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Flexural Behaviour of Fibre Reinforced Concrete Beams with Different Aspect Ratios

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Abstract
The performance of conventional concrete is enhanced by the addition of fibres in concrete. Consequently the brittleness in concrete is reduced, and its acceptable ductility is also ensured by this addition. In this paper the strength of concrete cubes, cylinders and beams cast using M_{25} grade concrete and reinforced with steel and polypropylene fibres is presented. Also hybrid fibres with crimped steel and polypropylene were used in a concrete matrix to study improvements in the strength properties of steel, polypropylene and hybrid polypropylene as well as steel (crimped) fibres of various proportion i.e., 0.25%, 0.5%, 0.75%, 1% and 0.5% (0.25% of steel and 0.25% of polypropylene), 0.75% (0.5% of steel and 0.25% of polypropylene, 0.25% of steel and 0.5% of polypropylene) and 1% of various combinations of hybrid fibres for 7,14 and 28 days. The main reason for synthetic fibres in the concrete matrix is to improve the post cracking response of the concrete to improve the energy absorption capacity and ductility as well as to provide crack resistance and control. The introduction of this type of concrete was brought in as a solution to develop concrete with enhanced flexural and tensile strength. In this paper we analysed and present a comparison between conventional concrete and fibre reinforced concrete, leading to a crack free structure.

Key words: *hybrid, steel fibres, polypropylene fibres, RC element, flexural strength.*

Introduction

Concrete containing cement, water, aggregate, and discontinuous, uniformly dispersed or discrete fibres is called fibre reinforced concrete. It is a composite obtained by adding a single type or a blend of fibres to a conventional concrete mix. Fibres can be in the form of steel fibres, glass fibres, natural fibres, synthetic fibres, etc.

Optimisation of mechanical and conductivity properties can be achieved by combining different kinds and sizes of fibres, such as in the case of PP and steel fibres, giving the attractive advantages of hybrid fibre systems. Hybrid fibre reinforced concrete (HFRC) is formed from a combination of different types of fibres which differ in material properties, remaining bonded together when added to concrete and also retaining their identities and properties. The combining of fibres, often called hybridisation, was investigated for M_{40} grade concrete at a volume fraction of 0.5% in this paper. Control and three hybrid fibre composites were cast using different fibre proportions of steel and polypropylene. Compressive strength, split tensile strength and flexural strength tests were performed and the results analyzed to associate with the fibre combinations above. Based on experimental studies, the paper identified fibre combinations that demonstrate the maximum compressive, split tensile and flexural strength of concrete. The relationship between compressive strength and split tensile strength and between compressive strength and flexural strength is presented. [1]

This paper presents the effect of the flexural behaviour of fibre reinforced concrete with and without elastomeric pads. A total of six reinforced concrete beams were cast and tested in the present investigation. Concrete of M_{20} grade was designed and crimped steel fibres, and polypropylene fibres were used in the hybrid form. The main variables considered were the volume fraction of (i) crimped steel fibres viz. 0.25%, 0.5% and 0.75%, and (ii) polypropylene fibres viz. 0.75%, 0.5%, and 0.25%. The combination of a 0.75% volume fraction of steel fibres and 0.25% volume fraction of polypropylene fibres gave better performance with respect to the strength and energy dissipation capacity than the other combinations [2]. In this investigation, we studied the behaviour of hybrid fibre reinforced concrete (HFRC) formed from metallic, mineral and polymeric fibres. Specimens were cast with up to 2% of fibres, partially replacing the weight of cement. This paper deals with the flexural behaviour of hybrid fibre. The material used was ordinary Portland 53 grade cement, fine aggregate and coarse aggregate. The concrete mix adopted was M_{25} grade with varying percentage of fibres. Casting and testing of hybrid fibre reinforced concrete specimens in different mixing percentages from 0-2 were performed. Five specimens, namely RCC, GFRC, SFRC, HFRC1, HFRC2 and companion specimens were cast and tested. The specimens' strength were tested for 7, 14 and 28 days and their behaviour studied under compression and tension as per the method recommended by Indian Standards. The results provide a comparison between the control concrete, GFRC, SFRC and hybrid fibre reinforced concrete [3]. The mechanical performance of hybrid fibre reinforced concrete (HFRC) was also studied. The addition of small closely spaced and uniformly dispersed fibres to concrete would act as a crack resistor and would substantially

Table 1. Physical properties of cement.

S. No	Physical properties	Test values	Reference code
1	Specific gravity	3.12	IS:1727-1967
2	Standard consistency	34%	IS:4031-1968 part-4
3	Setting in final	540 minutes	IS:4031-1968 part-5
4	Soundness test	0.90	Le-chatelier Apparatus IS:4031-1968
5	Compressive strength (28 days)	53.2Mpa	–

Table 2. Water quality analysis results.

S. No	Description	Water sample	Maximum permissible limit
1	PH value	7.5	6.0-9.0
2	Hardness(ppm)	360	1000
3	Sulphate (ppm)	210	400
4	Chloride (ppm)	205	500

Table 3. Properties of crimped steel fibre.

