STRUCTURAL PERFORMANCE OF BASALT FIBRE REINFORCED CONCRETE MADE WITH GGBFS AND RECYCLED AGGREGATE AS INGREDIENTS

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Abstract

Around the world, concrete is one of the second most consumed material only next to water and the amount of consumption was increased was rapidly increasing over the past few decades due to rapid growth in industrialization and urbanization. Because of continuous consumption of different ingredients of concrete results in drastic depletion of natural resources and demand on such ingredients also getting increased. In this study, fibre reinforced concrete of grade M30 was made with GGBFS (Ground Granulated Blast Furnace Slag) and RCA (Recycled Concrete Aggregate) obtained from C & D Waste (Construction and Demolition waste) were utilized as a substitute material for cement (0% to 50% at an interval of 10%) and coarse aggregate (0% to 100% at an interval of 20%) respectively. In addition, BF (Basalt Fibre) was added into the concrete mix by 0% to 0.9% at an interval 0.3%. Optimum level of GGBFS replacement and BF addition were determined with the help of strength properties and the RCA content was keep on varying from 0% to 100%. In this article, RC (Reinforced Concrete) beams were made with BFRC (Basalt Fibre Reinforced Concrete) which is of size 150*200*1800mm. Totally 6 beams were prepared with BFRC in order to check the structural behaviour of RC Beams. Numerical investigation was conducted on the RC beams with the help of finite element software (ANSYS) and the results were compared with the experiments. This study mainly focuses on structural performance of RC beams like load vs deflection behaviour and crack analysis.

Keywords: Basalt Fibre, BFRC, C & D Waste, GGBFS, Structural performance

1. Introduction

In Developing countries like India, economic growth of the country depends directly on the industrialization and infrastructure development of the country. Most of constructions made in recent decades were prepared as framed constructions by utilizing concrete as the main ingredient. As infrastructure continues to grow, cement production in India is reached 500 million tonnes by the end of 2020 and it may expect to reach 800 million tonnes by the end of the next decade (2030) [3]. On the other hand, production of cement will also release same amount of CO_2 into the atmosphere, it will also lead to various social and environmental issues like ozone depletion, greenhouse gases, global warming, etc., So, scientists, engineers and researchers are vigorously looking for utilization of the alternative binding material which are having almost similar characteristics of cement.

On the other hand, disposal problems associated with GGBFS obtained from blast furnaces which are used in cement and iron industry, which is rich in silica and alumina content [2]. In order to modify the cementitious properties of GGBFS, the molten slag must be cooled rapidly upon exiting the blast furnace. Quenching and cooling diminishes crystallization and converts molten slag into fine grained particles, typically smaller than a 4.75mm sieve [10]. Utilization of GGBFS in concrete will greatly reduce the amount of water content required. Hence, it could be a better alternative to cement which might also reduce the disposal problems associated with them [12, 13].

Basalt fibres are naturally available non-toxic materials, relatively cheap and available in chopped forms. When BF is added into concrete, they are responsible for strength, rigidity and reduction in shrinkage of concrete [1, 5].

Due to modern quarrying techniques, quarrying and consumption of aggregates around the world increases rapidly. It may result in various social and environmental problems. Because of the consistent efforts taken against the natural resource's depletion, the consumption of natural aggregates gets reduced and innovation of alternative materials for coarse aggregate (CA) were done [3, 4]. Dynamic efforts taken by the researchers, scientists and engineers; number of alternative materials were found which could be acting as a better alternative to CA. On the other hand, disposal of C & D wastes obtained from demolition of smaller structures is challenging task for the engineers [4]. Productive usage of such waste materials will reduce the overall cost of construction. It is also observed that, after primary and secondary dismantling, C & D wastes are at a size of 20mm which could be utilized as a CA or volume filler in concrete [7, 8].

Hence, in this investigation, cement and CA was partly substituted by GGBFS and processed RCA and BF's was added into the concrete in varying proportions (see Figure 1). In order to predict the performance of these materials in concrete, strength and structural behaviour of concrete mixes were determined at varying curing periods.

Figure 1 Main Ingredients of BFRC**.**

2. Properties of Ingredients

Different ingredients were utilized in the manufacturing of BFRC are as follows:

2.1 Binders

In this investigation, OPC 53 grade cement and GGBFS obtained from manufacturing of pig iron were used as the basic binding agents in BFRC [13]. GGBFS is generally siliceous in nature which is having 38.24% SiO_2, 36.82% CaO and 18.4% Al_2O_3 and 6.54% other alkalis. Physical properties of binders were illustrated in Table 1.

Table 1 The process yield and physical properties of the microcapsules.

Property	OPC 53	GGBFS
Bu. De (kg/m^3)	1650	1220
Color	Grey	Off white
Sp. Gr	3.15	2.94
Sp. Su. Ar (m^2/kg)	290	410

[Bu. De* **-** Bulk Density; Sp. Gr* **-** Specific Gravity; Sp. Su. Ar* **-** Specific Surface Area]

2.2 Aggregates

Aggregates are majorly characterized for their specific ability of volume filling in concrete of almost 60-75% of total volume. River sand confirms to Zone II and crushed gravels were the natural aggregates utilized in this investigation which occupies most spaces in the volume of concrete [14], and their respective properties were illustrated in Table 2. Recycled aggregates got from C & D wastes were utilized as a substitute material for CA and their physical properties are shown in Table 3. Gradation of each aggregates were determined by conducting sieve analysis which is shown in Figure 2.

