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SUSTAINABILITY OF NO-FINE CONCRETE WITH FIBRE REINFORCEMENT

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Abstract. No-Fine Concrete (NFC) is generally used to drain the excess water into the ground, from the earth's surface during heavy rainfall conditions. Durability of this type of concrete is a potential problem, which is governed by several factors such as lower values of compressive strength, high chance of clogging and less abrasion resistance under dynamic loading. This study is aimed to develop a more durable and sustainable NFC mixture to withstand abrasion load. The effects of different aggregate size, S1 (9.5 to 12.5 mm) and S2 (12.5 to 16 mm) with macro-synthetic fibre of varying lengths L1, L2 and L3 (i.e. 36, 47 and 60 mm) were examined and their properties were discussed. In this study, Loss-Angeles abrasion test setup (ASTM C1747) was used to evaluate the toughness, reveling index and Rotating-Cutter drill test setup (ASTM C944) was used to calculate the resistance against abrasion of NFC concrete mixtures such as disintegration, degradation at 28 days. From this research, it was found that the addition of fibre in NFC does not affect the strength and permeability but does affect the abrasion resistance of the concrete in a significant volume. It was also observed that the influence of fibre length was not as substantial as that of aggregate size.

Keywords: no-fine concrete, abrasion resistance, durability, permeability, sustainable concrete.

AIMS AND BACKGROUND

The influence of impervious pavements over the earth's surface gets worsen now-a-days causing high environmental impacts. It is also one of the identified sources for high pollutant load, in runoff over the watershed area and drained into the water bodies affecting the water quality. Pervious or No-Fine concrete (NFC) is prepared by adding less or zero fine aggregates from the concrete mix[1,2]. NFC is prepared by using cement, aggregate and water, thus the system consists of aggregate, cement paste binding the aggregates and acceptable voids content ranging 15 to 30% (Refs 3–5). These vertically connected voids network helps in discharge of excess water by reducing the runoff loss and maintaining the water table level[6].

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In this current research, the abrasion resistance of Fibre Reinforced No-Fine Concrete (FRNFC) was discussed. The focus on potential enhancements to toughness and durability offered by synthetic macro fibres helps to develop new applications of Pervious Concrete[7–9]. Construction of NFC pavements by replacing the conventional rigid pavement is one of the accepted methods of rainwaters harvesting[10]. The key components to address in this type of concrete is its durability parameters (i.e. abrasion, reveling and clogging resistance), which are limiting their applications in real time[11–13]. The choice of macro synthetic fibre over micro fibre is based on the lack of progress observed in various research programs performed for low dosages of microfibres[14].

Yaolu Ma et al.[15] analysed the clogging effect, reported on drainage of pervious concrete. Finite element models for pervious pavements along with hydromechanical coupling were proposed to determine the variation in coefficient of permeability, which was replicated by accounting the decrease in voids content and clogging percentage based on porous media theory and Biot's theory. In Fig. 1, a finite number of vertically connected voids are transformed into semi-connected voids, which were packed with water quickly at the starting time of permeability tests.

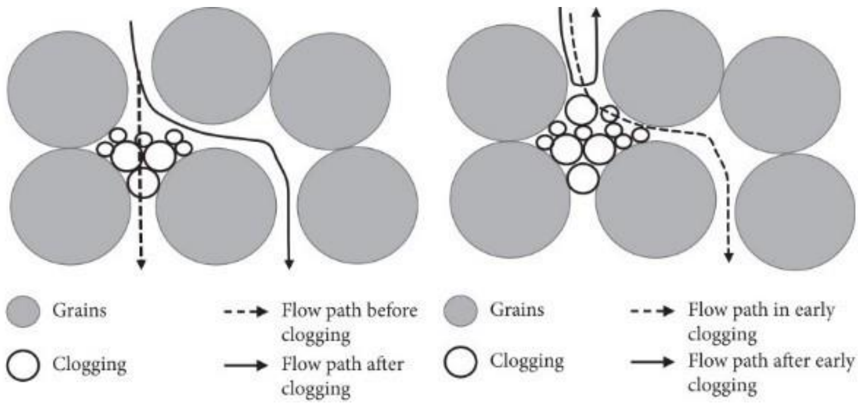


Fig. 1. Model taken by Yaolu Ma et al.[15]

Yunkang Rao et al.[16] have explored the non-homogeneity of pore-aggregate-cement paste structure along the vertical direction, using planar image analysis of concrete specimen slice faces taken with a digital camera, Canon EOS 6D Mark I, with a 90 mm fixed focal length photographic lens. Then the images were processed using software such as Image Processing Toolbox of Matlab (version:7.11.0) and Image Pro Plus (version:6.0) to characterise the vertical pore features. It is clearly observed that the pore morphology was mainly dominated by rounded (circle labels: small pores) and irregular pores (rectangular labels: large pores) in Fig. 2.

