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Studies on the Properties of Steel and Polypropylene Fibre Reinforced Concrete without any Admixture

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Abstract*— In this paper the strength of concrete cubes, cylinders and prisms cast using M30 grade concrete and reinforced with steel and polypropylene fibres are presented. Also, hybrid fibres with crimped steel and polypropylene were used in concrete matrix to study its improvements in strength and durability properties. The steel, polypropylene and hybrid polypropylene and steel (crimped) fibres of various proportion i.e., 4% of steel fibre, 4% of polypropylene fibre and 4% of hybrid polypropylene and steel (crimped) fibres each of 2% by volume of cement were used in concrete mixes. Besides cubes, cylinders of 150 mm x 300 mm of M30 grade concrete were cast with 4% of steel fibre and polypropylene fibre, respectively, by volume of cement. The rapid chloride permeability test and water absorption test were conducted on 7, 28, 56 and 90 days and the test results show that the addition of steel and polypropylene fibres to concrete exhibit better performance. Totally 160 specimens were cast and tested including conventional concrete for comparison. The test results show that use of steel fibre reinforced concrete improves compressive strength and split tensile strength.

***Index Terms* -Concrete, Polypropylene Fibre-Reinforced, Steel Fibre-Reinforced, Compressive Strength, Split Tensile Strength, Chloride Permeability, Water Absorption.**

I. INTRODUCTION

Portland cement is a very commonly used construction material. Concrete made with this cement has certain characteristics. It is relatively strong in compression but weak in tension and tends to be brittle. Because of the load and environmental changes, a micro crack appears in cement products. Therefore cement based materials have low tensile strength and cause brittle failure [1]. The weakness in tension can be overcome by the use of sufficient volume fraction of certain fibres. In order to improve the mechanical properties of concrete it is good to mix cement with fibre which have good tensile strength [1]. Adding fibres to concrete greatly increases the toughness of the material. The use of fibres also alters the behavior of the fibre matrix composite after it has cracked, thereby improving its toughness. Incorporation of steel and polypropylene materials in concrete significantly improve its bleeding, plastic settlement, thermal and shrinkage strains, and stress concentrations imposed by external restraints. Under an applied load, distributed micro cracks propagate to produce macro cracks. When loads are further increased, conditions of critical crack growth are attained at the tip of the macro cracks and the crack becomes unstable. The micro and macro fractioning process described above can be favorably modified by adding short and randomly distributed fibers of various suitable materials [2]. Concrete is durable and strong. The resistance of concrete to penetration by chlorides is an important factor in protecting reinforced concrete structure from premature deterioration. The test method to measure this property is commonly referred to as the rapid chloride permeability test (RCPT) [3]. ASTM C 1202 [4] states that the test method is suitable for the evaluation of materials and their proportions for design purpose and research development. The numerical result (total chloride passed in coulombs) from this test method must be used with caution.

II. OBJECTIVES OF THE STUDY

The objectives of the current research is to study the durability properties of M30 grade of concrete reinforced individually with 4% of steel and polypropylene fibres, respectively, as well as with hybrid fibres consisting of 2% steel and 2% polypropylene fibres, respectively, and to evaluate their strength at 7, 28, and 90 days.

III. RESEARCH SIGNIFICANCE

The research mainly focuses on the use of steel, polypropylene and hybrid polypropylene and steel (crimped) fibres in concrete. In this system steel fibre is strong and stiffer, and improves the first crack strength, while polypropylene fibre which is more flexible and ductile, leads to improved toughness and strain capacity in the post cracking zone [5]. In this experimental investigation an attempt has been made to study the compressive strength, split tensile strength of steel, polypropylene fibre and hybrid polypropylene and steel (crimped) fibre reinforced concrete. The characteristics of fibres used in this investigation are shown in Table 1.

Table 1 Fibre Properties

Fibre Type	Shape	Length (mm)	Equivalent diameter (mm)	Tensile strength (MPa)
Steel Fibre crimped		42	1.0	1100
ENDURO-600 Polypropylene fibre		50	0.6	550

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IV. MATERIALS AND METHODS

A. Cement

Ordinary Portland cement of 53 grade available in local market is used in the investigation. The cement used has been tested for various properties as per IS: 4031 [6] and found to be confirming to various specifications of IS: 12269 [7]. The specific gravity of cement was 3.15 and fineness was 3200/cm^2/gm.

