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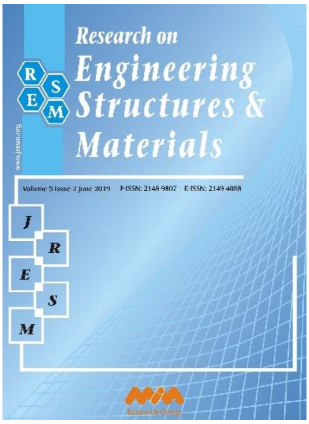

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Research Article

High performance fiber reinforced concrete – for repair in spillways of concrete dams

P.N. Ojha[1,a], Amit Trivedi[1,b], Brijesh Singh[1,c], Adarsh Kumar N. S.[1,d], Vikas Patel[*1,e], R.K. Gupta[2,f]

[1]*National Council for Cement and Building Materials, India*
[2]*NHPC Limited, India*

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Abstract

Hydraulic structures like spillways, glacis, etc. undergoes abrasion-erosion due to impact & cavitation losses due to the flowing water action. To overcome the deterioration of the concrete in such structures, addition of fibers to the concrete can be viable solution as it is known to increase the structural integrity of the concrete. A comparative study of various engineering characteristics using high strength concrete by incorporating steel fibers and micro polypropylene fibers has been carried out. Water/binder ratio of 0.23 has been kept constant for the study. Dosage for steel fibers is kept as 1, 1.25 and 1.5% by volume while for polypropylene fibers were kept as 1, 2 & 3 kg/m3. Engineering properties such compressive strength, flexural strength, toughness, energy absorption, splitting tensile strength, drying shrinkage, abrasion resistance, and water and air permeability of high-performance concrete with & without fibers in its fresh & hardened state are investigated in this paper. Based on the study, the steel fibers with 1.5% dosage are found to be more effective in countering the abrasive and repetitive loading which can be more effective in the repairs of spillways and glacis of concrete dams.

1. Introduction

The abrasive action of waterborne solid particles such as boulders, debris etc. at high velocity is one of the major issues while design of the hydraulic structures like spillways, glacis etc. Therefore, it is desired to develop a high-performance concrete that can provide high abrasion-erosion & cavitation resistance to sustain the high velocities & impact containing silt and rolling boulders over the hydraulic structures. This in turn will also reduce operation and maintenance cost of the structures.

Liu & Donald [1], Holland [2], Papenfus [3], Galvao, Portella & Kormann [4] reported that abrasion erosion resistance of concrete increases with the increase in compressive strength. Liu & Donald [1], Holland [2], Wu, Yen, Liu & Hsu [5] reported water-to-cement ratio as an important factor and recommended to adopt the lowest practical water-cement ratio where abrasion-erosion is of major concern. Liu & Donald [1], Holland [2], Kryzanowski, Mikos, Sustersic & Planinc [6], Papenfus [3] investigated the abrasion erosion resistance using different types of coarse aggregates in concrete composite. The test results indicate that abrasion erosion resistance of concrete increases with the increase in the hardness of coarse aggregates when the water to-cement ratio and compressive strength are kept constants and concluded that the hardest available

*Corresponding author: vikas.patel299@gmail.com
[a] orcid.org/0000-0003-1754-4488; [b] orcid.org/0000-0002-2594-4679; [c] orcid.org/0000-0002-6512-1968; [d] orcid.org/0000-0001-6125-4408; [e] orcid.org/0000-0002-2251-3849; [f] orcid.org/0000-0001-5021-3774
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aggregate should be used in new construction or repair of stilling basins or other hydraulic structures.

Holland [2] & Papenfus [3], ACI 546.R [7] & ACI 210.R [8] Committee reported that the concrete containing silica fume & high range water reducing agent has better abrasion erosion resistance where hard aggregate was not available to develop very high strength concrete. Liu & Donald [1], Holland [2], Papenfus [3], Galvao, Portella & Kormann [4] reported that impregnation of Polymer & Epoxy in concrete mix and Surface treatment with coatings like polyurethane improves abrasion-erosion resistance. Kryzanowski, Mikos, Sustersic & Planinc [6], Galvao, Portella & Kormann [4] investigated and found that the introduction of granular rubber/waste rubber with complementary polymer binder increases the abrasion-erosion resistance of concrete.

It is important to note the difference between erosion caused by impact forces such as cavitation caused by rocks and debris impacting at high velocity and type of erosion that occurs due to wearing action of low velocity particles. Contradictory data are available regarding the performance of SFRC on abrasion-erosion & cavitation. Liu & Donald [1], Holland [2] reported that FRC is less resistant to abrasion-erosion due to smaller particles at lower velocities when compared with concrete without fibers. This is because of the adjustments in the mixture proportions to accommodate the fiber requirement which reduces coarse aggregate content and increases the paste content. As per the ACI 544.4R [9] committee report both laboratory tests and full-scale field trials have shown Steel Fiber Reinforced Concrete (SFRC) has high resistance to cavitation's forces resulting from high-velocity water flow and the damage caused by the impact of large waterborne debris at high velocity.

