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INVESTIGATION ON BEHAVIOR OF BASALT FIBRE REINFORCED CONCRETE MADE WITH GGBFS, CONCRETE DEBRIS AND OPTIMIZATION OF INGREDIENTS

E. Rani
Research Scholar, Department of Civil Engineering,
Dr. M.G.R University, Chennai, Tamilnadu, India.

Dr. T. Felix Kala
Professor, Department of Civil Engineering, Dr. M.G.R University, Chennai, India

ABSTRACT

Rapid urbanization and globalization enhance the growth of a country. Over the past few decades, investments on the development of infrastructure facilities of the nation gets huge importance and the same which results in increasing demand on raw materials utilized for the construction such as cement and aggregates. On the other hand, there are numerous problems were arising when the disposal of slags and concrete debris takes place directly to the environment. In order to solve both the problems, it is proposed to utilise the disposed waste materials in the environment as a substitute material for concrete ingredients. In this study, cement and coarse aggregate were replaced partially by ground granulated blast furnace slag (GGBFS) (0% to 50% at an interval of 10%) and demolished concrete debris (CD) (0% to 100% at an interval of 20%) in M30 grade Basalt Fibre Reinforced Concrete (BFRC) with a basalt fibre (BF) content of 0%, 0.3%, 0.6% and 0.9% by volume of concrete. Optimum replacement percentages of GGBFS, CB and BF contents were optimized by experimental investigation done on strength properties of BFRC and Response Surface Methodology (RSM).

Keywords: Basalt fibre reinforced concrete, GGBFS, Concrete Debris, RSM Technique, Central Composite Design.

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1. INTRODUCTION

Around the globe, Demand over the raw materials used for the construction of structures using concrete are rapidly increasing due to scarcity of raw ingredients to meet the global need. Recent times, Indian construction sector is one of the fifth largest sector in the world. Production of cement will also produce equal amount of Carbon dioxide which will produces numerous environmental problems to the society like green house gases, global warming, etc., [12].

Ground granulated blast furnace slag is obtained from the blast furnaces used in the manufacturing of cement and pig iron which is having a high quantity of silica, alumina and lime. It could be act as a better replacement for cement in the production of concrete. In order to increase the cementitious nature of GGBFS, the hot molten slag will be cooled rapidly as it leaves the blast furnace [2] [3]. By replacing the cement with GGBFS will also reduces the water content required to make the concrete with proper true slump which happen due to the increased fineness of slag content (see Figure 1). Utilization of GGBFS has numerous advantages like reduced heat of hydration, permeability, leaching, chemical attack and alkali aggregate reaction [4]. It is also observed that replacement of cement by GGBFS will enhance the strength and durability properties of the concrete. The strength of concrete at early ages shows slightly lower than the conventional mixes, but when the curing period extended, the strength of concrete will get huge improvement than the conventional mixes [3] [4] [8]. So, 28 days strength properties such as compressive, splitting tensile and flexural only considered for optimization of ingredients.

Figure 1 GGBFS

Aggregates used in the construction are the most mined materials in the world. Modern quarrying techniques will increase the number of quarries at places where the huge amount of rock deposits available [1]. This will result in excessive utilization of aggregates to meet the global needs. In India, GDP rate was going on increasing by demolishing the smaller structures and new high-rise buildings are constructed.

India generates around 40MT of CD and most of the part was disposed directly to the environment and used as a embankments, pavements and earth fills. Japan is the only country recycles 96% of CD and the rest only kept as scrapped. In recent times, high quality CD will be recycled and generally recognized as a better replacement material for coarse aggregate [5] [7] [14]. So, productive use of waste CD in concrete will alleviates the problems associated with the disposal of demolished waste concrete. After successful demolition of concrete structures, the waste CD was kept in stockpiles and screened to remove the fine-grained particles from the debris (see Figure 2 and 3) [7] [9] [13]. Then the recycled aggregates could be replacing the coarse aggregate content in concrete without compromising the strength properties of concrete.

Figure 2 Stockpiling of Demolished CD

Figure 3 RCA after screening

Basalt fibre is a relatively new cheap construction material and it has many advantages over the other chopped fibres available in the market. Basalt is a natural dense igneous rock material, which is originated by rapid cooling of molten magma. Basalt fibre is naturally an inorganic and it is nontoxic (see Figure 4) [6] [16]. It is added to the concrete matrix, to improve the load carrying capacity, strength and stiffness of the concrete. It is also helpful to reduce the drying shrinkage of concrete. Recently, utilization of carbon fibres in concrete will maintain or improve the strength and durability of concrete. Moreover, current shortage of carbon fibres makes basalt fibres a good alternative [17].

