INFLUENCE OF POLYPROPYLENE FIBRES ON THE MECHANICAL AND DURABILITY PROPERTIES OF HIGH PERFORMANCE CONCRETE

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Abstract

This paper highlights the effect of polypropylene fibre on the mechanical and durability properties of High Performance Concrete (70MPa) containing silica fume as the mineral admixtures.

Four different fibre volume fractions (0%, 0.1%, 0.3% and 0.6%) were added to the HPC mixture. The addition of the fibre shows a mild decrease in the workability of the fresh property (Slump cone test) of HPC. Mechanical properties like Compressive strength, Split Tensile Strength, Flexural Strength, Modulus of Elasticity, Bond strength and Ultrasonic pulse velocity (UPV) test were conducted. Durability properties such as Water absorption test, Sorptivity test, Carbonation test, Sulphate attack test, Ammonium Chloride attack and Corrosion test were carried out.

Addition of PP fibres for 0.1% and 0.3% fibre increases gradually and later 0.6% fibre addition shows decrease in compressive strength compared to 0.1% and 0.3% fibre addition. However, there is an increase in strength for all the percentage of fibre because of the efficient filling effect of PP fibre in concrete specimens which minimize the crack propagation and crack width. The test results show that the addition of 0.1% and 0.3% fibre is more suitable and durable for making HPC based on the strength and durability properties.

Keywords: Polypropylene fibre, High Performance Concrete, Mechanical Properties, Durability properties

1. Introduction

Polypropylene fibres are cheap and popular materials used in the concrete technology and manufacture. There is a significant research work in progress about the properties and behaviour of Polypropylene fibre worldwide. Polypropylene fibres mitigate plastic and early drying shrinkage by increasing the tensile property of concrete and reduce the cracks [1]. PP fibre is introduced into the mixture to minimize brittleness of the matrix, thereby reducing the cracks in the concrete [2]. The addition of Polypropylene fibre enhances the compressive strength, tensile strength and flexural strength of HPC – due to the efficient

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filling effect of PP fibre in concrete specimens that minimises the crack propagation and crack width [3].

N. Flores Medina et al. (2014) conducted an experimental study on the different fibre volume fractions (0.03%, 0.06%, 0.09%, and 0.12%). The increment of PP fibre volume fraction reduces the water permeability depth and even the carbonation depth. PP fibres (upper to 0.07% volume fraction) are less permeable and the CO_2 diffusion is slower in time due to early age cracking control, producing more durable concretes [4]. Pengzhang et al. (2013) used X and Y shaped PP fibres with different proportion and determined that PP fibres shows better results in permeability, shrinkage, carbonation [5]. Jianzhuang Xiao et al. (2006) utilized PP fibres, blast furnace slag and silica fume in his HPC mixture and pointed out that there is no negative effects on compressive and flexural strength in addition of PP fibres [6]. There are different PP fibre producers with possible variations in the quality. Commercially available fibre was chosen to check the mechanical and durability property which is the foundation of this research study.

2. Experimental Program

2.1 Materials used

Cement: Ordinary Portland cement (OPC) of 53 grade conforming to IS 12269-1987 specifications [7].

Fine aggregate: River sand conforming to grading zone II and IS: 383-1970 [8] with specific gravity 2.65 and fineness modulus 2.71.

Coarse aggregate: Nominal size of 12mm with specific gravity 2.78 and fineness modulus 6.88.

Mineral admixtures: Silica fume of specific gravity 1.97 was used.

Superplasticizer: A modified polycarboxylic ether based superplasticizer, Glenium B233 was used to get the required workability.

Fibre: Polypropylene fibre conforms to Type III fibres under ASTM C 1116 [9] was added to the weight of cement.

2.2 Mixture Proportions

Four HPC mixture proportions were designed as per ACI 211-1[10], proposed method by Aitcin (1998) [11]. The details of the mixture proportions are given in Table 1. Control mixture (without fibre) was prepared and other three mixtures were made with the addition of PP fibres added at 0.1%, 0.3% and 0.6% to the weight of cement. Each mixture was represented as F0, F0.1, F0.3 and F0.6 where F0.6 denotes that the HPC mixture made with 0.6% PP fibres.

