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Flexural Performance of Fibre Reinforced Concrete with Polyolefin - Steel Hybrid Fibres

Natarajan.N , Deepan.S

***Abstract*—** This paper presents the results on the strength and ductility of hybrid fibre reinforced concrete (HFRC). A total of 30 concrete specimens were tested to study the effect of hybrid fibre reinforcement on the strength and ductility of fibre reinforced concrete. The fibre content dosage V_f ranged from 0.0 to 2.0%. Steel and Polyolefin fibres were combined in different proportions and their impact on strength and ductility studied. Addition of 2.0% by volume of hybrid fibres increases the above study parameters was about 72.52%, 98.0% and 83.0% respectively, when compared to the plain concrete. Empirical expressions for predicting the strength property of hybrid fibre reinforced concrete (HFRC) is proposed based on regression analysis.

***Keywords*—** Compressive strength; Ductility; Hybrid fibre reinforced concrete; Modulus of rupture; Polyolefin fibre; Steel fibre.

I. INTRODUCTION

Concrete is a relatively brittle material. Addition of fibres to concrete makes it more homogeneous and isotropic and transforms it from a brittle to a more ductile material[1-3]. The function of short-cut fibres as secondary reinforcement in concrete is mainly to inhibit crack initiation and propagation[4]. The basic purpose of using hybrid fibres is to control cracks at different size levels, in different zones of concrete (cement paste or interface zone between paste and aggregate) and at different loading stages. The large and strong fibres control large cracks. The small and soft fibres control crack initiation and propagation of small cracks[5-6]. This research work focuses on the polyolefin-steel hybrid fibres reinforced system. It has been shown recently that the hybrid composite can offer more attractive engineering properties because the presence of one fibre enables more efficient utilization of the potential properties of the other fibre[7-8]. However, the hybrid composites studied by previous researchers were focused on cement paste or mortar. Information available pertaining to the strength and ductility properties of hybrid fibre reinforced concrete is found to be limited. Hence an attempt has been made to study the strength and ductility properties of hybrid fibre reinforced concrete. A total of 30 specimens were cast and tested to determine the impact of hybrid fibres on the strength and ductility of fibre reinforced concrete (FRC).

An important role in modern requirements of construction works. Due to modernization, demolished materials are dumped on land & not used for any purpose. Such situations affect the fertility of land. Out of the total construction demolition waste, 40% is of concrete , 30% ceramic's, 5% plastics, 10% wood, 5%metal, & 10% other mixtures. For production of concrete, 70-75% aggregates are required. Out of this 60-67% is of coarse aggregate & 33-40% is of fine aggregate.

From environmental point of view, for production of natural aggregates of 1 ton, emissions of 0.0046 million ton of carbon exist where as for 1ton recycled aggregate produced only 0.0024 million ton carbon is produced. Considering the global consumption of 10 billion tons/year of aggregate for concrete production, the carbon footprint can be determined for the natural aggregate as well as for the recycled aggregate. The use of recycled aggregate generally increases the drying shrinkage creep & porosity to water & decreases the compression strength of concrete compared to that of natural aggregate concrete. It is nearly 10-30% as per replacement of aggregate. Recycling reduces the cost (LCC) by about 34-41% & CO2 emission (LCCO2) by about 23-28% for dumping at public / private disposal facilities.

A. Advantages of recycling of construction materials

- Used for construction of precast & cast in situ gutters & kerb's.
- Cost saving: - There are no detrimental effects on concrete & it is expected that the increase in the cost of cement could be offset by the lower cost of Recycled Concrete Aggregate (RCA).
- Save environment: - There is no excavation of natural resources & less transportation. Also less land is required.
- Save time: -There is no waiting for material availability.
- Less emission of carbon due to less crushing.

B. Limitations or disadvantages of recycling of construction material

- Less quality (e.g. compressive strength reduces by 10-30%).
- Duration of procurement of materials may affect life cycle of project.
- Land, special equipments machineries are required (more cost).
- Very high water absorption (up to 6%).
- It has higher drying shrinkage & creep.

