ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC) VOL. 15, NO. 2 (2014)
PAGES 169-178

EXPERIMENTAL INVESTIGATION ON BEHAVIOUR OF HYBRID FIBRE REINFORCED CONCRETE COLUMN UNDER AXIAL LOADING

KR Muthuswamy[1*] and GS Thirugnanam[2]

[1]Anna University Chennai, Sakthi Polytechnic College, Erode – 638 315, Tamil Nadu, India.

[2]Department of Civil Engineering, Institute of Road and Transport Technology, Erode–638316, Tamil Nadu, India.

Received: 10 February 2013; **Accepted:** 25 September 2013

ABSTRACT

Ductility and energy absorption capacity are the main requirement of earth quake resistant structures. Concrete can be modified to perform in a more ductile form by the addition of randomly distributed discrete fibres in the concrete matrix. This study presents the structural behaviour of hybrid fibre reinforced concrete column made with the combination of steel and glass fibres under axial loading. The various parameters like load carrying capacity, ductility, energy absorption capacity and toughness index of hybrid fibre reinforced concrete column are compared with that of conventional reinforced concrete column and steel fibre reinforced concrete column. It has been observed from the experimental investigation that the behaviour of HFRC column is relatively better than conventional reinforced concrete column and steel fibre reinforced concrete column in all respects.

Keywords: Fibre reinforced concrete; hybrid fibre; load carrying capacity; ductility; energy absorption; toughness index.

1. INTRODUCTION

Concrete is the most widely used man-made construction material. Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. In normal concrete, relatively low strength and elastic modulus are the result of high heterogeneous nature of structure of material, particularly the porous and weak transition zone, which exists in the cement paste aggregate interface. By densification and strengthening of transition zone, many desirable properties can be improved many fold.

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* E-mail address of the corresponding author: krmuthuswamy@gmail.com (KR Muthuswamy)

Silica fume may be added as partial replacement of cement to improve the qualities of transition zone. Silica fume in concrete has been found to give increased performance in both fresh and hardened states of concrete due to its very high pozzolanic reactivity [1]. The resulting product is known as high performance concrete. With partial replacement of cement by silica fume, mechanical properties viz., compressive strength, flexural strength, splitting tensile strength and stress-strain characteristics of concrete could be improved [2]. Column with silica fume undergoes more deformation than that of control columns of same area of steel, which shows the ductile behavior. The short column with 7.5% silica fume shows higher value of ultimate load capacity which is 21% higher than the control column [3].

The presence of micro cracks at the mortar-aggregate interface is responsible for the inherent weakness of plain concrete. The weakness can be removed by inclusion of fibres in the mix. The fibres help to transfer loads at the internal micro cracks. Such a concrete is called fibre reinforced concrete. Hybrid fibre reinforced concrete can be produced by suitably combining different types of fibres. The use of optimized combinations of two or more types of fibres in the same concrete mixture can produce a composite with better engineering properties than that of individual fibres. The addition of fibres to the conventional concrete is varying from 1- 2% by volume depending on the geometry of fibres and type of application. Addition of steel fibres to concrete matrix enhances the compressive and bond strength, and reduces slip [4]. The use of steel fibres in RC members enhanced the cracking strength, stiffness after cracking, thereby resulting in better deflection control [5]. The concrete columns confined by fibre composites can significantly enhance its strength and ductility as well as result in large energy absorption capacity [6]. Addition of fibres to high strength concrete mixtures in reinforced concrete columns not only prevents the premature spalling of the concrete cover but also increases the strength and ductility of the axially loaded reinforced concrete member [7]. Steel fibres enhance the fatigue strength; distinctly, at all stress levels. The larger the fibre content, the greater was the enhancement of fatigue strength [8]. The introduction of steel fibres into the mix arrest the early spalling of the cover and increase the load capacity as well as the ductility of the columns over that of comparable non fibre-reinforced specimens [9]. The addition of steel fibres to concrete enhances its toughness and strain at peak stress [10]. Addition of glass fibres in concrete improves the surface integrity of concrete, improves its homogeneity and reduces the probability of cracks. There is a significant increase in compressive strength, split tensile strength and flexural strength with the inclusion of glass fibres in concrete [11].