2.3 Preparation of the test specimens

Pan mixer of capacity 40 litres was used for mixing the concrete. Cement, fine aggregate and coarse aggregate, were mixed thoroughly in the mixer for 2 minutes along with the Polypropylene fibres dispersing by hand. During the mixing operation, 50% of water was added first and mixed thoroughly and the remaining water, mixed with super plasticizer, was added later along with silica fume. Concrete cubes of size 100mm×100mm×100mm were prepared for compressive strength, water absorption test, Sorptivity, Ammonium chloride attack, Sodium sulphate attack, Corrosion test and UPV test. Cylinder of 100mm×200mm for split tensile strength and modulus of elasticity. Beam size of 100mm×100mm×500mm for flexural strength, then the specimens were demoulded after 24 hours and immersed in the curing tank for 7days, 28 days, 56 days, 90 days.

Tab. 1-Mixture proportion for M70 grade HPC (in Kg/m^3)

Mix	Cement and Silica fume	Water	Fine aggregate	Coarse aggregate	SP	Fiber (% by weight of cement	Slump (mm)
F0	420+40	157	720	1130	5.5	0	140
F0.1	420+40	157	720	1130	5.5	0.42	132
F0.3	420+40	157	720	1130	5.5	1.26	128
F0.6	420+40	157	720	1130	5.5	2.52	120

3. Fresh Properties

The slump cone test was used to find the slump value of each mixture as per IS: 7320 - 1974 [12] Specifications. The addition of fibre decreases the slump at the rate of 6%, 9% and 14%. There was no drastic change in the slump by adding the fibre. For 0.6% addition of fibre, the slump loss was due to the compactness of fibre.

4. Mechanical Properties

4.1 Compressive Strength

Compressive strength of HPC mixtures was determined at 7, 28, 56 and 90 days in a Compressive Testing machine (CTM). The capacity of CTM is 3000kN with a constant loading rate of 140 kg/cm^2/min as per IS 516 Specifications [13]. The compressive strength of F 0.1, F0.3 and F0.6 mixtures were 4.76%, 6.68% and 1.22% related to control mixture clearly pictured in the Fig 1. The control mixture subjected to ultimate load leads to breakage because of cracks whereas the failure pattern of cubes with fibre addition shows mild cracks even at the application of ultimate load. This is due to the presence of PP fibre in concrete specimens which minimize the crack propagation and crack width.

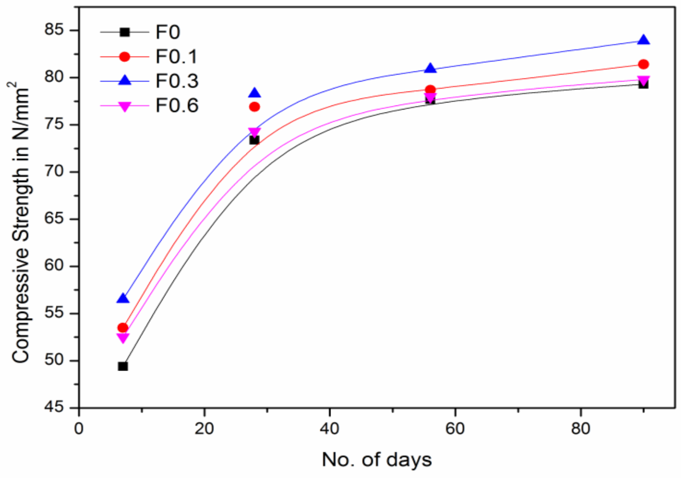

Fig 1: Compressive strength at different periods

4.2 Split Tensile Strength

The cylindrical specimen was placed horizontally on the CTM and the load is applied until failure of the diameter as per IS 5816, 1999 Standards [14]. The results of the tensile strength of HPC predict that the strength increases with the addition of fibre such that the addition of fibre in the concrete specimen increases the tensile strength at the rate of 22.12%, 44.05% and 21.08% for all F0.1, F0.3 and F0.6 mixtures compared to the control mixture. The increase in the tensile strength was mainly due to the strong interlocking of aggregate and cement paste due to the addition of PP fibres.

4.3 Flexural Strength

The flexural strength of HPC is tested on the flexural testing machine with a load carrying capacity of 100 kN at a constant loading rate of 180 kg/ min. The flexural strength enriches at the rate of 3.89%, 9.09% and 5.19% for the F0.1, F0.3 and F0.6 mixtures. Polypropylene fibre in the HPC mixture produces a bonding effect in the cement mortar. The correlation between compressive strength and flexural strength as per the experimental results was compared with the predicted correlation given by Carrasguillo Relation ($f_r=0.94f_c^{1/2}$), Burg and Ost relation ($f_r=1.03f_c^{1/2}$) and Khayat, Bickley relation ($f_r=0.23+0.12f_c-2.18\times10^{-4}(f_c)^2$). Experimental results exhibits higher value than all the predicted results when comparing the compressive strength and the flexural strength as shown in the Fig 2.

