reduced also the size of aggregates were changed. In the case of mix T6, aggregate size was reduced and replaced with some amount of fine aggregates as a replacement of coarse aggregates [11]. In the current study, the cement used was Ordinary Portland Cement of 53 Grade [12] (Tables 1, 2, 3 and 4).

Table 2 Aggregate properties

S. No.	Properties	Specified requirements	Result-1 10 mm	Result-2 20 mm
1	Impact value	30 or 45%	12.8	13.3
2	Abrasion value	30 or 50%	15.2	13.4
3	Water absorption	5%	0.58	0.53
4	Specific gravity	2.1–3.2	2.58	2.58
5	Crushing value	30%	13.1	13.2
6	Soundness	12%	6.4	5.1

Table 3 Trial mix of pervious concrete

Mix	Mix proportion	Max size coarse aggregates (mm)	Replacement of coarse aggregate with sand	W/C ratio
T1	1.5:3	20	0%	0.35
T2	1:4	20	0%	0.32
T3	1:4	20	0%	0.35
T4	1:4	10	10% 2.36 mm passing	0.35
T5	1:4	16	0%	0.32
T6	1:4	15	10% 2.36 mm passing and 90 microns retaining	0.35

Table 4 Mix design samples for clogging purpose

S. No.	Material	Mix (M1)	Mix (M2)
1	Aggregate	32.4 kg	33 kg
2	Cement	9 kg	8.25 kg
3	Sand	3.6 kg	0 kg
4	Water	2.88 kg	2.64 kg
5	Water/cement ratio	0.32	0.32
6	Cement/aggregate ratio	1:4 (10% replacement of coarse aggregates by sand)	1:4 (0% replacement of coarse aggregates by sand)

In addition to the above six samples, two separate samples (M1 and M2) were prepared for the artificial clogging system. The procedure and material properties were the same as that of the above-casted samples.

2.2 *Testing Mechanism*

Compressive Strength Test: Compression test is performed on UTM or CTM and the same cubes are cast as that of normal concrete (150 mm × 150 mm × 150 mm). Testing is done for 7, 14, and 28 days of curing age.

Permeability Test: The procedure of test on the apparatus is in accordance with [13].The apparatus consists of a cylindrical water reservoir with a hemispherical base of same diameter mounted on a moving stand. The cylindrical portion is not provided with covering on the top and to vary the flow from the hemispherical bottom portion, a value is connected to its base. A graduated pipe is attached to the external face of the cylindrical portion from top to bottom. The water reservoir of the apparatus is made of stainless steel and the stand is composed of casted iron.

A special type of stainless-steel cylinder specimen having diameter 12 inches and height 18 inches, having two marked lines at 10 mm and 15 mm at a height of 12 inches above the bottom to maintain the head between the two marked lines. The pervious concrete is filled up to the bottom mark of the cylinder keeping the 10 mm and 15 mm lines visible for head maintenance. The portion above the base marked line acts as the fitted ring for checking permeability instead of having an external ring (Fig. 1).

The time of infiltration is recorded and used in the following formula:

$$I = \frac{KM}{D^2} \times t \text{ In/hr.} \tag{1}$$

K = rate of permeability, M = mass of water, T = time of infiltration, D = diameter of the specimen.

Fig. 1 Infiltrometer and sample in a specimen

2.3 Mechanism Followed for Artificial Clogging

For artificial clogging, cylinder specimens of 12-inch diameter and 12-inch height were cast and the clogging operation was followed after 28 days of curing. Clogging was performed on two mixes M1 and M2 in the laboratory by artificial means where sand and clay were used as sediment material. Before proceeding with the artificial clogging mechanism, the infiltration rate was measured by using laboratory-based apparatus. After getting the initial results of all the samples, the sedimentation effect or clogging effect of all the samples were checked by following three ways: (a) By using sand only: Artificial clogging by using sand is done in consecutive six cycles in each cycle 10 g of sands is rolled over and infiltration rate was measured after every cycle. Overall, 100 g of sand were used and six readings of the infiltration were collected using sand as the sediment material for mix M1. In mix M2, six cycles were performed, and in each cycle, 25 g of sand were used, Overall, 150 g of sand were poured over**.** (b) By using clay only: Artificial clogging by clay is done using the same procedure as in the sandy mechanism. Six cycles with an increment of 10 g in each cycle is performed and a total of 60 g of clay were used in the first specimen. Similarly, six cycles with an increment of 25 g in each cycle were utilized to clog it artificially. (c) Combination of sand and clay: In this combination, 5 g of sand and 5 g of clay were mixed and rolled over the surface. Overall, six cycles were repeated and a total of 60 g of the mixture were used with an increment of 10 g in each cycle. And similarly, six cycles were repeated for the second sample, in which, 25 g of the mixture was rolled and a total of 150 g were utilized to clog the pervious concrete artificially (Fig. 2).