Figure 4 Chopped Basalt Fibre

Optimization of input parameters takes huge effort to conduct experimental investigation. In order to reduce the expenses and time involved in the experimentation, response surface methodology (RSM) is also used. RSM is a technique that contains of statistical analysis, where each response is linked to the number of variables to determine the impact, relationship and interaction between the variables and the responses [18] [20]. The most commonly used design method for determining the functional relationship between response and factors using Central Composite Design (CCD), an effective experimental design method used in RSM. Design Expert 11 software was used for the design, mathematical modelling, statistical analysis and optimization of process variables (see Figure 5) [19] [20] [21].

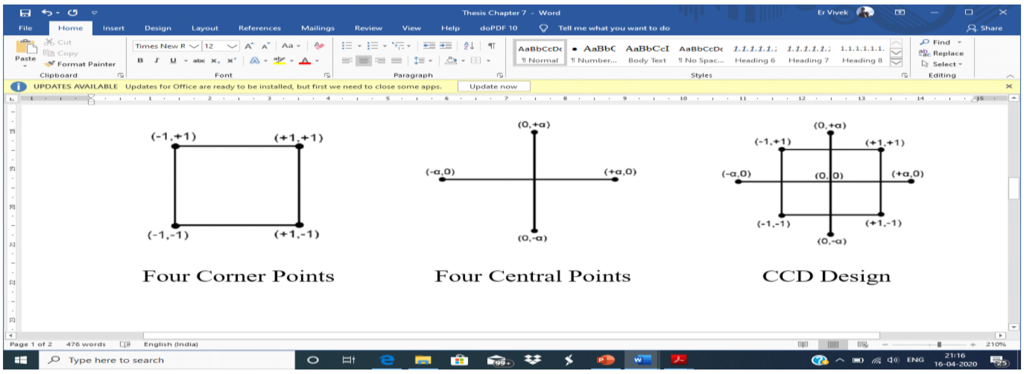

Figure 5 CCD Design Module

In this study, basalt fibre reinforced concrete made with and without basalt fibres of 0% to 1% at an interval of 0.25% by volume. And cement and coarse aggregate were replaced partially with varying percentages of GGBFS and recycled concrete debris. Optimization of such input parameters were done, Based on the experimental investigation and RSM technique.

2. MATERIAL PROPERTIES

Different materials used in this investigation are cement (OPC 53), GGBFS (slag from Penna Cement Company), river sand, gravel, recycled concrete aggregate (from Concrete debris), basalt fibre, water and super plasticizers. Properties of the materials used are illustrated in the following tables.

Table 1 Properties of Cement and GGBFS

Property		Cement	GGBFS
Specific surface area (m^2/kg)		290	410
Specific gravity		3.18	2.94
Bulk density (kg/m^3)		1650	1220
Soundness (mm)		2.1	-
Colour		Grey	Off white
Strength (MPa)	14 days	45.48	-
	28 days	56.11	-
Setting time (Hrs)	Initial	1.25	-
	Final	6	-

Table 2 Chemical Composition of Cement and GGBFS (%)

Composition	Cement	GGBFS
CaO	66.10	36.82
SiO_2	21.40	38.24
Al_2O_3	4.60	18.40
Fe_2O_3	4.91	0.80
SO_3	2.00	1.80
MgO	0.90	7.20
K_2O	0.80	0.60
TiO_2	0.33	0.74
ZrO_2	0.01	0.03

Table 3 Properties of Aggregates

Property		Fine Aggregate	Coarse Aggregate	
		River Sand	Gravel	Concrete Debris
Type		Natural	Natural	Recycled Aggregate
Shape		Spherical	Angular	Irregular/Angular
Size (mm)	Max	4.75	20	20
	Min	-	12.5	12.5
Specific Gravity		2.62	2.58	2.44
Fineness Modulus		2.64	6.54	6.38
Bulk Density (kg/m^3)		1725	1520	1275
Grade		Zone II	-	-
Water Absorption (%)		0.95	1.10	3.20
Crushing Value (%)		-	21.50	-
Impact Value (%)		-	14.50	13.80