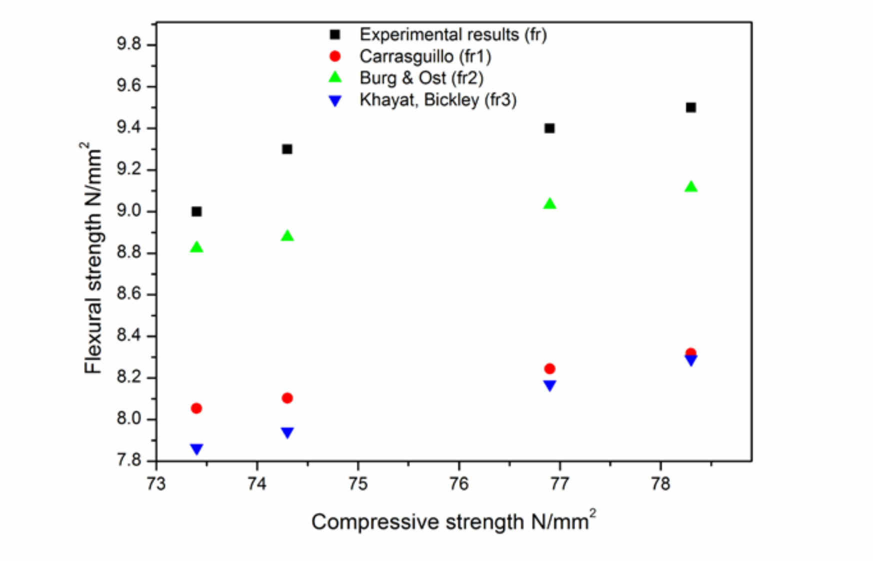

Fig 2: Experimental vs Predicted values

4.4 Bond strength

Bond strength was tested as per IS 2770 Part (1): 1967 (reaffirmed 2002) [15] to check the bonding effect of the PP fibre. Reinforcing bars of 12mm diameter were provided vertically along the central axis with the embedded length of the bar 90mm inside the concrete cube. Fibre addition in the HPC mixture enhances the bond strength at the rate of 12.53%, 16.70% and 20.86% with respect to the control mixture. Addition of fibre creates perfect bonding between the cement, fine aggregate and coarse aggregate in the HPC mixture which is evident from the Table 2.

Tab. 2: Strength properties of mixtures

Mixture	Bond strength (N/mm^2)	Modulus of Elasticity (Gpa)	UPV (m/s)
F0	14.15	39.87	4750
F0.1	15.92	41.59	4750
F0.3	16.51	42.39	4765
F0.6	17.10	40.08	4750

4.5 Modulus of Elasticity

A cylindrical specimen of size 100mm×200mm was loaded in the compression testing machine. The vertical and transverse deformations are measured at every 10kN increment by using the extensometers and then the elastic modulus at 28 days is determined as per IS: 516-1959 Standards. The Elastic modulus indicates a gradual increase at about 4.31% and 6.32% for F0.1 and F0.3 mixture later increases at about 0.52% for F0.6 mixture as shown in Table 2.

4.5 UPV test

The ultrasonic pulse velocity test is a non-destructive test to predict the strength of the concrete correlated to its compactness. IS 13311 (1): 1992 [16] classified the concrete as excellent, good, medium and doubtful for the UPV values ranges from 4500 m/s and above, 3500–4500 m/s, 3000–3500 m/s and below 3000 m/s respectively. UPV values of the concrete with the addition 0.1%, 0.3% and 0.6% fibre were relatively equal compared to the control mixture and classified as excellent since the measured values were greater than 4500 m/s clearly shown in Table 2. The UPV value increases with the increase in the compressive strength and it is directly proportional to the Compressive Strength. The compactness of the concrete increased with the presence of PP fibre, which helps in reducing the porosity of the concrete [17].

5. Durability Properties

5.1 Water absorption test

The specimens were taken out from the curing tank after 28 days to measure the water saturated weight and then dried in an oven at a temperature of 105°C until the specimen reaches uniform mass. The oven dried specimens were weighed after cooling and water absorption was calculated as per ASTM C642-97 [18] standards. Fibre fills the pores in the HPC mixture, creating dense packing of the concrete ingredients. Therefore the water absorption reduces by 7.14%, 10% and 17.86% for the F0.1, F0.3 and F0.6 mixtures.