S. No	Property	Values
1	Equivalent Diameter, mm	0.15 to 1.00
2	Specific Gravity, kg/m3	7840
3	Tensile Strength, MPa	345 to 3000
4	Young's Modulus. GPa	200
5	Ultimate Elongation, %	3 to 10
6	Thermal Conductivity, 1%	1% 2.74
7	Aspect Ratio	50 to 100

improve its properties. This type of concrete is known as fibre reinforced concrete. The addition of more than one type of fibre in concrete is known as hybrid fibre reinforced concrete. In this study we used steel fibres and polypropylene fibres Fibre to reinforce materials that are weaker in tension than in compression. Steel fibre and polypropylene fibre were used as hybrid fibres in different proportions: 0.25%, 0.5%, 0.75%, and 1% in this study. Experiments were conducted to study the effect of steel fibre and polypropylene fibre in different proportions in hardened concrete. Compressive strength tests on a cube and flexural strength tests on a beam were carried out to study the properties of hardened concrete [4]. A brief review was conducted of various studies on steel and polypropylene hybrid fibre reinforced concrete reported by various researchers in published literature (i.e. journals and books). Hybrid fibres with crimped steel and polypropylene were used in a concrete matrix to study the improvements in strength and durability properties. 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 M_{30} 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 after 7, 28, 56 and 90 days, and results show that the addition of steel and polypropylene fibres to concrete exhibits better performance. A total of 160 specimens were cast and tested, including conventional concrete for comparison. The test results show that the use of steel fibre reinforced concrete improves the compressive strength and split tensile strength [5].

Experimental programme

Materials used

The various materials used in this project and their physical and mechanical properties are given in the subsequent sections.

Cement

In this study, Ordinary Portland Cement (OPC) of 53 Grade was used throughout, conforming to the IS 12269:1987 standard. Mechanical properties of the cement were studied, which are presented in ***Table 1***.

Aggregates

The aggregate in the matrix or principal structure consists of a relatively inert, fine and coarse material. The aggregate for concrete varies in size, but in any mix particles of different sizes are used. The particle size distribution is called the grading of the aggregate. While producing good quality concrete, aggregate is used from at least two size groups.

Fine aggregate

Fine aggregate collected from the Cauvery river bed near Trichy was used for experimental study, with a fineness modulus of 2.58, specific gravity of 2.62 and bulk density of 1.65 g/cm^3. Sand confirming zone-III and without moisture content was stored in a room and used for casting specimens. Properties of the sand were determined as per IS-383:1970.

Coarse aggregate

Coarse aggregate collected from a quarry (Srinivasa blue metals, from Reddiyar Chatram Dindigul) from crushed granite of 20 mm and 12 mm maximum size, conforming to IS 383-1970, was used. The fineness modulus of the coarse aggregate is 6.74, the bulk density 1.54 g/cm^3 and specific gravity 2.75.

Water

The water used in the concrete was clean and free from such impurities as suspended solids, organic matter and dissolved salts, which are frequently contained in natural water and which may adversely affect the properties of concrete, especially setting and hardening. Water is essential for the hydration of cement. Generally portable water is considered suitable for concreting, as per IS 456-2000, but excessive water is the primary cause of drying shrinkage cracks. The physical properties of water are presented in ***Table 2***.

Polypropylene fibre

This was a synthetic carbon polymer produced as continuous mono – filaments with a circular cross section or tape of rectangular cross section that can be chopped to a required length. It was manufactured by the Radhekrishna Chemical Malad West company, Mumbai (India), and obtained from Moon Opticals, Madurai (India).

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. Polypropylene is reasonably economical, and can be made translucent when uncoloured, but it is not as readily made transparent as polystyrene, acrylic or certain other plastics. It is often opaque or coloured using pigments. Polypropylene has good resistance to fatigue, and perfectly isotactic polypropylene has a melting point of 171 °C, while for commercial isotactic polypropylene it ranges from 160 to 166 °C.

Steel fibre

Steel fibres are classified into the following types: straight, hooked, paddled, deformed, crimped, and irregular. In this work, crimped types of steel fibre were used, manufactured by Jayesh Associate, near Wall Tax Road, Chennai, Tamil Nadu, India.

The composition of steel fibres generally includes carbon steel or stainless steel. The length dimension ranges from 6.4 mm to 76 mm, while the diameter is from 0.25 mm to 0.75 mm. Steel fibres are described by the convenient parameter "aspect ratio", determined by the length to diameter ratio, varying from 20 to 100. According to ASTM A 820 standards, the minimum yield strength of steel fibres should be 50,000 psi (345 Mpa). The steel fibre used in this project is crimped type steel fibre of 30 mm length and less than 0.5 mm thickness in various percentages of the total volume of concrete. The properties of used crimped steel fibres are given in ***Table 3***.

Superplastisiser

The superplastisiser used in this project was a brown coloured liquid concrete and mortar waterproofing admixture, which is a modified polymer liquid admixture that acts as highly efficient plasticiser; it was obtained from Sri Velavan Traders Private limited, Goripalayam, Madurai (India).

Super plasticisers are essential sulfonic compounds attached to the polymer backbone at regular intervals. These can be added at a range of 0.15% to 3.0% of the weight of cement, which is higher as compared to plasticisers.

