No Fine Concrete Pavement—A Sustainable Solution for Flood Disaster Mitigation

R. Jeya Prakash, B. Soundara, and Christian Johnson

Abstract No Fine concrete (NFC) pavement is an ecologically sensible and sustainable substitute for conventional impervious concrete or asphalt pavement structures. Due to the omission of fine aggregates, the concrete can exhibit a porous structure called Pervious or No Fine concrete (NFC). The key design of the NFC system is to introduce acceptable void content so that excess runoff water does freely infiltrate being a self-resilient infrastructure. This can be achieved by controlling or totally removing the proportion of fine aggregates from the mixture design. In this current research, the mechanical properties including compressive strength, split tensile strength, and the hydraulic conductivity (i.e., permeability) of Fibre Reinforced No Fine Concrete (FRNFC) were discussed. Fibres with an effective length of 36 mm, and dosage rates of 0.15, 0.30 and 0.45% are taken for this present investigation. The volume fraction of the water to binder ratio is kept constant at 0.28. The addition of fibre doesn't have substantial effects on strength parameters and diminish the permeability of NFC to an insignificant degree. However, this polypropylene fibre reinforcement is done, to ensure the durability parameters such as abrasion and freeze–thaw resistance which are the perennial concern for implementation.

Keywords No fine concrete · Fibre reinforcement · Permeability · Porosity · Flood mitigation · Sustainable concrete

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C. Ghosh and S. Kolathayar (eds.), *A System Engineering Approach to Disaster Resilience*, Lecture Notes in Civil Engineering 205, https://doi.org/10.1007/978-981-16-7397-9_19

1 Introduction

1.1 Problem Statement

No Fines Concrete (NFC) is an extremely sustainable, environmentally friendly material that creates an open cell structure due to the absence of fine aggregates which allows permeability in it. The storm water runoff loss estimated in the rural areas and villages was about 14–19% with above 80% of infiltration rates. Besides, the same measured in urban areas reach up to 94% of runoff losses allowing only 6% of volume for infiltration [1]. This is an effect of increased volume of impervious layer over the surface of the earth in urban areas, causing high environmental impacts [2]. This is also considered to be a source of pollution, in which various pollutants over the surface are washed and mixed into the water bodies at the time of runoff [3]. To reduce this adverse effect of storm water runoff, there should be a proper drainage facility and rainwater harvesting at the source level should be encouraged among the residents. The government has taken many steps to spread awareness about rainwater harvesting and its benefits, but still, this method is not suitable for cities like Chennai with densely populated. This can also be avoided by installing pervious or NFC pavements, besides these environmental benefits some of the drawbacks like less strength, durability, and high chance of clogging restrict its application in real-time [4].

1.2 Research Significance

The Literature study inferred that the durability parameters such as the resistance offered against abrasion and freeze–thaw durability of NFC have been enhanced significantly due to the addition of fibre, but still, there is no technical guidance about the dosage and fibre length [5, 6]. Further, literature shows a variety of compressive strength values ranging from 3.5 to 25 N/mm^2 [7]. If the strength is of primary concern, NFC can be produced by several practices such as increasing the compaction energy, confinement to the sample, etc., with low permeability [8]. The main objective of this study is to produce an optimal mixture proportion for FRNFC with higher performance in strength parameters without compromising their permeability value and to investigate the effects of aggregate size, aggregate to binder ratio, and the fibre proportion on their mechanical and hydraulic properties.

2 Methodology

Methodology of this research includes the selection of aggregates as in Fig. 1 and the selection of fibre as in Fig. 2.