Lin & Cheng [10] studied the performance of inclusion of steel fibers and silica fume in the concrete composite and found that abrasion resistance of concrete is improved by 8-15%. Hu & Yin [11] studied the impact angle of abrasion and found that steel fibers improve erosion resistance at low impact angle (ø=15 degree). Stig Ostfjord [12], Papenfus [3] & ACI 544.1R [13] reported that adding fibers in concrete can enhance toughness, moment capacity, tensile strength, stiffness and brittleness of concrete. Stig Ostfjord [12], ACI 544.1R [13], Shah & Jenq [14], Gopalaratnam & Shah [15], Kamal, Kassimi & Ghoddousi [16] concluded that steel fibers can absorb the deformation energy of concrete and reduce the risk of cracking. While designing the abrasion resistant concrete, abrasion resistance alone should not be emphasized rather the abrasion resistance of concrete should be assessed based on different parameters that defines the mechanical properties of concrete. Mechanical properties such as compressive strength, tensile strength, aggregate strength, modulus of elasticity, toughness, impact strength, chemical Admixtures, surface polishing & coatings, curing and other additives (Silica Fume and fibers) must be assessed in order to assess the abrasion-erosion & cavitation resistance [17].

Satish Sharma et.al. [18-19] concluded that the addition of 5% silica fume shows significant improvement in compressive strength, flexural strength, static modulus of elasticity, split tensile strength, drying shrinkage and water permeability. Inclusion of steel fiber increases the abrasion resistance of concrete. The inclusion of silica fume might have enhanced the bond between steel fibers and paste. Bond strength between fibers and paste is another important factor, associated with abrasion resistance. Based on the results, the recycled concrete and recycled fiber concrete with the proposed mix design have a high compressive strength, and due to relatively high porosity of the recycled aggregate concrete, its density has decreased by 2.48% and its water absorption increased by 54% compared to the natural concrete [20].

The exceptional characteristics of high-performance fiber reinforced concrete in comparison to conventional concrete make it a very good choice for long- span bridges and high-rise buildings (21) and in recent many attempts have been made to characterize the behavior of fiber-reinforced concrete (FRC) both experimentally and numerically in various conditions (22, 23, 24, 25). Various types of fibers such as natural and polymeric, e.g. polypropylene (PP) may be used to enhance the performance of concrete for different applications. The enhancement of different types of fibers on the flexural strengths and toughness is mainly attributed to the fiber crack-bridging and load-carrying capacities wherein the fibers alter the failure pattern and results in the ductile failure of concrete. Specimens with hooked-end fibers show the best flexural performance. An increase in volume fractions of both steel and polypropylene fibers leads to an increase in the compressive, splitting tensile and flexural strengths of concrete (26, 27). The post-peak ductility of concrete is improved and the strength degradation is alleviated with increasing fiber volume fraction and steel fiber aspect ratio (28, 29, 30). In addition, specimens with corrugated and hooked-end fibers exhibit a better failure behavior than specimens with straight fibers, with multiply micro-cracks induced by mechanical interlocks of deformed steel fibers observed at the main cracks (31, 32, 33).

The research program presented herein sets out to test a comprehensive number of HPC specimens with substantially varied parameters to expand the database of test results of the developed HPC. The subsequent objective is to study and quantify the material's post-cracking characteristics of SFRC specimen, to improve or sustain abrasion-erosion & cavitation problems associated with hydraulic structures.

2. Experimental Program

2.1. Constitutive Materials

Following concrete making materials have been used for the investigations on high performance concrete:

- Ordinary Portland Cement (OPC) 53 Grade satisfying to the specification of IS:12269-2013[34] [Table 1]
- Silica Fume (SF) satisfying to the specification of IS:15388-2003[35], [Table 1]
- Fine (Zone-II) & Coarse aggregate (20mm downsize) satisfying to the specifications as per IS: 383-1970[36] [Table 2],
- Potable water
- Polycarboxylic Ether (PCE) based super plasticizer satisfying to the specification of IS:9103[37]
- Fibers: (i) Hooked end steel fibers of 0.55mm diameter with an aspect Ratio of 63 satisfying to the specification of ASTM A 820[38]. The Material test certificate of tensile strength provided by manufacturer is 1468.99N/mm2 where minimum requirement is 345 N/mm2 as per ASTM A 820.
- (ii) Micro Polypropylene with properties as given in table 3 ware used.

Table 1. Physical, Chemical and Strength Characteristics of Cement

Characteristics		OPC -53 Grade	Silica Fume
Physical Tests:			
Fineness (m^2/kg)		320.00	22000
Soundness Autoclave (%)		00.05	-
Soundness Le Chatelier (mm)		1.00	-
Setting Time Initial (min.) & (max.)		170.00 & 220.00	-
Specific gravity		3.16	2.24
Chemical Tests:			
Loss of Ignition (LOI) (%)		1.50	1.16
Silica (SiO_2) (%)		20.38	95.02
Iron Oxide (Fe_2O_3) (%)		3.96	0.80
Aluminium Oxide (Al_2O_3)		4.95	-
Calcium Oxide (CaO) (%)		60.73	-
Magnesium Oxide (MgO) (%)		4.78	-
Sulphate (SO_3) (%)		2.07	-
Alkalis (%)	Na_2O & K_2O	0.57 & 0.59	0.73 & 2.96
Chloride (Cl) (%)		0.04	-
IR (%)		1.20	-
Moisture (%)		-	0.43

Table 2. Properties of Aggregates

Property		Granite		Fine Aggregate
		20 mm	10 mm	
Specific gravity		2.70	2.69	2.64
Water absorption (%)		0.32	0.35	0.72
Sieve Analysis Cumulative Percentage Passing (%)	40 mm	100	100	100
	20 mm	95	100	100
	10 mm	7	95	95
	4.75 mm	0	19	87
	2.36 mm	0	2	68
	1.18 mm	0	0	38
	600 µ	0	0	10
	300 µ	0	0	2
	150 µ	0	0	0
	Pan	0	0	100

