Behaviour of Hybrid fibre in RC column with basalt and E-glass fibre under axial loading

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ABSTRACT

This paper investigates the behaviour of the hybrid fibre, i.e. a combination of E glass and basalt fibre, added in the reinforced concrete column. A total of 6 columns were cast with Conventional Concrete (CC) and Hybrid Fibre Reinforced Concrete (HFRC) to study the structural performance of the column. The concrete was made of cement, manufacturing sand (m-sand), coarse aggregate as major ingredients. In the column, 2% of Basalt fibre along with the E-Glass fibre of 1% were added to the concrete to make the HFRC. Column was tested under universal testing machine with static axial load and deflectometer was placed at the sides of the column to measure the displacement. The axail and laterall deformation of the column was measured using the deflectometer. The strain of the column was determined with the recorded data. The stiffness of the column with respect to the loads was calculated. The lateral buckling of the CC and HFRC columns were calculated and compared.Both CC and HFRC shows a similar mode of failure with the application of the load. The experimental results of the columns were compared with theoretical value and concluded with the performance column with and without fibre added.

Keywords: Fibre reinforced concrete, Concrete Column, Stress vs Strain, Stiffness, Buckling.

INTRODUCTION

The concrete can be made with a sustainable cementitious matrix with addition of the recycled fibre. The cracks formation in concrete can be in control due to the toughness of the fibre in concrete (Antonio et al., 2017). Vitor et al. (2018) says that the Hybrid fibre in concrete can utilize the combined effect of multiple fibres at a time in concrete. Many research was proved to be beneficial with using hybrid fibre with the combination of carbon, glass, steel and polypropylene (Hsie et al., 2008). The usage of fibre in concrete has proved in increasing the delay in the strain development in the reinforcement bar of concrete (Vitor et al. 2018). Fibre in other forms like wrap made of fibre reinforced polymer (FRP) and FRP rebar can also take a major part in a significant increase of strength and durability properties (Weina et al., 2018). Steel confined concrete was compared with FRP confined concrete to check the performance by many research studies (Aliakbar G and Togay O, 2018; Theodoros et al., 2008; Alper et al., 2008).

The FRP was very much used in the construction field for the retrofitting of the damaged columns as a confined device (Zhao et al., 2020; Wang, 2019; Lin, 2020). In the recent research, the column as a confined tube was tested to determine different structural behaviour. The fibre in the concrete column can help in relieving the brittleness with increased ductility, even with a smaller diameter (Na et al. 2020). It is very common that the flexure, bending or torsions will be there for beams, plates or shells. It is also encountered in the columns when it undergoes axial or lateral pressure (Punmia et al., 2011). This paper investigates the influence of the basalt and E-glass fibre in the reinforced concrete column under axial loading.

MATERIALS PROPERTIES AND PROPORTIONING

The conventional concrete columns and hybrid fibre reinforced concrete columns were made for testing and comparing the result. The ordinary Portland cement (OPC) 53 grade confirmed to IS 8112 (1989) was included in the concrete as a binder with maximum weight of 450kg/m^3. The specific gravity of the cement was tested in the laboratory and determined as 3.1. In order to manufacture sustainable concrete and also due to the high demand for river sand, Manufacturing sand (M-Sand) was used in the concrete. The maximum size of the M-sand was restricted to 4.75mm, and its specific gravity was determined as 2.7 by testing it. The stone was crushed to the maximum size of 20 mm and used as coarse aggregate for the manufacturing of the concrete. The coarse aggregate's was calculated with the test results as 2.8.

The HFRC was made with the confinement of the E-glass and basalt fibre with the optimized proportioning of 1% and 2%, respectively. The HFRC, with this combination, has already proved its behaviour in mechanical and flexural properties (Rathod D and Sundaramoorthy M, 2021). The tensile strength of the basalt fibre is found to be 2950 MPa and its Young's Modulus was determined as 86 GPa, respectively. Similarly, for the E-glass fibre with tensile strength and Modulus of elasticity, 2500 MPa and 81 GPa respectively was used in the manufacturing of the concrete. The mix design was done confirming to IS 10262 (2009), and the ratio of the cement: M-sand: coarse aggregate: water was determined to be 1: 1.54: 2.38: 0.4, respectively.