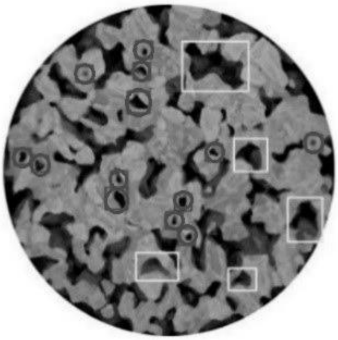


Fig. 2. Pore distribution of NFC from Image Pro Plus 6.0 software

EXPERIMENTAL

The materials used in this project included OPC 53 grade cement, single graded aggregates of size S1 (9.5 to 12.5 mm) and S2 (12.5 to 16 mm). Macro synthetic fibres of varying length L1, L2 and L3 (i.e. 36, 47 and 60 mm) were received free of cost from Bajaj Reinforcement LLP, Maharashtra whose properties are tabulated in Table 1.

Table 1. Fibre properties

Properties	Specific gravity	Tensile strength (MPa)	Youngs modulus (GPa)	Melting point (°C)
Macro synthetic fibre tuff	0.90–0.92	550–640	6–10	159–179

To stabilise the fibre reinforcement and enhance the desire mechanical characteristics such as workability of the mixtures, bond strength between aggregates and cement paste, some chemical admixtures like, a Viscosity modifying agent (VMA): Eucoplacant-721, and a Water reducing agent (WRA): Auramix-400, conforming to the requirement of IS-9103:1979 sponsored by FORSAC Chemicals Pvt. Ltd., Chennai were used for the entire study[17,18]. Locally available portable water from Nandha Engineering College campus conforming to IS-456:2000 and aggregates from Blue Metals Pvt. Ltd., Perundurai region were used and their characteristics are tabulated in Table 2.

Table 2. Aggregate properties

Properties		Specific gravity	Water absorption (%)	Bulk density (kg/m³)	Impact value (%)	Crushing value (%)
Coarse aggregates	S1	2.68	1	1513	16.36	18.21
	S2	2.94	1	1542	16.82	18.55

Mix proportion. An aggregate to binder ratio was kept as 4.5:1 with a fibre proportion of 0.30% throughout the study as per the observations made in previous study[10], and the water to binder ratio was maintained as 0.28. The water reducing agent WRA: Auramix-400 was added to both conventional and Fibre Reinforced No-Fine Concrete taken in an optimal dosage of 0.25%.

Table 3. Mix design of conventional and FRNFC samples

Mix ID	Cement (kg/m^3)	Aggregate (kg/m^3)	Water (kg/m^3)	Fibre (kg/m^3)	WRA (g/m^3)	VMA (g/m^3)
CN_1	258	1129	46.4	–	645	–
FN_{11}	244	1071	44.0	4.27	611	733
FN_{12}	244	1071	44.0	4.27	611	733
FN_{13}	244	1071	44.0	4.27	611	733
CN_2	258	1151	46.4	–	645	–
FN_{21}	244	1091	44.0	4.27	611	733
FN_{22}	244	1091	44.0	4.27	611	733
FN_{23}	244	1091	44.0	4.27	611	733

The Conventional and FRNFC mixes with varying aggregate size (9.5 to 12.5 mm, 12.5 to 16 mm) and fibre length (36, 47 and 60 mm), arrived are given in Table 3. The Mixes identified with 'CN_{xy}' refers to Conventional NFC mix and 'FN_{xy}' refers to Fibre-reinforced NFC mix. The suffix xy indicates the aggregate size and fibre length used in that particular mix, for example, FN_{11} represents FRNFC mix with S1 size of aggregate and L1 length of fibre.

TEST METHODS

This section includes various test procedures conducted to evaluate the performance and behaviour of Fibre Reinforced No-Fine Concrete based on the standard test procedures[19–23].