The following are properties of the superplastisiser:

- Improves workability without increased water content
- Allows easier compaction, leading to denser concrete and superior surface finish
- Increased strength and durability
- Reduced shrinkage
- Choloride free – does not attack reinforcement

Table 4. *Different proportions of fibres used.*

S. No	Notation	Steel fibres by volume of concrete, %	Polypropylene fibres by volume of Cconcrete, %
1	CC	0	0
2	S1	0.25	0
3	S2	0.5	0
4	S3	0.75	0
5	S4	1	0
6	P1	0	0.25
7	P2	0	0.5
8	P3	0	0.75
9	P4	0	1
10	H1	0.25	0.25
11	H2	0.25	5
12	H3	0.5	0.25
13	H4	0.5	0.5
14	H5	0.75	0.25
15	H6	0.25	0.75

Table 5. *Compaction factor test.*

S. No	Notation	Percentage of fibres added		Compaction factor	Slump value
		Steel fibres by volume of concrete, %	Polypropylene fibres by volume of concrete, %		
1	CC	0	0	0.9	2.1
2	S1	0.25	0	0.89	1.9
3	S2	0.5	0	0.88	1.8
4	S3	0.75	0	0.85	1.2
5	S4	1	0	0.82	1.0
6	P1	0	0.25	0.89	1.8
7	P2	0	0.5	0.87	1.6
8	P3	0	0.75	0.85	1.2
9	P4	0	1	0.84	1.1
10	H1	0.25	0.25	0.87	1.75
11	H2	0.25	0.5	0.86	1.35
12	H3	0.5	0.25	0.85	1.45
13	H4	0.5	0.5	0.81	1.0
14	H5	0.75	0.25	0.80	1.2
15	H6	0.25	0.75	0.80	1.1

Experimental methodology

Properties of materials:

Average specific gravity of cement = 3.12
Fineness of cement = 2.6%
Standard consistency of cement paste = 30%
Average specific gravity of sand = 2.58
Fineness modulus for sand = 2.56
Average specific gravity of CA = 2.75
Aggregate impact value of coarse aggregate = 13.92
Fineness modulus of CA = 9.96

Mix design

The mix design for M_{25} grade concrete was as per IS: 10262 – 2009, which can be defined as the process of selecting suitable ingredients of concrete and determining their relative quantities with the object of producing as economically as possible concrete of certain minimum properties, notably consistent strength and durability.

Design stipulations

Characteristic compressive strength at 28 days = 25 N/mm^2
Maximum size of aggregate = 20 mm
Type of aggregate Crushed rock
Degree of quality control = Good
Type of exposure = Moderate

Characteristics of material

The cement
Type of cement used = Ordinary Portland cement

Figure 1. *Failure of cube under compression.*

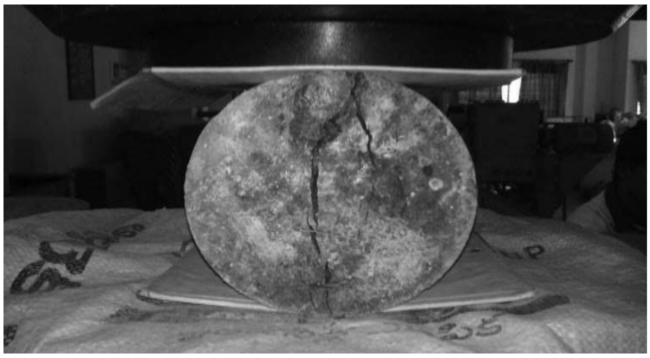

Figure 2. *Failure of cylinder under split tension.*

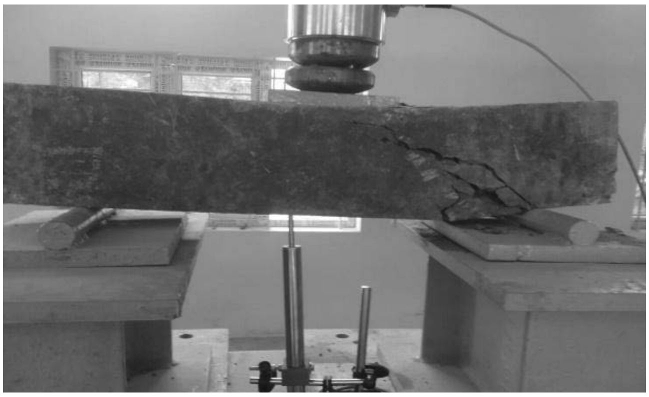

Figure 3. *Flexural test.*

Specific gravity of cement = 3.12
Cement = 3.1cum
Fine Aggregate = 3.73 cum
Coarse Aggregate = 8.61 cum
Water = 22 liters

Mix propertion

The following different mix proportions of fibres were used in this work as shown in ***Table 4***.

Tests on fresh concrete

The aim of the experimental program was to study the properties of fresh and hardened concrete using various proportions of fibres. The tests conducted on standard specimens are presented in the successive sections. The compaction factor test values are given in ***Table 5***.