Table 3. Properties of Polypropylene Fiber

Properties	Value
Cut length (mm)	12
Effective diameter (micron)	20-40
Specific gravity	0.90-091
Melting point (^{0}C)	160-165
Elongation (%)	20-60
Alkaline stability	Very good
Young's modulus (MPa)	>4000

2.2 Mixture Proportion and Concrete Production

The control concrete was designed & optimized using 10% silica fume by weight of cement as per IS: 10262[39]. Mix proportions for fiber reinforced concrete were optimized using different percentages of steel and polypropylene fibers for the desired slump. Since hooked end steel fibers of 1, 1.25 & 1.5% by concrete volume & micro-Polypropylene fiber dose of 1 kg/m3, 2 kg/m3 & 3kg/m3 was adopted for the study, some adjustments were done in the mix proportions to maintain the required slump. The dose of PCE based superplasticizer is adjusted and the ratio of fine to coarse aggregate is adjusted accordingly. Concrete mix proportions are shown in Table 4.

For conducting studies, the concrete mixes were prepared in pan type concrete mixer. Before use, the moulds were properly painted with mineral oil, casting was done in three different layers and each layer was compacted on vibration table to minimize air bubbles and voids. After 24 hours, the specimens were demoulded from their respective moulds. The laboratory conditions of temperature and relative humidity were monitored during the different ages at 27±2oC and relative humidity 65% or more. The specimens were taken out from the tank and allowed for surface drying and then tested in saturated surface dried condition.

Table 4. Concrete Mix of Control and Fiber Reinforced Concrete

Type of concrete	Designation	Water (kg/m^3)	OPC (kg/m^3)	SF (kg/m^3)	HRWRA (kg/m^3)	CA (kg/m^3)	FA (kg/m^3)	Fibers (kg/m^3)
Control	CM	131.1	570	64	9.51	1093.0	625.0	0.00
SFRC 1%	S1	131.1	570	64	10.30	1132.2	693.8	78.50
SFRC 1.25 %	S2	131.1	570	64	11.10	1126.6	693.8	98.13
SFRC 1.5%	S3	131.1	570	64	11.89	1126.6	699.5	117.75
PFRC 1kg/m3	P1	131.1	570	64	9.51	1093.0	630.7	1.00
PFRC 2kg/m3	P2	131.1	570	64	10.30	1160.3	619.3	2.00
PFRC 3kg/m3	P3	131.1	570	64	11.10	1160.3	619.3	3.00

*OPC= Ordinary Portland Cement, SF=Silica fume, CA=Coarse Aggregate, FA=fine Aggregate, HRWRA=High Range Water Reducing Agent/Admixtures, SFRC=Steel fiber reinforced concrete & PFRC= Polypropylene fiber reinforced concrete

The laboratory conditions were maintained as per Indian Standard during casting, placing & testing of concrete specimen i.e. 27±2oC and 65±5 RH. The slump, measured as per IS: 1199 [40] of control concrete was 150mm. It was observed that the slump value decreases with the introduction of fibers into the mixture which affects the workability of the concrete. To maintain the required workability slump of 130-150 mm, dose of PCE based HRWRA is adjusted and more fines are added to mix.

The air content of mixes was measured as per ASTM C 231 [41] (pressure method) and it was found that it increases with introduction of steel fibers by 30 to 50%. The wet density of CM and PFRC was around 2542kg/m3 while slightly more density was observed for SFRC mix i.e., 2560kg/m3. The setting times (both initial and final) of all mixes were determined as per IS:8142 [42] and were found to be fairly similar i.e., 7.5 hours & 9.2 hours respectively.

3. Test Setup

3.1. Mechanical Parameters: Compressive Strength, Flexural Strength and Splitting Tensile Strength

The compressive and flexural strength tests were carried out at 3, 7 and 28 day's age on cubes (150 mm) and beams (100 × 100 × 500 mm) respectively. The test procedure followed during the tests was in conformity with IS: 516 [43] for compressive strength test and ASTM C1609 [44] for flexure strength test. Splitting tensile strength test was carried out at 3, 7 and 28 day's age on cylinder specimen (150 mm diameter & 300 mm length) as per in IS: 5816 [45]. Drying Shrinkage test was carried out on prism (75 × 75 × 300 mm) at 28 day's age as per IS: 1199 [40].