FABRICATION OF THE SPECIMEN

The column of six numbers was fabricated in a circular shape with 150mm diameter and 650mm height. The column was short since the length to diameter ratio is less than 12 as per IS 456 (2000). The concrete was cast with the designed mix ratio using conventional materials and the optimized fibre ratio. The column was cast in the formwork, which was applied with lubricant in the inner surface for easy removal. The specimens were split into two different groups, one with CC and another with HFRC. The concrete specimens were cast with 3 different reinforcement bars in each category.

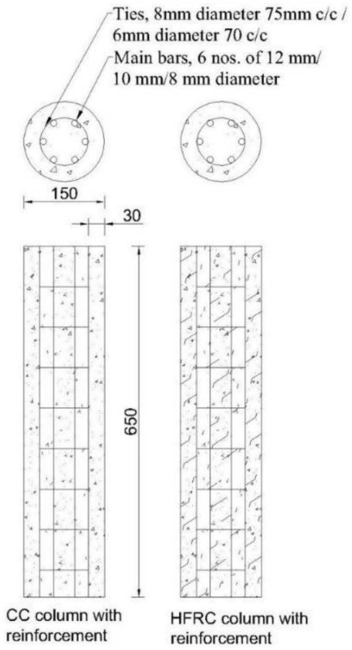


Figure 1 CC and HFRC column with reinforcement

Figure 2 CC and HFRC specimens

The column with CC was named as CCC, and with HFRC was denoted by HCC. The reinforcement bars details provided for the column are mentioned in Table 1. The reinforcement was provided to each group of the specimen with different main and transverse reinforcements. The details of the column with the reinforcement were given as graphical representation in Figure 1.

The varying reinforcement was provided to compare the influence of the fibre as a reinforcing element in the concrete. The minimum longitudinal reinforcement for a column must be 0.01 times the gross area of the column's cross-section (ACI 318-19). The concrete was then filled into the form, which was erected with reinforcement and well compacted to avoid honeycombs. The concrete specimens were kept for curing for 28 days to achieve better strength. Figure 2 shows the casted specimen with CC and HFRC.

Table 1 Details of the reinforcement bars

Specimen	**Reinforcement bars**		**Area of the steel reinforcement**		**Remarks**
	Main reinforcement	**Transverse reinforcement**	**Minimum longitudinal reinforcement as per ACI 318-19**	**Area of reinforcement provided (m^2)**	
CCC1	6 nos. of 12 mm diameter	8mm diameter 75mm c/c	0.01 times of Column’s cross section area = 0.000177 m^2	0.000452	No additives added.
CCC2	6 nos. of 10 mm diameter	8mm diameter 75mm c/c		0.000377	
CCC3	6 nos. of 8 mm of diameter	6mm diameter 70mm c/c		0.000301	
HCC1	6 nos. of 12 mm diameter	8mm diameter 75mm c/c		0.000377	Additionally, E-glass fibre of 1% and basalt fibre of 2% were added
HCC2	6 nos. of 10 mm diameter	8mm diameter 75mm c/c		0.000452	
HCC3	6 nos. of 8 mm of	6mm diameter		0.000301	

	diameter	70mm c/c			

EXPERIMENTAL SETUP

The column was kept in the universal testing machine (UTM) to apply the static axial load. A baseplate was kept at the bottom of the column in order to have an even platform. A cylindrical cap attached with a plate at its top was placed over the column for the uniform application of the load and to avoid the uncertain eccentricity. Two deflectometer were placed on the opposite sides of the column at its mid-height to measure the buckling of the concrete column. Then another deflectometer was placed at the baseplate, as shown in Figure 3, to measure the displacement due to compression of the column subject to the axial loading. The capacity of the testing machine used to apply the load was to the maximum of 100kN. The static axial load was applied to the specimen, and with the interval of 20 kN, the displacement readings were noted. The maximum load and the respective deflection were also noted in the deflectometer. Likewise, all the specimens were tested with the universal testing machine.