B. Coarse aggregate

Crushed angular granite metal of 20 mm size from a local source was used as coarse aggregate. The specific gravity of 2.71 and fineness modulus of 4.07 was found from testing [8].

C. Fine aggregate

River sand was used as fine aggregate. The specific gravity of 2.60 and fineness modulus 2.65 was found in the investigation.

D. Steel fibre

Typically steel fibres have equivalent diameters of 0.15 mm to 2 mm and length from 7 mm to 75 mm. Aspect ratio generally ranges from 20 to 100. Aspect ratio is defined as the ratio between fibre length and its equivalent diameter, which is the diameter of a circle with an area equal to the cross section area of the fibre. Steel fibres have high tensile strength ranging from 0.5 - 2.0 GPa with modulus of elasticity of 200 GPa.

E. Polypropylene fibre

Polypropylene fibre, a synthetic carbon polymer, is produced as continuous mono – filaments, with circular cross section that can be chopped to required length (or) tape of rectangular cross section (Fig. 1). Polypropylene fibres are tough but with low tensile strength and modulus of elasticity. They have plastic stress-strain characteristics. Furthermore, their ability to cause interference with the capillary forces by which water bleeds to the surface of concrete reduces the risk of plastic settlement due to water evaporation. A blend of steel and polypropylene fibre can combine structural elements with plastic cracking in fresh concrete and drying shrinkage cracking in hardened concrete and to improve post-cracking toughness. Micro synthetic fibres also increase resistance to spalling in fire situation.

Fig. 1 Endura-600, Macro synthetic Poly Propylene fiber

V. EXPERIMENTAL PROGRAMME AND DISCUSSION OF RESULT

A. Compressive strength test result:

For compressive strength test, cube specimens of dimensions 150 mm × 150 mm × 150 mm were cast using M30 grade of concrete with 4% of steel fibre, 4% of Polypropylene fibre and 4% of hybrid Polypropylene and steel (crimped) fibres of each of 2% of volume of cement, separately. Vibration was given to the moulds using table vibrator. The top surface of the specimen was leveled and finished. After 24 hours, the specimens were demoulded and transferred to curing tank wherein they were allowed to cure for 7 days, 14 days, 21 days and 28 days. After 7, 14, 21 and 28 days of curing, these cubes were tested on digital compression testing machine as described in [9].

Fig. 2 Cube testing in CTM

The failure load was noted. In each category, three cubes were tested and their average value is reported. The compressive strength was calculated as follows: Compressive strength (MPa) = Failure load / Cross sectional area Results of compressive strength for M30 grade of concrete on cube specimens are shown in Table 2.

Table 2 Results of Compressive strength

Sl. No.	Type of concrete	Compressive strength N/mm^2			
		7 days	14 days	21 days	28 days
1.	Conventional Concrete (C.C.)	18	20	33	35
2.	Concrete with SFRC	26	32	32	41
3.	Concrete with PPFRC	20	22	38	39
4.	Concrete with HYBRID	20	22	23	30

Note:

- CC – Conventional Concrete
- SFRC – Steel Fibre Reinforced Concrete
- PPFRC – Poly Propylene Fibre Reinforced Concrete
- HYBRID – Both Steel and Poly Propylene Fibre (Crimped)

The comparative results for compressive strength of concrete cube between conventional concrete, steel fibre reinforced concrete, Polypropylene fibre reinforced concrete,

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and hybrid Polypropylene and steel (crimped) fibres specimens are shown in Fig. 3.