Table 2 Properties of Natural Aggregates

Property	River sand	Gravel
Max. size (mm)	4.75	20
Shape	Spherical	Angular
Sp. Gr	2.62	2.58
Fi. Mo	2.64	6.54
Bu. De (kg/m^3)	1725	1520
Wa. Ab (%)	0.95	1.10
C & I Value (%)	-	21.5 & 14.5

[Fi. Mo* - Fineness Modulus; Wa. Ab* - Water Absorption; C & I Value* - Crushing & Impact Value]

Table 3 Properties of Recycled Aggregate

Property	Recycled Aggregate
Max. size (mm)	20
Shape	Irregular
Sp. Gr	2.44
Fi. Mo	6.38
Bu. De (kg/m^3)	1275
Wa. Ab (%)	3.20
I Value (%)	13.8

[I Value* - Impact Value]

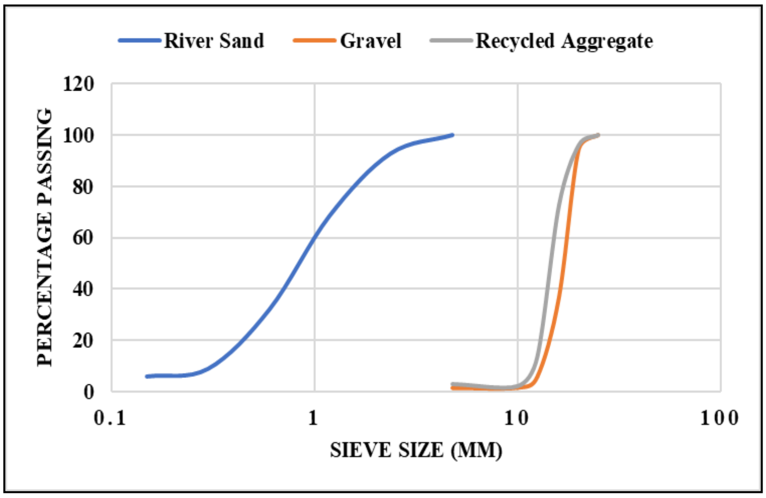

Figure 2 Sieve Analysis on Aggregates

2.3 Basalt Fibre

Commercially available chopped basalt fibre was utilized in this study which is having specific gravity of 2.75, tensile strength and modulus of elasticity are 4kN/mm^2 and 87*10^{3}N/mm^2 respectively [5, 18].

2.4 Fluid Content

Conventional potable drinking water confirmatory to BIS 456:2000 was used in the preparation and curing of concrete specimens. To alter the workability of BFRC, Conplast SP430 of 2.5% was added into the concrete matrix whenever required.

3. Mix Proportion

BFRC of M30 grade was designed with ingredients which are possessing the above-mentioned properties as per the specifications prescribed in BIS 10262:2019 and the same is illustrated in Figure 3 [14, 30]. Final Mix ratio arrived in this investigation after all corrections is 1:1.37:2.5 with a w/c ratio of 0.4.

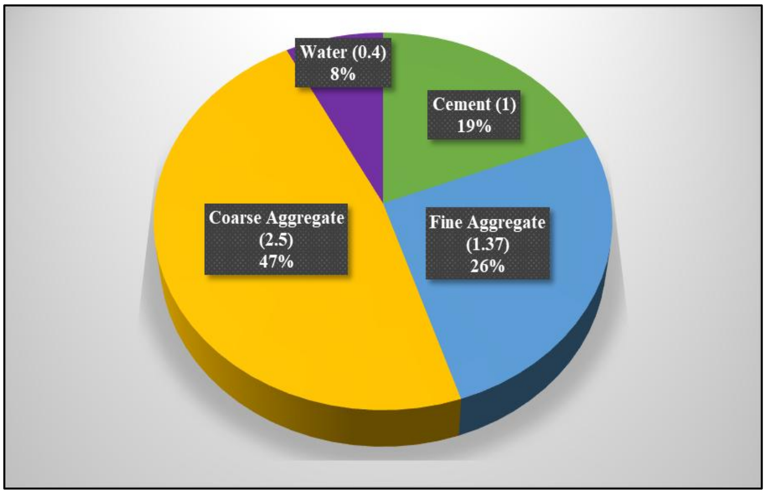

Figure 3 Mix Proportion for M30 grade BFRC

4. Experimental Investigation

In this article, strength and structural performance of BFRC specimens made with varying proportions of GGBFS, BF and RCA were studied thoroughly. Experimentation was done in two phases. First phase is about the strength properties of BFRC specimens which deals with the optimization of GGBFS, BF with the help of various strength properties of concrete [7, 23]. In second phase, the structural performance of RC beams made with the optimum parameters derived in previous stage were studied and the results were compared with the numerical results from finite element software package (ANSYS).

4.1 Strength Properties

4.1.1 Performance of GGBFS and BF on strength properties of BFRC

Optimization of different ingredients utilized for the manufacturing of concrete will get huge effort to derive experimentally. At the initial stage, cement was partly replaced by GGBFS (0%, 10%, 20%, 30%, 40% and

50%) and BF (0%, 0.3%, 0.6% and 0.9%) was added into the concrete mix [24, 10]. Based on the strength properties (Compressive strength – CS), optimum replacement and addition of GGBFS and BF were derived and used for further parts of the investigation.

Table 4 Strength Properties of BFRC made with GGBFS and BF

Mix ID	GGBFS – % replacement	BF - % addition	CS (MPa) @ varying curing periods (days)			
			3	7	14	28
BFRC-0-0	0	0	16.0	28.0	33.9	38.7
BFRC-10-0	10	0	16.6	29.2	35.2	40.3
BFRC-20-0	20	0	17.3	30.3	36.6	41.9
BFRC-30-0	30	0	17.8	31.3	37.9	43.2
BFRC-40-0	40	0	16.7	29.3	35.4	40.4
BFRC-50-0	50	0	15.6	27.4	33.1	37.9
BFRC-0-0.3	0	0.3	16.2	28.7	36.2	40.4
BFRC-10-0.3	10	0.3	17	29.7	37.5	41.9
BFRC-20-0.3	20	0.3	17.9	31.8	39.1	43.6
BFRC-30-0.3	30	0.3	18.9	32.3	40.5	44.9
BFRC-40-0.3	40	0.3	16.7	30.9	37.8	42.2
BFRC-50-0.3	50	0.3	15.8	28.1	35.3	39.4
BFRC-0-0.6	0	0.6	17.1	28.3	38.3	42.7
BFRC-10-0.6	10	0.6	17.7	29.5	39.7	44.3
BFRC-20-0.6	20	0.6	18.4	30.4	41.2	46.0
BFRC-30-0.6	30	0.6	20.0	34.0	42.7	47.4
BFRC-40-0.6	40	0.6	17.8	29.5	40.0	44.6
BFRC-50-0.6	50	0.6	16.6	27.5	37.3	41.6
BFRC-0-0.9	0	0.9	14.2	24.6	31.9	35.6
BFRC-10-0.9	10	0.9	14.8	25.7	33.1	36.9
BFRC-20-0.9	20	0.9	15.4	26.4	34.4	38.4
BFRC-30-0.9	30	0.9	16.7	27.7	35.7	39.6
BFRC-40-0.9	40	0.9	14.9	24.6	33.3	37.2
BFRC-50-0.9	50	0.9	13.9	23.0	31.1	34.7