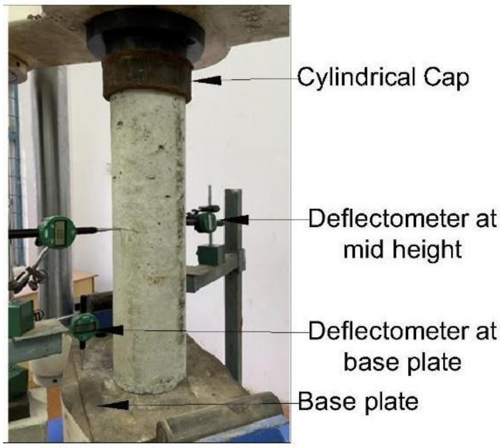


Figure 3 Column test setup in UTM

LOAD VS DISPLACEMENT

The parameter determined are stress, lateral deformation, axial strain, buckling and stiffness for both CC and HFRC columns. The column was set up for the testing under axial loading. The deflectometer was placed, and the value from it was noted with the constant increment of load. The results were compiled and compared with each other. The values are tabulated in Table 2, comparing the CC and HFRC displacement concerning the axial load.

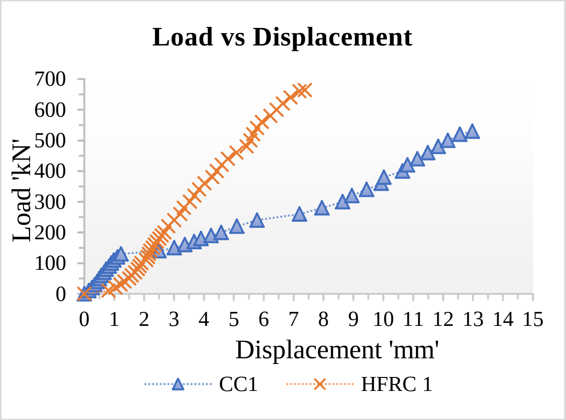
Table 2 Load vs Displacement

Load, p (kN)	**Stress, σ (N/mm^2)**	**Displacement, δ_a (mm)**						**Strain, Δ_l**					
		CC 1	**HFRC 1**	**CC 2**	**HFRC 2**	**CC 3**	**HFRC 3**	**CC 1**	**HFRC 1**	**CC 2**	**HFRC 2**	**CC 3**	**HFRC 3**
0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.566171	0.15	0.81	0.16	0.41	0.5	0.43	0.0002	0.0012	0.0002	0.0006	0.0007692	0.0007
20	1.132343	0.26	1.04	0.36	0.52	0.9	0.6	0.0004	0.0016	0.0006	0.0008	0.0013846	0.0009
30	1.698514	0.35	1.21	0.56	0.61	1.09	0.74	0.0005	0.0019	0.0009	0.0009	0.0016769	0.0011
40	2.264685	0.43	1.34	0.74	0.68	1.19	0.85	0.0007	0.0021	0.0011	0.001	0.0018308	0.0013
50	2.830856	0.5	1.5	0.87	0.74	1.27	0.94	0.0008	0.0023	0.0013	0.0011	0.0019538	0.0014
60	3.397028	0.57	1.59	1.01	0.79	1.38	1.02	0.0009	0.0024	0.0016	0.0012	0.0021231	0.0016
70	3.963199	0.66	1.7	1.21	0.88	1.43	1.08	0.001	0.0026	0.0019	0.0014	0.0022	0.0017
80	4.52937	0.73	1.79	1.48	0.97	1.51	1.15	0.0011	0.0028	0.0023	0.0015	0.0023231	0.0018
90	5.095541	0.83	1.85	1.64	1.01	1.62	1.23	0.0013	0.0028	0.0025	0.0016	0.0024923	0.0019
100	5.661713	0.9	1.91	1.83	1.07	1.72	1.31	0.0014	0.0029	0.0028	0.0016	0.0026462	0.002
110	6.227884	0.99	2.07	2.01	1.12	1.85	1.46	0.0015	0.0032	0.0031	0.0017	0.0028462	0.0022
120	6.794055	1.11	2.13	2.18	1.17	1.94	1.52	0.0017	0.0033	0.0034	0.0018	0.0029846	0.0023
130	7.360226	1.23	2.16	2.34	1.23	2.07	1.58	0.0019	0.0033	0.0036	0.0019	0.0031846	0.0024
140	7.926398	2.5	2.21	2.6	1.28	2.22	1.66	0.0038	0.0034	0.004	0.002	0.0034154	0.0026
150	8.492569	3.01	2.29	2.7	1.33	2.33	1.74	0.0046	0.0035	0.0042	0.002	0.0035846	0.0027
160	9.05	3.36	2.36	2.77	1.38	2.4	1.81	0.00	0.00	0.00	0.00	0.00	0.00