Slumpt test

The slump cone is a a mould of 1.6 mm thick galvanised metal in the form of the lateral surface of the frustum of a cone with a base 200 mm in diameter, a top 100 mm in diameter and height of 300 mm. The base and top shall be open and parallel to each other and at right angles to the axis of the cone. The mould shall be provided with a foot piece on each side for holding the mould in place, and with handles for lifting the mould from the sample. The tamping rod is a round, straight steel rod 16 mm in diameter and approximately 600 mm in length. The tamping end shall be a hemisphere 16 mm in diameter. The slump values for the fresh concrete are qiven in ***Table 5***.

Tests on hardened concrete

The aim of the experimental program is to study the properties of hardened concrete using various proportions of fibres. The tests conducted on the standard specimens are presented in the succeeding sections.

Cube compresion test

This test was conducted as per IS 516-1959. Cubes of a standard size of 150 mm x 150 mm x 150 mm were used to find the compressive strength of the concrete. Specimens were placed on the bearing surface of the UTM, with

Table 6. *Compression test values at 7.14 and 28 days.*

S. No	Notation	Percentage of fibres		7 day's strength		14 day's strength		28 day's strength	
		Steel	PP	Load, kN	Comp. St	Load, kN	Comp.St	Load, kN	Comp.St
1	CC	0	0	365.06	16.22	485.53	21.57	730.04	32.44
2	SC1	0.25	0	370.10	16.44	492.23	21.87	740.20	32.88
3	SC2	0.5	0	379.73	16.89	505.04	22.46	759.46	33.78
4	SC3	0.75	0	390.64	17.36	519.55	23.08	781.28	34.72
5	SC4	1	0	398.62	17.71	530.16	23.55	797.24	35.42
6	PPC1	0	0.25	368.10	16.36	489.57	21.76	736.20	32.72
7	PPC2	0	0.5	377.73	16.78	502.38	22.32	755.46	33.56
8	PPC3	0	0.75	390.00	17.33	518.70	23.05	780.00	34.66
9	PPC4	0	1	397.89	17.69	529.19	17.69	795.78	35.38
10	HY1	0.25	0.25	510.82	21.62	529.19	28.75	1021.64	41.72
11	HY2	0.25	0.5	501.22	19.66	666.63	26.15	1002.44	39.32
12	HY3	0.5	0.25	524.00	24.58	697.05	32.69	1048.00	43.32
13	HY4	0.5	0.5	513.45	22.82	682.88	30.35	1026.90	42.23
14	HY5	0.75	0.25	526.60	26.56	700.37	35.32	1053.30	45.64
15	HY6	0.25	0.75	509.22	20.86	677.26	27.74	1018.44	40.62

a capacity of 100 tons without eccentricity, and a uniform rate of loading of 550 Kg/cm^2 per minute was applied until the failure of the cube, as shown in ***Figure 1***. The maximum load was noted and the compressive strength calculated. The results are tabulated in ***Table 6***.

Split tensile test

Cylinders of 150 mm (dia) x 300 mm (height) size were cast. The test was carried out by placing a cylindrical specimen horizontally between the loading surface of a compression testing machine and a load is applied until the failure of the cylinder along the vertical diameter, as shown in ***Figure 2***. The results are tabulated in ***Table 8***.

Flexural test

Beams of 150 mm x 150 mm x 1000 mm size were tested using a flexure testing machine. The specimen is simply supported on the two rollers of the machine, which are 600 mm apart, with a bearing of 50mm from each support. The load is applied on the beam from the two rollers, placed above the beam with a spacing of 200 mm. The load is applied at a uniform rate such that the extreme fibre stress increases at 0.7 N/mm^2/min i.e., the rate of loading is 4 kN/min. The load is increased till the specimen fails, as shown in ***Figure 3***. The maximum value of the load applied is noted down. The appearance of fracture on the faces of the concrete and any unique features are noted.

Results and discussion

This chapter presents the test results of various tests conducted in the experimental investigation of the behavior of hardened concrete. Hardened tests were conducted on beams for flexural strength, cubes for compressive strength and cylinders for split tensile strength with and without fibres in order to establish the service load and ultimate load under static loading conditions. Analysis was made for the load carrying capacity, deflection and crack pattern, and presented in this work.

Compression test results

Compression test values at 7, 14 and 28 days for cube specimens are given in ***Table 6***. Fifteen cube specimens cast and cured of 7 days, one control cylinder, denoted as CC, and the remaining fourteen as SC_1, SC_2, SC_3 and SC_4 were mixed with different ratios of steel fibre. The compressive strength of 7 day's cured specimens SC_1, SC_2, SC_3 and SC_4 without steel fibre mixed is 16.44, 16.89, 17.36 and 17.71 N/mm^2; similarly for