5.2 Sorptivity test

Three concrete specimens of size 100mm×100mm×100mm for each mixture were dried in an oven for 105°C till it reaches the constant mass and then allowed to cool and the weight of the concrete specimens was noted. The specimen was then sealed on all sides except the surface which was in contact with water. Concrete specimens were placed on the support device, the water level in the pan was 3mm as per ASTM C1585-13 [19]. The rate of Sorption can be measured with the increase in the mass of specimen when exposed to water at every 5min, 10 min, 20 min, 30 min and 1 hour respectively. The sorptivity ranges by decreasing at 10%, 20% and 30% for the HPC mixtures. The rate of sorption is directly proportion to the water absorption for all the mixtures as shown in Fig 3.

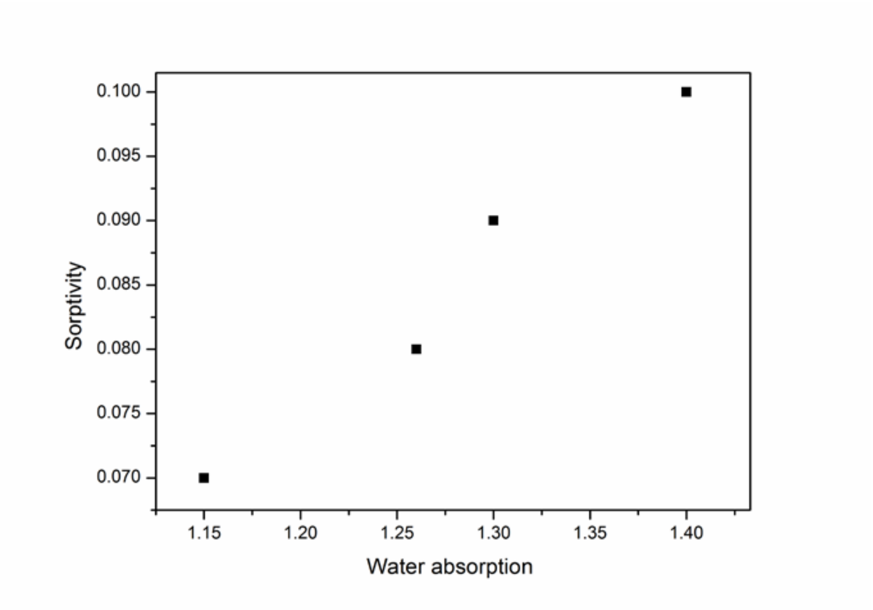

Fig 3: Water absorption vs Sorptivity

5.3 Ammonium Chloride attack test

Ammonium chloride causes serious deterioration in concrete by causing weight loss, reduction in strength and crack propagation. The concentration of the ammonium chloride solution was 2% with the pH of about 6.9. The concrete specimen undergoes continuous wetting and drying process. During the wetting process, the concrete cubes were immersed in the ammonium chloride solution for 2 weeks in a separate container for each cube. Then the ammonium chloride solution was dried in the container and left for 2 weeks. The completion of wetting and drying process causes one cycle. At the end of each cycle at every month, weight loss was calculated as per AS 1141.24-1974 [20]. Ammonium chloride attack for the period of 5 months was clearly pictured in the Fig 4.

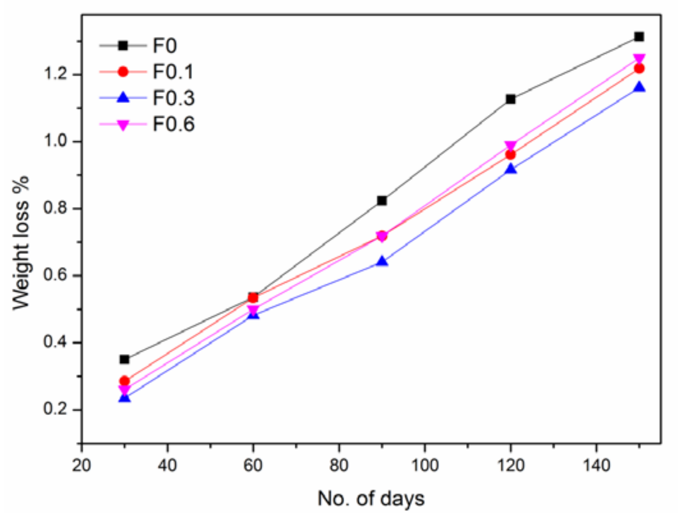

Fig 4: Ammonium Chloride attack at different periods

5.4 Sulphate attack test

Concrete structures are affected by the aggressive environments such as sulphate attack which causes deterioration in concrete. Sulphate attack is mainly because of the soil, ground water, fertilizer industry and steel making industries. The concentration of the sodium sulphate solution was 2% with the pH of 7.48. The concrete cubes were immersed in the sodium sulphate solution for 15 days and then left to dry for the next 15 days. Then the weight of the concrete specimen was noted and percentage of weight loss is calculated every month. Sulphate attack at various time periods was displayed in the Fig 5 as per ASTM C1012/C1012M – 13 [21].