	874							52	36	43	21	36923	28
170	9.624912	3.67	2.43	2.83	1.44	2.49	1.86	0.0056	0.0037	0.0044	0.0022	0.0038308	0.0029
180	10.19108	3.9	2.51	2.97	1.5	2.61	1.9	0.006	0.0039	0.0046	0.0023	0.0040154	0.0029
190	10.75725	4.24	2.59	3.1	1.54	2.73	1.96	0.0065	0.004	0.0048	0.0024	0.0042	0.003
200	11.32343	4.58	2.68	3.31	1.58	2.84	2.08	0.007	0.0041	0.0051	0.0024	0.0043692	0.0032
220	12.45577	5.1	2.81	3.51	1.67	3.07	2.29	0.0078	0.0043	0.0054	0.0026	0.0047231	0.0035
240	13.58811	5.78	3.01	3.64	1.75	3.29	2.54	0.0089	0.0046	0.0056	0.0027	0.0050615	0.0039
260	14.72045	7.2	3.21	4.1	1.83	3.53	2.66	0.0111	0.0049	0.0063	0.0028	0.0054308	0.0041
280	15.8528	7.95	3.33	4.33	1.89	3.74	2.83	0.0122	0.0051	0.0067	0.0029	0.0057538	0.0044
300	16.98514	8.64	3.53	4.57	1.95	3.99	2.99	0.0133	0.0054	0.007	0.003	0.0061385	0.0046
320	18.11748	8.95	3.68	4.8	2.03	4.22	3.15	0.0138	0.0057	0.0074	0.0031	0.0064923	0.0048
340	19.24982	9.44	3.84	5.08	2.1	4.49	3.37	0.0145	0.0059	0.0078	0.0032	0.0069077	0.0052
360	20.38217	9.93	4.02	5.37	2.26	4.78	3.58	0.0153	0.0062	0.0083	0.0035	0.0072769	0.0055
380	21.51451	10.02	4.28	5.64	2.34	5.13	3.77	0.0154	0.0066	0.0087	0.0036	0.0078923	0.0058
400	22.64685	10.64	4.43	5.9	2.4	5.49	3.98	0.0164	0.0068	0.0091	0.0037	0.0084462	0.0061
420	23.77919	10.81	4.6	6.27	2.49	5.98	4.22	0.0166	0.0071	0.0096	0.0038	0.0092	0.0065
440	24.91154	11.14	4.8	6.64	2.59	6.5	4.63	0.0171	0.0074	0.0102	0.004	0.01	0.0071
460	26.04388	11.49	5.09	7.14	2.68	7.34	4.97	0.0177	0.0078	0.011	0.0041	0.0112923	0.0076
480	27.17622	11.84	5.43	7.64	2.77	7.93	5.98	0.0182	0.0084	0.0118	0.0043	0.0122	0.0092
500	28.30856	12.16	5.56	9.33	2.85	8.35	8.76	0.0187	0.0086	0.0144	0.0044	0.013	0.0115
520	29.44091	12.56	5.65	-	2.97	-	10.06	0.0193	0.0087	-	0.0046	-	0.0118
540	30.57325	12.98	5.78	-	3.13	-	-	0.02	0.0089	-	0.0048	-	-
560	31.7	-	5.94	-	3.45	-	-	-	0.00	-	0.00	-	-

