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Effect on Compressive Strength of Concrete using Steel Fiber with varying Sizes of Cube Specimens

Prakash Mondal and Dilip Kumar Singha Roy

Department of Civil Engineering, National Institute of Technology Durgapur, West Bengal, India, 713209.

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ABSTRACT

It is well known fact that concrete displays a brittle behaviour and very little tensile capacity. This type of brittleness can be reduced by incorporation of fibers in concrete which lead to better strength properties and impact resistance. This paper presents on the study of compressive strength properties of concrete cube specimens with and without addition of discrete steel fiber of two different propositions. It is imperative to note that the 28 days mean compressive strength have been used to characterize the three types of concrete, i.e., plain control concrete, fully fiber reinforced concrete and retrofitted concrete, based on the experimental results obtained through direct compression test of cube specimens. Concretes containing steel fibers reinforced at the same volume fraction (1%) were compared in terms of compressive strength properties for three different sizes of cube specimens, namely150x150x150mm, 100x100x100mm, 70.6x70.6x70.6mm. In addition, comparative analysis on the experimental results of compressive strength for all the three types of concrete has been made. It is observed that steel fiber enhanced the strength properties and impact resistance of concrete as compared to the plain concrete results. It is also found comparable results between fully fiber reinforced concrete and retrofitted concrete. It is further observed that the strength is increasing consistently to the decreasing sizes of specimens.

Introduction

Over the years , fiber-reinforced concrete (FRC) has extensively been used in different structural and non-structural applications such as pavements, floors, overlays, industrial slabs, and shotcerate linings etc., where the major concerns are toughness and first-crack strength in flexure [1,2]. Banthia et al. have estimated that more than 150000 metric tons of FRC have been used [3]. Depending on the distribution and orientations of fibers in cement matrix, the addition of fibers makes the cementitious material more isotropic and transforms it from a brittle to a quasi- ductile material. In fact, the real benefits of adding fibers to concrete become evident at the stage of post-cracking. Before that, the fiber has no significant effect on concrete mechanical properties [4]. It is believed that the randomly oriented fibers in concrete control the opening of macro cracks and limit crack propagation which considerably improve strength and ductility of the material [5]. Several research works have been done to quantify the enhanced properties of FRC materials and, particularly to compare the effect of various types of fibers [6]. Balaguru and Shah [7] have reported that in general, the effect of the addition of steel–fiber on compressive strength is insignificant whereas in some cases, up to 25% increase in compressive strength was found. Meanwhile, considerable improvement in strain at stress peak and toughness are usually observed, as well as an enhanced tensile strength, resistance to fatigue [2,8], impact [2], blast loading, and abrasion as reported by Bindiganville et al [8]. Flexural strength, tensile strength, strain capacity and spalling are also enhanced [9]. However, such improvement can only be reached when using the appropriate type and amount of fibers distributed throughout the concrete mass.

Rossi et al. [10] have reported that fibers, in lengths higher than 20 mm, diameter greater than 0.4 mm and in commonly used proportions less than 2% in volume, mainly act after the cracking of the matrix. Furlan et al. [11] have reported that the characteristics of concrete significantly changed when a large volume of fibers is added. However, Shah et al. [12] have observed that tensile strength of concrete is not considerably modified when the volume of fiber added is lower than 2% while it improves ductility and control of cracks, even in case of very low volume lower than 0.5% such as polypropylene or organic fibers.

Recently, the inclusion of different types of by-products in cement-based materials becomes more and more a common practice [13–17]; however, most of these investigations have mainly focused on the use of supplementary cementitious materials, mineral admixtures or recycled aggregates in concrete. It is expected that various other types of solid and industrial recycled waste by-products can also be used in concrete materials for different purposes.

The present study investigates on the efficiency of steel fiber distribution in concrete mass and sizes of cube specimens in terms of compressive strength of concrete. Apart from the plain concrete, the current study concentrated on two types of composites: fully-fiber reinforced composites and retrofitted composites which contain same types and lengths of fibers.

Objectives of the present Work

I. To study the effect of steel fiber on ultimate load carrying capacity and failure pattern of concrete specimens for all types of mixes**.**

II. To study and compare the compressive strength of plain, fully fiber reinforced and retrofitted concrete for different sizes of cube specimens.