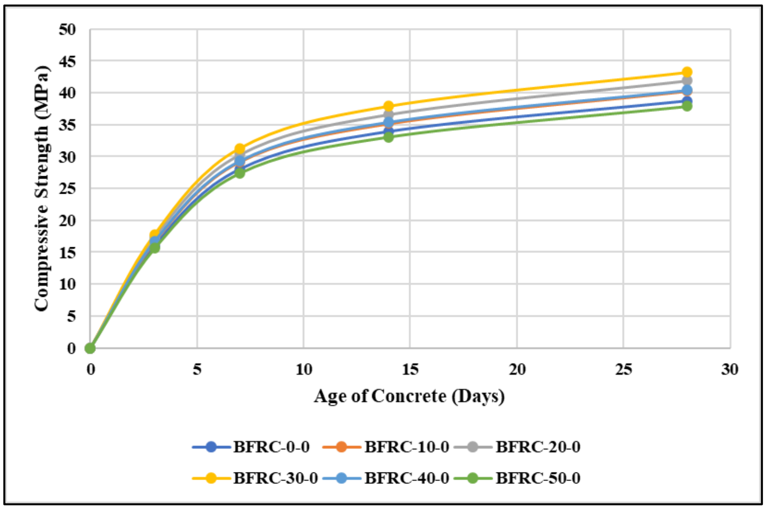

Figure 4 Age vs Strength of BFRC (0% BF)

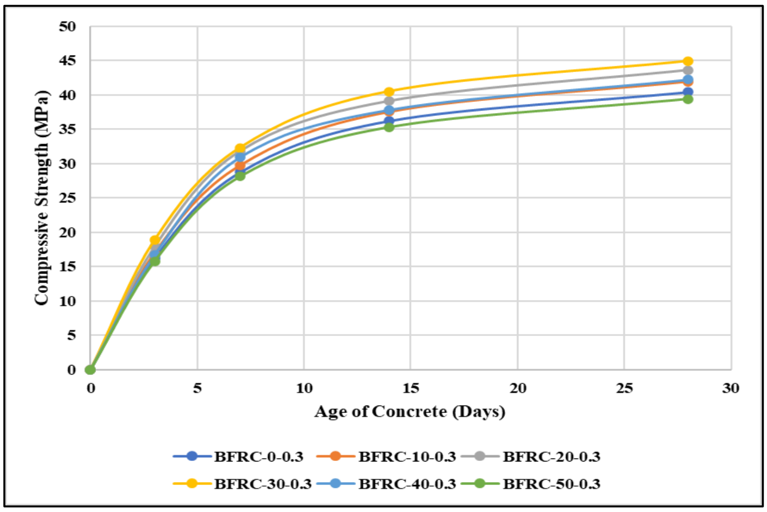

Figure 5 Age vs Strength of BFRC (0.3% BF)

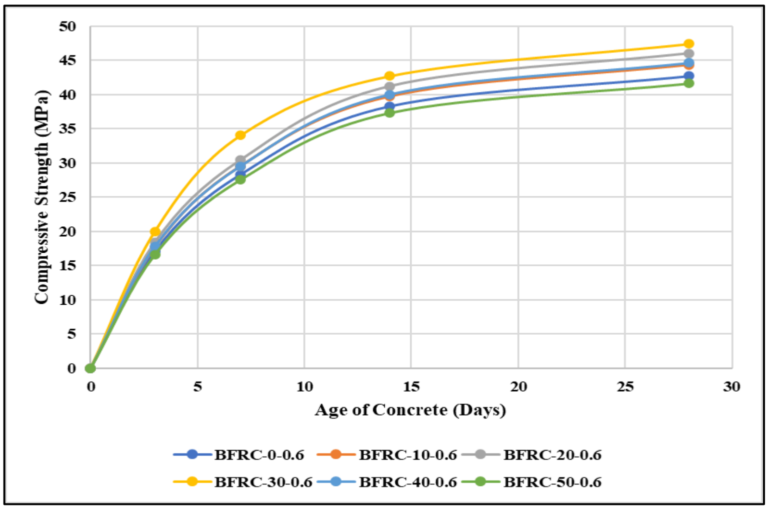

Figure 6 Age vs Strength of BFRC (0.6% BF)

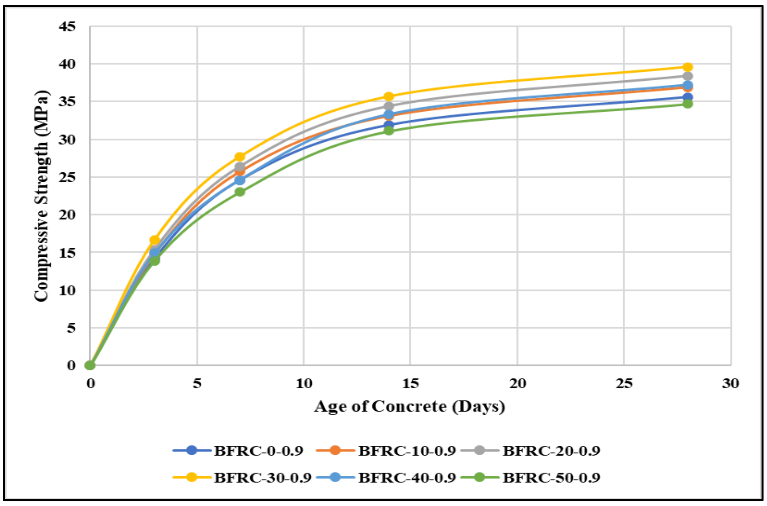

Figure 7 Age vs Strength of BFRC (0.9% BF)

Since GGBFS has 36.82% of CaO, the rate of strength attainment is slow at earlier ages and they greatly reduce the amount of water content required which is results in reduction of heat of hydration. From figure 4 to 7, it is found that the GGBFS replacement at 30% replacement level produces higher strength in all ages and all combinations of fibre content. Kaviya et al (2017) [16] concluded that the replacement of cement by GGBS will give better results up to 30% replacement level, but according to Chaithra et al (2015) [17] the replacement of cement by GGBS was increased to 40% when the conventional river sand is replaced by quarry sand. Hence it is concluded that the optimum replacement percentage of GGBFS by cement was 30% which was utilized in the further parts of this investigation.