	0559								91		53		
580	32.83793	-	6.22	-	3.74	-	-	-	0.0096	-	0.0058	-	-
600	33.97028	-	6.43	-	-	-	-	-	0.0099	-	-	-	-
620	35.10262	-	6.64	-	-	-	-	-	0.0102	-	-	-	-
640	36.23496	-	6.9	-	-	-	-	-	0.0106	-	-	-	-
660	37.3673	-	7.2	-	-	-	-	-	0.0111	-	-	-	-
664	37.59377	-	7.38	-	-	-	-		0.0114	-	-	-	-

The load and deflection were plotted in the graph as shown in Figure 4a,4b and 4c for the CC and HFRC columns with varying reinforcements. The maximum load taken by CC1, CC2 and CC3 were 540, 503 and 494kN, respectively. With the increase in reinforcement provided, the load-carrying capacity also increases. Similarly, the concrete column added with fibre, i.e., HFRC1, HFRC2 and HFRC3, were taken the load of 664, 580 and 520kN, respectively. The addition of fibre in concrete could help the structure to withstand more load compared to the concrete without fibre. The column under axial load has shown up in a range of 11% to 18% increment of the load-carrying capacity with the addition of fibre. The fibre has influenced the load-carrying capacity along with the reinforcement provided in the concrete. The HFRC1 has the maximum load-carrying capacity of 664kN and thus shows the high confinement in the concrete can increase the ultimate load.



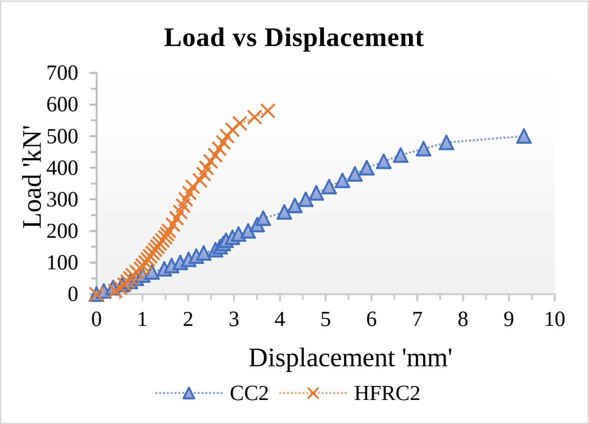


Figure 4a Load vs Displacement, CC1 & HFRC 1

Figure 4b Load vs Displacement, CC2 & HFRC2

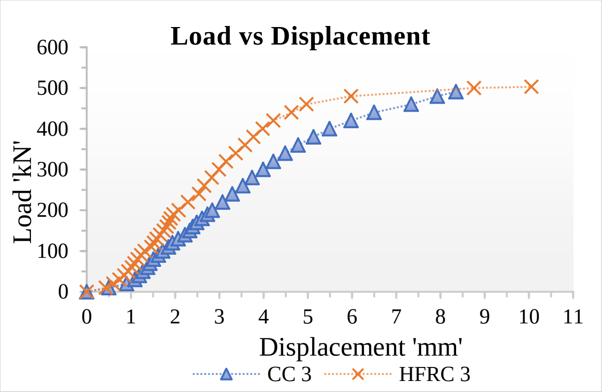


Figure 4c Load vs Displacement, CC3 & HFRC 3

The vertical deformation that occurred in the column with the application of the lateral load was measured using the deflectometer attached to the baseplate. The values measured were then tabulated in Table 2 and plotted in Figures 4a, 4b and 4c. The column with the fibre had less deformation with more load. The maximum deflection was found as 12.98mm for CC1 at the load of 540kN, whereas the minimum was recorded for the HFRC2 with the deformation of 3.74mm at 580kN. From the graphs, it is observed that the deformation at the early application of the load was almost nearby. While the load applied increases, the increment rate of the deformation for the CC was increases compared to the HFRC.