Tele:
E-mail address: prakashmondalnit@gmail.com

III. To study the effect of addition of fibers on strength and ductility properties of all types of concrete mixes.

IV. To study the compressive stress–strain behaviour of cube specimens for all types of concrete mixes.

Experimental Programme

A 54 numbers of cube specimens of three different sizes namely 150x150x150mm, 100x100x100mm, 70.6x70.6x70.6mm were cast and tested, to determine the compressive strength properties for three different types of concrete, i.e., plain concrete, fully fiber concrete, and retrofitted fiber concrete. All specimens were cast using ready mix concrete of M25 grade. Discrete steel fibers of 1% by volume of the concrete mass and having constant aspect ratio (L/d) of 40 were used in both types of fiber concrete. The detailed cube specimens for plain concrete, fully fiber concrete and retrofitted concrete have shown in Fig.1.

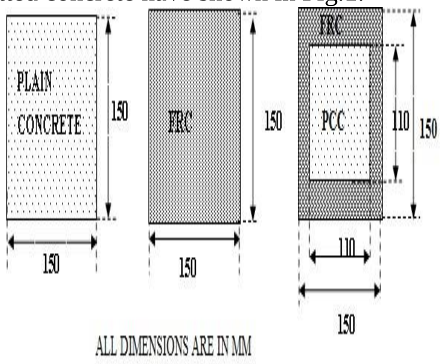


Fig 1. Top view of cube specimens

Materials and Methods

Cement

Portland Pozzolona Cement as per IS: 1489(part 1)-1991, has been used throughout the investigation.

Fine Aggregate

River sand having specific gravity of 2.63, fineness modulus of 3.29 and water absorption of 2.11 % has been used. The sand also conforms to the grading zone III as per (IS: 383-1970) Indian Standard specifications.

Coarse Aggregate

Crushed stone aggregates of 12.5 mm size with fineness modulus of 5.72 and 10 mm size with fineness modulus of 3.76 blended well graded aggregate having specific gravity of 2.81 have been used throughout the investigation..

Water

Portable water free from any harmful ingredients like oils, alkalis, sugars, salts and organic materials has been used for mixing and curing of the concrete specimens.

Steel Fiber

The steel fibers used in the present study were round and straight fibers of diameter 1.0mm. The fiber volume has been used in the concrete mixes was 1% by volume of concrete reinforced.

Mix Design

The concrete mix design has been made using the guidelines as per IS: 10262 – 2009 to produce M25 grade of workable concrete.

Specimen Designation

The design mix concrete of M25 grade was used to prepare three different types of concrete, i.e., plain control concrete, fully fiber reinforced concrete and retrofitted concrete. For each type of concrete again three different sizes of cube specimens namely, 150x150x150mm, 100x100x100mm and 70.6x70.6x70.6mm were cast. Total 54 numbers of cube specimens, i.e six numbers of cubes were cast for each type of concrete and specimen sizes. Potable water was used for mixing and 28 days curing of all the specimens. The abbreviation and designation of the specimens were made and presented below:

Designation

B - for big size cube (150 x150x150 mm),
M - for medium size cube (100x100x100mm),
S - for Small size Cube (70.6x70.6x70.6mm)

Abbreviations

Type 1

Plain Control Concrete

- CUBPI - Big size Cube made of Plain concrete.
- CUMPI - Medium size Cube made of Plain concrete.
- CUSPI - Small size Cube made of Plain concrete.

Type 2

Fully Fiber Concrete

- CUBFI - Big size Cube fully fiber reinforced, i.e., discrete steel fibers are randomly distributed throughout the full mass of the concrete.
- CUMFI - Medium size Cube fully fiber reinforced, i.e., discrete steel fibers are randomly distributed throughout the full mass of the concrete.
- CUSFI - Small size Cube fully fiber reinforced, i.e., discrete steel fibers are randomly distributed throughout the full mass of the concrete.

Type 3

Retrofitted Concrete

- CUBRI – Big size Cube Retrofitted concrete prepared by encasing the central plain concrete by discrete steel fibers randomly distributed throughout mass of peripheral concrete.
- CUMRI - Medium size Cube Retrofitted concrete prepared by encasing the central plain concrete by discrete steel fibers randomly distributed throughout mass of peripheral concrete.
- CUSRI - Small size Cube Retrofitted concrete prepared by encasing the central plain concrete by discrete steel fibers randomly distributed throughout mass of peripheral concrete.