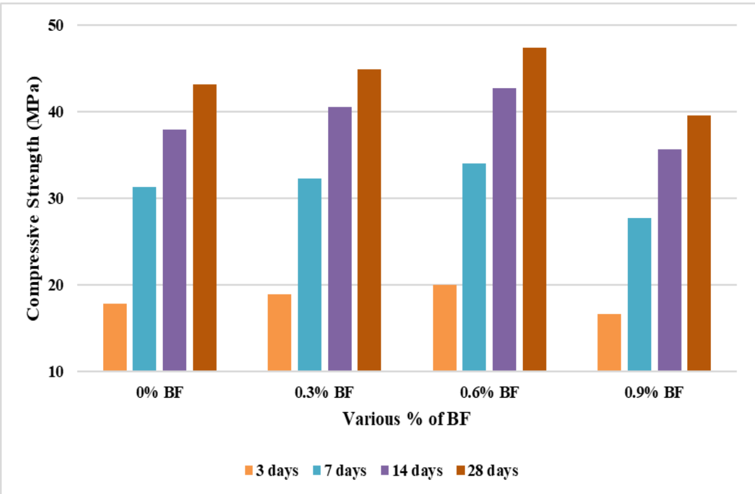

Figure 8 Effect of BF on Strength Properties of BFRC

From figure 8, it is observed that addition of 0.6% BF into the concrete mix will produce better results in all ages of concrete. According to Kirthika et al (2018) [20] and Venkada Priya et al (2020) [22] concluded that the utilization of basalt fibre in BFRC, the optimum results were obtained at 0.5% addition of BF based on strength properties. It is found that the usage of BF in BFRC made with 30% replacement of GGBFS increases the optimum strength properties at 0.6% of BF. Hence the optimum percentage of adding BF in M30 grade concrete was considered as 0.6% was further utilized in the next stages of the investigation.

4.1.2 Performance of RCA on strength properties of BFRC

Recycled concrete aggregates obtained from C & D wastes were processed before they are utilized in the production of BFRC. RCA replaces the coarse aggregate content by 0% to 100% at an interval of 20% in BFRC, and the replacement percentage of cement by GGBFS and percentage of BF addition was kept constant as 30% and 0.6% respectively [14, 23]. The strength properties (Strength under Compression, Split tension and Flexural - CS, STS and FS) were evaluated at varying periods of curing and tabulated in Table 5 to 7.

Table 5 % Replacement of RCA on Strength Properties of BFRC (A)

Mix ID	% replacement of RCA	CS (MPa) @ varying periods (Days)			
		3	7	14	28
BF-0-RC	0	20.0	34.0	42.7	47.4
BF-20-RC	20	20.8	33.4	44.6	49.5
BF-40-RC	40	22.4	35.8	47.9	53.1
BF-60-RC	60	19.6	31.3	41.8	46.4
BF-80-RC	80	18.0	28.7	38.4	42.6
BF-100-RC	100	14.6	23.3	31.2	34.6

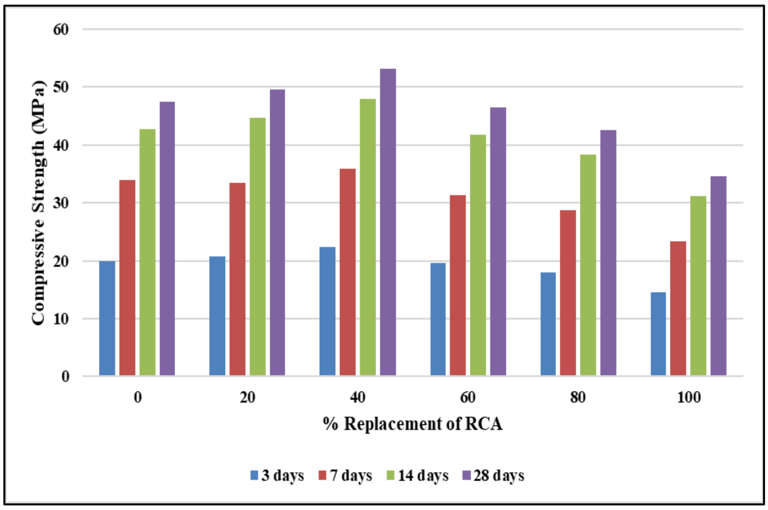

Figure 9 Replacement of RCA on Strength Properties of BFRC (A)

Table 6 % Replacement of RCA on Strength Properties of BFRC (B)

Mix ID	% replacement of RCA	STS (MPa) @ varying periods (Days)

		3	7	14	28
BF-0-RC	0	2.51	3.17	3.67	3.9
BF-20-RC	20	2.56	3.24	3.75	3.98
BF-40-RC	40	2.65	3.36	3.88	4.13
BF-60-RC	60	2.48	3.14	3.63	3.85
BF-80-RC	80	2.38	3.01	3.48	3.69
BF-100-RC	100	2.15	2.71	3.13	3.32

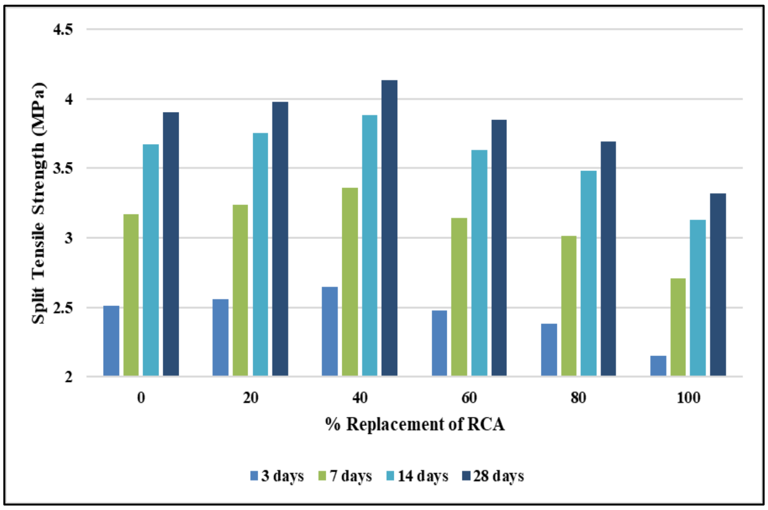

Figure 10 Replacement of RCA on Strength Properties of BFRC (B)