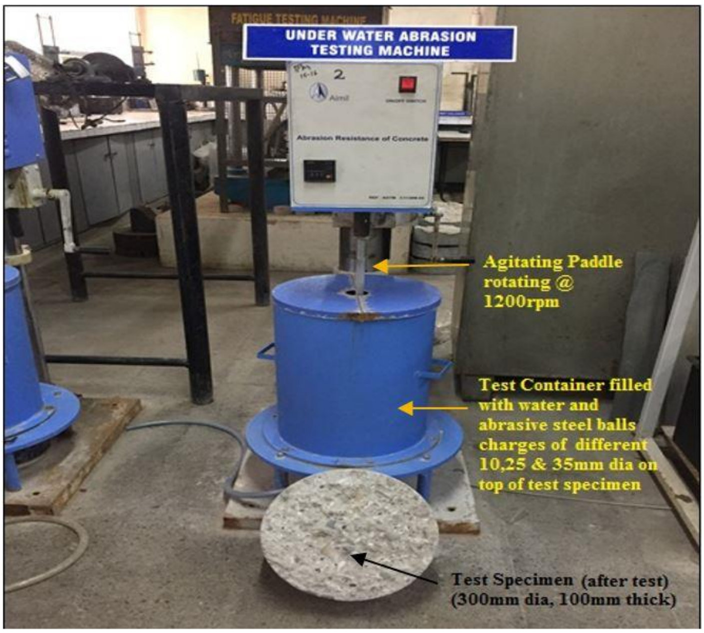
3.2. Flexure Toughness Test

The flexure test apparatus consisting of a three-point bending with pin and roller type supports was used. The specimen size was 100 × 100 × 500 mm with clear span of 400 mm. Test was carried out as per the provisions of ASTM C 1609 [27]. Test was carried out in displacement control mode in a servo controlled closed-loop system with a bending yoke where Linear Variable Displacement Transducers (LVDT) were mounted on the sides of the yoke around the specimen. These LVDT's were connected to display unit to measure the net deflection at the center of the beam. Experimental setup is shown in Fig. 1. The test facility is specifically developed to study the post cracking behavior of fiber reinforced concrete and measure the flexural toughness of the test specimen.

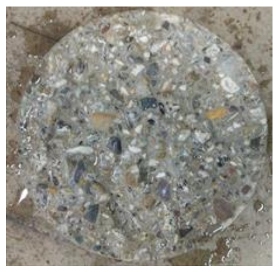
Fig. 1 Experimental flexure toughness test setup as per ASTM C 1609[27].

3.3 Abrasion Resistance Test (Under Water Method) as per ASTM C1138

The abrasion test (under water method) was carried out at 28 days on a concrete specimen with dimensions of 300 mm diameter and 100 mm thickness as per the procedure given in ASTM C-1138. The test set up and specimen of abrasion test (under water method) is shown in Fig. 2.



1.Specimen before test



2. Specimen after test

Fig. 2 Abrasion test (Under water method) setup as per ASTM C 1138

The initial mass of the concrete specimen (Diameter 300±2 mm & Height 100±13 mm) were recorded in air & in water, then the specimen was kept in test container with surface to be tested facing up on the seating blocks. The agitation paddle was placed such that the bottom of paddle was 38±5 mm above the surface of specimen. The abrasive charges (Steel balls) were placed on the surface of specimen and water was added upto 165±5 mm above surface of specimen. Then the agitating paddle was rotated at the rate of 1200±100 rpm. The specimen was removed from test container at the end of every 12-hours of operation and the abraded material was flushed off & surface of specimen was dried off. The mass of specimen was recorded again in air & water. The test was repeated for six times of 12-hours periods for a total of 72 hours and final mass loss was recorded.

3.4 Abrasion Resistance Test (Revolving Disk Method) as per ASTM C 779

The abrasion test was carried out at accelerated 28 days on a concrete slab of size 300 × 300 mm with 100 mm thickness as per the procedure given in ASTM C-779 (46). The test set up and specimen of abrasion test (revolving disk method) is shown in Fig. 3.

1.Specimen before test

2. Specimen after test

Fig. 3 Abrasion Test (Revolving Disk Method) Setup as per ASTM C 779

3.5 Water and Air Permeability

Water permeability test was carried out at the age of 28 day's age on concrete cylinder (150 mm diameter & 150 mm height) as per DIN-1048[47] and Air permeability test at 28 days was carried out on slabs (300 × 300 × 100 mm) using Torrent Permeability tester.

4. Result and Discussion

4.1. Mechanical Parameters: Compressive Strength, Flexural Strength & Splitting Tensile Strength

4.1.1. Compressive Strength

The result of compressive strength at 3, 7 & 28 days of control & fiber reinforced concrete is shown in Fig. 4. Test result indicates that the compressive strength of control concrete and micro polypropylene fiber reinforced concrete specimens are fairly similar. There is a substantial increase in the compressive strength of steel fiber reinforced concrete as compared to control concrete. The compressive strength of the steel fiber-reinforced concrete is maximum at 1.25 & 1.5% steel fibers with 12 & 14% increment respectively.

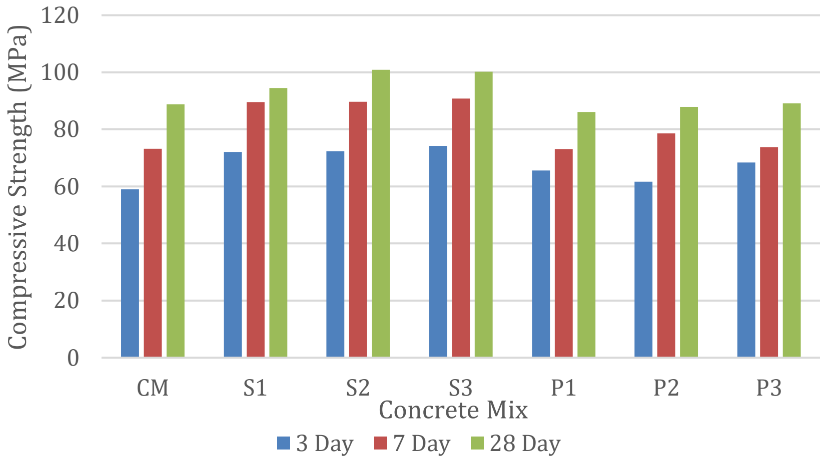


Fig. 4 Compressive Strength at 3, 7 and 28 Days

The significant increase in compressive strength of the concrete with steel fibers is a result of increased concrete integrity wherein steel fibers randomly distributed in concrete matrix binds the composites together and restricts the disintegration upon loading to peak stress.

4.1.2. Flexural Strength

Flexural strength at 3, 7 & 28 days of the mixes (CM, SFRC & PFRC) covered in the study is shown in Fig. 5. From test results it is observed that there is an increase in the flexural strength with the introduction of fibers into the mix. For micro polypropylene fibers reinforced concrete the increments are in the range of 7% to 18% and for steel fiber reinforced concrete it varies from 20% to 42%.