For all types and sizes of concrete specimens, I indicates number of sample tested, i.e., 1, 2, 3 etc.

Test Procedure for Compressive Strength

Specimens were tested in a compression testing machine till failure. These tests were carried out under load control at a rate of 0-2 kN/sec using an electro–hydraulic universal testing machine which has a load capacity of 3000 KN. The specimens were loaded using a 1000 kN Load Cell to monitor the load. Axial and radial strains were measured using a linear voltage differential transducer (LVDT) as shown in Fig 2. The test process was monitored on a computer screen, and all loads and deformations data were recorded and stored through data logger.

Fig 2. Testing set-up, Cube Specimen for Compressive Strength

The compressive strength properties of concrete were evaluated following the procedure stated as per Indian standard code of practice [21] and average compressive strength results of six cube specimens was considered for each type and size of concrete.

Results and Discussion

Cube Compressive Strength of Big Size Specimen

The average compressive strength results of cube specimens for all the three types of concrete mixes at the age of 28 days are presented in Tables-1. These average compressive strengths are found to be 27.07 MPa, 28.17 MPa and 28.14 MPa for plain control concrete, fully fiber reinforced concrete and retrofitted concrete respectively. The average values of compressive strength for fully fiber reinforced (CUBF) and retrofitted concrete (CUBR) is increased by 4.064% and 3.953% respectively as compared to that of the plain concrete control cube (CUBP). On the other hand, fully fiber reinforced concrete and retrofitted concrete have shown similar compressive strength results, that is, CUBF is 0.107 per cent higher than CUBR.

It is evident from the above discussions that both fully fiber reinforced concrete and retrofitted concrete have shown comparatively higher compressive strength than that of the plain concrete. It is also evident that compressive strength values are more or less same for both the fully fiber reinforced concrete and retrofitted concrete. Therefore, instead of distributing fiber in the whole volume/mass of the specimen, only in peripheral concrete volume/mass can be used to distribute fiber for strengthening purposes, leading to savings of costly steel fibers.

Cube Compressive Strength of Medium Size Specimen

The average compressive strength results of cube specimens for all the three types of concrete mixes at the age of 28 days are presented in Tables-2 The average compressive strength values are obtained as 28.62 MPa, 31.47 MPa and 31.1 MPa for plain control concrete, fully fiber reinforced concrete and retrofitted concrete respectively. These average values of compressive strength for both fully fiber reinforced concrete and retrofitted concrete are increased by 9.958% and 8.665% respectively in comparison to that of plain control concrete in case of medium size of specimen. On the other hand, fully fiber reinforced concrete have shown only marginal increase in compressive strength as compared to the retrofitted concrete and CUMF strength value is only 1.189 per cent higher than CUMR strength value.

It is evident from the above discussions that the fully fiber reinforced concrete and retrofitted concrete have depicted higher compressive strength values than that of the similar plain control concrete. It is also observed that compressive strength values are more or less same for both the fully fiber reinforced concrete and retrofitted concrete.

Cube Compressive Strength of Small Size of Specimen

The respective compressive strength values of plain control concrete, fully fiber reinforced concrete and retrofitted concrete for small size specimens are 31.26 MPa, 35.94 MPa and 35.71 MPa at the age of 28 days and these values can be seen from Tables - 3. The average values of compressive strength for fully fiber reinforced concrete and retrofitted concrete are found to increase by 15% and 14% in comparison to that of similar plain control concrete. On the other hand, fully fiber reinforced concrete and retrofitted concrete have shown very close compressive strength value and the difference is only 0.64 per cent more for fully fiber reinforced concrete.

It is evident from the above discussions that the fully fiber reinforced concrete and retrofitted concrete has shown higher compressive strength while plain concrete has shown comparatively lower compressive strength. It is also noted that compressive strength values are more or less same for both the fully fiber reinforced concrete and retrofitted concrete.

Stress–Strain Curves

The main parameters that affect stress–strain relationships are maximum stress (usually considered to be the compressive strength of concrete), peak strain (corresponding to the maximum stress) and ultimate strain (strain at which failure is defined). The stress-strain plots for all the tested cube specimens of plain, fully fiber reinforced and retrofitted concrete are shown in Figs.3, 4.and 5 respectively. In this present work, it is seen that the strain values for fully fiber reinforced concrete and retrofitted concrete specimens were found to be higher than those obtained from the plain control concrete specimen. Such peak strain values which are particularly significant when the steel fiber is used in the concrete.