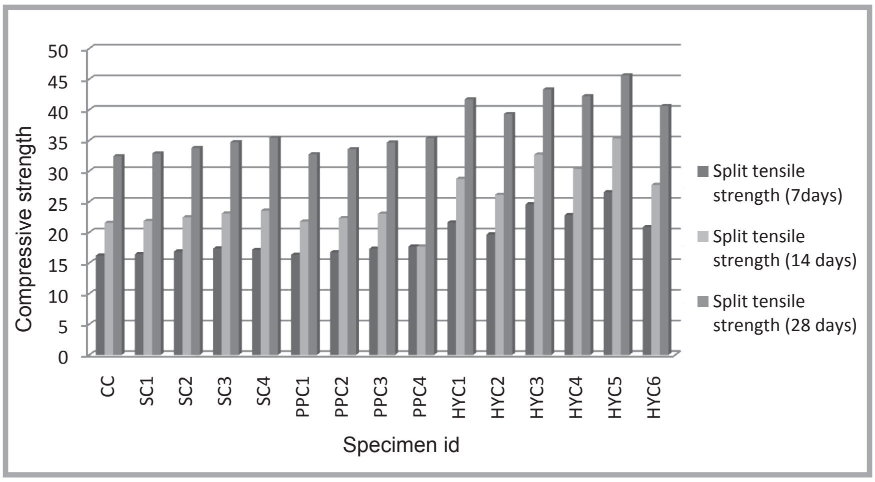

Figure 4. *Compressive strength of controlled and fibre added concrete cubes.*

Table 7. *Mean, standard deviation and coefficient variation for concrete with and without fibres added .*

Specimen ID	Compressive strength x	$(x - \bar{x})^2$
CC	32.44	22.91
SC1	32.88	18.83
SC2	33.78	11.83
SC3	34.72	6.25
SC4	35.42	3.24
PPC1	32.72	20.25
PPC2	33.56	13.39
PPC3	34.66	6.55
PPC4	35.38	3.38
HY1	41.72	20.25
HY2	39.32	4.41
HY3	43.32	37.21
HY4	42.23	25
HY5	45.64	70.89
HY6	40.62	11.56
	$\bar{x}$ = 37.22	275.95

Table 8. *Split tensile test values at 7, 14 and 28 days.*

S. No	Notation	Percentage of fibres		7 day's strength		14 day's strength		28 day's strength	
		Steel	PP	Load, kN	Split.St	Load, kN	Split. St	Load, kN	Split.St
1	CC	0	0	252.22	3.57	289.62	4.10	324.99	4.60
2	SCY1	0.25	0	257.87	3.65	298.85	4.23	334.17	4.73
3	SCY2	0.5	0	262.82	3.72	305.21	4.32	340.53	4.82
4	SCY3	0.75	0	272.00	3.85	315.09	4.46	350.42	4.96
5	SCY4	1	0	274.83	3.89	319.34	4.52	360.31	5.10
6	PPCY1	0	0.25	254.34	3.60	293.20	4.15	328.52	4.65
7	PPCY2	0	0.5	259.99	3.68	296.73	4.20	332.06	4.70
8	PPCY3	0	0.75	262.82	3.72	307.33	4.35	342.65	4.85
9	PPCY4	0	1	272.00	3.85	312.98	4.43	347.59	4.93
10	HY1	0.25	0.25	302.38	4.28	337.71	4.78	373.03	5.28
11	HY2	0.25	0.5	289.66	4.10	325.70	4.61	361.02	5.11
12	HY3	0.5	0.25	303.80	4.30	339.12	4.80	375.15	5.31
13	HY4	0.5	0.5	317.92	4.50	358.90	5.08	394.23	5.58
14	HY5	0.75	0.25	353.25	5.29	409.06	5.79	445.80	6.31
15	HY6	0.25	0.75	275.53	3.90	312.27	4.42	347.59	4.92

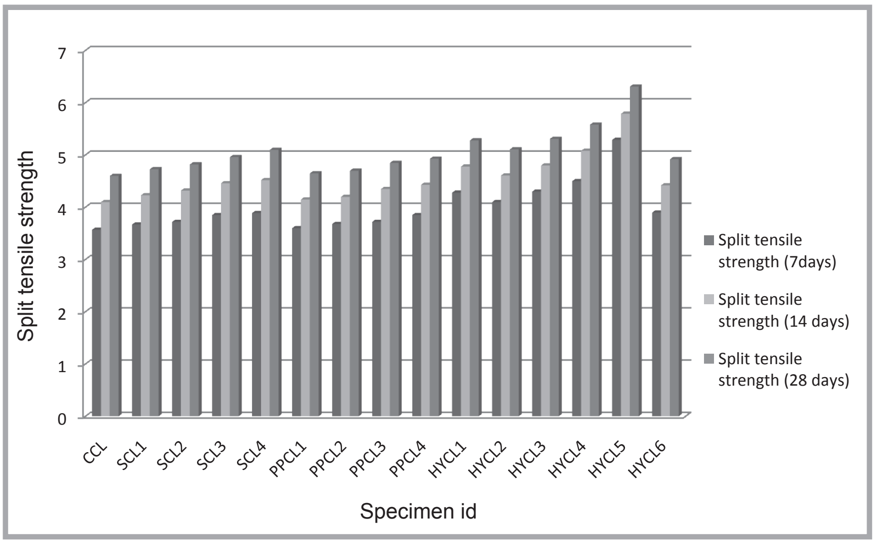

Figure 5. *Split tensile strength of control and fibre added concrete cylinders.*

Table 9. *Mean, standard deviation and coefficient of variation for concrete with and without fibres added.*