Table 4 Sieve Analysis Report on Aggregates

Sieve Size (mm)	Cumulative % of material passing		
	River Sand	Gravel	Concrete Debris
25	-	100	100
20	-	94.4	96
16	-	36.9	72.7
12.5	-	5.8	13.6
10	-	1.5	2.1
4.75	100	1.4	2.9
2.36	93.8	-	-
1.18	56.4	-	-
0.60	46.1	-	-
0.30	14	-	-
0.15	0	-	-

Table 5 Properties of Basalt Fibre

Property	Value
Fibre Type	Chopped – Basalt fibre
Specific Gravity	2.75
Strain at Breaking	0.0315
Tensile Strength (MPa)	4000
Elastic Modulus (GPa)	87

In order to make the workable concrete, commercially available super plasticizers (CONPLAST SP430) are used and water confirming to BIS 456:2000 was used for the preparation and curing of concrete [22].

3. MIX PROPORTION

Mix design for M30 grade BFRC was done as per the guidelines mentioned in BIS 10262:2019 and illustrated in Table 6 [22] [27]. To improve the workability of concrete, Super plasticizer was used in the concrete at 2.5% by volume wherever required.

Table 6 Mix Proportion

Ingredients	Cement	Fine Aggregate	Coarse Aggregate	Water
Quantity (kg/m^3)	483	662	1208	193
Mix Ratio	1	1.37	2.5	0.4

4. EXPERIMENTAL INVESTIGATION

In this study, BFRC was prepared with different replacement percentages of Cement and coarse aggregate with GGBFS and CD, and fibres are added into the concrete by different volume fractions of fibres. Strength properties of BFRC of M30 grade were assessed by conducting tests on compressive, split tensile and flexural strength at 28 days and illustrated in Table 6 to 9. Based on the results, optimized replacement percentages were determined.

Table 6 Strength of BFRC without fibres

Strength (MPa)	**Mix ID**	**RCA Replacement %**					
		0	20	40	60	80	100
Compression	BFRC0-0GG	38.7	39	41.4	40.1	36.3	28.2
	BFRC0-10GG	40.2	41.3	43.3	40.9	37.8	29.5
	BFRC0-20GG	41.8	43.2	45.7	42	38.3	30.1
	BFRC0-30GG	43	44.9	48.2	42.1	38.6	31.4
	BFRC0-40GG	40.4	42.2	45.9	39.9	36.3	29.7
	BFRC0-50GG	37.8	42	42.7	38.4	35.1	27.8
Split Tension	BFRC0-0GG	3.38	3.39	3.50	3.44	3.27	2.88
	BFRC0-10GG	3.44	3.49	3.58	3.47	3.34	2.94
	BFRC0-20GG	3.51	3.57	3.68	3.52	3.36	2.97
	BFRC0-30GG	3.56	3.64	3.78	3.53	3.37	3.04
	BFRC0-40GG	3.45	3.53	3.68	3.43	3.27	2.95
	BFRC0-50GG	3.34	3.52	3.55	3.36	3.21	2.86
Flexure	BFRC0-0GG	4.16	4.18	4.31	4.24	4.03	3.54
	BFRC0-10GG	4.25	4.30	4.41	4.28	4.11	3.62
	BFRC0-20GG	4.33	4.40	4.53	4.34	4.14	3.66
	BFRC0-30GG	4.39	4.49	4.66	4.35	4.16	3.74
	BFRC0-40GG	4.26	4.35	4.54	4.23	4.03	3.63
	BFRC0-50GG	4.11	4.34	4.38	4.15	3.96	3.51