STRESS VS STRAIN

The strain of the columns for the different columns at each load was determined. The stress calculated and the respective strain for all the CC and HFRC columns are tabulated in Table 2.

Figure 5 is having the stress and strain plotted for the CC and HFRC columns. The graph clearly explains that the HFRC specimens were having the better resistance for the stress and lesser strains for the respective stress. The stress and the strain for CC and HFRC were compiled and compared. The maximum strain value of 0.02 was measured for the ultimate stress of 30.5N/mm^2 for the CC1 specimen. The respective fibre added specimen, i.e., HFRC1, was getting the strain of 0.0114 at its peak stress of 37.59N/mm^2.

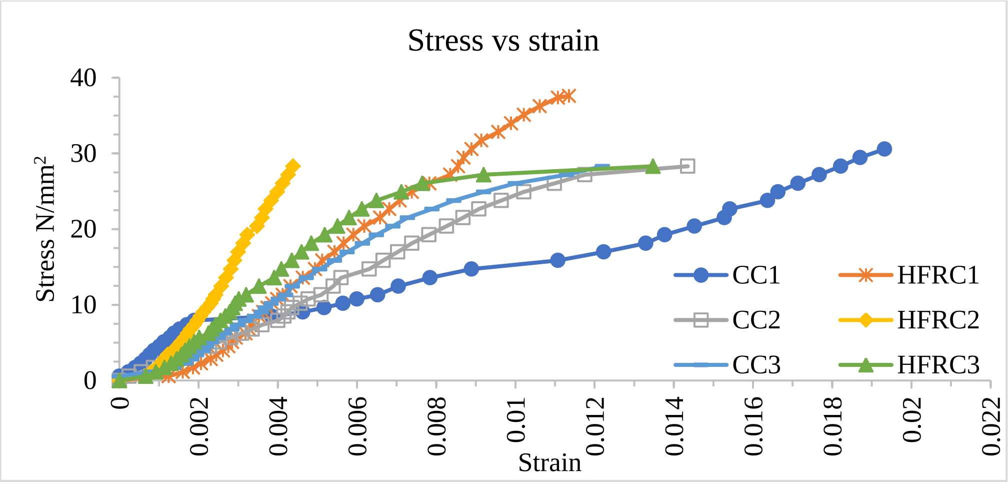


Figure 5 Stress vs Strain, CC & HFRC

The relationship shows that the addition of the fibre may resist major stress at limited strain. Similarly, for CC2 and CC3, the maximum strain was determined as 0.0144 and 0.013, respectively. The HFRC2 and HFRC3 were recorded with the maximum strain value of 0.0058 and 0.0118.

LATERAL BUCKLING

The lateral deformation of the column with the application of the axial load was measured using the deflectometer attached to the sides of the specimen. The specimen, while buckling with respect to each loading, was recorded and determined. The maximum buckling for the CC and HFRC columns is tabulated in Table 3. The maximum buckling of CC1, CC2 and CC3 were determined as 2.33, 4.13 and 4.42 mm, respectively. The reinforcement provided in the specimen helps to resist more buckling. Similarly, for HFRC1, HFRC2 and HFRC3, the buckling was determined as 0.57, 1.04 and 2.36 mm, respectively. While comparing the specimen with and without fibre, HFRC has nearly 4 times lesser lateral deformation. The addition of fibre along with the reinforcement provided could be able to resist the load against lateral deformation.

Table 3 Lateral displacement, CC and HFRC

Specimen details	**Maximum Load, p (kN)**	**Peak Stress, σ_{max} (N/mm^2)**	**Maximum lateral displacement, δ_l (mm)**
CC1	540	30.57325	2.33
HFRC1	664	37.59377	0.57
CC2	494	28.30856	4.13
HFRC2	580	32.83793	1.04
CC3	503	28.30856	4.42
HFRC3	520	29.44091	2.36