Flow table test. The consistency in flow percentage of a freshly prepared concrete mix can be determined by Flow table test. Based on the flow % obtained, a mix can be categorised into several types with respect to the workability (Table 4) with reference to the standard of IS:1199-1959. The average diameter of spread in six symmetrical directions in the table is used to measure the flow as given in equation (1):

$$\text{flow } \% = \frac{\text{spread diameter (cm)}}{25} \times 100 \tag{1}$$

Table 4. Workability of mixture with respect to flow (%)

Flow (%)	0–20	21–60	61–100	101–120	121–150
Workability	very low	low	medium	high	too high

Compressive strength test. This test is generally calculated for concrete cube specimen to evaluate their quality and performance. The values given further (compressive versus split tensile strength) were based on the average values obtained from the compressive strength test of three cube specimens of standard dimension of 150 × 150 × 150 mm on 7 and 28 days of curing.

Split tensile strength test. This test is calculated for cylindrical specimens of standard dimensions of 150 mm diameter × 300 mm height, the values tabulated further (compressive versus split tensile strength) were based on the average values obtained from three test samples. Since the application of this type of concrete is restricted to pavements, testing of beams (Flexural strength test) is neglected.

Hydraulic conductivity. It is a property which permits fluids to flow through interconnecting voids, it can be measured in terms of permeability (k) and infiltration (I). Here, permeability was measured with a constant head permeameter, and infiltration – by a double ring infiltrometer.

Abrasion resistance test methods. These test methods were used to determine the raveling resistance (ASTM C1747) and surface wearing (ASTM C944). Loss-Angeles abrasion test apparatus was used to determine the toughness, raveling index and a Rotating-Cutter drill press apparatus was used to determine the disintegration, degradation. Cylindrical samples with diameter and height 100 mm were used in these tests.

RESULTS AND DISCUSSION

FLOW INDEX

The flow index is a direct measure of workability of a freshly prepared concrete mix. The effects of change in aggregate size and change in fibre length on the consistency in flow percentage are discussed in details in Table 5.

Table 5. Flow index value

Mix ID	CN_1	FN_{11}	FN_{12}	FN_{13}	CN_2	FN_{21}	FN_{22}	FN_{23}
Flow (%)	98	111	106	104	90	101	96	91

The consistency in flow percentage of a fresh concrete mix was inversely proportional to aggregate size, i.e. the flow index increases with decrease in aggregate size. The flow index of a given fresh concrete mix was also inversely proportional to the fibre length, i.e. the flow index decreases with increase in fibre length. The elevated values of flow index observed in the fibre – reinforced NFC mix were highly due to the addition of viscosity modifying agent: Eucoplacant-721.

COMPRESSIVE VERSUS SPLIT TENSILE STRENGTH

This section presents and discusses the test values of cursing and tensile strength for both conventional and Fibre reinforced NFC mix specimen to evaluate their quality and performance on 7 and 28 days of curing (Table 6, Fig. 3).

Table 6. Compressive versus split tensile strength value

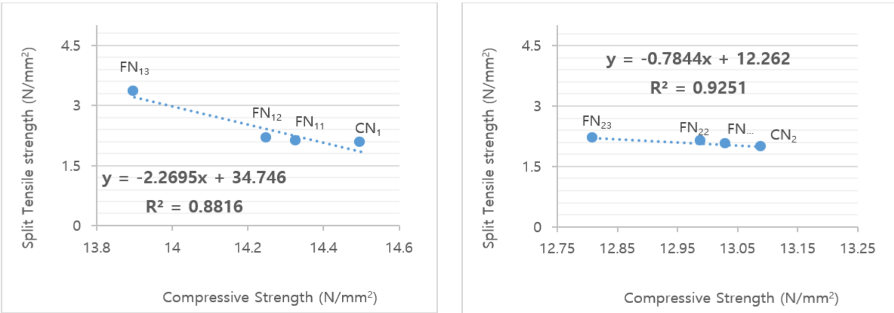
Mix ID	Unit weight (kg/m^3)		Compressive strength (N/mm^2)		Split tensile strength (N/mm^2)
	wet	dry	7 days	28 days	28 days
CN_1	1960	1840	10.45	14.50	2.06
FN_{11}	2000	1850	10.28	14.33	2.10
FN_{12}	2015	1875	10.22	14.25	2.18
FN_{13}	2020	1840	10.05	13.90	3.33
CN_2	1980	1850	9.96	13.09	1.97
FN_{21}	1985	1860	9.81	13.03	2.04
FN_{22}	2005	1875	9.66	12.99	2.11
FN_{23}	2015	1880	9.55	12.81	2.20