Specimen ID	Split tensile strength x	$(x - \bar{x})^2$
CC	4.60	0.20
SCY1	4.73	0.10
SCY2	4.82	0.05
SCY3	4.96	0.008
SCY4	5.10	0.025
PPCY1	4.65	0.16
PPCY2	4.70	0.12
PPCY3	4.85	0.20
PPCY4	4.93	0.014
HY1	5.28	0.052
HY2	5.11	0.003
HY3	5.31	0.06
HY4	5.58	0.28
HY5	6.31	1.58
HY6	4.92	0.016
	$\bar{x}$ = 5.05	2.89

Table 10. *Flexural test values at 28 days.*

So. No	Initial crack, kN	Deflection, mm	Load, kN	Deflection, mm
CB	12	1.25	30	2.1
SB1	23	1.05	46	3.5
SB2	20	1.15	48	3.2
SB3	18	1.25	49	3.4
SB4	21	1.20	45	2.1
PPB1	10.5	1.40	38	3.5
PPB2	13.5	1.15	43	2.30
PPB3	12	1.20	40	2.60
PPB4	25	1.05	45	2.80
HYB1	18	1.00	47	2.5
HYB2	10	0.8	45.5	2.4
HYB3	17	1.00	46	2.1
HYB4	21	1.15	52	3.5
HYB5	17	0.95	43	2.80
HYB6	18	0.80	51	3

polypropylene mixed specimens PPC_1, PPC_2, PPC_3 and PPC_4 it is 16.36, 16.78, 17.33 and 17.69 N/mm^2, and for those with mixed fibres of steel and polypropylene HY_1 HY_2, HY_3, HY_4, HY_5 and H_6 it is 21.62, 19.66, 24.58, 22.82, 26.56 and 20.86, respectively.

The compressive strength (7 days) of the control cubes is 16.22 N/mm^2, the average compressive strength of SS_1 to SS_4 – 17.10 /mm^2, the average compressive strength of PP_1 to PP_4 – 17.04 N/mm^2, and the average compressive strength of HY_1 to HY_6 is 22.68 N/mm^2.The combination of an average of three fibres is 5.14, 4.81 and 28.48%, respectively, which it is greater compared to the control cubes.

Another fifteen cube specimens were cast and cured for 14 days, three control cubes, denoted as CC, and the remaining fourteen as SC_1, SC_2, SC_3, and SC_4 were mixed with different ratios of steel fibre. The compressive strength of 14 day's cured specimens without steel fibre mixed in is 21.87, 22.46, 23.08 and 23.55 N/mm^2 for SC_1, SC_2, SC_3, and SC_4; similarly for polypropylene mixed specimens PPC_1, PPC_2, PPC_3 and PPC4 it is 21.76, 22.32, 23.05 and 27.67 N/mm^2, and for specimens with mixed fibres of steel and polypropylene HY_1, HY_2, HY_3, HY_4, HY_5 and HY6 it is 28.75, 26.15, 32.69, 30.35, 35.32 and 27.74, respectively.

The compressive strength (14 days) of the control cubes is 21.57 N/mm^2 the average compressive strength of SS_1 to SS_4 – 22.74 N/mm^2, that of PP_1 to PP_4 – 23.68 N/mm^2, and that of HY_1 to HY_6 is 28.48 N/mm^2. The combination of an average of three fibres is 5.14, 8.9 and 28.48%, respectively, which is greater compared to the control cubes.

The remaining fourteen cube specimens cast and cured for 28 days, three control cubes, denoted as CC, and the remaining fourteen as SC_1, SC_2, SC_3, and SC_4 were mixed with different ratios of steel fibre. The compressive strength of 28 day's cured specimens without steel fibre mixed in SC_1, SC_2, SC_3, and SC_4 is 32.88, 33.78, 34.72 and 35.42 N/mm^2; similarly for polypropylene mixed specimens PPC_1, PPC_2, PPC_3 and PPC_4 it is 32.72, 33.56, 34.66 and 35.38 N/mm^2, and for specimens with mixed fibres of steel and polypropylene HY_1, HY_2, HY_3, HY_4, HY_5 and H6 it is 41.72, 39.32, 43.32, 42.23, 45.64 and 40.62, respectively. The compressive strength of controlled and fibre added concrete cubes is shown in ***Figure 4***.

The average compressive strength (28 days) of the control cube is 32.2 N/mm^2, the average compressive strength of SC_1 to SC_4 – 34.08 N/mm^2, that of PC_1 to PC_4 – 42.14 N/mm^2, and that of HY_1 to HY_6 is 5.41 N/mm^2. The combination of an average of three fibres is 5.14, 4.81 and 23.01%, respectively, which is greater compared to the control cubes. ***Table 7*** shows the mean, standard deviation and coefficient of variation for concrete with and without fibres added for compression test.

Mean strength = $\frac{\sum x}{n} = \frac{\sum 558.3}{15}$ = 37.22

Standard deviation $\sigma = \sqrt{\frac{(x-\bar{x})^2}{n-1}} = \sqrt{\frac{275.95}{14}}$ = 4.43

Standard deviation σ = 4.43

The arithmetic mean or the average value of the number of test results gives no indication of the extent of the variation in strength. However, this can be ascertained by relating the individual strength to the mean strength and determining the variation from the mean with the help of the properties of the normal distribution curve, with the standard deviation increasing with increasing variability. ***Table 5*** illustrates the values.