STIFFNESS AND MODULUS OF ELASTICITY

The stiffness of the CC and HFRC were determined with the load and deflection values. The stiffness of the column within the elastic limit ($k_{e)}$ and the maximum stiffness (k_{max}) are listed in Table 4. The calculated stiffness values are compared in the Figure 6 for CC and HFRC. The maximum stiffness within the elastic limit for CC1, CC2 and CC3 were found to be 43.67, 55.55 and 62.8 $\times 10^3$ N/mm, respectively. Similarly, for the HFRC1, HFRC2 and HFRC3 were determined as 84.08, 137.14 and 96.07 $\times 10^3$ N/mm, respectively. The stiffness of the column has increased more than 2 times with the addition of fibre than the conventional concrete. The maximum stiffness of the column was found for the HFRC2 with the value of 155.08 N/mm. The HFRC1 had more rigidity, thus reduces the ultimate stiffness than the HFRC2. Also, in CC, the column with less reinforcement had the maximum stiffness due to the reduced rigidity.

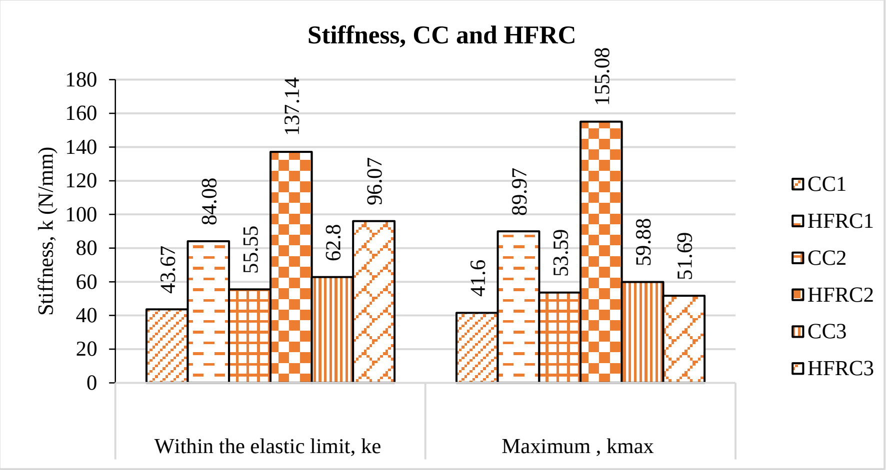


Figure 6 Stiffness, CC and HFRC

Table 4 Stiffness, CC and HFRC

Specimen details	**Maximum load in the elastic limit, p_e $\times 10^3$(N)**	**Maximum axial displacement within the elastic limit, δ_{ae} (mm)**	**Maximum axial stress within the elastic limit, σ_a (N/mm^2)**	**Maximum axial strain within the elastic limit, Δ_{lae}**	**Maximum stiffness within the elastic limit, k_e $\times 10^3$ (N/mm)**	**Maximum stiffness of the specimen, k_{max} (N/mm)**
CC1	200	4.58	11.32	0.007	43.67	41.6
HFRC1	280	3.33	15.85	0.0051	84.08	89.97
CC2	130	2.34	7.36	0.0036	55.55	53.59
HFRC2	240	1.75	13.59	0.0027	137.14	155.08
CC3	130	2.07	7.36	0.0032	62.8	59.88
HFRC3	220	2.29	12.45	0.0035	96.07	51.69

CONCLUSIONS

The study involves testing of CC and HFRC columns under axial loading. With the acquired results, the deflection, lateral deformation, corresponding stress and strain and the stiffness were determined and compared.

- The maximum deformation under axial load was compared, and the columns with fibre had a higher load-carrying capacity. The deformation was less in the HFRC with the increase in the loading. The HFRC was having a high load-carrying capacity of more than 20% than the CC. The HFRC1 column has the maximum load carrying capacity of 664kN which is due to the additional reinforcement of the fibre provided.

- The stress was calculated for the CC and HFRC columns with their load-carrying capacity. There was a comparable range of increase in the stress for the HFRC ranging 15% to 18% than CC. However, the strain was limited for HFRC than the CC, even with the increase in stress. Even with the maximum load taken by HFRC1, the strain was nearly 20% lesser compare to the CC columns.
- The addition of fibre has proved to be limiting the lateral buckling compared to CC columns. The CC columns had nearly 4 times more lateral displacement compare to the HFRC.
- Due to high rigidity, the stiffness of the CC and HFRC was in control for the higher reinforced concrete. The HFRC2 had better stiffness with a value of 155.08N/mm. The CC3 was having less reinforcement compare to other columns, and no additional confinement provided may be the reason for the high stiffness of all conventional concrete specimens.