Failure Modes

It is observed that the plain concrete control specimens have exhibited very little cracking prior to failure and the failure occurred suddenly indicating a brittle nature of failure as shown in Fig.6. Similar observations are also made for both the fully fiber reinforced concrete and retrofitted concrete.

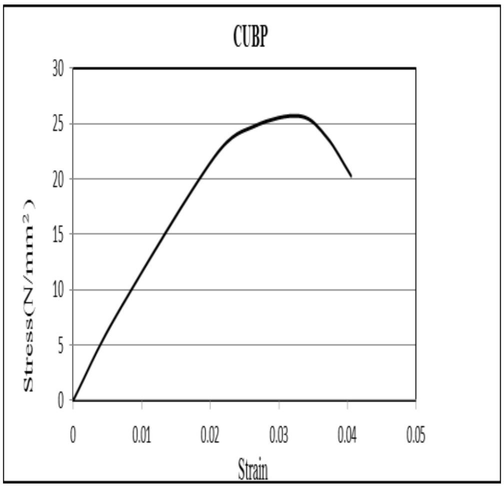


Fig 3. Compressive stress–strain curves for Plain concrete (Cube-150x150x150)

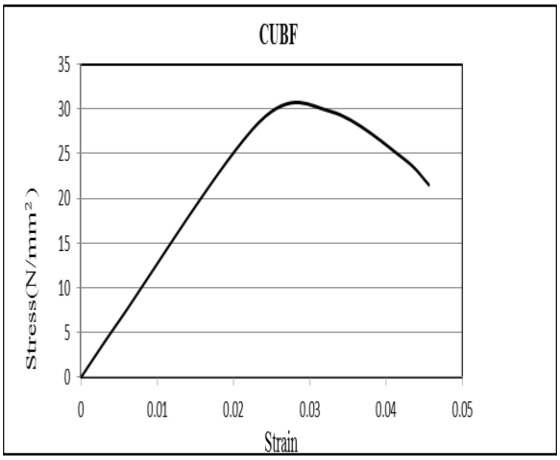


Fig 4. Compressivstress–strain curves for fully fiber reinforced concrete (Cube-150x150x150)

Table 1. Compressive Strength of Big size Concrete Specimens

Types of cubes	Compressive Strength in (N/mm2)	Types of cubes	Compressive Strength in (N/mm2)	Types of cubes	Compressive Strength in (N/mm2)
CUBP1	26.71	CUBF1	28.04	CUBR1	28.35
CUBP2	27.42	CUBF2	28.71	CUBR2	28.4
CUBP3	27.78	CUBF3	28.35	CUBR3	27.82
CUBP4	25.64	CUBF4	27.55	CUBR4	28.62
CUBP5	27.78	CUBF5	27.95	CUBR5	27.33
CUBP6	27.11	CUBF6	28.4	CUBR6	28.18
Average Compressive Strength in (N/mm2)	27.07	Average Compressive Strength in (N/mm2)	28.17	Average Compressive Strength in (N/mm2)	28.14

Table 2. Compressive Strength of Medium size Concrete Specimens

Types of cubes	Compressive Strength in (N/mm2)	Types of cubes	Compressive Strength in (N/mm2)	Types of cubes	Compressive Strength in (N/mm2)
CUMP1	28.3	CUMF1	31.5	CUMR1	28.8
CUMP2	28.6	CUMF2	31.8	CUMR2	35
CUMP3	28.5	CUMF3	31.7	CUMR3	30.6
CUMP4	28.6	CUMF4	31.3	CUMR4	34.6
CUMP5	29.6	CUMF5	31.5	CUMR5	27.6
CUMP6	28.1	CUMF6	31	CUMR6	30
Average Compressive Strength in (N/mm2)	28.62	Average Compressive Strength in (N/mm2)	31.47	Average Compressive Strength in (N/mm2)	31.10