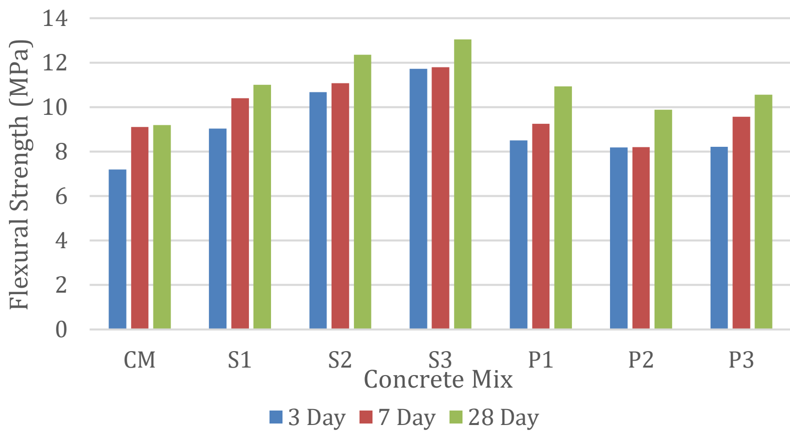


Fig. 5 Flexural Strength at 3, 7 and 28 Days

The increase in the flexural strength of the concrete can be attributed to the bridging action of fibers which acts as a tensile reinforcement and subsequently increases the flexural capacity of the beam. Fibers addresses the tensile strength by two mechanisms wherein first mechanism it reduces the crack propagation by bridging action while in second mechanism it delays the crack initiation by contribution to the loading before initiation of cracks at surface.

4.1.3. Splitting Tensile Strength

Splitting tensile strength at 3, 7 & 28 days of control & fiber reinforced concrete is shown in Fig. 6. Test results indicate that the tensile strength of control and micro polypropylene fiber reinforced concrete specimens are almost similar. In case of SFRC, there is a substantial increase in the tensile strength compared to control by about 40% to 75%. Uniformly distributed Fibers acts as a tensile reinforcement due which this significant increase in splitting tensile strength can be seen. A part of initial load is taken by the steel fibers and full load is transferred to the concrete once the fibers fails by pull out or break out of the fibers from the concrete matrix.

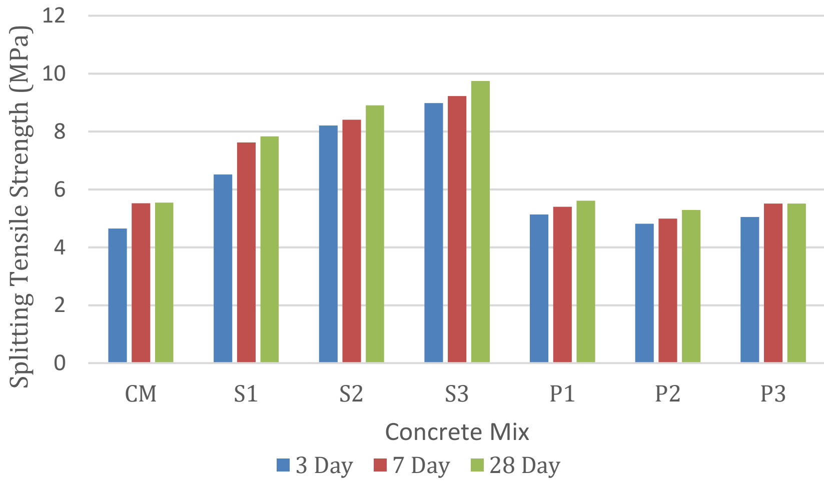


Fig. 6 Splitting Tensile Strength at 3, 7 and 28 Days

4.1.4. Load – Deflection Behavior

Based on test results of SFRC segments (S1, S2 & S3) as shown in Fig. 7 and Fig. 8, addition of steel fibers into the mix result in ductile response in load deflection curve. The load-deflection response of fibre reinforced concrete generally starts by an initial portion that is linearly elastic up to a certain load and then deviates from its linearity. This is often identified as the onset of first cracking in the matrix. If the cement matrix is not reinforced with fibers, first cracking is followed by a sudden drop in the load-deflection curve, and failure occurs which is observed in case of control concrete. The addition of steel fibers mostly influences the response of the concrete mixture after the onset of initial cracks by the bridging action. These fibers reduce the crack propagation by addressing the tensile loads and acts as a tensile reinforcement which results in the ductile failure while the control concrete being brittle in nature undergoes sudden failure.