Natarajan.N , Student Mahendra Engineering college, thiruchancode, Tamilnadu (phone: 9047751624; e-mail: natarajannh@gmail.com).
S.Deepan, Assistant Professor, Mahendra Engineering college, thiruchancode , Tamilnadu .

II. MATERIAL PROPERTIES

Materials used for making concrete in this study include natural and recycled materials. Concrete is made of three basic components water, aggregate and Portland cement, where coarse aggregate are embedded in a matrix form and bounded together with cement or binder which fills the space between the particle and glues them together. Natural aggregate are obtained from natural rock. They are inert filter material and depending upon their size they are separated into fine and coarse aggregate. Recycled aggregate were obtained from demolished concrete waste from multi storied building about 35-40 years old. The demolished concrete blocks were manually crushed into the required size and grading was done according to IS Code.

A. Cement

Grade 53 Ordinary Portland Cement conferming to IS 12269-1987[3] was used in this study. The brand of cement used was Dalmia superroof cement. The cement has been tested for various properties and the result obtained satisfy the IS specification. The physical properties of cement are shown in Table I

Table 1 - Physical properties of Fibre

Fibre Properties	Fibre details	
	Polyolefin	Steel
Length (mm)	48	30
Size/Diameter (mm)	1.22×0.732 mm	0.5 mm
Aspect Ratio	39.34	60
Density (kg/m^3)	920	7850
Specific Gravity	0.90-0.92	-
Young's Modulus (GPa)	6	210
Tensile strength (MPa)	550	532

B. The fine aggregate used in this experimental investigation was manufactured sand (M-sand) confirming to zone II.

- *Specific gravity*

The specific gravity of fine aggregate is found by using pycnometer and was done according to IS 2386(Part 3)-1963[4]. The specific gravity of natural fine aggregate was obtained as 2.68.

Specific gravity (Trial 1) = 2.77
Specific gravity (Trial 2) = 2.60
Average value of specific gravity for natural fine aggregate = 2.68

- *Water absorption*

Water absorption is defined as the percentage of water absorbed by an aggregate when immersed in water. Water absorption was calculated according to IS 2386(Part 3)-1963[4]. The water absorption of natural fine aggregate was obtained as 13.89%.

- *Sieve analysis*

Sieve analysis of aggregate is done in order to find out the particle size distribution of the aggregate and according to it the grading of aggregates can be done. According to sieve analysis fineness modulus is found out and it is a ready index of coarseness or fineness of the material. The test was conducted according to IS 2386(Part 1)-1963[4]. The results obtained from sieve analysis are shown in Table

Table 2 - Sieve analysis of natural fine aggregate

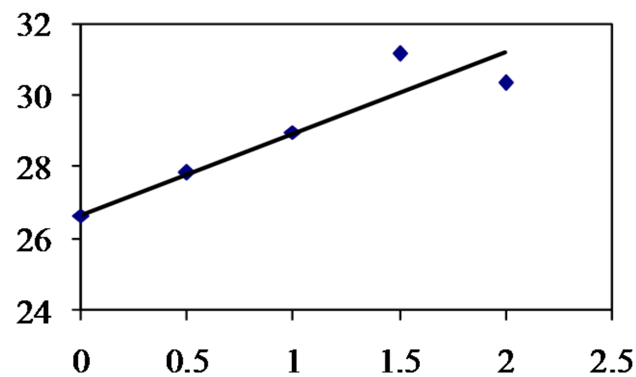


Fig .1 Particle size distribution graph for natural fine aggregate

C. Natural Coarse Aggregate

Crushed granite aggregates particles passing through 12mm and retained on 4.75mm I.S sieve was used as natural coarse aggregates. Coarse aggregate contributes significantly to the structural performance of concrete, especially strength, durability and volume stability. It occupies more than 70 % of the volume of concrete.