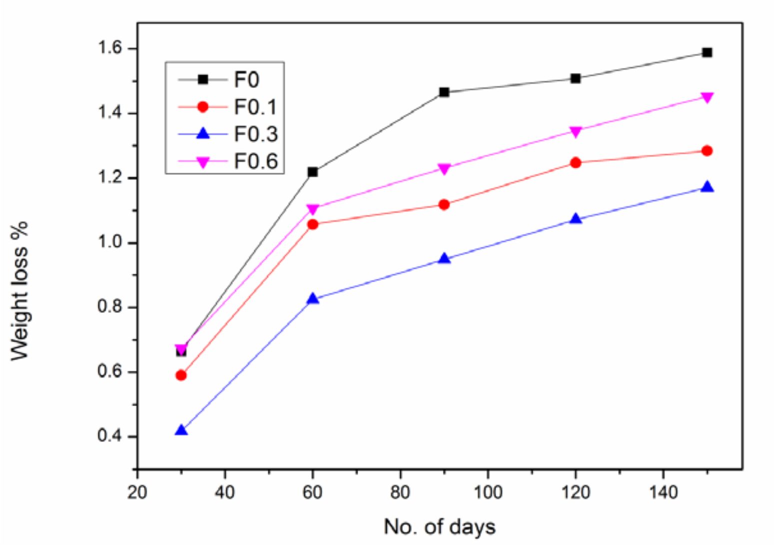

Fig 5: Sulphate attack at various time periods

5.5 Corrosion test

ASTM G1-03 [22] Standard was followed for preparing, cleaning, and evaluating corrosion test specimens. Reinforcing bar of 12mm diameter and 60 mm long was placed inside the each concrete specimen at the time of casting with the cover distance of 20mm. The initial weight of the reinforcement bars were noted after cleaning the rods as per ASTM G1-03 and placed inside the concrete specimen. After curing of specimens, ponding was made for each specimen and then allowed for ponding using the sodium chloride solution of about 2%. The concrete specimens were allowed for continuous wetting and drying process with the ponding of sodium chloride solution. The specimens were tested every month for calculating the corrosion effect. Gravimetric method was adapted to predict the corrosion behaviour. The concrete specimens were broken to get the embedded rod. The rod was cleaned using 500 ml concentrated hydrochloric acid, 500 ml distilled water and 3.5 gm. of hexamethylene tetramine. Then the final weights of rods were found out. The difference in weight (gravimetric loss) is a quantitative average of the corrosion attack. From the initial and final weight, loss in weight due to corrosion is determined as per ASTM G1-03 for the period of 3 months.

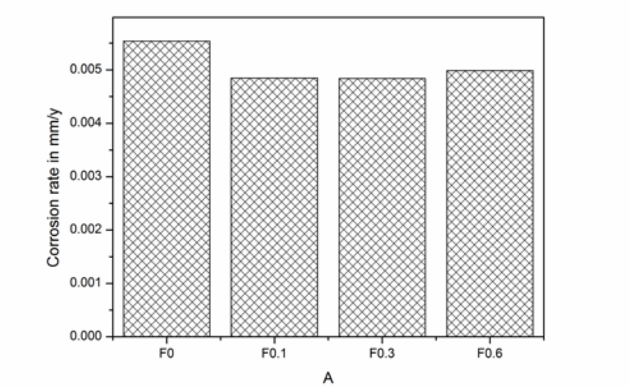

Fig 6: Corrosion rate

6. Conclusion

Addition of PP fibres reduces the slump at only of minor proportions. Hardened properties such as Compressive strength, Split tensile strength, Flexural strength, Bond strength and Non-destructive test (UPV test) exhibits adding PP fibres 0.3% attains the ultimate strength. Addition of fibre has no negative effects on Compressive strength, Split tensile strength, Flexural strength and UPV test, but the influence of higher content of fibre eventually decreases the strength. The results of the durability test such as Water absorption, Sorptivity, Ammonium Chloride test, Sulphate attack test and Corrosion test predicts 0.3% fibre addition is more durable than the other mixture. Fibre addition at 0.3% weight of cement attains maximum strength and more durable.

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