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Mechanical Properties of Hybrid Fiber Reinforced Concrete

Anithu Dev[1], Dr. Sabeena M.V[2]

[1] P.G. Student, Department of Civil Engineering, AWH Engineering College, Kozhikode, Kerala, India
[2] Professor and Head, Department of Civil Engineering, AWH Engineering College, Kozhikode, Kerala, India

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Abstract - *Engineering properties such as compressive strength, splitting tensile strength, modulus of rupture, modulus of elasticity of normal concrete (NC), steel fibre reinforced concrete (SFRC) and hybrid fiber reinforced concrete have been obtained from standard tests and compared. A total of 36 specimens were tested for determining the mechanical properties. The grade of concrete used was M25. The total volume of fibers was fixed as 0.5% of total volume of concrete. Six concrete mixes were selected for study. Which include control mix without fibers, steel fiber reinforced concrete (SFRC) with 0.5% steel fibers and four hybrid fiber reinforced (HFRC) concrete of steel and polyester fibers with total volume fraction as 0.5%. In general, the addition of fibres improved the mechanical properties. However the increase was found to be nominal in the case of compressive strength (8.51%), significant in the case of splitting tensile strength (61.63%), modulus of rupture (24%), modulus of elasticity (64.92%) at 0.35% steel fibers and 0.15% polyester fibers. An attempt was made to obtain the relation between the various engineering properties with the percentage of fibers added.*

Key Words: Hybrid fiber reinforced concrete, Polyester fiber, Mechanical properties, Steel fibers

1. INTRODUCTION

Concrete is the most widely used man made construction material in the world. The properties of concrete have variation in tension and compression. Concrete is strong in compression but very weak in tension. It is very brittle in nature. Internal micro cracks are inherently present in concrete and its weak tensile strength is due to the propagation of such micro cracks. Hence, the use of normal concrete as a structural material is limited to situation where significant tensile stresses and stain do not develop. The failure of concrete structures will be sudden, which are subjected to earthquake, blast or suddenly applied loads. Plain, unreinforced concrete is a brittle material, with low tensile strength and a low strain capacity.[1]

The concept of using fibers as reinforcement is not new. Fibers have been used as reinforcement since ancient times. Historically, horsehair was used in mortar and straw in mud bricks. In the early 1900s, asbestos fibers were used in concrete. By the 1960s, steel, glass, and synthetic fibers such as polypropylene fibers were used in concrete and research in to new fiber reinforced concretes continues today. Fiber Reinforced Concrete is type of concrete containing fibrous material which increases many of its engineering properties. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers. Each of which lend varying properties to the concrete. Fibers having lower modulus of elasticity are expected to enhance strain performance whereas fibers having higher modulus of elasticity are expected to enhance the strength performance. The randomly oriented steel fibres in concrete arrest microcracking mechanism of cracks and limit crack propagation, thus improving strength and ductility. Steel fibres increases elastic modulus, decreases brittleness, controls crack initiation, and its subsequent growth and propagation (2).

Hybrid Fiber Reinforced Concrete (HFRC) is a combination of different types of fibers, which differ in material properties, remain bonded together when added in concrete and retain their identities and properties. In HFRC, two or more different types of fibers are rationally combined to produce a composite that derives benefits from each of the individual fibers and exhibits a synergistic response. [3] The hybrid combination of metallic and non-metallic fibers can offer potential advantages in improving the properties of concrete. The use of different types of fiber in a suitable combination may potentially improve the mechanical properties of concrete and result in synergic performance. Recently studies have been carrying out in the area of hybrid fibers but hybridization with steel and polyester fibers are limited. Hence this area is focused in this study.

2. METHODOLOGY

- Materials required for the experiments were procured and their properties were found as per IS codes.
- Mix design of M25 grade concrete was done as per IS 10262-2009.
- Specimens for determining mechanical properties with control, 0.5% SFRC and hybrid (steel and polyester) fiber reinforced concrete mix were prepared.
- Optimum combination of fibers contents were obtained from compressive strength , split tensile strength, flexural strength and modulus of elasticity of concrete.
- Obtain the relation between the various engineering properties with the percentage of fibers added.

3. EXPERIMENTAL PROGRAMME

The experimentation involves the comparative study of effect of steel fibers and hybrid (steel and polyester fibers) on compressive, split tensile, flexural strength and modulus of elasticity of M25 grade concrete at 28 days of curing. Six mixes were selected for the study. Which include control mix without fibers, steel fiber reinforced concrete (SFRC) with 0.5% steel fibers and four hybrid fiber reinforced (HFRC) concrete of steel and polyester fibers with total volume fraction as 0.5%. Designation of mixes is shown in Table-1.