- *Specific gravity*

The test was conducted as per IS: 2386 (part III)-1963[3], and the value of specific gravity of natural coarse aggregate is 2.688. According to M.S Shetty [5] in Concrete Technology, the average specific gravity of rock varies from 2.6-2.8.

Specific gravity (Trial 1) = 2.688
Specific gravity (Trial 2) = 2.688
Average value of specific gravity for natural coarse aggregate = 2.688

- *Water absorption*

Water absorption is defined as the percentage of water absorbed by an aggregate when immersed in water. The water absorption of the natural coarse aggregates is found according to IS: 2386 (Part 3) – 1963 [4].

Water absorption of 12 mm aggregate = 1.95%

Water absorption of 6mm aggregate = 2.5%

- *Sieve analysis*

Sieve analysis of aggregate is done in order to find out the particle size distribution of the aggregates and according to it grading of aggregates can be done. The sieve analysis is done as per IS 383-1970 [4]. The particle size distribution is shown in Table 3.3.

D. Recycled Fine Aggregate

The recycled fine aggregates are obtained from the crushed concrete aggregate passing through 4.75mm I.S sieve.

- *Specific gravity*

The test was conducted as per IS: 2386 (part III)-1963[3], and the value of specific gravity of recycled fine aggregate is 2.47.

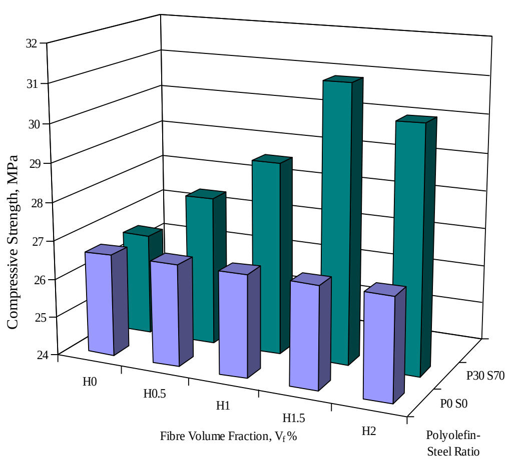
Specific gravity (Trial 1) = 2.42
Specific gravity (Trial 2) = 2.525
Average value of specific gravity for recycled fine aggregate = 2.47

- *Water absorption*

Water absorption is defined as the percentage of water absorbed by an aggregate when immersed in water. Water absorption was calculated according to IS 2386(Part 3)-1963[4]. The water absorption of recycled fine aggregate was obtained as 23.456%.

- *Sieve analysis*

Sieve analysis of aggregate is done in order to find out the particle size distribution of the aggregates and according to it grading of aggregates can be done. The sieve analysis is done as per IS 383-1970 [4].



III. MIX DESIGN

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The purpose of designing is of two fold. The first object is to achieve the stipulated minimum strength. The second object is to make the concrete in the most economical manner .Cost wise all concretes depend primarily on two factors; namely cost of material and cost of labor.

Considerable need has been felt for formulating standard recommendation guidelines for proportioning of concrete mixes. The need has been further emphasized by the importance given to design mix concrete according to IS 456. The proportioning of concrete mix consist of determination of the quantities of respective ingredients necessary to produce concrete having adequate, but not excessive, workability and strength for a particular loading and durability for the exposure to which it is subjected. Emphasize is laid on making most economical use of available materials so as to produce concrete of the required attributes at the minimum cost. The assumption made in mix design is that the compressive strength of workable concrete is, by and large governed by the water cement ratio. Another most convenient relationship applicable to normal concrete is that for a given type, size and gradation of aggregate the amount of water determines its workability.

Cement and concrete sectional committee decided to evolve standard recommended guidelines for the mix design, it is furnished in IS 10262. However the standard does not debar the adoption of any other accepted method of mix design. This chapter describes the details of mix design carried out and detail of different specimens casted.