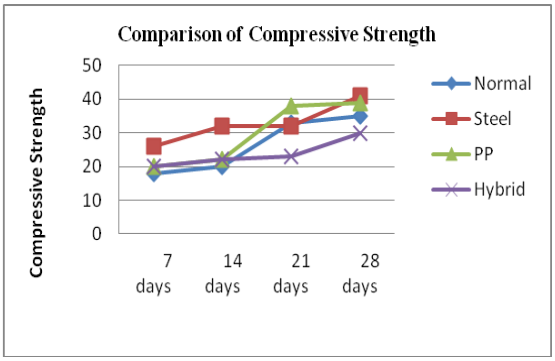

Fig. 3 Comparisons of compressive strength

The comparison of the 7, 14, 21, and 28 days cube strength results shows that,

1. Cubes of SFRC (Steel Fibre Reinforced Concrete) for 7 days show 41% increase in compressive strength with 14th and 21st days equal strengths and at 28 days 14% increase when compared to conventional concrete of M30 grade.
2. Compressive strength of PPFRC (Polypropylene Fibre Reinforced Concrete) at 7, 14, 21, and 28 days show an increase in percentages of 11, 10, 18 and 11, respectively when compared to conventional concrete for M30 grade.
3. Hybrid Polypropylene and steel (crimped) fibres 7, 14, 21, and 28 days compressive strength results show a decrease in compressive strength for percentage of 22, 10, 3, and 9, respectively, when compared to conventional concrete for M30 grade of concrete.

B. Split Tensile strength test result:

Direct tension test of concrete is seldom made because of difficulties in mounting the specimens and uncertainties as to the secondary stresses induced by the holding devices. An indirect test for tensile strength of concrete developed originally in Brazil has been standardized by ASTM and is in general use [10]. Accordingly, 3 specimens of cylindrical shape of diameter 150 mm and length 300 mm were tested under a Compression Testing Machine of 2000 kN capacity under a compressive load across the diameter along its length till the cylinder splits (Fig. 4).

Fig. 4 Compression testing machine

The tension develops in a direction at right angles to the line of action of the applied load. The Split Tensile strength was calculated as follows:

Split Tensile strength (MPa) = $2P / \pi DL$ [11].

where, P = Failure load,

L = Length of cylinder, and

D = Diameter of cylinder

Results of tested cylindrical specimens for M30 grade of concrete are shown in Table 3.

Table 3 Results of Split tensile strength

Sl. No.	Type of concrete	Split Tensile Strength N/mm^2			
		7 days	14 days	21 days	28 days
1.	Conventional Concrete(C.C.)	1.48	2.0	2.2	2.2
2.	Concrete with SFRC	3.0	3.2	2.67	2.9
3.	Concrete with PPFRC	1.82	2.2	2.8	2.6
4.	Concrete with HYBRID	1.6	1.7	2.2	2.1

The comparative results for split tensile strength of concrete cylinder of conventional concrete, steel fibre reinforced concrete, Polypropylene fibre reinforced concrete, and hybrid Polypropylene and steel (crimped) fibres specimens are shown in Fig. 5.

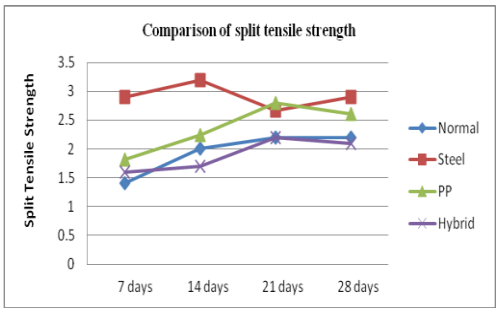

Fig. 5 Comparison of split tensile strength

The comparison of the 7, 14, 21, and 28 days split tensile strength of cylinders in the case of SFRC show an increase of 100%, 60%, 21% and 45%, respectively, when compared to conventional concrete for M30 grade of concrete. In the case of PPFRC split tensile strength results show an increase of 21, 10, 27 and 25 per cents at 7, 14, 21, and 28 days, respectively, when compared to conventional concrete for M30 grade of concrete. In the case of concrete reinforced with Hybrid Polypropylene and steel (crimped) fibres, split tensile strength results show 7% increase in 7 days, 15% decrease in 14 days, equal strength in 21 days and 5% increased in 28 days when compared to conventional concrete for M30 grade of concrete.

C. Rapid Chloride Permeability Test:

According to ASTM C1202 [4] test, a water-saturated, 50 mm thick, 100 mm diameter concrete specimen is subjected

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to applied DC voltage of 60 V for 6 hours using the apparatus and the cell arrangement as shown in Fig. 6.