REFERENCES

Vitor MAM, Leonardo RL and Flavio AS (2018) On the mechanical behaviour polypropylenes steel and hybrid fibre reinforced concrete *Construction and Building Materials* **188:** 280–291.

Antonio C, Paula F, Carmine L, Enzo M and Marco P (2017) On the mechanical response of hybrid fibre reinforced concrete with recycled and industrial steel fibers. *Construction and Building Materials* **147**: 286-295.

Hsie M, Tu C and Song PS (2008) Mechanical properties of polypropylene hybrid fiber-reinforced concrete. *Materials Science and Engineering A* **494**: 153–157

Weina M, Kamal H K and Yi B (2018) Flexural behaviors of fiber-reinforced polymer fabric reinforced ultra-high performance concrete panels. *Cement and Concrete Composites* **93**: 43–53

Aliakbar G and Togay O (2018) Fiber-reinforced concrete containing ultra-high-strength micro steel fibers under active confinement. *Construction and Building Materials* **187**: 299-306.

Theodoros CR, Athanasios IK, Panos DK, Ralejs T (2008) Analytical modeling of plastic behavior of uniformly FRP confined concrete members. *Compos. Part B* **39**: (7–8) 1104–1113.

Alper I, Onder P, Emre K, Cem D, Nahit K (2008) FRP retrofit of low and medium strength circular and rectangular reinforced concrete columns. *J. Mater. Civ. Eng.* **20**: (2) 169–188.

BIS (Bureau of Indian Standard) (1989) IS 8112-1989, *Specification for 43-Grade Ordinary Portland Cement*, BIS, New Delhi, India.

BIS (Bureau of Indian Standards) (2009) IS 10262-2009, *Guidelines for concrete mix design proportioning*, BIS, New Delhi, India.

Rathod D and Sundaramoorthy M (2021) Effect of hybrid E-glass and basalt fibre on the flexural behaviour of concrete. *Proceedings of the Institution of Civil Engineers - Construction Materials* , 1-11. https://doi.org/10.1680/jcoma.20.00051

ACI (American Concrete Institute) (2019) ACI 318-19, Building code requirements for reinforced concrete and commentary, Farmington Hills, United States of America.

Zhao HC, Ye YY, Zeng JJ, Zhou JK and Ouyang Y (2020), Polyethylene terephthalate fibre-reinforced polymer-confined concrete encased high-strength steel tube hybrid square columns: Axial compression tests, Structures 28, 577–588.

Wang YL, Cai GC, Li YY, Waldmann D, Larbi AS and Tsavdaridis KD (2019), Behavior of circular fiber-reinforced polymer-steel-confined concrete columns subjected to reversed cyclic loads: experimental studies and finite-element analysis, J. Struct. Eng. 145(9) :04019085.

Lin G, Zeng JJ, Teng JG and Li LJ (2020), Behavior of large-scale FRP-confined rectangular RC columns under eccentric compression, Eng. Struct. 216 : 110759 https://doi org/10.1016/j.engstruct.2020.110759

BIS (Bureau of Indian Standard) (2000) IS456-2000, Indian Standard Plain and Reinforced Concrete Code of Practice. BIS, New Delhi, India

Na L, Yiyan L, Shan L and Danying G (2020), Axial compressive behaviour of steel fibre reinforced self-stressing and self-compacting concrete-filled steel tube columns, Engineering Structures 222, https://doi.org/10.1016/j.engstruct.2020.111108

Punmia BC, Ashok Kumar Jain & Arun Kumar Jain, 2011. Limit State Design of Reinforced Concrete. Laxmi Publications (P) Ltd, New Delhi, © 2007, reprinted 2011: 63 & 397.