Table 7 % Replacement of RCA on Strength Properties of BFRC (C)

Mix ID	% replacement of RCA	FS (MPa) @ varying periods (Days)			
		3	7	14	28
BF-0-RC	0	3.16	3.94	4.37	4.73
BF-20-RC	20	3.23	4.02	4.47	4.84
BF-40-RC	40	3.34	4.17	4.63	5.02
BF-60-RC	60	3.13	3.90	4.33	4.68
BF-80-RC	80	3.00	3.73	4.15	4.48
BF-100-RC	100	2.70	3.36	3.74	4.03

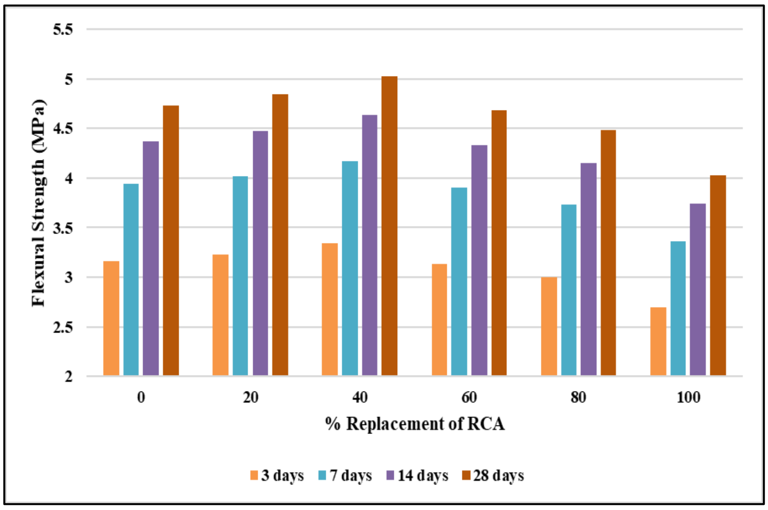

Figure 11 Replacement of RCA on Strength Properties of BFRC (C)

Utilization of RCA content in BFRC greatly influences the strength properties of concrete. Up to 40% replacement of CA by RCA shows increment in strength properties, further increase in RCA content gradually reduces the strength properties at all ages of concrete. According to Limbachiya et al. (2000) [15] and Mandal et al. (2002) [21] found that RCA had zero influence on the CS of concrete up to 30% replacement by weight; However, the CS decreased by more than 30% for the RCA content. Hence, 40% replacement of RCA with coarse aggregate was utilized for the remaining parts of the investigation.

4.2 Structural Properties

Totally 6 beams were casted with BFRC mixes and cured for 28 days which are made with 30% of GGBFS and 0.6% of BF with varying percentages of RCA content from 0% to 100% at an interval of 20%. Beam of size 150 * 200 * 2000mm with a supported length of 1800mm [2]. Clear cover provided reinforcement in all directions is 25mm. Reinforcement detailing and dimensions of RC beams were illustrated in Figure 12.

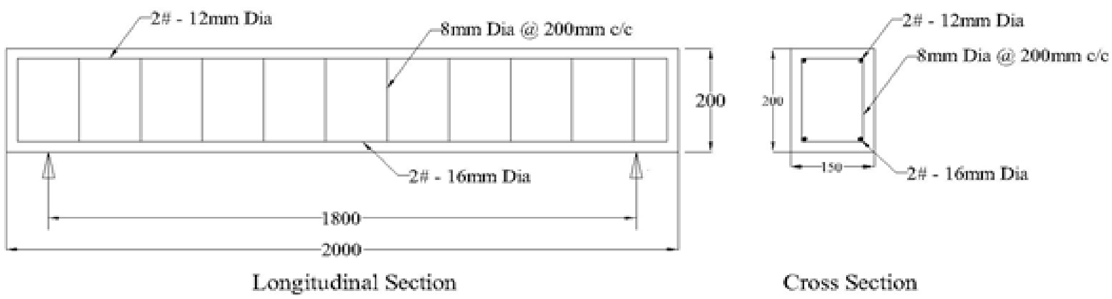

Figure 12 Reinforcement detailing of RC Beams

4.2.1 Experimental investigation on Structural properties of RC Beams

The beams were loaded with two point linear loading conditions and the deflections were measured with the help of LVDT at three different locations such as mid span and (L/3) distance from both supports [6]. Collected data on load and midspan deflections were mentioned in Table 8 whereas the summary of investigation was shown in Table 9 and 10.