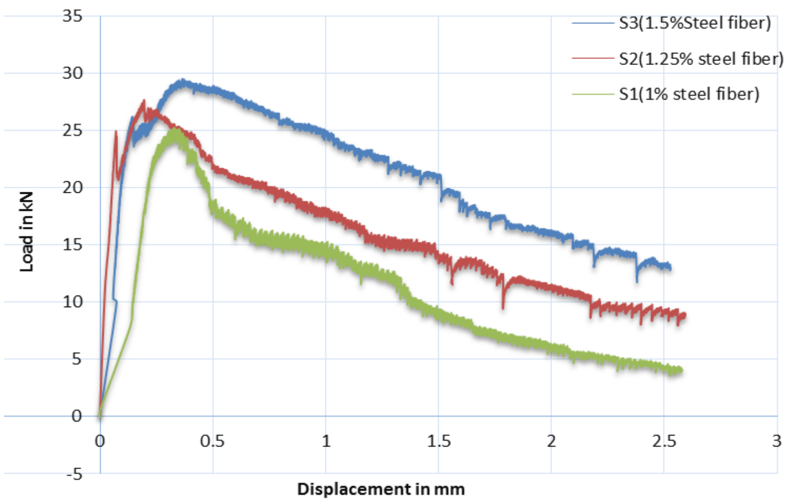


Fig. 7 Load - Displacement Curves of SFRC (S1, S2 & S3) Specimen at 7 Day

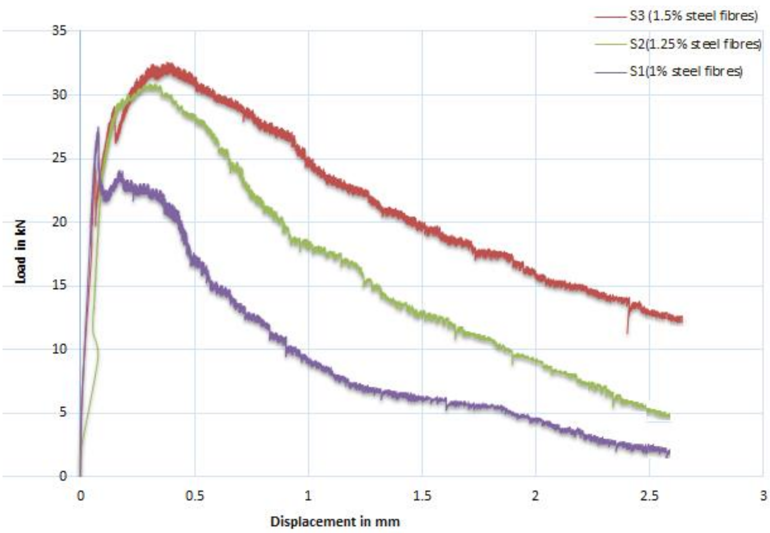


Fig. 8 Load - Displacement Curves of SFRC (S1, S2 & S3) Specimen at 28 Day

4.1.5. Mode of Failure

Steel fibers in concrete allows the bridging of cracks, which aids in increasing the ductility of the concrete after the post cracking stage. The crack behaviour of S1, S2 & S3 also shows different pattern. S1 shows single crack whereas S2 & S3 shows multiples cracks, this maybe because, if the fibre content in the mix is more, it is possible that the load- bearing capacity of the fibers is greater than the load on the composite at the first crack. Additional loading will result in additional cracks, until the matrix is divided into a number of segments separated by cracks. The cracking may stop when the stress transferred to the matrix no longer exceeds the cracking load. For all practical purposes, the load-deflection response of fibre reinforced cement composites can be classified as either "strain-softening" or "strain-hardening. As per Naaman [31], High performance fiber reinforced cement composites are a class of FRC composites characterized by a strain hardening behavior in tension after first cracking, accompanied by multiple cracking up to relatively high strain levels.

From load-deflection curve of SFRC at 28 days S1 shows strain softening, the load carrying capacity decreases gradually after the onset of first crack load of 27.5 kN, whereas S2 & S3 show strain hardening i.e. even after the onset of first cracks load at 28.3kN & 29.4kN the segment load carrying capacity increases till it reaches ultimate crack load at 30.8kN & 32.3 kN respectively which is tabulated in Table 5.

The area under load- deflection curve from 0 to L/150 (here L=400 mm) is the flexural toughness which is the apparent amount of energy absorbed by the specimen. The toughness of Steel Fibre Reinforced Concrete analyzed as per ASTM C 1609[25] from the load – deflection curve at 28days strength are 27, 43 & 59 Joules respectively for S1, S2 & S3 mix.

Table 5. Summary of Parameters Obtained from Load-Deflection Curve Of SFRC Specimen as per ASTM C 1609[28] at 28 Days

Parameters	HS-SFRC		
	S1	S2	S3
Fist peak Load in kN	27.5	28.3	29.4
Peak load in kN	-	30.8	32.3
Fist Peak Strength in MPa	11.0	11.32	11.76
Peak Strength in MPa	-	12.32	12.92
Residual load at net deflection of L/600 in kN	13.8	24.7	29.5
Residual strength at net deflection of L/600 in MPa	5.52	9.88	11.80
Residual load at net deflection of L/150 in kN	3.20	7.20	12.6
Residual strength at net deflection of L/150 in MPa	1.28	2.88	5.04
Area Under the load vs net deflection curve 0 to L/150 in Joules	27.0	43	59

Strength is calculated as PL/bd2, where P=load in kN at corresponding displacement. L=length of specimen in mm, b= width of specimen in mm and d =depth of specimen in mm.

4.2. Durability Parameters: Drying Shrinkage, Abrasion, Water and Air Permeability

4.2.1. Drying Shrinkage

The result of drying shrinkage of control & fiber reinforced concrete is shown in Fig. 9. From the figure, a reduction in drying shrinkage can be observed of 20% to 37% in PFRC as compared to the control while in case of SFRC reduction of 8 to 29% is observed. Fibers incorporated in concrete are known to control cracking arising from drying and/or plastic shrinkage behaviour in the cementitious matrix. The mitigation of drying shrinkage aids the concrete aesthetically and also by controlling and preventing shrinkage cracks the durability of concrete can be enhanced.