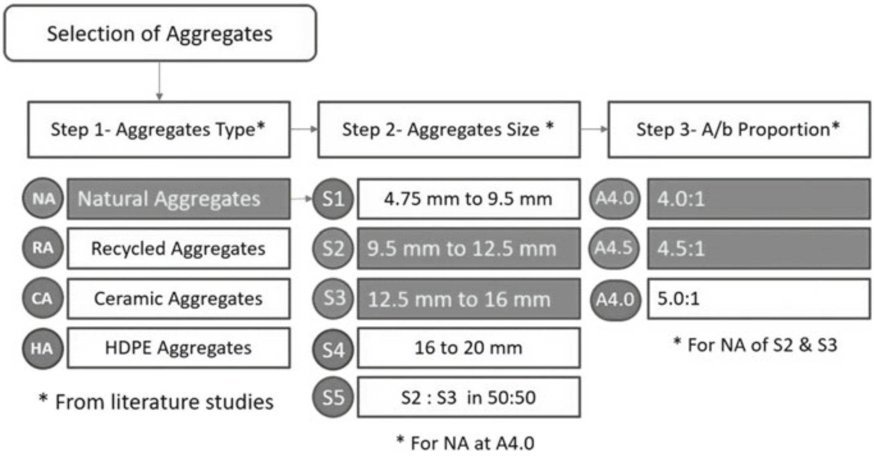


Fig. 1 Selection of aggregates

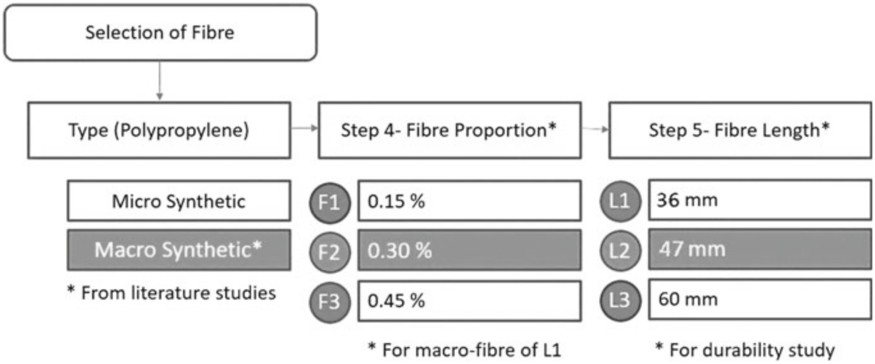


Fig. 2 Selection of fibre

Among the various type of aggregates and fibre: natural aggregates and macro synthetic fibres are taken for this study based on the literature study conducted [9, 10]. This paper presents the test values of structural and hydraulic properties of fibre reinforced no fine concrete. The additional characteristics such as effects of fibre length on the resistance against abrasion and freeze and thaw, the pore size distribution of FRNFC can be studied using imaging technology [11].

3 Material Properties and Testing

This section presents the test results of the materials used in this study. Among the various grades of cement available in the market, Ordinary Portland cement of 53

Table 1 Properties of OPC 53 grade based on test results

Specific gravity	Fineness (%)	Standard consistency (%)	Initial setting time (min)	Final setting time (min)	Bulk density (kg/m^3)
3.15	8	30	33	570	1411

grade—Zuari Cement (Commercial name) opts for this study [12]. The various test results of cement are given in Table 1.

The aggregates are categorized into S1, S2, S3 and S4 [13, 14] (S1—passing through 9.5 mm sieve and retained on 4.75 mm sieve, S2—passing through 12.5 mm sieve and retain on 9.5 mm sieve, S3—passing through 16 mm sieve and retained on 12.5 mm sieve and S4—passing through 20 mm sieve and retained on 16 mm sieve) and their test results are given in Table 2. The aggregates of the same size range produce high values of permeability. Whereas aggregates of the different sizes are used in the same mixture, the lower size aggregate fill the pore space between the large aggregate resulting in high strength but comparatively very less permeability. The aggregate to binder ratios of 4.0:1, 4.5:1, and 5.0:1 are taken and their effects on mechanical and hydraulic properties of NFC have been examined. For NFC, the optimum water cement ratio can be taken between 0.26 and 0.30 [2] and in this study, it is kept constant as 0.28.

The macro synthetic polypropylene fibre of 0.15, 0.30, and 0.45% in the volume of cement is added to NFC to study their effects and their properties are listed in Table 3.