Table -1: Mix designation

Sl. No.	Designation	Steel Fiber (%)	Recron3S Fiber (%)
1	NC	0	0
2	SFRC	100	0
3	HFRC 1	90	10
4	HFRC 2	80	20
5	HFRC 3	70	30
6	HFRC 4	60	40

3.1 Materials and Mix Proportion

Ordinary Portland cement (OPC) conforming to IS: 12269:2013 [8], M sand with a specific gravity of 2.47 conforming to Grading Zone II of IS 383: 1970 (reaffirmed 2011) [9], and coarse aggregate having a maximum size of 20 mm with a specific gravity of 2.74 were used for the investigation. Hooked End Steel fibres and Recron 3S polyester fibres used for this study are shown in Fig-1(a) and Fig-1(b), and their properties are given in Table-2. In this study as per IS: 9103-1999 (reaffirmed 2013) [10] Conplast SP430 with specific gravity 1.22 was used as super plasticizer to obtain required workability.

(a) (b)

Fig-1 Fibres used, (a) Hooked End Steel fibres (b) Recron 3S polyester fibres

Mix designs for M25 grade concrete was done as per IS 10262:2009(reaffirmed 2014) [11]. After five trials final mix proportion was found out. The same mixture proportions were used for all the specimens. The addition of fibers reduced the workability of concrete and the dosages of super plasticizer were adjusted to maintain the workability. The mix proportion details are given in Table-2.

Table-2: Mix proportion

Materials	Quantity (kg/m^3)
Cement	383
Fine aggregate	737
Coarse aggregate	1113
Water	172
Super plasticizer	3.83

3.2 Casting of Specimens

For the preparation of test specimens, cement, M-sand, coarse aggregate admixture and water were used. Firstly mixing of dry materials was done in a drum type mixer. Super plasticizer was mixed with water and was then added to the dry materials. The required quantities of steel and polyester fibers were taken according to the volume fraction and these fibers were added during mixing. Workability of fresh concrete was checked using a standard slump cone. The freshly mixed concrete was poured layer by layer, into standard cubes of size 150mm for compressive strength test, 150 × 300 mm cylinders for splitting tensile test and modulus of elasticity and into 100 × 100 × 500 mm prisms for finding modulus of rupture. Total number of layers was three. Each layer was compacted by giving 35 strokes per layer with standard tamping bar. The top surface was levelled using a smooth trowel after compaction. For each mix cubes, cylinders and prism were caste. Each specimen was tested after 28 days of curing period.

3.3 Test Methods

The compressive strength tests were carried on concrete cubes as per IS 516:1959 (reaffirmed 2013)[13]. The cubes were loaded in the Compression testing machine of 1000kN capacity until failure. The splitting tensile tests, were carried on cylinders in accordance with IS 5816: 1999 (reaffirmed 2013)[14] and was split along its length in the Universal testing machine of 600kN capacity. For finding the modulus of rupture, two point loading tests were conducted on prisms as per IS 516:1959 (reaffirmed 2013). In this investigation, for finding the modulus of elasticity, testing was carried out on cylinders as per IS: 516-1959 (reaffirmed 2013).

4. RESULTS AND DISCUSSIONS

4.1 Fresh Concrete Properties

Here slump test were carried out for finding the workability of concrete for each mix. Slump values obtained for different mixes are shown in Table-3. The workability of concrete was decreased while adding fibers and hence Conplast SP430 was used as a super plasticizer for maintaining workability.

Table -3: Slump values of different mixes

Mix designation	Slump value (mm)	Slump designation
NC	76	True slump
SFRC	68	True slump
HFRC1	70	True slump
HFRC2	71	True slump
HFRC3	72	True slump
HFRC4	70	True slump

From the Table it is clear that the addition of fibers decreases the workability. Among all the six mixes the slump value for 0.5% SFRC is obtained as the minimum. On hybridizing by replacing the steel fibers with polyester fiber there will be an increase in workability were observed. However for HFRC4 (0.3% steel +0.2% polyester) a little decrease in slump value was observed. This may be due to the balling effect of fibers at higher volume fractions.

4.2 Compressive Strength

Table-4 gives the average values of test results of compressive strength. From the Table it can be noted that all the fiber reinforced concrete shows improvement in the compressive strength. 0.5% SFRC shows the maximum increase and is about 11.19% of NC. There are no significant changes in compressive strength of all HFRC mixes in comparison with SFRC.