The scope of this research is to investigate the performance of reinforced concrete column with hybrid fibres under axial load with respect to ultimate strength, ductility, energy absorption and toughness. The results are then to compare with fibreless RC column and steel fibre reinforced concrete column.

2. EXPERIMENTAL INVESTIGATIONS

2.1 Materials used

Ordinary 53 grade Portland cement with specific gravity of 3.15 was used in this study. River sand with a specific gravity of 2.54 conforming to grading zone II as per I.S 383-1970 was used. The coarse aggregate used was crushed granite stone with a specific gravity of 2.60 conforming to well graded aggregate having maximum size of 12.5mm as per I.S 383-1970 [14]. Silica fume was added as partial replacement of cement at 7.5% by weight of cement in order to get high performance concrete [12]. A super plasticizer named Conplast - SP 430 was added to get the required workability. The round crimped steel fibres of 1% by volume of concrete having 0.5 mm diameter, 30mm length and aspect ratio 60 was used to get SFRC [13]. Alkali resistant glass fibres with optimum proportion of 0.03% volume fraction of concrete having filament diameter 14microns, 12mm length and aspect ratio 857.1 was used for this work in addition to steel fibres to prepare HFRC [11]. M30 grade concrete mix was designed as per IS 10262-1982 [15, 16]. The details of mix proportion calculated are shown in Table 1.

Table 1: Details of Concrete mix proportion

Material required	Binder		Fine aggregate	Coarse aggregate	Water
	Cement	Silica fume			
Weight in kg/m^3	393.83	31.91	536.39	1167.1	191.58
Proportion	0.925	0.075	1.26	2.74	0.40

The size of RC Column specimens chosen for experimental study was 150mm diameter and 700mm height. The longitudinal reinforcement consists of 6 numbers of 8mm diameter bars and lateral ties consist of 6mm diameter bars with 100mm spacing.

2.2 Casting of Column specimens

Three sets of columns namely plain RC column, SFRC column and HFRC column were cast. PVC moulds were used for casting the columns. The mould was kept ready with the reinforcement cage placed in position with required cover on all faces. The required quantities of concrete ingredients were mixed thoroughly. After mixing the ingredients, fibres were added and mixed to ensure uniform dispersion of fibres. The concrete was filled in layers in the mould and compacted well using needle vibrator. The columns were kept in the mould for one day. The columns were then removed from the mould and stored in the water for 28 days curing.

2.3 Experiment set-up

The columns were taken out after 28 days curing and cleaned for testing. The column was supported with steel circular box at top and bottom enabling partial fixity condition and to prevent the local crushing. The column specimens are adjusted in such a way that the centre line of the axial load coincides with the longitudinal axis of the column. The compressometer was fixed in the middle region of the column to observe the axial deformation. All the columns were tested for axial compression in the 1000KN universal testing machine. The test set-up is shown in figure 1.

Figure 1. Test setup

3. TEST RESULTS

3.1 Load- Deformation behaviour

The loading was applied gradually and the deformation readings were taken at regular intervals of 50kN. The column was gradually loaded upto the ultimate load level. As the load level was increased in each interval, the observed deflection in compressometer was greater than that it was in earlier interval. The results of axial load and corresponding deformation have been recorded in Table 2. The load versus deformation curve of HFRC column has been plotted as shown in figure 2.