LIST OF SPECIMENS

SB_1	NATURAL COARSE AGGREGATE + NATURAL FINE AGGREGATE
SB_2	RECYCLED COARSE AGGREGATE + NATURAL FINE AGGREGATE
SB_3	RECYCLED COARSE AGGREGATE + RECYCLED FINE AGGREGATE
SB_4	RECYCLED COARSE AGGREGATE + NATURAL FINE AGGREGATE (RESIDUAL MORTAR)
SB_5	RECYCLED COARSE AGGREGATE + NATURAL FINE AGGREGATE (CEMENT AND FINE AGGREGATE REDUCED BY 10%)
SB_6	RECYCLED COARSE AGGREGATE + NATURAL FINE AGGREGATE (CEMENT AND FINE AGGREGATE REDUCED BY 20%)
SB_7	RECYCLED COARSE AGGREGATE + NATURAL FINE AGGREGATE (CEMENT AND FINE AGGREGATE REDUCED BY 30%)
SB_8	RECYCLED COARSE AGGREGATE + RECYCLED FINE AGGREGATE (CEMENT REDUCED BY 10%)

SB_9	RECYCLED COARSE AGGREGATE + RECYCLED FINE AGGREGATE (CEMENT REDUCED BY 20%)
SB_{10}	RECYCLED COARSE AGGREGATE + RECYCLED FINE AGGREGATE (CEMENT REDUCED BY 30%)

A. Design of control mix

Mix design of SB_1

Density of solid block = 1800 kg/m^3 (IS 2185 (Part 1):2005)
Ratio = 1:3:6
Sum = 10
Volume of solid block = 0.0015 m^3 (190mm x 90mm x 90mm)
w/c ratio = 0.5
Amount of cement = $\frac{1}{10}$ x 0.0015 x 1800 = 0.27 kg/m^3
Amount of fine aggregate = $\frac{3}{10}$ x 0.0015 x 1800 = 0.81 kg/m^3
Amount of coarse aggregate = $\frac{6}{10}$ x 0.0015 x 1800 = 1.62 kg/m^3
Amount of water = 0.5 x 0.27 = 0.135 lit

Mix design for SB_2

Density of solid block = 1800 kg/m^3 (IS 2185 (Part 1):2005)
Ratio = 1:4:8
Sum = 13
Volume of solid block = 0.0015 m3 (190mm x 90mm x 90mm)
w/c ratio = 0.5
Amount of cement = $\frac{1}{13}$ x 0.0015 x 1800 = 0.207 kg/m^3
Amount of fine aggregate = $\frac{4}{13}$ x 0.0015 x 1800 = 0.830 kg/m^3
Amount of coarse aggregate = $\frac{8}{13}$ x 0.0015 x 1800 = 1.66 kg/m^3
Amount of water = 0.5 x 0.207 = 0.103 lit

IV. TEST PROCEDURES

In order to determine the properties of solid blocks made with NCA and RCA various test are done. The different tests are given below.

A. Determination of compressive strength

The main aim was to determine the compressive strength of solid blocksprepared with NCA and RFA. The test specimens are of size 190 x 90 x 90 mm for each mix three blocks were cast and compression test was done after 28 days Curing. Compaction was done using table vibrator. The block for testing was place in the compression testing apparatus as shown in the figure. The compressive strength was obtained by dividing the ultimate applied load by the cross- sectional area of the cube.

B. Determination of block density

Two blocks were taken at random from the samples selected and then dried constant mass in a suitable oven heated to approximately 100^{o}C. After cooling the blocks to room temperature the dimensions of each block shall be measured in centimeters and the overall volume computed in cubic centimeters. The block shall be weighed in kilograms and the density of each block can be calculated as follow,

$$\text{Density} = \frac{\text{Mass of block in kg}}{\text{Volume of specimen in cm3}} \times 10^6 \ kg/m^3$$

The average of two blocks shall be taken as average density.