Table 2 Aggregate properties based on test results

Aggregate size	Specific gravity	Water absorption (%)	Bulk density (kg/m^3)
S1—4.75–9.5 mm	2.86	0.98	1595
S2—9.5–12.5 mm	2.68	1	1513
S3—12.5–16 mm	2.94	1	1542
S4—16–20 mm	2.91	1.15	1660

Table 3 Properties of macro synthetic polypropylene fibre

Specific gravity	Effective length (mm)	Aspect ratio	Young's modulus (kN/mm^2)	Tensile strength (kN/mm^2)	Bulk density (kg/m^3)
0.91	36	46	4.0	0.55	910

3.1 Casting and Curing of Test Samples

The concrete was batched and mixed using a rotating-drum mixer for appropriate mixing, and the fibres were added at last by sprinkling to ensure uniform mixing [15]. Then the prepared mixture was placed in cube molds of 150 mm × 150 mm × 150 mm size and cylindrical molds of 150 mm diameter and 300 mm height for the estimation of compressive and split tensile strength respectively. For permeability check using constant head permeameter, the samples are prepared by placing the mixtures in PVC cylindrical molds of 100 mm diameter and 200 mm height. The casted specimens are demolded after 24 h and subjected to curing for 28 days. All the test for strength parameters was conducted according to IS:516–1959.

3.2 Test Procedures

Flowtable Test. The Flowtable test is conducted to calculate the consistency in flow percentage and can be used to determine the workability of a freshly prepared concrete mix. It consists of a circular table, fixed with a rotating wheel and a mold is firmly placed over the center of table in which the concrete is filled in two layers. After leveling the surface, the mold is removed steadily upward without disturbing the sample. The flow table is raised and dropped from a height of 12.5 mm, 15 times in about 15 s. The average diameter of spread in six symmetrical directions in the table is used to measure the flow.

$$\text{Flow}\,\% = \frac{\text{Spread diameter(in cm)} - 25}{25} \times 100$$

Compressive Strength. Compressive strength is generally calculated for concrete cube specimen to evaluate their quality and performance. The values tabulated in Tables 4, 5, and 8 were reported based on the average values obtained from the compressive strength test of three cube specimens on 7 and 28 days of curing.

Split Tensile Strength. Cylindrical specimens of standard dimensions were tested against a split tensile strength test, after curing for 28 days. All the values tabulated were based on the average values obtained from three test samples. Since the application of this type of concrete is restricted to pavements applications, testing of beams (Flexural strength test) is neglected.

Hydraulic Conductivity. Hydraulic conductivity or Permeability is a property of any porous material which permits the flow of fluids through their interconnecting voids [16] and is measured using a constant head permeameter for cylindrical samples with 100 mm diameter and 200 mm height. The samples are subjected to vacuum wash, to get more accurate results.

Table 4 Trial mix design (for varying aggregate size, w/b ratio of 0.3 and A/b ratio of 4.0:1)

Mix ID	Mix name	Cement (kg/m^3)	Aggregate (kg/m^3)	Water (l/m^3)	Compressive Strength (N/mm^2)		Split Tensile strength (N/mm^2)	Flexural strength (N/mm^2)	Permeability (cm/s)
					7 days	28 days			
M1	A4.0S1	267	1208	53.0	11.12	15.86	1.53	2.87	0.89
M2	A4.0S2	267	1146	53.0	8.57	12.32	1.47	2.42	1.26
M3	A4.0S3	267	1168	53.0	5.36	8.65	1.32	2.34	1.40
M4	A4.0S4	267	1258	53.0	4.67	6.07	1.15	1.86	1.53
M5	A4.0S5	267	1157	53.0	10.28	14.87	1.40	2.15	0.97

Table 5 Trial mix design (for varying A/b ratio, aggregate size—S2 and S3, w/b ratio of 0.3)

Mix ID	Mix name	Cement (kg/m^3)	Aggregate (kg/m^3)	Water (l/m^3)	flow %	Compressive strength (N/mm^2) 7 days	Compressive strength (N/mm^2) 28 days	Split Tensile strength (N/mm^2)	Flexural strength (N/mm^2)	Permeability (cm/s)
M2	A4.0S2	267	1146	53.0	110	8.57	12.32	1.47	2.42	1.26
M3	A4.0S3	267	1168	53.0	104	5.36	8.65	1.32	2.34	1.40
M6	A4.5S2	244	1178	48.4	98	10.45	14.50	2.06	2.12	1.37
M7	A4.5S3	244	1201	48.4	90	9.96	13.09	1.97	2.03	1.58
M8	A5.0S2	225	1205	44.6	84	7.81	8.49	1.34	1.98	1.06
M9	A5.0S3	225	1228	44.6	52	4.94	7.14	1.23	1.56	1.14

4 Mix Design

The effects of aggregate size and proportion on No Fine Concrete (NFC) are studied, based on the test results the best performing mixes [17] were taken to investigate the effects of fibre reinforcement.