Table 6 also discusses the wet and dry unit weight of the concrete sample and the wet unit weight of the freshly prepared mixes was calculated using equation (2):

$$\text{unit weight}_{\text{wet}} = \frac{w_2 - w_1}{v}, \tag{2}$$

where w_1 is the weight of empty mold; w_2 – the weight of fresh concrete with mold, and v – the volume of concrete (cube mold – 0.0034 m^3).

The change in aggregate size has a substantial effect in compressive strength and split tensile strength, i.e. the larger size aggregates fail to bond with the cement mortar properly, which results in achieving poor strength properties. It is also observed that the slight increase in tensile strength is dependent on the length of fibre added as shown in Fig. 3.



(*a*) S1: 9.5 to 12.5 mm (*b*) S1: 12.5 to 16 mm

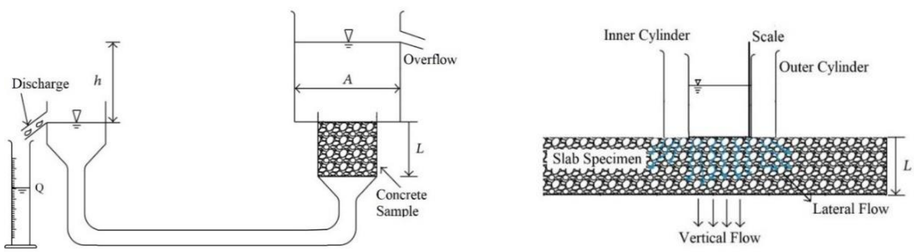
Fig. 3. Relationship between compressive strength and split tensile strength

HYDRAULIC CONDUCTIVITY

Permeability. Permeability (k) is tested for cylindrical samples, as shown in Fig. 4*a* using equation (3). The samples are subjected to vacuum wash, before testing to get more accurate results. The values of permeability are given in Table 7, and graphically explained in Fig. 5.

$$k = (QL)/(Ah\ \Delta t), \tag{3}$$

where Q is the volume of discharge (m^3); L – the specimen length (0.1 m); A – the cross section area of cylinder (m^2); h – the water head (m), and Δt – the time interval (s).



(a) Constant head permeameter (*b*) Double ring infiltrometer

Fig. 4. Test setup for measuring permeability (k) and infiltration rate (I)

Infiltration (I). It consists of two cylindrical rings, one of diameter 300 mm (inner cylinder) and other 600 mm (outer cylinder) placed over the slab specimen of size 1000 mm and depth 100 mm as shown in Fig. 4*b*. Initially water is poured into the cylinder and then the rapidity of infiltration of the water is noted using the scale attached with respect to the time and depth of infiltration into the slab specimen using equation (4). The values of Infiltration rate are given in Table 7, and graphically explained in Fig. 5.

$$I = (4V)/(3.14\ D_i^2\ \Delta t), \quad (4)$$

where V is the volume of water added in time Δt (m^3); D_i – the diameter of inner cylinder (300 mm), and Δt – the time interval (s).

Table 7. Hydraulic conductivity versus fibre length

Mix ID	Permeability, *k*		Infiltration, I^*	
	(cm/s (in./h))	(COV %)	(cm/s (in./h))	(COV %)
CN_1	1.37 (1942)	34.2	0.32 (454)	3.1
FN_{11}	1.36 (1928)	15.8	0.30 (425)	18.6
FN_{12}	1.34 (1899)	0.7	0.29 (411)	–
FN_{13}	1.28 (1814)	19.9	0.28 (397)	4.2
CN_2	1.58 (2239)	7.7	0.38 (539)	4.6
FN_{21}	1.54 (2183)	10.0	0.35 (496)	3.3
FN_{22}	1.52 (2154)	1.3	0.33 (468)	1.7
FN_{23}	1.48 (2098)	28.8	0.31 (440)	3.2

* The total infiltration test setup was placed over a sandy substratum of depth 30 cm (approx.); COV – Coefficient of variance.