Table 8 Load vs Deflection Values

0% RCA		20% RCA		40% RCA		60% RCA		80% RCA		100% RCA	
P (kN)	Δ (mm)	P (kN)	Δ (mm)	P (kN)	Δ (mm)	P (kN)	Δ (mm)	P (kN)	Δ (mm)	P (kN)	Δ (mm)
0	0	0	0	0	0	0	0	0	0	0	0
4.38	0.96	5.45	1.24	5.05	1.09	5.59	1.35	5.74	1.34	4.94	0.82
9.12	1.50	11.29	1.88	10.51	1.71	11.57	2.05	10.69	2.03	15.33	2.35
13.79	2.20	16.24	2.50	15.88	2.50	16.64	2.73	15.93	2.83	20.71(IL)	2.92
18.72	3.00	25.21(IL)	3.62	21.55	3.42	22.95	3.95	21.43	3.90	25.44	3.43
23.44(IL)	3.51	28.20	4.24	26.71	4.01	27.48(IL)	4.63	26.63(IL)	4.45	30.55	4.05
27.85	4.03	33.68	5.14	30.14(IL)	4.59	34.51	5.61	32.78	5.14	35.72	4.81
33.08	4.75	39.15	5.81	38.09	5.42	40.12	6.34	37.19	5.86	40.91	5.63
37.56	5.53	44.98	6.79	43.24	6.30	46.10	7.41	43.02	7.27	46.58	6.57
42.02	6.29	50.80	7.92	48.37	7.75	52.06	8.64	48.05	8.48	51.11	7.45
46.85	7.18	56.43	8.98	53.94	8.19	57.83	9.80	53.38	9.41	56.67	8.32
51.50	8.04	61.74	10.02	59.29	9.66	63.28	10.94	58.93	10.52	61.60	9.34
56.47	8.89	67.90	11.37	65.01	10.13	69.59	12.41	64.05	11.58	66.97	10.50
61.21	10.05	73.39	14.66	70.47	11.46	75.22	15.99	69.59	13.10	71.98	13.31
70.71	12.79	79.00	18.84	81.41	14.58	80.97	20.56	74.92	16.38	76.90	18.15
75.38	17.73	83.05	23.98	86.79	20.21	85.11	26.16	80.34	21.55	81.81(UL)	22.57
76.75	19.70	84.30(UL)	24.84	87.22	22.46	86.40(UL)	27.11	83.33	25.86	80.55	25.00
78.24(UL)	22.71	83.31	28.13	90.21(UL)	25.89	85.38	30.70	85.10(UL)	29.90	80.18	28.41
77.25	28.74	81.84	31.23	88.94	30.84	83.87	34.08	84.06	35.51	79.87	31.82

[P* - Load; Δ* - Midspan Deflection; IL* - Initial Crack Load; UL* - Ultimate Load]

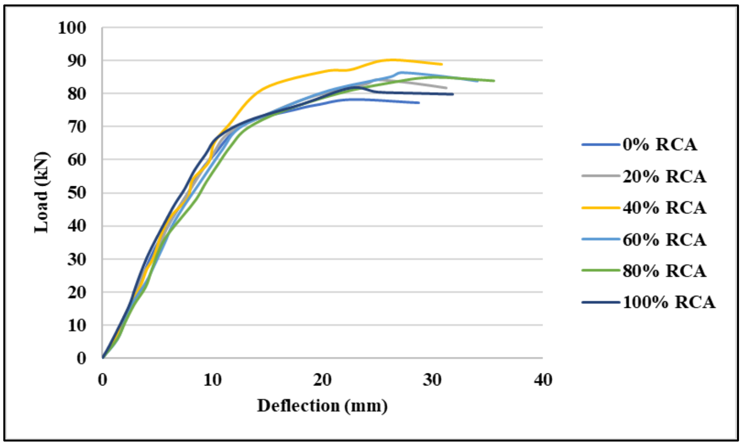

Figure 13 Load vs Deflection curves

Table 9 Load carrying capacities of RC Beams

% of RCA Replacement	IL (kN)		UL (kN)		P_{ini} / P_u (%)	UD (mm)	
	P_{ini} (kN)	% Diff.	P_u (kN)	% Diff.		(mm)	% Diff.
0	23.4	-	78.2	-	29.92	28.74	-
20	25.2	7.69 (↑)	84.3	7.80 (↑)	29.89	31.23	8.66 (↑)
40	30.1	28.63 (↑)	90.2	15.35 (↑)	33.37	30.84	7.31 (↑)
60	27.5	17.52 (↑)	86.4	10.49 (↑)	31.83	34.08	18.58 (↑)
80	26.6	13.68 (↑)	85.1	8.82 (↑)	31.26	35.51	23.56 (↑)
100	20.7	11.54 (↓)	81.8	4.60 (↑)	25.31	31.82	10.72 (↑)

[UD* - Ultimate Mid Span Deflection]

Table 10 Crack analysis

% of RCA Replacement	Crack Length (mm)		Crack Width (mm)	
	@ IL	@ UL	@ IL	@ UL
0	5	11	0.7	3
20	6	10.7	0.7	2.9
40	5	10.2	0.7	2.3
60	6	10.5	0.8	2.6
80	6	11	0.9	2.7
100	7	11.7	0.9	3