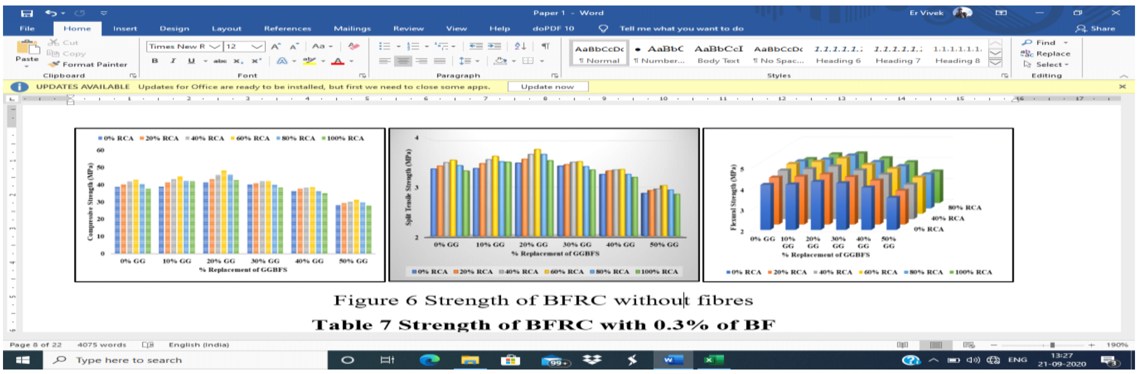

Figure 6 Strength of BFRC without fibres

Table 7 Strength of BFRC with 0.3% of BF

Strength (MPa)	**Mix ID**	**RCA Replacement %**					
		0	20	40	60	80	100
Compression	BFRC0.3-0GG	40.4	40.7	43.2	41.8	37.9	29.4
	BFRC0.3-10GG	41.9	43.1	45.2	42.7	39.4	30.8
	BFRC0.3-20GG	43.6	45.1	47.7	43.8	40.0	31.4
	BFRC0.3-30GG	44.9	46.9	50.3	43.9	40.3	32.8
	BFRC0.3-40GG	42.2	44.0	47.9	41.6	37.9	31.0
	BFRC0.3-50GG	39.4	43.8	44.6	40.1	36.6	29.0
Split Tension	BFRC0.3-0GG	3.51	3.53	3.64	3.58	3.40	2.99
	BFRC0.3-10GG	3.58	3.63	3.72	3.61	3.47	3.06
	BFRC0.3-20GG	3.65	3.71	3.82	3.66	3.49	3.09
	BFRC0.3-30GG	3.71	3.79	3.93	3.67	3.51	3.16
	BFRC0.3-40GG	3.59	3.67	3.83	3.57	3.40	3.07
	BFRC0.3-50GG	3.47	3.66	3.69	3.50	3.34	2.97
Flexure	BFRC0.3-0GG	4.32	4.34	4.48	4.40	4.18	3.68
	BFRC0.3-10GG	4.41	4.47	4.58	4.45	4.27	3.76
	BFRC0.3-20GG	4.50	4.57	4.71	4.51	4.30	3.80
	BFRC0.3-30GG	4.56	4.66	4.84	4.51	4.32	3.88
	BFRC0.3-40GG	4.42	4.52	4.72	4.39	4.18	3.77
	BFRC0.3-50GG	4.27	4.51	4.55	4.31	4.11	3.65