Table 2: Axial load–Axial deformation test results

Sl. No.	Load in kN	Axial deformation in the column in mm		
		Plain RC	SFRC	HFRC
1	0	0	0	0
2	50	0.06	0.02	0.01
3	100	0.21	0.13	0.07
4	150	0.35	0.27	0.15
5	200	0.51	0.40	0.24
6	250	0.68	0.55	0.34
7	300	0.84	0.70	0.43
8	350	1.05	0.84	0.55
9	400	1.23	1.00	0.67
10	450	1.41	1.16	0.78
11	500	1.58	1.30	0.91

12	550	1.76	1.46	1.02
13	590	1.94	---	---
14	600	---	1.60	1.16
15	650	---	1.74	1.28
16	664	---	1.78	---
17	704	---	---	1.40

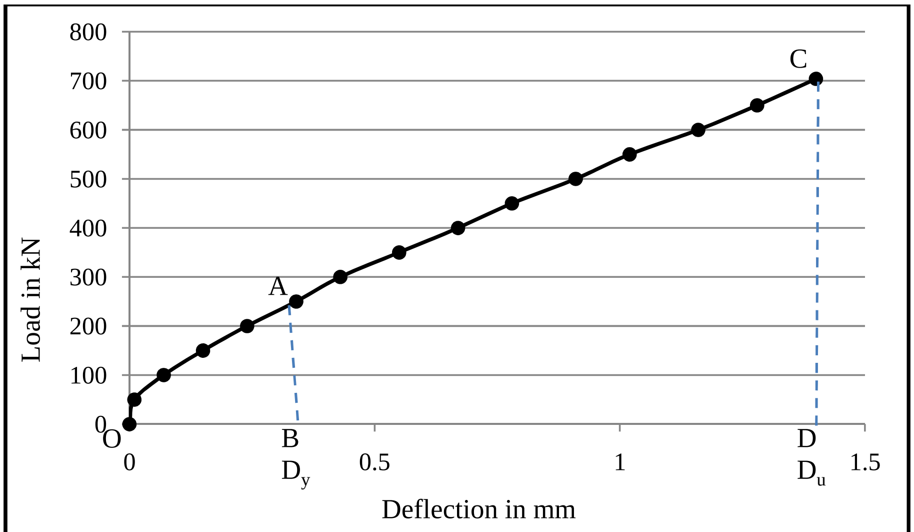

Figure 2. Load–deformation curve of HFRC column

3.2 Load Carrying Capacity

The load carrying capacity of the HFRC columns was 704kN whereas the corresponding values of plain RC and SFRC columns were 590kN and 664kN respectively as mentioned in Table 3.

3.3 Ductility Factor

The ductility value has been calculated as the ratio of ultimate or maximam deformation (D_u) to the yield deformation (D_y). The yield deformation can be determined from the load- deformation curve by assuming bilinear behavior of the column specimen. The ductility factor of the plain RC, SFRC and HFRC columns were 2.7, 3.5 and 4.7 respectively as shown in Table 3.

3.4 Energy Absorption Capacity

The energy absorption capacity was calculated as the total area (OCD) under the load deformation curve. The relative energy absorption capacity of HFRC column was 600kN-mm whereas the corresponding values of conventional RC and SFRC columns were 560kN-mm and 580kN-mm respectively as shown in Table 3.

3.5 Toughness Index

Toughness index is defined as the ratio of ultimate energy (calculated as the area under the load deformation curve OCD) to the energy at yield (calculated as area under the curve OAB) from the figure 2. The toughness index values of the columns plain RC, SFRC and HFRC were 6.2, 8.3 and 12 respectively as shown in Table 3.

Table 3: Ductility, Energy absorption and toughness index of columns

Type of Column	Ultimate load carrying capacity in kN	Ductility factor	Energy absorption in kN-mm	Toughness index
Plain RC	590	2.7	560	6.2
SFRC	664	3.5	580	8.3
HFRC	704	4.7	600	12

4. DISCUSSION OF RESULTS

The test results of HFRC column were compared with that of conventional RC and SFRC columns.

4.1 Load Carrying Capacity

The load carrying capacity of the HFRC column was 19% greater than that of plain RC column and 6% greater than SFRC column. It is seen from the experimental investigation that the ultimate load carrying capacity increases considerably in HFRC column compared to plain RC column and SFRC column.