Fig. 6 RCPT Test set up

In one reservoir 3% NaC1 solution is filled and in the other reservoir a 3% NaOH solution. The total charge passed is determined and this is used to rate the concrete according to the criteria given in Table 4. Test results of Rapid Chloride Permeability Test (RCPT) for ordinary concrete and SFRC, PPFRC and HYBRID fibre reinforced cement concrete are given in Table 5.

Table 4 Rating of Chloride Permeability

Charge passing in Coulombs	Chloride permeability Rating (As per ASTM C 1202 criteria)
Greater than 4000	High (H)
2001 to 4000	Moderate (M)
1001 to 2000	Low (L)
100 to 1000	Very low (VL)
Less than 100	Negligible (N)

The comparative results for Rapid Chloride Permeability Test of conventional concrete, steel fibre reinforced concrete, Polypropylene fibre reinforced concrete, and hybrid specimens are shown in Fig. 7.

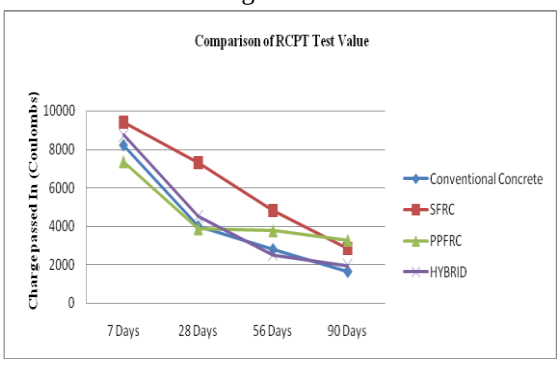

Fig. 7 Comparison of RCPT Value

D. Testing of specimens:

Rapid Chloride Permeability Test conforming to ASTM C 1202 [4] was the first test proposed for rapid qualitative assessment of Chloride Permeability of concrete [12]. In this test cylinder disc specimens of diameter 100 mm and thickness 50 mm were used. The diffusion test consists of two chambers and was specially fabricated for the test. On one side, sodium chloride solution was filled and on the other side 0.3N sodium hydroxide solution was poured. The chloride ion from chamber 1 was forced to enter chamber 2 through the centrally placed concrete specimen, under the influence of voltage as well as difference in concentration of chloride ion on either side of the specimen. The record time is set as 30 minutes and also the log time as 6 hours and the electric charged passed I in Coulomb was calculated using the equation [13].

$$I = 900 \times [2 (I_0 + I_{360}) + (I_{30} + I_{60} + I_{90} + I_{120} + I_{150} + I_{180} + I_{210} + I_{240} + I_{270} + I_{300} + I_{330})]$$

where

I_0 = Initial current reading in mA.

I_{30} = Current reading at 30 minutes in mA.

I_{60} = Current reading at 60 minutes in mA.

I_{90} = Current reading at 90 inutes in mA.

I_{120} = Current reading at 120 minutes in mA.

I_{150} = Current reading at 150 minutes in mA.

I_{180} = Current reading at 180 minutes in mA.

I_{210} = Current reading at 210 minutes in mA.

I_{240} = Current reading at 240 minutes in mA.

I_{270} = Current reading at 270 minutes in mA.

I_{300} = Current reading at 300 minutes in mA.

I_{330} = Current reading at 330 minutes in mA.

I_{360} = Current reading at 360 minutes in mA.

The results of Rapid chloride permeability test are given Table 5

Table 5 Results Of Rapid Chloride Permeability Test

Grade of Concrete	Type of Concrete	Chloride permeability Charge passed (Coulombs)							
		7 days		28 days		56 days		90 days	
M30	Conventional Concrete (C.C.)	8200	H	3990	M	2785	M	1620	L
	SFRC	9400	H	7295	H	4810	H	2835	M
	PPFRC	7350	H	3851	M	3750	M	3250	M
	HYBRID	8750	H	4510	H	2510	M	1960	L

E. Water Absorption Test

The water absorption by immersion is determined according to the Belgian Standard NBN B15 – 2159.[14] Principally the test consists of two major steps. First the concrete specimens are immersed in water until the change in

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mass during 24 hours is less than 0.1 %. The saturated mass obtained is called M_S. Second, the specimens are dried in a ventilated oven at a temperature of 105° plus or minus 50° C until the difference in mass during 24 hours is less than 0.1%. The dry mass is called M_D. The water absorption by immersion (w) is expressed as the water up take relative to the dry mass.

$$w = (M_S - M_D) / M_D$$

The prediction capacity of the water absorption with respect to the durability of the concrete is certainly not better than the prediction capacity of the compressive strength [13] and [15]. The results of water absorption test with age are given Table 6.