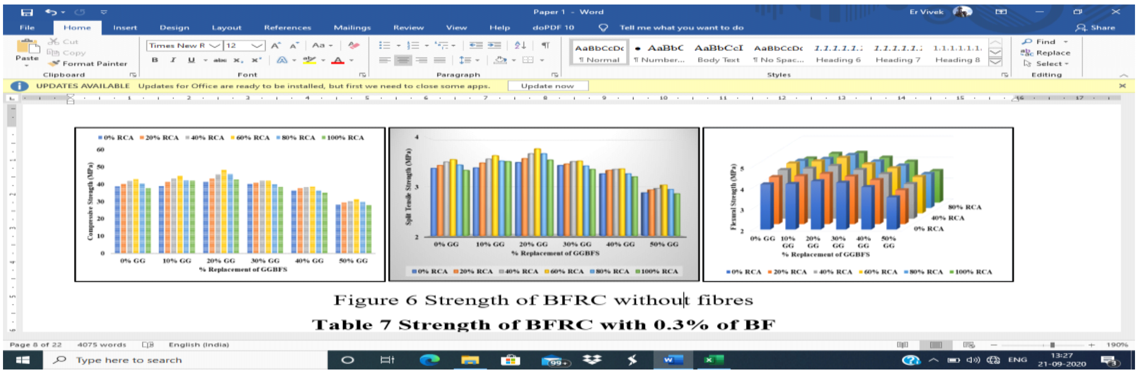

Figure 7 Strength of BFRC with 0.3% of BF

Table 8 Strength of BFRC with 0.6% of BF

Strength (MPa)	**Mix ID**	**RCA Replacement %**					
		0	20	40	60	80	100
Compression	BFRC0.6-0GG	42.7	43.0	45.6	44.1	40.0	31.0
	BFRC0.6-10GG	44.3	45.5	47.7	45.1	41.6	32.5
	BFRC0.6-20GG	46.0	47.6	50.4	46.3	42.2	33.2
	BFRC0.6-30GG	47.4	49.5	53.1	46.4	42.6	34.6
	BFRC0.6-40GG	44.6	46.5	50.6	43.9	40.0	32.7
	BFRC0.6-50GG	41.6	46.3	47.1	42.3	38.7	30.6
Split Tension	BFRC0.6-0GG	3.69	3.71	3.82	3.76	3.57	3.14
	BFRC0.6-10GG	3.76	3.81	3.91	3.79	3.64	3.21
	BFRC0.6-20GG	3.83	3.90	4.01	3.84	3.66	3.24

Strength (MPa)	**Mix ID**	**RCA Replacement %**					
		0	20	40	60	80	100
	BFRC0.6-30GG	3.90	3.98	4.13	3.85	3.69	3.32
	BFRC0.6-40GG	3.77	3.85	4.02	3.75	3.57	3.22
	BFRC0.6-50GG	3.64	3.84	3.87	3.68	3.51	3.12
Flexure	BFRC0.6-0GG	4.48	4.50	4.65	4.57	4.34	3.82
	BFRC0.6-10GG	4.58	4.64	4.75	4.62	4.43	3.90
	BFRC0.6-20GG	4.67	4.74	4.89	4.68	4.46	3.94
	BFRC0.6-30GG	4.73	4.84	5.02	4.68	4.48	4.03
	BFRC0.6-40GG	4.59	4.69	4.90	4.56	4.34	3.91
	BFRC0.6-50GG	4.43	4.68	4.72	4.47	4.27	3.79