Fig. 2 Sample before infiltration and after infiltration

3 Results and Discussions

3.1 Compressive Strength

The compressive strength of porous concrete is influenced by different factors like cement content, w/c ratio, aggregate characteristics, and compaction extent during placement. The graph below clearly shows the gradual increase in compressive strength from 7 to 28-day curing age in all mixes. It is observed from the graph that mix T1 shows higher strength at all curing ages of 7, 14, and 28 days. The 14- and 28-day curing age compressive strengths were increased by 38% and 54%, respectively, when compared to 7-day strength of the same mix T1. Moreover, not much change in compressive strength was observed from mix T2 to T5 at all ages of 7-, 14-, and 28-day curing. Furthermore, fair values of compressive strength were observed for mix T6, where 7-day curing strength was observed as 13.2 MPa. The increase in compressive strength up to 36% and 54%, respectively, at 14- and 28-day curing ages was observed, which was quite good as compared to other mix proportions (Fig. 3).

3.2 Infiltration

The variation of aggregates size and water–cement ratio is the key factor to maintain the specified value of infiltration. It is clearly observed from the graph that mix T1 have zero permeability because the ratio of cement with respect to aggregate was very high and the size of aggregates was between 4.75 and 20 mm, smaller sized aggregates are responsible for making the mix impermeable. The rate of infiltration shows a gradual increase from T1 to T5 mixes. A prominent decrease in infiltration was

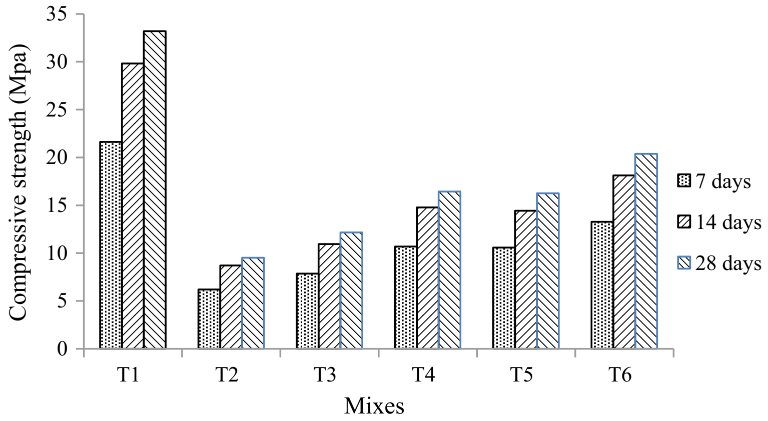

Fig. 3 Compressive strength variation

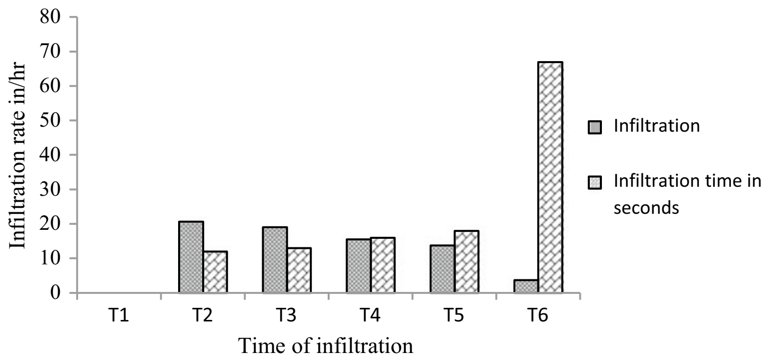

Fig. 4 Infiltration rate (mm/s)

observed in mix T6, this is because a good range of coarse aggregates with a maximum size of 10 mm and 10% of fine aggregates (2.36 mm) were used but the infiltration range was under drainage limits. The time of infiltration was approximately 3 times more and infiltration was 2.7 times less in case of mix T6 when compared to mix T5 (Fig. 4).

3.3 Results of Artificial Clogging of Mix M1

The observations and results of artificial clogging with sand, clay, and combination of both clay and sand, and the variation of infiltration rate under different conditions are discussed for mix M1 (Tables 5, 6 and 7).