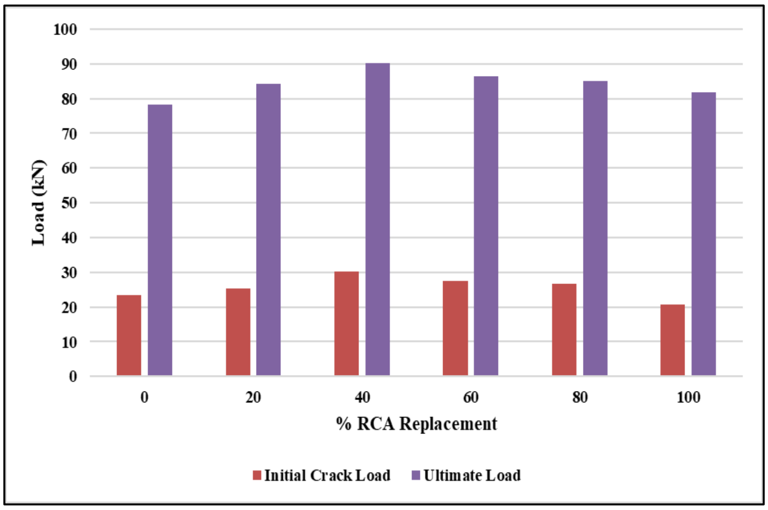

Figure 14 Comparison of Load Carrying capacity of RC Beams

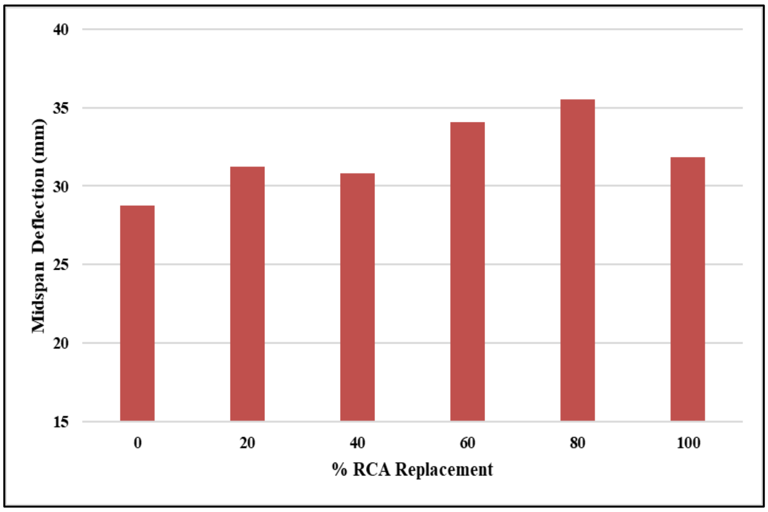

Figure 15 Comparison of Mid span deflection

The flexural test on RC beams showed that both the initial crack load and the ultimate load carried by the specimens increased as the percentage of RCA material replaced with the natural coarse aggregate increased. Whereas in RCC beams the 100% replacement of RCA content does not create any marginal increase in strength properties [24, 25]. From figure 14, it is concluded that the 40% replacement of RCA shows better resistance against flexural loading whereas it carries an initial crack and ultimate load of 29kN and 99kN respectively which is 26.1% and 23.8% higher than the RC beams made without RCA content. Increase in quantity of RCA reduces the strength gradually beyond the replacement of 40%, but considerable improvement in resistance was observed due to the utilization of basalt fibre and GGBFS which creates a better bonding between the ingredients of BFRC.

4.2.2 Numerical investigation on Structural properties of RC Beams

Recently, numerical investigation has become one of the best ways to predict the behavior of structure, heat, and fluid problems without experimentation. Hence, in this investigation, numerical investigation on RC beams under two-point linear loading was conducted by finite element software package of ANSYS 19.2 which is helpful in determining the behaviour of RC beams within short duration and higher accuracy [9, 27]. The various properties of components of RC beams were illustrated in Table 11 and the figures 16 to 18 explains the various steps involved in the analysis of beams in ANSYS workbench.

Table 11 Properties of different components of RC beams

Material	Property	Value
Concrete	Ultimate CS (MPa)	53.1
	Ultimate STS (MPa)	4.15
	E (GPa)	36.38
	f_{ck} (MPa)	30

Rebars, Loading and Supporting blocks	E (GPa)	210
	1/m	0.31

[E* - Young's Modulus; 1/m* - Poisson's ratio]

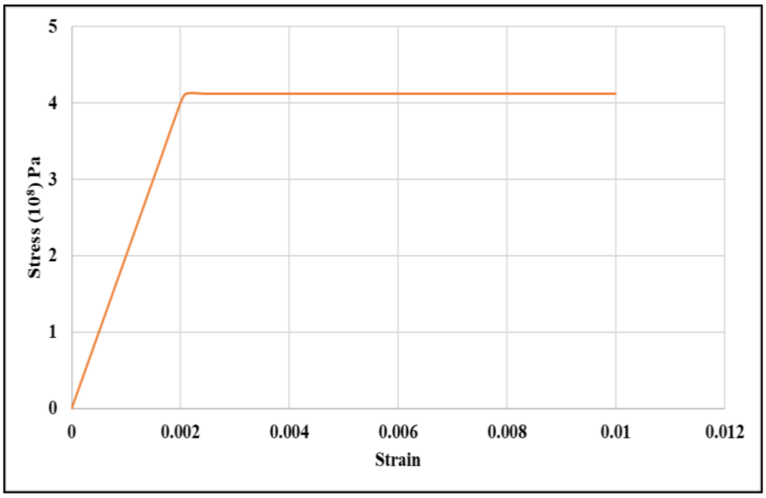

Figure 16 Stress Strain curve for Concrete

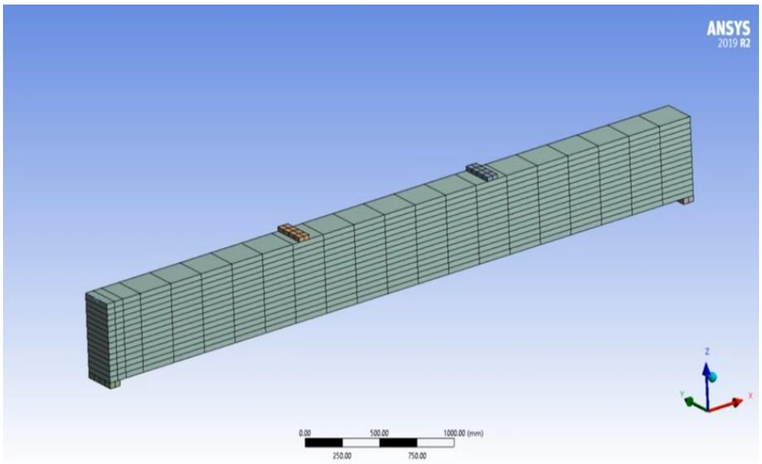

Figure 17 Completed Beam Model

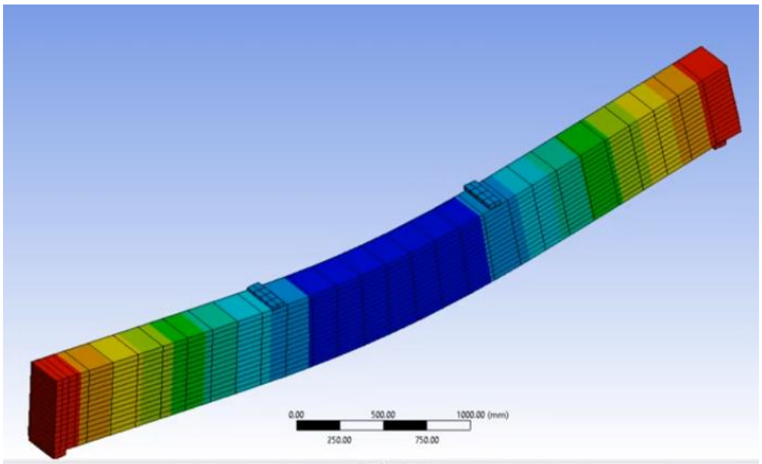

Figure 18 Deformation of beams along z axis

Table 12 Comparison of Experimental and Numerical Results

% of RCA Replacement	IL (kN)			UL (kN)			UD (mm)		
	Ex.R	Nu.R	Ex.R/Nu.R	Ex.R	Nu.R	Ex.R/Nu.R	Ex.R	Nu.R	Ex.R/Nu.R
0	23.4	28.3	0.83	78.2	84.7	0.92	28.74	30.17	0.95
20	25.2	30.7	0.82	84.3	91.9	0.92	31.23	32.38	0.96
40	28.8	32.2	0.89	88.5	96.3	0.92	33.8	33.16	1.02
60	27.5	31.5	0.87	86.4	94.2	0.92	37.08	34.91	1.06
80	26.6	28.5	0.93	85.1	85.1	1.00	35.51	35.83	0.99
100	20.7	27.1	0.76	81.8	80.8	1.01	31.82	38.76	0.82
Mean			0.85			0.95			0.97
Standard deviation			0.06			0.04			0.08