ABRASION RESISTANCE

Raveling index (*r*). In this study, toughness and reveling index of FRNFC specimens were determined using ASTM C1747. Three concrete cylinders of each diameter and height 100 mm (4 in) for each mixture design cured for 7 days were taken and placed into a standard Loss-Angeles abrasion device without steel balls and run for 500 revolutions.

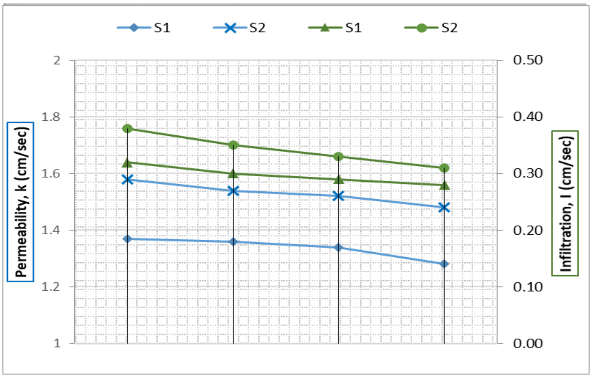


Fig. 5. Permeability versus infiltration

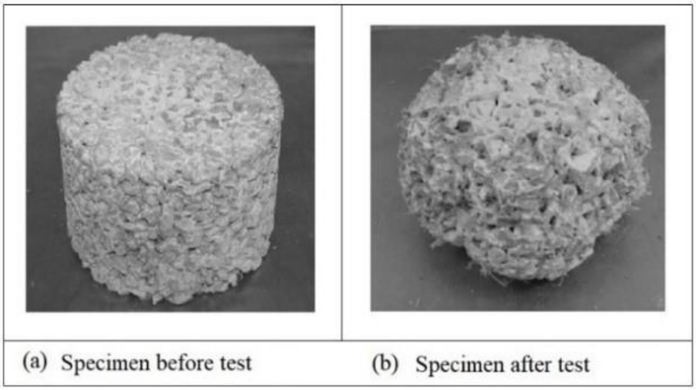


Fig. 6. Specimen subjected to Loss-Angeles abrasion test

The specimens which completely degrade into loose aggregate are not durable and the same with spherical in shape as shown in Fig. 6 are highly tough enough. The average mass loss values are given in Table 8. The raveling index values vary between 0.68 and 0.78 which were estimated using the following equation:

$$r = 1 - m_r/M_t, \tag{5}$$

where m_r is the raveling mass loss (g) and M_t – the total mass of three cylindrical specimen (g).

Table 8. Abrasion resistance versus fibre length

Mix ID	LA abrasion test (ASTM C1747)				Rotating-Cutter drill test (ASTM C944)			
	total mass M (kg)	mass loss m_r (kg)	% loss	raveling index, r	surface abrasion (g)	SD (g)	COV (%)	surface wearing (s)
CN_1	17.97	5.82	32.4	0.68	15	2.0	13.33	0.26
FN_{11}	16.79	4.18	24.9	0.75	6	0.9	14.43	0.10
FN_{12}	17.19	4.06	23.6	0.76	7.5	0.5	6.67	0.13
FN_{13}	16.47	3.56	21.6	0.78	9	1.3	14.70	0.16
CN_2	18.24	5.25	28.8	0.71	13	1.7	13.32	0.22
FN_{21}	17.29	4.52	26.1	0.74	5.2	2.0	39.11	0.09
FN_{22}	16.43	4.02	24.5	0.76	6.5	1.8	27.74	0.11
FN_{23}	17.18	3.82	22.2	0.78	7.8	1.0	13.29	0.13

Surface wearing (*s*). Surface wearing test method using Rotating-Cutter drill press apparatus (ASTM C944) consists of a drill press to lock and rotate the cutter at a velocity of 200 rpm and exert a single load of 98 N or a dual load of 197 N on the test specimen surface for 2 min. Then, the specimen is removed, and the surface is cleaned using a soft brush to remove the debris and weighted to the precision of 0.1 g. Figure 7 shows a test setup of Rotary-Cutter drill and explains it is working. The surface wearing value varies between 0.09 and 0.26% as shown above (Table 8) estimated using equation (6), from which it was clear that the addition of fibre has a positive impact on abrasion losses due to surface wearing up to 60%. This shows a significant contribution of fibre in durability aspects of FRNFC. The relationship between raveling index and surface abrasion are given in Fig. 8.

$$s = (m_a/M) \times 100\%, \tag{6}$$

where m_a is the raveling mass loss (g) and M – the mass of cylindrical specimen (g).