The compressive, split tensile strength, and permeability values are based on the average value of three samples [18–20]. It is observed that the mixture containing S1, S2, and S3 produces a high value of compressive strength compared to the mixture containing S4. This is because the thin film of cement pastes forms better bonding with smaller-sized aggregates. While considering the coefficient of permeability, the mixture containing S3 and S2 performs well compared to that of the mixture containing S1.

This may be caused because of the decrease in pore size with a decrease in the nominal size of the aggregates. A new mixture ID, M5 is prepared with the aggregates of sizes S2 and S3 in equal proportion (i.e., 50:50). In which about 40% of pores in S3 type aggregates are filled with S2, and thereby increasing the strength parameters and decreasing the overall porosity. From the results obtained, further testing is restricted to the aggregate size of S2 and S3. Thus, the effects of aggregate proportion on NFC are studied for S2 and S3 with an aggregate to binder ratio of 4.0:1 (A4.0), 4.5:1 (A4.5), 5.0:1 (A5.0). Change in aggregate to binder ratio affects the workability of the mixture to a significant extent [21]. The increase in aggregate proportion decreases the flow value index and has produced a significant increase in strength parameters up to an extent but holds comparatively low permeability.

The further increase in aggregate proportion (i.e., >5.0:1) reduces the strength parameters, which may be due to the insufficient binder paste around the aggregates. And it is also very hard to work with mixtures containing high aggregate contents. Similarly, for mixtures with less aggregate content (i.e., <4.0:1) the flow value index increases, and segregation takes place. From the above trial mixes in Table 5, it is highly recommended to choose M2, M3, M6, and M7 for finding the effects of varying fibre proportions (Table 6).

Fibre reinforcement may reduce some specific performance, to stabilize and enhance the desired mechanical characteristics of Fibre Reinforced No Fine Concrete (FRNFC) such as bond strength between aggregates and cement paste, workability of the mixtures, additional admixtures such as viscosity modifying agent, VMA (Eucoplacant-721) and water-reducing agent, WRA (Auramix-400) confirming to the requirement of IS: 9103–1979, are added in optimal dosage as given in Table 7.

Along with these two admixtures, 12 mixture designs were prepared for three dosages of varying fibre proportions 0.15% (F1), 0.30% (F2) and 0.45% (F3) as shown in Table 8.

Table 6 Workability of mixture with respect to flow percentage

Flow percentage	0–20%	20–60%	60–100%	100–120%	120–150%
Consistency	Dry	Stiff	Plastic	Wet	Sloppy

Table 7 Admixtures composition

Admixture	VMA	WRA
Dosage (%)	0.30	0.25

5 Result and Discussion

This section presents the test results for FRNFC specimens containing various fibre proportions in Table 8. It includes the effects of change in aggregate size and proportion, the effects of change in fibre proportion in their mechanical and hydraulic characters of various mixture proportions. The volume fraction of water to binder ratio is kept constant at 0.28 for all mixtures.

5.1 Effect of Change in Aggregate Size

The aggregate size determines the pore structure of concrete, say for smaller aggregates the pores present were also small, and for larger aggregates, the pore structure was comparably large. The above conditions changed vice-versa considering the strength parameters. The line chart in Fig. 3, stretches the effects of aggregates size on permeability and strength parameters. From this, we can evidently notice that with the increase in aggregate size, strength decreases, and permeability increases.

For A4.0S5 (M5), the sudden increase in compressive strength is due to the usage of different size aggregates. Here the pore space between the larger size aggregates was filled by the lower size aggregates resulting in high strength but comparatively very less permeability. Thus, the mixture proportions A4.0S2 and A4.0S3 (i.e., M2 and M3) are taken for further studies to examine the effects of aggregate to binder proportions.