The result of the mean strength is 37.22 N/mm^2, the standard deviation 4.43 MPa and the coefficient of variation is 0.11 % for the cube specimen with and without fibres added.

Split tensile test results

The split tensile test values at 7.14 and 28 days for cylinder specimen are given in ***Table 8.***

Mean strength = $\frac{\sum x}{n} = \frac{\sum 75.75}{15}$ = 5.05

Standard deviation $\sigma = \sqrt{\frac{(x-\bar{x})^2}{n-1}} = \sqrt{\frac{2.89}{14}}$ = 0.45

Standard deviation σ = 0.45

The result of the mean strength is 5.05 N/mm^2, standard deviation 0.45 MPa and coefficient of variation – 0.08 % for a cube specimen with and without fibres added. ***Table 9*** shows the mean, standard deviation and coefficient of variation values for concrete with and without fibres added for split tensile test.

A total of forty five cylinders were cast and cured for 7, 14 and 28 days three as control cylinders, denoted as CC, and the remaining forty two as SCY_1, SCY_2, SCY_3 & SCY_4 for steel fibre reinforced concrete, PCY_1, PCY_2, PCY_3 & PCY_4 for polypropylene fibre reinforced concrete and the remaining fifteen HY_1, HY_2, HY_3, HY_4, HY_5 & HY_6 for a combination of steel and polypropylene.

Fifteen cylindrical specimens were cast and cured for 7 days, one as a control cylinder, denoted as CCY, with the remaining fourteen as SCY_1, SCY_2, SCY_3, and SCY_4 mixed with different ratios of steel fibre. The split tensile strength of the 7 day's cured specimens without steel fibre mixed in SCY_1, SCY_2, SCY_3 and SCY_4 , the split tensile strength value is 3.65, 3.72, 3.85 and 3.89 N/mm^2; similarly for the polypropylene mixed specimens PCY_1, PCY_2, PCY_3 and PCY_4 it is 3.60, 3.68, 3.72 and 3.85 N/mm^2, and for specimens with mixed fibres of steel and polypropylene HY_1, HY_2, HY_3, HY_4, HY_5 and HY_6 it is 4.28, 4.10, 4.30, 4.50, 5.29 and 3.90, respectively.

The split tensile strength (7 days) of the control cylinder is 3.57 N/mm^2, the average split tensile strength of SS_1 to SS_4 – 3.77 N/mm^2, that of PP_1 to PP_4 – 3.71 N/mm^2 , and that of HY_1 to HY_6 is 4.39 N/mm^2. The combination of an average of three fibres is 5.30, 3.77 and 18.67%, respectively, which is greater compared to the control cylinders.

Another fifteen cylindrical specimens were cast and cured for 14 days, three control cylinders, denoted as CC, and the remaining fourteen as SCY_1, SCY_2, SCY_3, and SCY_4 were mixed with different ratios of steel fibre. The split tensile strength of 14 day's cured specimens without steel fibre mixed in SCY_1, SCY_2, SCY_3 and SCY_4 is is 4.23, 4.32, 4.46 and 4.52 N/mm^2; similarly for polypropylene mixed specimens PCY_1, PCY_2, PCY_3 and PCY_4 it is 4.15, 4.20, 4.35 and 4.43 N/mm^2, and for specimens with mixed fibres of steel and polypropylene HY_1, HY_2, HY_3, HY_4, HY_5 and HY_6 it is 4.78, 4.61, 4.80, 5.08, 5.79 and 4.42, respectively.

The split tensile strength (14 days) of the control cylinder is 4.10 N/mm^2, the average split tensile strength of SS_1 to SS_4 – 4.38 N/mm^2, that of PP_1 to PP_4 – 4.28 N/mm^2 , and that of HY_1 to HY_6 is 4.91 N/mm^2.The combination of an average of three fibres is 6.39, 4.2 and 16.5%, respectively, which it is greater compared to the control cylinders.

The remaining fourteen cylindrical specimens cast and cured for 28 days, three control cylinders denoted as CC, with the remaining fourteen, denoted as SCY_1, SCY_2, SCY_3 and SCY_4, being mixed with different ratios of steel fibre. The split tensile strength of the 28 day's cured specimens without steel fibre mixed in SCY_1, SCY_2, SCY_3 and SCY_4, the split tensile strength value is 4.73, 4.82, 4.96 and 5.10 N/mm^2; similarly for polypropylene mixed specimens PCY_1, PCY_2, PCY_3 and PCY_4 it is 4.65, 4.70, 4.85 and 4.93 N/mm^2, and for specimens with mixed fibres of steel and polypropylene HY_1, HY_2, HY_3, HY_4, HY_5 and HY_6 it is 5.28, 5.11, 5.31, 5.58, 6.31 and 4.92, respectively.

The average split tensile strength (28 days) of the control cylinder is 4.60 N/mm^2 that of SS_1 to SS_4 – 4.90 N/mm^2, that of PP_1 to PP_4 – 4.78 N/mm^2, and that of HY_1 to HY_6 is 5.41 N/mm^2. A combination of an average of three fibres is 6.12, 3.76 and 15.12 %, respectively, which is greater compared to the control cylinders.