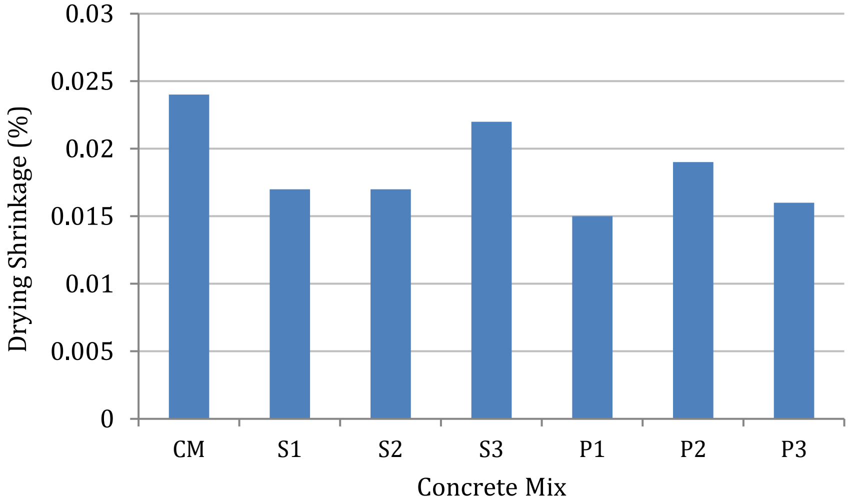


Fig. 9 Drying Shrinkage at 28 Day

4.2.2. Abrasion Resistance Test (Under Water Method) as per ASTM C1138

From the test result (Fig. 10), the 28 days age cumulative abrasion volume loss in m3 for control mix is 110 x 10^{-6} m3 and for Steel fiber reinforced concrete mix of 1 % to 1.5% of steel fibers by volume varies from 102 x 10^{-6} to 120 x 10^{-6} m^3 while for concrete mix with polypropylene fibers volume loss varies from 111 x 10^{-6} to 109 x 10^{-6} m3.

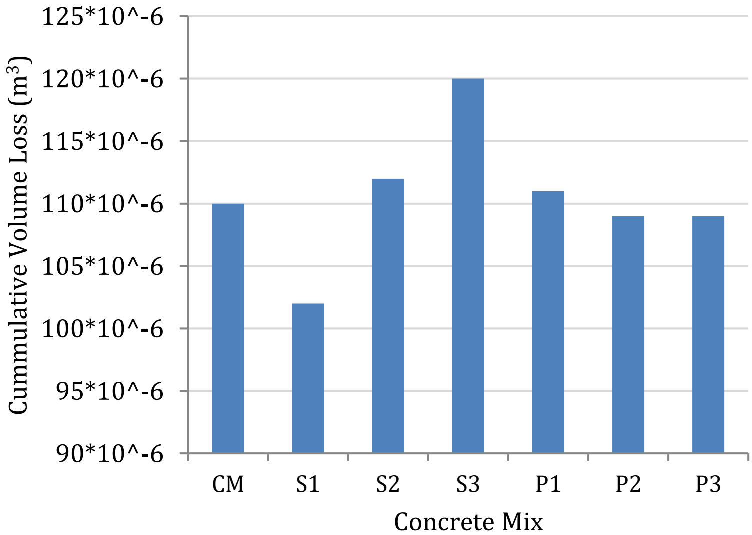


Fig. 10 Abrasion Resistance Test (Under Water Method)

This test result shows varying abrasion loss when steel fibers are introduced into the mix, more abrasion volume loss is observed as compared to control mix. This is primarily due to abrasion of mortar part of concrete as in SFRC, adjustments were made in the mix proportions to accommodate steel fibers which reduces coarse aggregate content and increases the paste content. It was observed that the coarse aggregates in concrete were not getting abraded in this test.

4.2.3. Abrasion Resistance Test (Revolving Disk Method) as per ASTM C 779

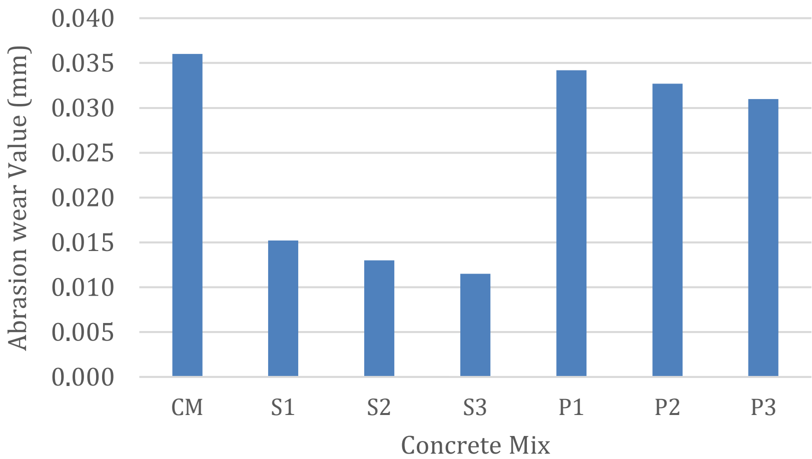


Fig. 11 Abrasion Wear Value at 28 Day

From Fig. 11, the inclusion of fibers produced an improvement in the abrasion resistance of the concrete. In this study, it was found that the most significant improvement was achieved with the optimum inclusion of steel fibers at 1.5 % by volume, it can be also seen that abrasion wear decreases with increase in fibers percentage. The reduction in abrasion wear value of SFRC to that of control concrete is 58 to 68% & 5% to 13.89% for PFRC.

Considering the test results of both methods of abrasion resistance tests, SFRC can be a viable solution for repairs and construction specific elements critical to erosive or abrasive action in hydraulic structures. By increasing the integrity of the concrete, steel fibers hold the composites together and reduces the disintegration of aggregates and thus addresses the problem of cavitation and erosion of concrete constituents.