[Ex.R* - Experimental Results; Nu.R* - Numerical Results]

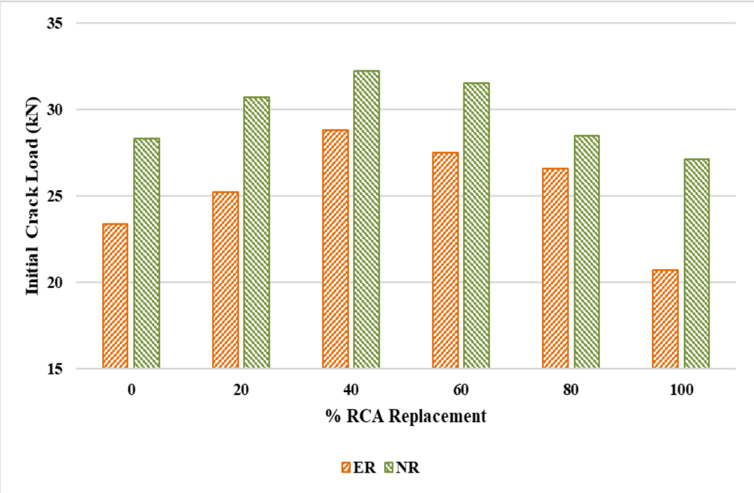

Figure 19 Comparison of IL

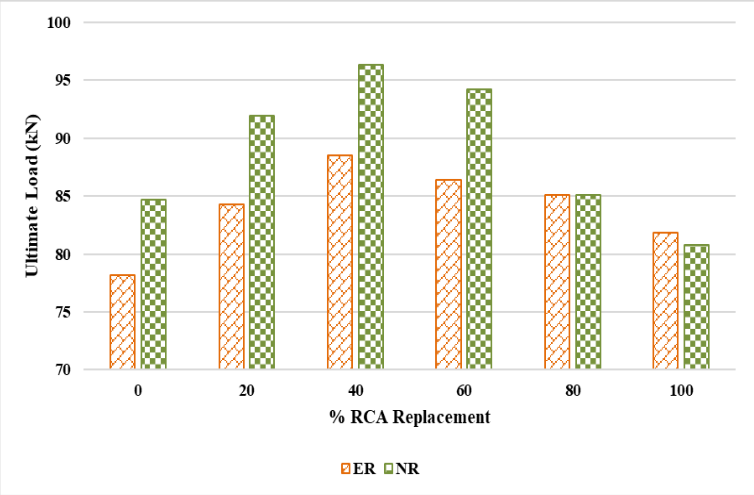

Figure 20 Comparison of UL

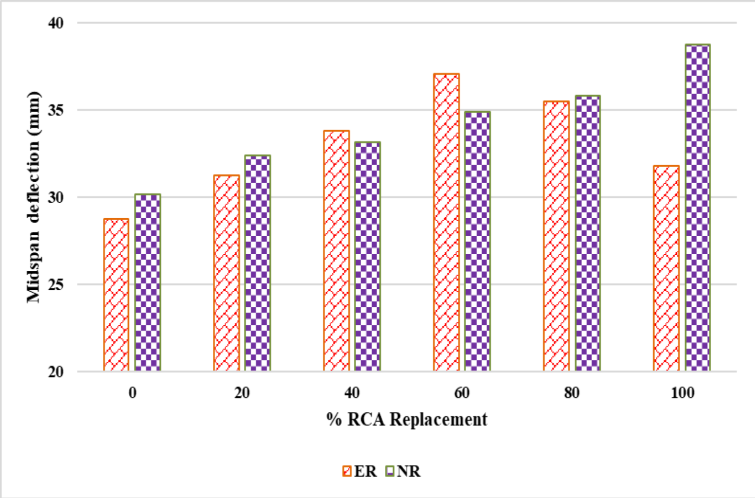

Figure 21 Comparison of UD

5. Conclusions

The following are the conclusions are obtained from the detailed investigation carried out on BFRC specimens made with varying proportions of GGBFS, RCA and BF.

- Utilization of cheap and waste materials like GGBFS, RCA and BF in concrete could be a better alternative for the various ingredients of concrete like cement and coarse aggregate.
- Basalt fibres are added into the concrete in order to reduce the shrinkage effect of concrete and thereby increases the strength of concrete to some extent.
- Notable results were observed in BFRC specimens when they are made with 30% of GGBFS and 0.6% of BF under the considerations on strength properties which produces results 11 ± 1.5% than the conventional mixes in respective mixes.
- It is also observed that the attainment of strength in earlier ages of concrete was slower than the attainment of strength in later ages.
- Optimum results were observed when the usage of RCA in BFRC up to 40% replacement which is producing 12.03% better results than the specimens made without RCA. Further increase in RCA content will gradually reduces the strength properties at all ages of curing.
- Load vs deflection behaviour of RC beams made with different proportions of RCA almost show similar nature.
- It is concluded that the 40% replacement of RCA shows better resistance against flexural loading whereas it carries an initial crack and ultimate load of 30.1kN and 90.2kN respectively which is 28.63% and 15.35% higher than the RC beams made without RCA content.

- Numerical results predicted on RC beams under two point linear loading, correlates well with the experimental results such as standard deviation of number of results on IL, UL and UD were 0.06, 0.04 and 0.08 respectively.

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