Table 5 Clogging with sand for mix M1

S. No.	Cycle No.	Amount of sand (g)	Time of infiltration (s)	Infiltration rate (in/hr.)
1	0	0	67	525.995
2	1	10	69	510.748
3	2	20	73	482.762
4	3	30	77	457.683
5	4	40	85	414.607
6	5	50	95	370.964

Table 6 Clogging with clay for mix M1

S. No.	Cycle No.	Amount of clay (g)	Time of infiltration (s)	Infiltration rate (in/hr.)
1	0	0	67	525.995
2	1	10	75	469.888
3	2	20	85	405.076
4	3	30	100	352.416
5	4	40	115	306.449
6	5	50	133	264.974

Table 7 Clogging with sand and clay for mix M

S. No.	Cycle No.	Sand (g)	Clay (g)	Total sediment (g)	Time of infiltration (s)	Infiltration rate (in/hr.)
1	0	0	0	0	67	525.995
2	1	5	5	10	71	496.361
3	2	10	10	20	81	435.082
4	3	15	15	30	88	400.473
5	4	20	20	40	102	345.506
6	5	25	25	50	116	303.807

It is clearly seen from the above observations that, at initial stages of artificial clogging test, change in the rate of infiltration was very less with an insertion of 10 g of sand, clay, or both combined in mix M1. But there is a gradual decrease in the infiltration rate from cycle one onwards. In the last cycle, when sediment (sand) used for artificial clogging was 50 g and time of infiltration was 95 s, the decrease in infiltration was only 30% when compared with the control cycle (cycle zero). Furthermore, a 50% decrease in infiltration was observed when sediment for artificial clogging was clay as compared with the control cycle. Moreover, a 42% decrease in infiltration was seen in the combined case of artificial clogging where sediment utilized was 50 g (both sand and clay) in mixture state.

3.4 Results for Artificial Clogging for Mix M2

The observations and results of artificial clogging with sand, clay, and combination of both clay and sand, and the variation of infiltration rate under different conditions are discussed for M2 mix (Tables 8, 9 and 10).

The observation table clearly shows that there is a prominent decrease in infiltration from the initial cycle to cycle 4. The decrease in infiltration by artificial clogging when sediment used for clogging is sand is 85% compared to the control cycle (cycle zero). Furthermore, clogging effect by clay is more prominent than by sand. The result shows that there is a 90% decrease in infiltration when the last cycle (cycle 4) was compared to the control cycle. Moreover, the effect of clogging by the combination of both sand and clay was approximately the same as that of clay clogging alone. The decrease in infiltration was approximately 90% on making a comparison with the initial control cycle. Thus, it is observed that the effect of clay on the rate of infiltration was prominent as compared to the effect of sand and combination. But the effect of sand on artificial clogging is more in M2 as compared to mix M1. This is because the void ratio is more in case of M2, as no fines were used unlike in the case of M1.

Table 8 Clogging with sand for mix M2

S. No.	Cycle	Sand (g)	Time of infiltration (s)	Infiltration rate (in/hr.)
1	0	0	13	2710.897
2	1	25	19	1854.824
3	2	50	35	1006.904
4	3	75	57	618.274
5	4	100	86	409.786

Table 9 Clogging with clay for mix M2

S. No.	Cycle	Clay (g)	Time of infiltration (s)	Infiltration rate (in/hr.)
1	0	0	13	2710.897
2	1	25	23	1532.246
3	2	50	48	734.201
4	3	75	82	429.776
5	4	100	130	271.089

Table 10 Clogging with sand and clay for mix M2

S. No.	Cycle	Sand (g)	Clay (g)	Total sediment (g)	Time of infiltration (s)	Infiltration rate (in/hr.)
1	0	0	0	0	13	2710.897
2	1	12.5	12.5	25	21	1678.174
3	2	25	25	50	43	819.573
4	3	32.5	32.5	75	79	446.097
5	4	50	50	100	121	291.253

4 Conclusion

The following conclusions were drawn from the whole study of pervious concrete:

Clogging effect by clay is dominating both mixes (M1 and M2). In mix M1, the clogging effect by clay was 20% more and in case of M2, it was only 5% more than sand. So, it is here clearly concluded that pervious concrete is deteriorated more by clay than sand sediments. While replacing coarse aggregates by 10% of fine aggregates, fair to good strength is achieved without being compromising with the infiltration rate. So, clay sediment is more worrisome than sand sediment. Furthermore, pervious concrete can be used for low to moderate traffic pavements if the proper percentage of fines is used which enhances the strength of concrete.

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