5.2 Effect of Change in Aggregate Proportion

The change in aggregate proportion readily affects the workability of mixtures. The mixtures with high aggregate contents are hard to work and the mixtures with less aggregate content are easy to work, have high value of flow index. The effect of change in aggregate to binder ratio in permeability and flow index is given by Fig. 4, and this variance observed was most likely due to an increase in surface tension of the aggregates. From these observations, mixtures with compromising permeability and flow index A4.0S2, A4.0S3, A4.5S2, and A4.5S3 (i.e., M2, M3, M6 and M7) are taken to study the effects of change in fibre proportions.

The mixture proportions are prepared in such a manner by controlling the void content and fresh unit weight to produce less difference in harden unit weight of the samples and to study the exact effect caused by the fibers [22]. The observations

Table 8 Mix designs (with varying fiber proportion for selected trial mixes)

Mix ID	Mix name	Cement (kg/m^3)	Aggregate (kg/m^3)	Water (l/m^3)	Fibre (g/m^3)	Chemical admixtures		Flow (%)	Unit weight (kg/m^3)		Compressive Strength (N/mm^2)		Split tensile strength (N/mm^2)	Flexural strength (N/mm^2)	Permeability (cm/s)
						WRA (g/m^3)	VMA (g/m^3)		Wet	Dry	7 days	28 days			
M10	A4.0S2F1	267	1146	50.6	401	668	802	108	1960	1850	8.63	13.11	1.82	2.91	1.21
M11	A4.0S2F2	267	1146	50.6	802	668	802	103	1975	1860	8.92	13.66	2.01	3.32	1.18
M12	A4.0S2F3	267	1146	50.6	1203	668	802	96	1985	1860	9.06	13.72	2.43	3.45	1.11
M13	A4.0S3F1	267	1168	50.6	401	668	802	104	1980	1855	5.54	8.99	1.6	2.83	1.36
M14	A4.0S3F2	267	1168	50.6	802	668	802	99	1995	1860	6.02	9.87	1.98	3.21	1.2
M15	A4.0S3F3	267	1168	50.6	1203	668	802	93	2010	1870	6.95	9.94	2.62	3.33	1.07
M16	A4.5S2F1	244	1146	46.4	366	610	732	98	1990	1865	11.04	15.11	2.71	2.86	1.34
M17	A4.5S2F2	244	1146	46.4	732	610	732	90	2015	1875	11.61	15.63	3.13	3.24	1.26
M18	A4.5S2F3	244	1146	46.4	1099	610	732	82	2020	1885	12.15	15.98	3.61	3.35	1.19
M19	A4.5S3F1	244	1168	46.4	366	610	732	90	1995	1870	9.96	13.21	2.19	2.79	1.55
M20	A4.5S3F2	244	1168	46.4	732	610	732	81	2005	1875	9.99	13.57	2.45	3.2	1.41
M21	A4.5S3F3	244	1168	46.4	1099	610	732	73	2015	1880	10.13	13.72	2.64	3.35	1.26