Table 6 Results of Water Absorption

Grade of concrete	Type of concrete	7 days water absorption (%)	28 days water absorption (%)	56 days water absorption (%)	90 days water absorption (%)
M30	C.C	6.65	6.4	6.3	5.8
	SFRC	6.63	6.7	6.4	5.8
	PPFRC	5.44	7.1	6.7	6.1
	HYBRID	7.79	7.2	6.6	5.9

The comparative results for water absorption by immersion test of conventional concrete, steel fibre reinforced concrete, Polypropylene fibre reinforced concrete, and hybrid specimens are shown in Fig. 8.

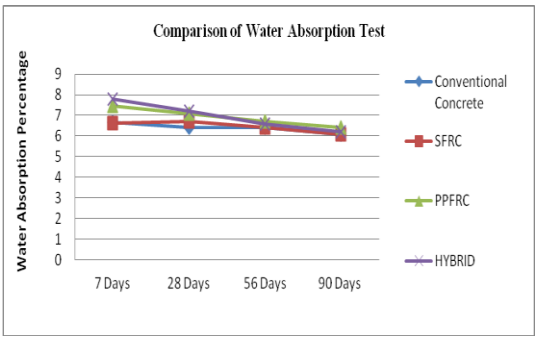

Fig. 8 Comparison of Water absorption test Value

VI. CONCLUSION

Based on the experimental results the following conclusions are drawn. Using three types of fibers with 4% by volume of cement the results were compared with the conventional concrete specimen. The concrete mix with 4% steel fiber shows that the concrete was stiff and difficult to compact. In addition to this, concrete with shorter fiber has better workability as compared to longer fiber. The concrete mix with 4% Endura-600 Macro synthetic Polypropylene fiber shows that concrete was more slippery and difficult to compact. Increase in compressive strength of SFRC was observed to be in range of 3 per cent to 60 per cent between 7 and 28 days. The compressive strength of PPFRC was observed to increase between 10 per cent and 18 per cent for 7 and 28 days. Corresponding values for Hybrid concrete was increased by 3 per cent to 22 per cent for 7 to 28 days when compared to conventional concrete. In conventional concrete, specimen splits into two halves exactly under the loaded area, but using SFRC, PPFRC, Hybrid fibers cylinders did not split into halves under the loaded area. Because of toughness it did not yield to sudden breakage. An increase in ductility of the specimens by the introduction of fibers was observed in this investigation. Chloride Permeability for conventional concrete and Hybrid specimens was low and a SFRC and PPFRC specimen was medium according to ASTMC 1202 criteria. Water absorption results of SFRC and Hybrid specimens are equal to conventional concrete. But in the case of PPFRC it was 4% increase than conventional concrete.

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He has to his credit 7 books and chapters in books as well as over 300 papers. The H-index of his publications is 74. He has published papers in Tamil and Hindi. He is a *Peer Reviewer* of five International and six National Journals.

He is a recipient of several awards, including International Engineer of the Year 2012 and International Educator of the Year 2012 of the International Biographical Centre, Cambridge, England; Tmt. V. Lakshmi Bangaru Adigalar Award of Excellence 2012; Indira Gandhi Shiromani Award 2011 of India International Friendship Society; CIDC Vishwakarma Award 2011; Excellence Award from Adhiparasakthi Engineering College 2011; Excellence Award from Adhiparasakthi Engineering College 2010; Bharat Jyoti Award of India International Friendship Society 2008; Best Citizens of India Award of International Publishing House 2008; Col. C. N. Bajpai Award of the Institution of Engineers (India) 2004; Maharashtra Centre – ICI Award of Indian Concrete Institute 2000; and Dr Meenakshisundaram Endowment Gold Medal 1976 of Madurai University. He was honored by Tamil Nadu Magazine Publishers Association (TAMPA) as Beneficial Creator in 2011.

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