Table 3. Compressive Strength of Small size Concrete Specimen

Types of cubes	Compressive Strength in (N/mm2)	Types of cubes	Compressive Strength in (N/mm2)	Types of cubes	Compressive Strength in (N/mm2)
CUSP1	31.50	CUSF1	36.11	CUSR1	35.71
CUSP2	31.90	CUSF2	35.91	CUSR2	35.10
CUSP3	31.30	CUSF3	35.71	CUSR3	35.51
CUSP4	30.10	CUSF4	36.11	CUSR4	36.31
CUSP5	31.10	CUSF5	35.71	CUSR5	35.91
CUSP6	31.70	CUSF6	36.11	CUSR6	35.71
Average Compressive Strength in (N/mm2)	31.26	Average Compressive Strength in (N/mm2)	35.94	Average Compressive Strength in (N/mm2)	35.71

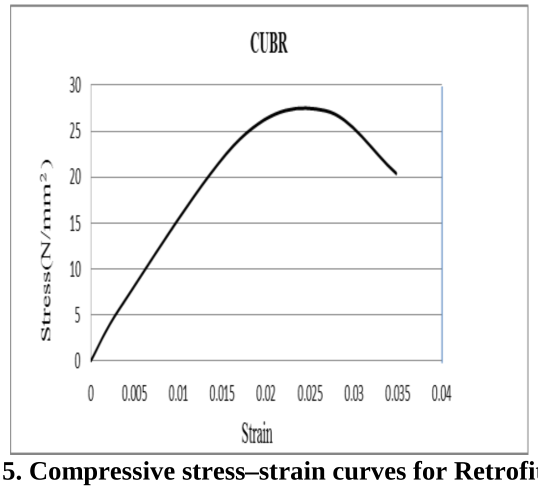
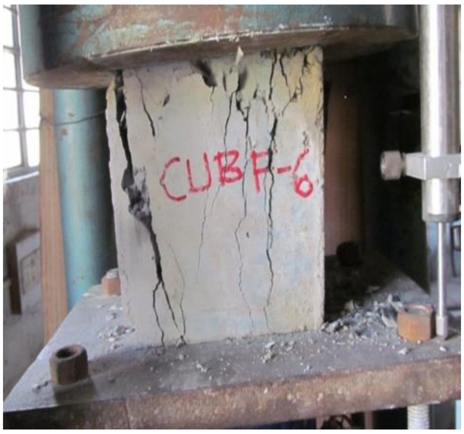
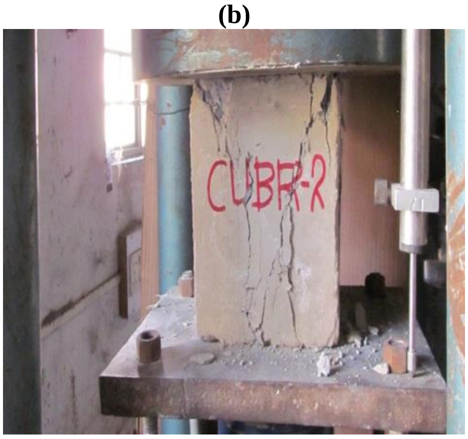


Fig 5. Compressive stress–strain curves for Retrofitted concrete (Cube-150x150x150)

(a)



(b)



(c)

Fig 6. Failure modes of (a) Plain Concrete, (b) Fully fiber reinforced concrete and (c) Retrofitted Concrete Cube

Conclusions

The main conclusions arising from this study are as follows:

1. The FRC concrete specimens have shown improvement in terms of first crack load, ultimate load and deflection characteristics when compared to those of the corresponding control concrete specimens without any fiber.
2. The overall performances the FRC concrete specimens were superior to those of the control concrete specimens.
3. The addition of discrete steel fiber in concretes either fully and partially (peripheral concrete volume) have shown comparatively higher strength, that is, compressive strengths as compared to the plain control concrete strengths.
4. The average values of compressive strength for both fully fiber reinforced concrete and retrofitted concrete have shown enhanced values as compared to that of the plain control concrete.
5. The compressive strength values are more or less same for both the fully fiber reinforced concrete and retrofitted concrete.
6. Distribution of fiber in the whole volume/mass of the specimen is not required; instead only in peripheral concrete volume/mass can be used to distribute fiber for strengthening purposes, leading to savings of costly steel fibers.
7. Size of the specimens has remarkable effects on the strengths irrespective of the type of concrete and shape of specimen. With decrease in size of the specimen the strength values, that is, compressive is found to increase to a considerable extent.

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