Table-4: Compressive strength of concrete

Mix designation	Compressive strength (N/mm^2)	Percentage increase
NC	29.78	-
SFRC	33.11	11.19
HFRC1	32.22	8.21
HFRC2	32.11	7.83
HFRC3	32.44	8.96
HFRC4	32.67	9.70

4.3 Splitting Tensile Strength

Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. The test results are given in Table-5.

Table-5: Splitting tensile strength of concrete

Mix designation	Split tensile strength (N/mm^2)	Percentage increase
NC	2.18	-
SFRC	3.44	57.95
HFRC1	3.26	49.35
HFRC2	3.33	52.60
HFRC3	3.55	62.99
HFRC4	3.41	56.49

It is clear from the Table that addition of fibers has a significant effect on split tensile strength. HFRC3 gives the maximum value of split tensile strength and which is more than that of SFRC. An attempt is made to relate the split tensile strength with a parameter which influenced the strength of FRC. For SFRC and HFRC, improvement in strength is dependent on volume fraction V_f and resistance offered by the fibers to the crack formation and propagation. Shape and aspect ratio also influence the pull out strength. Hence a fiber factor (F), which consists of, the above mentioned parameters were introduced and is given as,

$$F=[(I_f/d_f)V_f]_{steel} + [(I_f/d_f)V_f]_{polyester}$$

The relation between split tensile strength (f_{ct})and $F\sqrt{f_c}$ were plotted as shown in Chart-1 and the regression equation thus obtained is,

$$f_{ct}= -0.119(F\sqrt{f_c})^2+ 0.772\ F\sqrt{f_c}+2.281$$

where f_{ct} and f_c are in N/mm^2

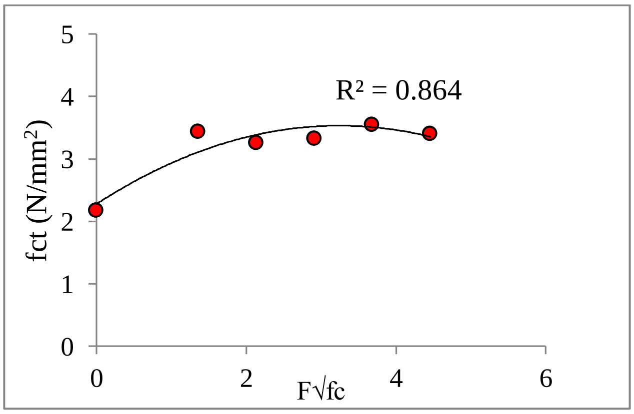

Chart-1: Relationship between f_{ct} and $F\sqrt{fc}$

4.4 Modulus of Rupture

Flexural strength is also known as modulus of rupture is a material property, defined as the stress in a material just before it yields in flexure test. The transverse bending test is most frequently employed, in which a specimen is having either a circular or a rectangular cross-section is bend until fracture using a two point load test technique.

The test results are given in Table- 6. From the Table it can be noted that steel and polyester fibers has a significant role in improving the flexural strength of concrete. All the hybrid fiber combination shows improvement in flexural strength than that of mono fiber reinforced concrete (SFRC). However, a reduction in strength at 0.2% of polyester fiber content (HFRC4) has been found. This may be due to the balling effect of fiber at higher fiber contents.

Table-6: Modulus of rupture of concrete

Mix designation	Flexural strength (N/mm^2)	Percentage increase
NC	4.64	-
SFRC	5.68	22.41
HFRC1	5.88	26.72
HFRC2	6.00	29.31
HFRC3	6.30	34.48
HFRC4	6.04	30.17

An attempt is made to relate the modulus of repture (f_{cr})and F√f and were plotted as shown in Chart-2 and the regression equation thus obtained is,