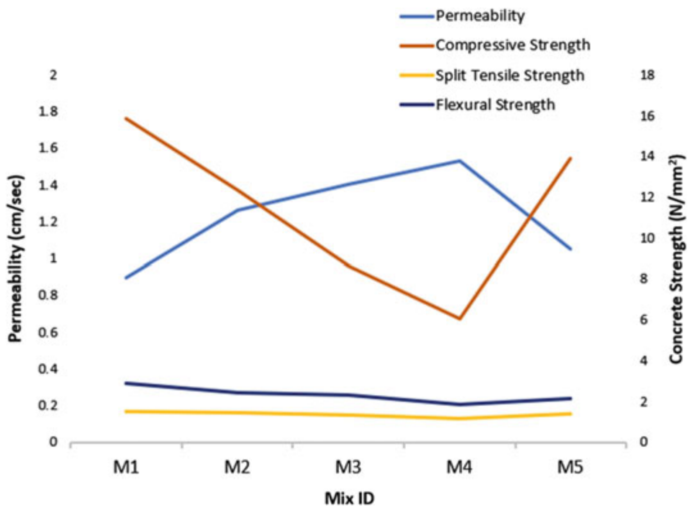


Fig. 3 Effect of change in aggregate size

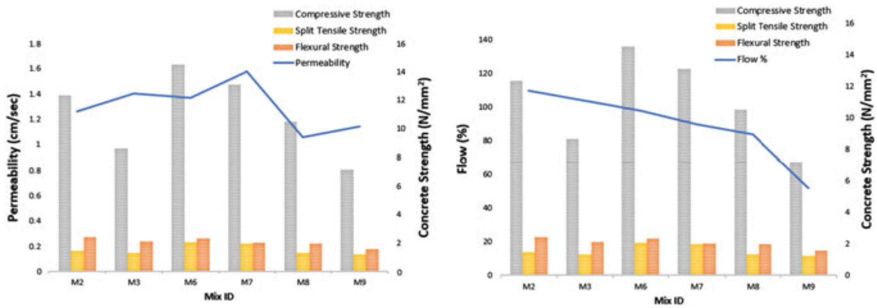
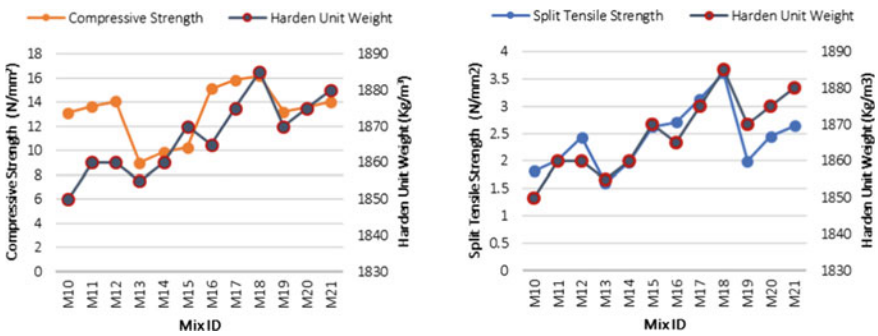


Fig. 4 Effect of change in aggregate proportion

made show that there is an appropriate relationship between the hardened (or) dry unit weight [23, 24] and compressive strength/split tensile strength as shown in Fig. 5a, b.

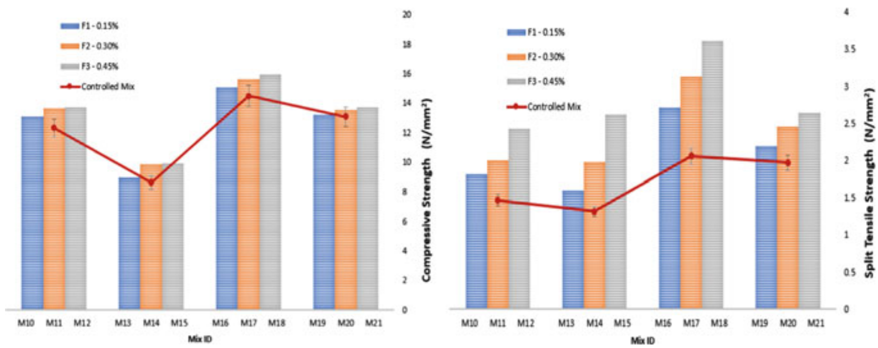
5.3 *Effect of Change in Fibre Proportion*

Mechanical Effects. Based on the reported preliminary test results (Table 5), the four mixtures M2, M3, M6, and M7 were taken for finding the effects of varying fiber proportion F1(0.15%), F2(0.30%) and F3(0.45%). There was no significant change observed in compressive strength values after adding fibre in Fig. 6a, but



(a) Compressive Strength at 28 days (b) Split Tensile Strength at 28 days

Fig. 5 Relationship between harden unit weight and Strength parameters



(a) Compressive Strength at 28 days (b) Split Tensile Strength at 28 days

Fig. 6 Effect of fibre reinforcement in NFC

still, the fibre reinforcement has enhanced the strength gradually to the mixture up to a minimum extent. While considering the split tensile strength, the fibre adds an additional tensile property to the controlled mix (i.e., mix without fibre) Fig. 6b.

Hydraulic Effect. Permeability is the most desirable factor for NFC, fibre reinforcement has a diminishing effect on it. Permeability decreases with fibre content and increases slightly with aggregate size and proportion as shown in Fig. 7 and has a linear relation with hardened unit weight.