C. Determination of water absorption

The test specimens shall be completely immersed in water at room -temperature for 24 h. The specimens shall then be weighed, while suspended by a metal wire and completely submerged in water. They shall be removed from the water and allowed to drain for one minute by placing them on a 10 mm or coarser wire mesh, visible surface water being removed with a damp cloth and immediately weighed. Subsequent to saturation, all specimens shall be dried in a ventilated oven at 100^{0}C to 115°C for not less than 24 h and until two successive weightings at intervals of 2 h show an increment of loss not greater than 0.2 percent of the last previously determined mass of the specimen. The water absorption was obtained as follow.

$$\text{Water absorption in } kg/m^3 = \frac{A-B}{A-C} \times 1000$$

$$\text{Water absorption in percentage} = \frac{A-B}{B} \times 100$$

Where,
A = wet mass of unit, in kg
B = dry mass of unit, in kg
C = suspended immersed mass of units, in kg.

The average of two blocks shall be taken as average value for water absorption.

D. *Determination of moisture movement*

The specimens shall be immersed in water for 4 days, the temperature being maintained at 27 ± 2°C for at least 4 h prior to the removal of the specimen and the wet length measured. The moisture movement shall be determined as the difference between the dry and wet lengths and expressed as a percentage of the dry length for each specimen.

V. TEST RESULTS

The results of test on solid blocks like compressive strength, moisture movement, water absorption and density of blocks were obtained. They are discussed in this chapter.

A. Compressive strength test

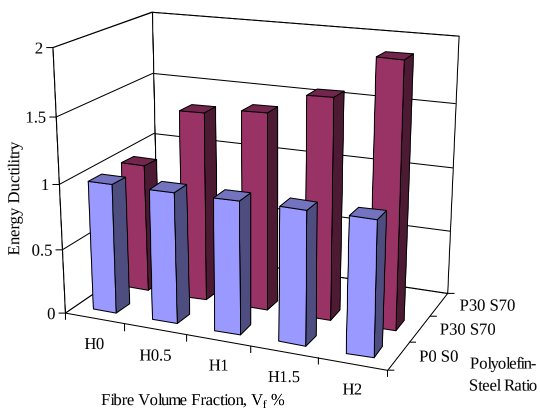
The compressive strength of solid blocks with NCA as well as with RCA was determined. As per IS 2185 Part1 2005 the solid concrete blocks are used as load bearing units and shall have a block density not less than 1 800 kg/m^3 and these shall be manufactured for minimum average compressive strength of 4.0 and 5.0 N/mm^2 respectively..Average compressive strength in 28 days

Compressive strength of solid blocks with NCA and RCA was compared.

B. Ductility

The block density of solid blocks with NCA as well as with RCA was determined. As per IS 2185 Part1 2005 the solid concrete blocks shall have a block density not less than 1 800 kg/m^3.

Block density of solid blocks with NCA and RCA was compared.



C. Block Density

The water absorption of solid blocks with NCA as well as with RCA was determined. As per IS 2185 Part1 2005 the water absorption, being the average of two units shall not be more than 10 percent by mas .Water absorption of solid blocks with NCA and RCA was compared.

D. Moisture movement

The moisture movement of solid blocks with NCA as well as with RCA was determined. The moisture movement of the dried blocks on immersion in water, being the average of two units, shall not exceed 0.09 percent.

Moisture movement of solid blocks with NCA and RCA was compared.

VI. Conclusion

Based on the test results of this investigation, the following conclusions are drawn:

- Addition of fibres has significant improvement on the compressive strength when compared to the plain concrete.
- HFRC beams exhibit enhanced strength in flexure. The values of modulus of rupture increased up to 72.52% compared to their plain concrete counterparts.
- HFRC beams provide ductility indices up to 1.98 compared to the plain concrete specimens.
- Empirical expressions that predict the influence of fibre contents on the strength and ductility properties of hybrid fibre reinforced concrete is proposed. These expressions give a close estimate of the experimental results.

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