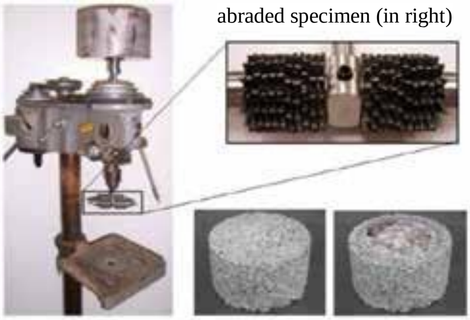


Fig. 7. Specimen before and after surface wearing test

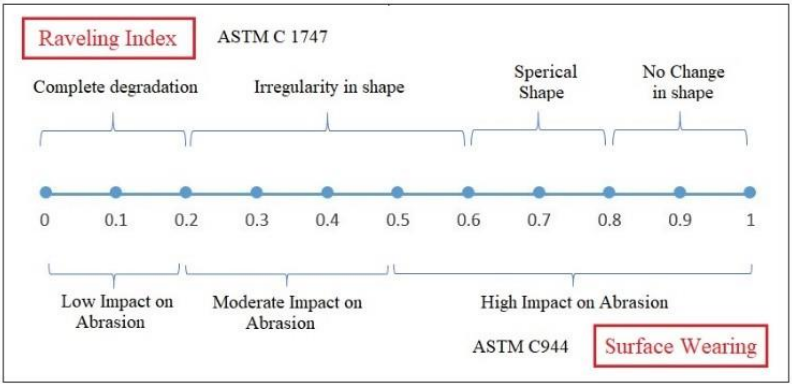


Fig. 8. Raveling index versus surface wearing

This testing indicates the relative resistance against wear of casted cylindrical specimens of diameter 100 mm (4 in) and height 100 mm (4 in) of FRNFC concrete cured for not less than 28 days. Before testing, the specimens should be cleaned with a brush on both sides to remove any loose materials. The test was performed for three cylinders on its both sides and the mass losses were recorded, a total of six values were taken for each mixture. Since the raveling index tested between three samples at once, it has null standard deviation (SD) and coefficient of variation (COV%) whereas surface wearing had high COV %, showing irregularity in fibre distribution. This condition can be enhanced by taking necessary precautions while adding fibres.

CONCLUSIONS

The effects of aggregate size and fibre length were examined and the average values for compressive strength lies between 12.81 and 14.50 N/mm^2, the average values for split tensile strength ranges between 1.97 and 3.33 N/mm^2. The permeability values of FRNFC ranges from 1.28 to 1.58 cm/s and the infiltration values of ranges from 0.28 to 0.38 cm/s with respect to the mixture design. Through which, the concrete exhibits pervious behaviour and the values are within the acceptable limit as stated in literatures. The accumulation of fibre does not produce any considerable changes in compressive strength and reduce the hydraulic conductivity of NFC to an insignificant degree. From the overall observations, the mixture proportion with length 47 mm for both aggregate size 9.5 to 12.5 mm and 12.5 to 16 mm, (i.e. FN12 and FN22) had performed well against strength, hydraulic and durability parameters in a sustainable way and based on the test results the following conclusions were drawn:

1. The consistency in flow percentage of a fresh concrete mix were inversely proportional to the aggregate size and the fibre length. The increased in the flow index of FRNFC comparing to the conventional mixes was due to the addition of viscosity modifying agent.

2. The larger size aggregates fail to bond with the cement mortar properly due to the presence of larger size voids, which results in achieving poor strength properties comparing to that of the smaller aggregates whereas fibre does not affect its mechanical or hydraulic properties.

3. There are several minor factors which influence the strength with respect to the aggregate size such as inter transition zone between aggregates and binder. This can be studied in detail using micro structural analysis.

4. The addition of macro synthetic fibres reduces the permeability and infiltration rate of the test samples. This is observed to be most significant for high dosage of long fibres, say 0.33 and 0.49%. Infiltration rate was about 5 times lesser compared to the permeability values of the corresponding mixture.

5. Abrasion resistance was significantly high for the mixtures containing fibres for both ASTM C1747 and ASTM C944. This shows clearly that the durability of NFC samples was increased by the addition of macro synthetic fibres irrespective of dosage or fibre length.

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