$$f_{cr} = -0.117(F\sqrt{f_c})^2 + 0.843\, F\sqrt{f_c} + 4.66$$

where f_{cr} and f_c are in N/mm^2

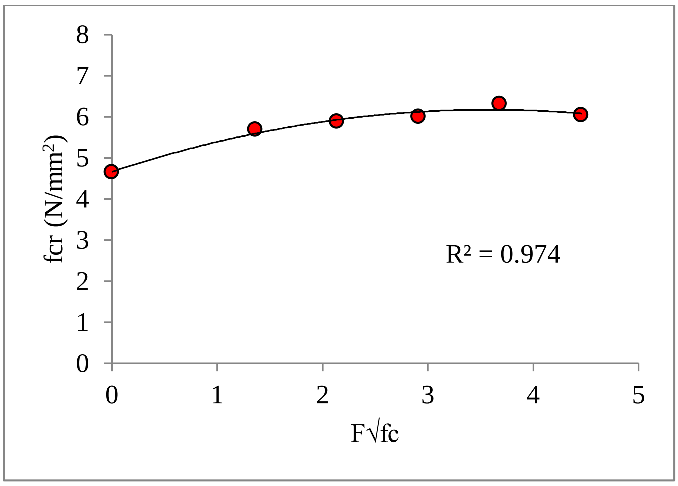

Chart-2: Relationship between f_{cr} and F√fc

4.5 Modulus of Elasticity

The modulus of elasticity of concrete would be the property for the case when the material is treated as elastic. In the laboratory determination of the modulus of elasticity of the concrete, a cylinder is loaded and unloaded (stress not exceeding one third of f_{ck}) for three or four cycles, the stress strain curve is plotted after the residual strain has become almost negligible and the average slope of the stress strain curve is taken and is known as static modulus of elasticity by drawing the trend line. Here an extensometer is used for the determination of modulus of elasticity. The values of modulus of elasticity are tabulated in Table-7.

Table-7: Modulus of elasticity of concrete

Mix designation	Modulus of elasticity (N/mm^2)	Percentage increase
NC	19249.82	-
SFRC	24062.28	25.00
HFRC1	23779.19	23.53
HFRC2	23779.19	23.53
HFRC3	24534.09	27.45
HFRC4	22646.85	17.65

All the fiber reinforced concrete shows significant improvements in Modulus of elasticity. The Modulus of elasticity values was found to be nearly equal for SRFC and HFRC3. The maximum increase is about 27.45% for HFRC3 with 0.3% steel and 0.15% polyester fibers. An attempt was made to obtain a relation between compressive strength f_C and modulus of elasticity E_C of HFRC using the fiber factor. For this, a graph was plotted between E_C and F√f_C as shown in Chart-3.

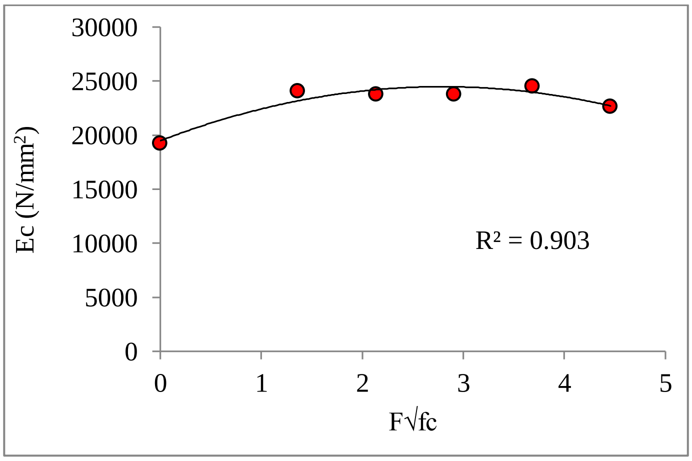

Chart-3: Relationship between E_C and F√fc

Regression equation obtained for the plot is given below.

$$E_c = -641.0(F\sqrt{f_c})^2 + 3580\, F\sqrt{f_c} + 19490$$

where E_c and f_c are in N/mm^2

4. CONCLUSIONS

Based on the investigation of the mechanical properties of mono and hybrid fiber reinforced concrete, following conclusions were arrived at.

1. The addition of fibers decreases the workability. Among all the six mixes the slump value for 0.5% SFRC is obtained as the minimum.

2. On hybridizing by replacing the steel fibers with polyester fiber there will be an increase in workability was observed but at higher polyester volume fractions workability decreases.

3. Maximum compressive strength is obtained for SFRC with 0.5% steel fibers with 11.19% increase than NC. The variation of compressive strength among HFRC was marginal.

4. The addition of fibers has a significant effect on split tensile strength. HFRC3 (0.35% steel and 0.15% polyester) gives the maximum value of split tensile strength and which is more than that of SFRC by 3.2%.

5. Addition of fibers play fibers plays a significant role in improving the flexural strength of concrete. For SFRC with 0.5% steel fibers the modulus of rupture increased about 22.41%. For all HFRC mixes the modulus of rupture increased with respect to SFRC. Maximum value is obtained for HFRC3 and there is 34.48% increase than NC.

6. The modulus of elasticity for NC is obtained as 19249.82 N/mm^2. A significant increase is observed for all FRC mixes. The maximum value is obtained for HFRC3 i.e. 24534.09 N/mm^2.

7. The strength models developed for HFRC predicts the splitting tensile strength, modulus of rupture and modulus of elasticity satisfactorily.

NOTATIONS

E_c	modulus of elasticity o f concrete
f_c	28 days compressive strength
f_{cr}	flexural strength of concrete
f_{ct}	split tensile strength of concrete

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