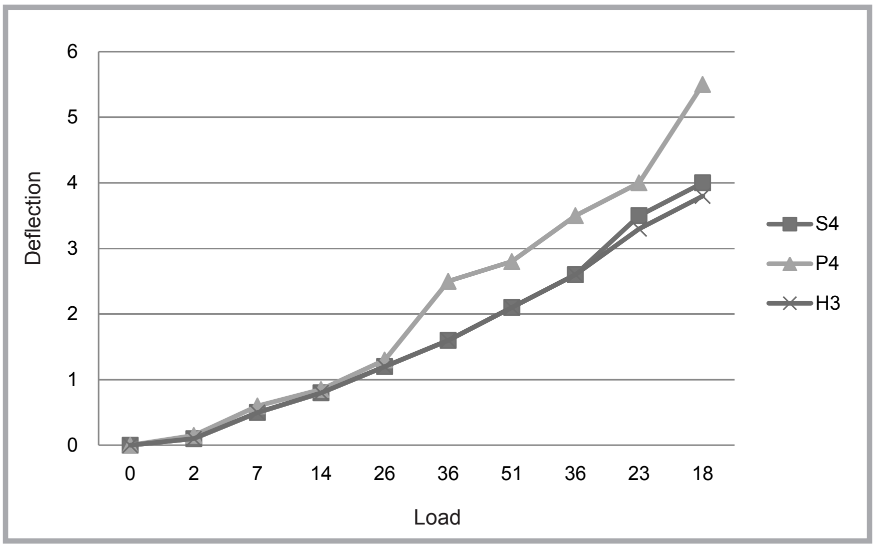

Figure 6. *Load vs deflection in control and fibre added concrete beam.*

Flexural test results

The flexural test values at 28 days for beams are presented in ***Table 10***.

Deflection and an initial crack were noticed in the course of the investigation. The first crack emerged in the control beam CB at 12 kN, with flexural cracks appearing along it. It was clear that the beam's breakdown in flexure had minimal energy assimilation well before the breakdown. The average ultimate load of the control beam is 30 kN. Similarly the initial crack for the steel fibre reinforced concrete beam, the polypropylene fibre

RC beam and hybrid fibre RC beam is 23, 20, 18, 21, 10.5, 13.5, 12, 25, 18, 10, 17, 21, 17 and 18, respectively, and finally for those beams it was 46, 48, 49, 45, 38, 43, 40, 45, 47, 45.5, 46, 52, 43 and 51 m respectively. Details are presented in ***Table 10***.

The crack model comprised a sheer flexural crack. When the load is changed, the deflection decreased in the end as compared to the control beams, and the flexural strength is found to go up. In the control specimen (CB), where the initial crack load is 12 kN, the deflection rises when the load is increased to 30 kN. In the case of various specimens for the ultimate load, the deflection is assessed. The flexural strength is found to change in all specimens according to the initial crack load and ultimate load. The load vs deflection in controlled and fibre added beam is shown in ***Figure 6***.

At the maximum prescribed load, the deflection was decreased for different ratios of fibre present in the reinforced concrete beam. CB is 2.1, SSB_1 to SSB_4 – 3.5, 3.2, 3.4 and 2.1. PPB_1 to PPB_4 – 3.5, 2.3, 2.6 and 2.80, and HYB_1 to HYB_6 were found to have 2.4, 2.1, 3.5, 2.80, and 3 deflection for the control beams, respectively. With fibre added in the reinforced concrete beam, the strength and stiffness increase, while deflection and cracks in the beam decrease.

Flexural strength analysis for the different specimens and the control specimens showed that the average flexural strength is 8.8 N/mm^2, as compared to the steel fibre RC beam, which is 13.91 N/mm^2, increasing by 36.73%; for the polypropylene fibre RC beam it is 12.29 N/mm^2, increasing by 28.39%, and for the hybrid fibre RC beam it is 14.04 N/mm^2, increasing by 37.32%. Moreover the flexural strength result of the retrofitted beam is higher than for the control beam.

Conslusions

The steel fibres (crimped) and polypropylene fibres used together in this project showed considerable improvement in all the properties of concrete when compared to conventional concrete, such as

- The average compressive strength (28 days) of the control cubes is 32.44 N/mm^2, compared to a strength increase of 4.3 N/mm^2, a percentage rise of 11.8%, for wrapped specimens.
- The compressive strength (28 days) of SS is increased by 5.14%, PP by 4.8% and HY (SS+PP) by 23% when compared to the average compressive strength of the control cubes.
- The average split tensile strength (28 days) of the control cubes is 4.60 N/mm^2, as compared to the strength increase of 0.43 N/mm^2, a rise of 8.7%, for wrapped specimens.
- The split tensile strength (28 days) of SS is increased by 6.12%, PP by 3.7% and HY (SS+PP) by 33.4 % when compared to the average split tensile strength of the control cylinders.
- Flexural strength (modulus of rupture) is increased by 25.85% for 1% (0.75% of steel and 0.25% of polypropylene) of the total volume of concrete.
- The hybrid fibres produce good mechanical properties compared to the mono fibres.
- As the percentage of polypropylene increases in the hybrid fibre, the strength decreases fibre.
- When the percentage of fibre in the concrete increases, the deflection and cracks decrease.

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