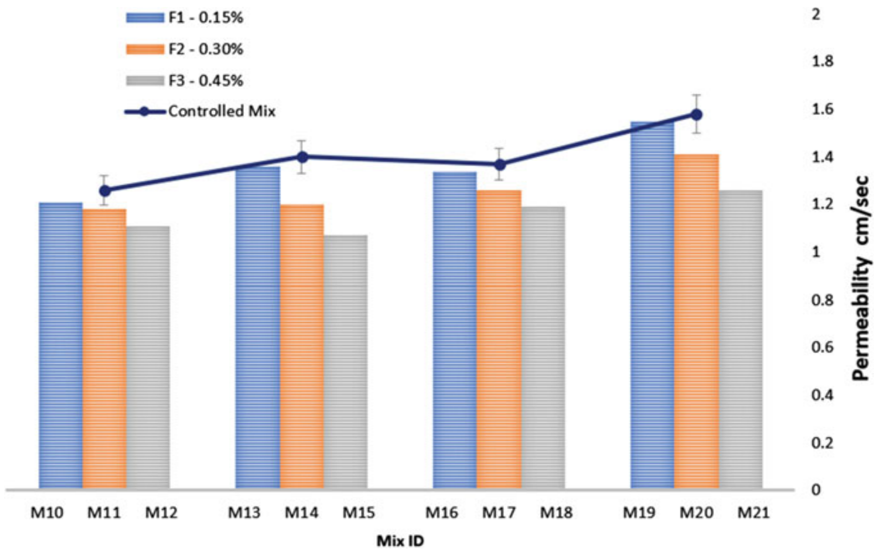


Fig. 7 Effect of fibre reinforcement in permeability of NFC

6 Conclusion

This experimental investigation presents the effects produced on mechanical and hydraulic properties of FRNFC with various experiments such as flow table test, compressive strength test, split tensile test, constant head permeability test.

About 21 mixture proportions (M1-M21) were prepared and studied in detail. The effects of aggregate size and proportions were examined for M1-M9. In addition, the effects of fibre with constant effective length 36 mm and three dosages of proportion (0.15, 0.30 and 0.45%) were tested on the sample mixtures M2, M3, M6, M7, and the following conclusions are drawn.

(1) The average values for compressive strength range from 8.99 to 16.18 N/mm^2 and the average values for split tensile strength ranges from 1.60 to 3.61 N/mm^2. Which is found to be, within the limit as reported in various literature.
(2) The permeability values of FRNFC range from 1.07 cm/s to 1.55 cm/s with respect to the mixture design. Through which, the concrete exhibits pervious behavior, and the values are within the acceptable limit as stated in literature.
(3) This result clearly indicates that both the compressive strength and permeability of FRNFC linearly depend on the dry unit weight of the samples.
(4) The aggregates' size has a significant effect on both structural and hydraulic properties of NFC. The increase in aggregate size increases the pore size and thus the coefficient of permeability, due to the lack of bonding the strength decreases.
(5) The change in aggregate to binder ratio mainly affects the workability of mixtures i.e., the mixtures with high aggregate proportion are hard to work

and for the mixtures with less aggregate content the flow value index increases, and segregation takes place. The variances observed were most likely due to surface tension of the aggregates. However, the water to binder ratio has an inverse effect to that of the aggregate to binder ratio in NFC.

(6) The accumulation of fibre doesn't produce any considerable changes in compressive strength and reduces the hydraulic conductivity of NFC to an insignificant degree.

(7) From the overall observations, the mixture proportion with fibre content had shown a gradual performance compared to conventional concrete.

Finally, it was concluded from the study that polypropylene macro synthetic fibre of 30% and aggregate to binder ratio 4.5:1 for both aggregate size 9.5–12.5 mm and 12.5–16 mm, (i.e., A4.5S2F2 and A4.5S3F2) was the most promising mixture proportion among the various mixtures tested against both strength and hydraulic parameters.

Acknowledgements I wish to express my deep sense of gratitude and sincere thanks to my research supervisors Dr.B.Soundara and Dr. S.Christian Johnson for their inspiring guidance, constant encouragement. And I am thankful to the Management of Nandha Engineering College, Perundurai and Excel Engineering College, Namakkal (former workplace) for the facilities provided and general support during the entire work.

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