4.2.4. Water Permeability

Concrete Samples were cast and tested for water permeability after 28 days of water curing. Results of the test from Fig. 12 indicates significant decrease in the permeability of concrete with the addition of steel fibers. Test result shows that in SFRC specimen water penetration is almost negligible as the reduction of water penetration percentages vary from 61% to 99%. This is most likely due to the stitching and multiple cracking effect of the steel fibers. Steel fibers seems more effective as compared to polypropylene fibers as per the experimental results.

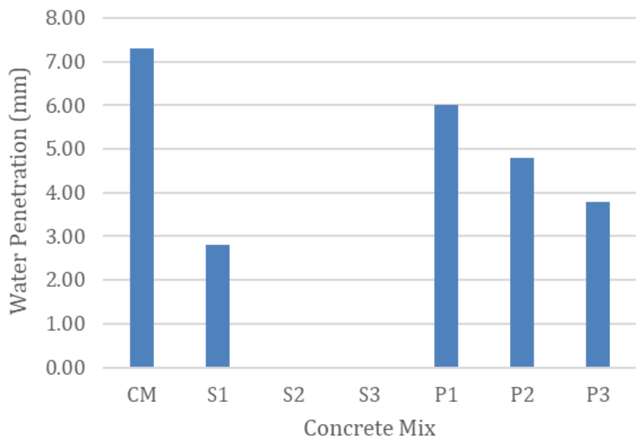


Fig. 12 Water Penetration at 28 Day

4.2.5. Air Permeability

From Fig. 13 it is observed that the air permeability coefficient (kT-16m2) value of SFRC specimens are less than that of control concrete by 80% to 91% and while in case of PFRC specimens values are 14 to 76% less than the control. The result indicates the quality of concrete as good. The permeability coefficient decreases with increase in steel fibers percentage by volume in the mix.

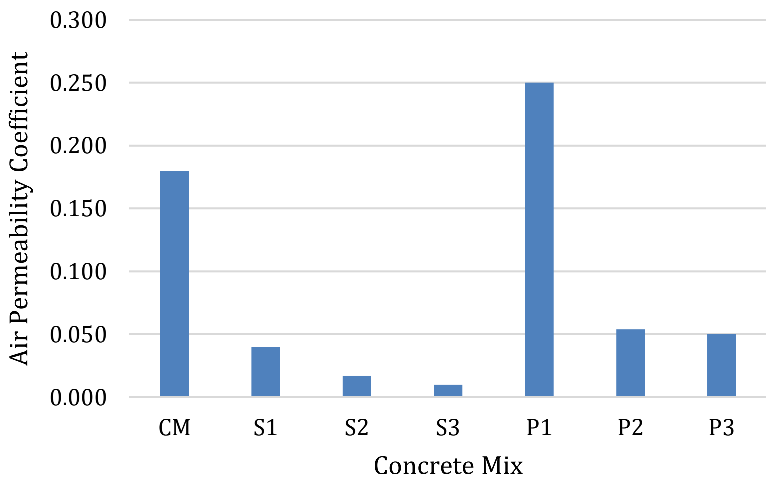


Fig. 13 Air Permeability Coefficient at 28 Day

The reduction in air and water permeability of the SFRC reduces the ingress of chlorides, sulphates, etc. from the constant contact of water. Further, this reduction in permeability can be attributed to the reduced number and depth/width of the micro cracks on the surface of concrete due to incorporation of steel fibers. Bridging action of steel fibers plays an important role in increasing the overall integrity of the concrete.

5. Conclusion

The addition of different fibers affects the different properties and steel fibers have been proven more efficient in addressing the abrasion and erosion in the hydraulic structures. Following conclusions can be drawn with respect to the properties studied:

- High Strength Steel Fiber Reinforced Concrete incorporating 1, 1.25 & 1.5% steel fibers have improved mechanical & durability properties substantially as compared to Control & Polypropylene Fiber Reinforced Concrete of same water to binder ratio. Addition of polypropylene fibers will not be a viable solution wherein abrasive and repetitive loading is applicable.
- Among the three HS-SFRC mix selected for evaluation, the mix with 1.5% steel fibers shows maximum strain hardening behavior in the load deflection curve indicating that the specimen can absorb more energy, comparatively.
- The Toughness or energy absorption & residual strength of HS-SFRC with 1.5% steel fiber content is highest compared to HS-SFRC with 1% & 1.25% steel fibers. Therefore, HS-SFRC with 1.5 % steel fiber can sustain higher impact at higher velocities and will result in lesser deterioration of concrete by flowing water containing large debris, boulders, etc.
- This test result for abrasion resistance test (Under water method) shows varying abrasion loss when steel fibers are introduced into the mix, more abrasion volume loss is observed as compared to control mix. The test results for abrasion resistance test (Revolving Disk method) shows the reduction in abrasion wear value of SFRC compared to that of control concrete in the range of 58 to 68%. Therefore, considering both the results of both tests use of steel fibers will be more efficient and effective against the abrasive action water in hydraulic structures.
- Air and water permeability has been substantially reduced upon addition of steel fibers which will increase the resistance to ingress of chlorides, sulphates and other ions and will enhance the durability of the concrete.
- With the overall improvement in engineering characteristics as reported in this paper, the optimized mix incorporating 1.5% steel fibers is found suitable for application in spillways where cavitation due to impact is of major concern & 1.25% to 1.5% for abrasion-erosion in glacis.

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