4.2 Load- Deformation behaviour

The comparison of axial load and the corresponding axial deformation of all the columns is shown in figure 3. The HFRC column had lesser displacement upto ultimate stage of loading when compared with that of conventional RC and SFRC columns.

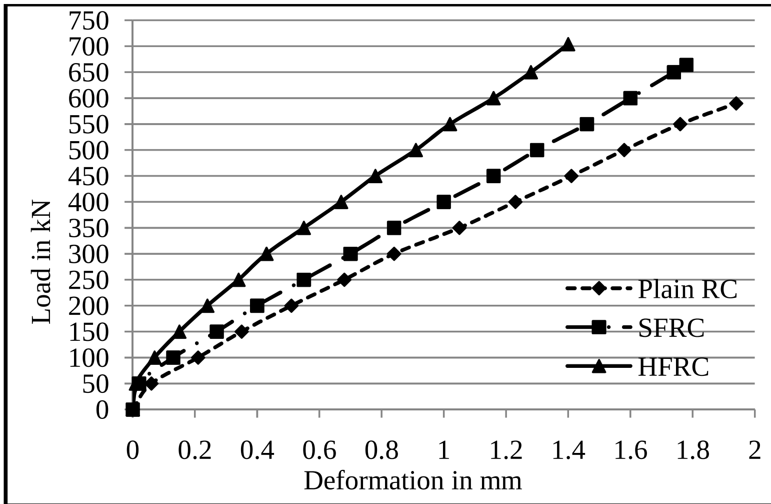

Figure 3. Comparison of load-deformation curves

4.3 Ductility Factor

It has been observed that the ductility of HFRC column is 74% higher than that of plain RC column and 34 % higher than that of SFRC column. Hence the hybrid fibre reinforced concrete behaves as a ductile material required for an earthquake resistant structure.

4.4 Energy Absorption Capacity

The energy absorption capacity of HFRC column is 7% higher than that of plain RC column and 4% higher than that of SFRC column. The energy absorption capacity of the column is improved marginally with the inclusion of hybrid fibres. There is no significant improvement in energy absorption of HFRC column when compared with SFRC column.

4.5 Toughness Index

The toughness index of HFRC column is 94% higher than that of plain RC column and 45% higher than that of SFRC column. It shows that hybrid fibres reinforced concrete column has almost twice tough as compared to plain RC column and 1.5 times tough as compared to SFRC column which is an essential requisite for an earthquake resistant structure.

4.6 Mode of failure

When the column was gradually loaded, longitudinal cracks have been developed. As the load increases the crack width also increased. The ultimate failure occurs in plain RC column by crushing of specimen and spalling of cover concrete as seen from figure 4. The failure of SFRC column was occurred after the formation of numerous cracks as seen in figure 5. The fibres restrict the growth of cracks. The cover concrete remains intact while failure occurs due to crushing. The failure pattern of HFRC column exhibits only hair line cracks/minor cracks thus restricting the growth of cracks upto ultimate load level. At ultimate stage, the load was suddenly reduced because of the local crushing failure at top as shown in figure 6.

Figure 4. Failure pattern of plain RC column

Figure 5. Failure pattern of SFRC column

Figure 6. Failure pattern of HFRC column

5. CONCLUSIONS

Based on the experimental investigation reported, the following conclusions are drawn.

- The load carrying capacity of the RC column is improved significantly with the addition of hybrid fibres.
- The ductility of HFRC column is 1.74 times greater than that of plain RC column and 1.34 times greater than that of SFRC column.
- There is a marginal improvement in energy absorption capacity of RC column with the inclusion of hybrid fibres.
- The toughness index of RC column is improved almost two folds with the addition of hybrid fibres. The toughness index of HFRC column is 45% greater than that of SFRC column.
- In general it is found that HFRC column has higher values of ductility, energy absorption and toughness when compared with plain RC column and SFRC column which are needed for earth quake resistant structures.

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