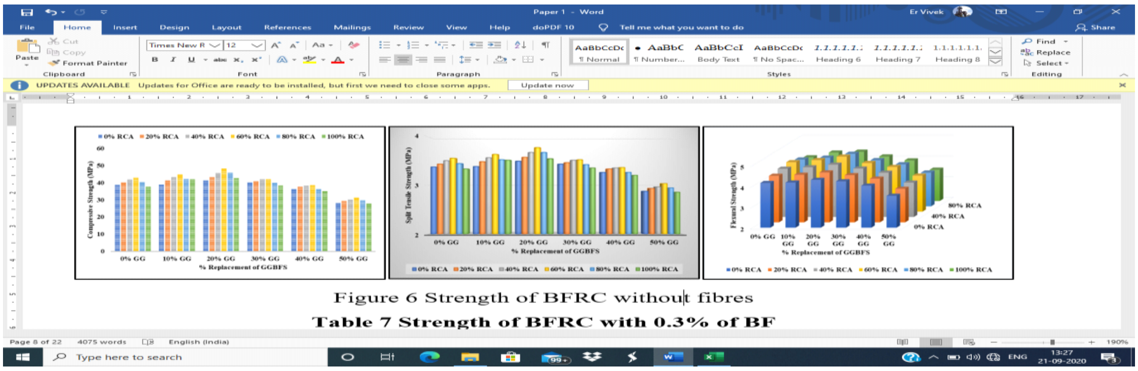

Figure 8 Strength of BFRC with 0.6% of BF

Table 9 Strength of BFRC with 0.9% of BF

Strength (MPa)	**Mix ID**	**RCA Replacement %**					
		0	20	40	60	80	100
Compression	BFRC0.9-0GG	35.6	35.9	38.1	36.8	33.4	25.9
	BFRC0.9-10GG	36.9	38.0	39.8	37.6	34.7	27.1
	BFRC0.9-20GG	38.4	39.7	42.0	38.6	35.3	27.7
	BFRC0.9-30GG	39.6	41.3	44.3	38.7	35.5	28.9
	BFRC0.9-40GG	37.2	38.8	42.2	36.7	33.4	27.3
	BFRC0.9-50GG	34.7	38.6	39.3	35.3	32.3	25.6
Split Tension	BFRC0.9-0GG	3.23	3.24	3.34	3.29	3.12	2.75
	BFRC0.9-10GG	3.29	3.34	3.42	3.32	3.19	2.81
	BFRC0.9-20GG	3.35	3.41	3.51	3.36	3.21	2.84
	BFRC0.9-30GG	3.41	3.48	3.61	3.37	3.23	2.90
	BFRC0.9-40GG	3.30	3.37	3.52	3.28	3.12	2.82
	BFRC0.9-50GG	3.19	3.36	3.39	3.22	3.07	2.73
Flexure	BFRC0.9-0GG	4.15	4.17	4.31	4.23	4.02	3.54
	BFRC0.9-10GG	4.24	4.30	4.40	4.28	4.11	3.62
	BFRC0.9-20GG	4.33	4.39	4.53	4.34	4.13	3.65
	BFRC0.9-30GG	4.38	4.48	4.65	4.34	4.15	3.73
	BFRC0.9-40GG	4.25	4.35	4.54	4.22	4.02	3.62
	BFRC0.9-50GG	4.11	4.34	4.37	4.14	3.95	3.51

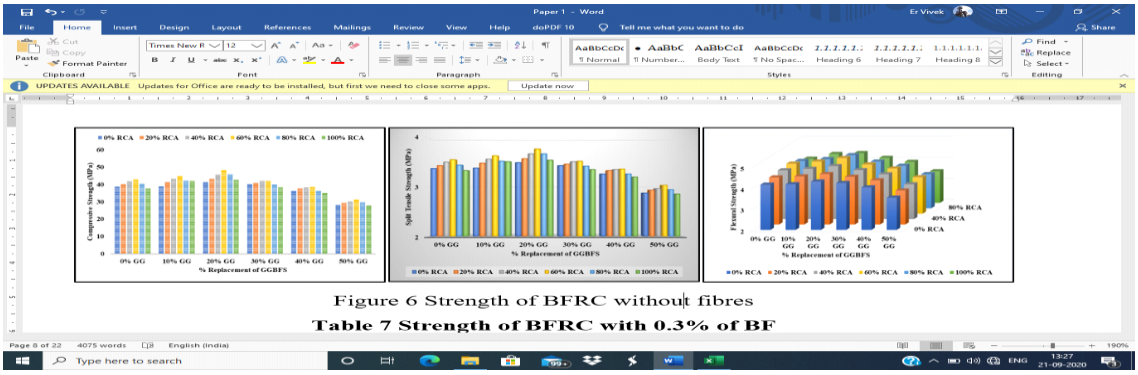

Figure 9 Strength of BFRC with 0.9% of BF

Rate of strength gain was reasonably slower at earlier ages, since the pozzolanic action takes place in BFRC mix was slow and depends on the amount of CaO in GGBFS. Since the utilization of GGBFS, reduces the amount of heat during hydration. GGBFS has a constructive effect on creation of Calcium Hydroxide, but it might reduce the quality of concrete [4].

Usage of CD as an RCA in concrete gradually reduces the strength of concrete during the increasing % of RCA takes place. Replacement of coarse aggregate with RCA also reduces the quality of concrete whereas the structure of hardened concrete was porous in nature which in turn absorbs more water during hydration & curing [9]. Use of BF will enhance the strength of concrete mix to huge extent whereas it helps the BFRC mixes to reach the target strength [12].

It is observed that the BFRC mixes were made with varying replacement percentages of GGBFS and RCA shows better results upto some extent which is 30% and 40% respectively. Usage of these elements in concrete might reduce the quality of concrete, but shows improved results on BFRC mixes with and without BF. 0.6% addition of BF in the matrix enhances the results to huge extent. For these optimum parameters, BFRC mixes produces compressive, split tensile and flexural strength of 53.1, 4.13 & 5.02MPa respectively at 28 days.

5. OPTIMIZATION BY RSM TECHNIQUE

In this study, there are three input parameters (Replacement % of GGBFS and RCA, % addition of BF) & one output response (28 days Compressive strength) is taken into account for the better optimization of input parameters. Design Expert is a commercially available software that supports in the design & interpretation of multifactorial experiences. It offers a wide range of designs, including factorials, fraction factors & composite designs. It can knob both process & mix variables. It offers comparative tests, screening, characterization, optimization, robust design of parameters, mixing designs and combined designs. Table 11 illustrates the design matrix which is completely made of input parameters and output responses. It is helpful in the determination of optimum operational parameters.

Table 10 Desirable range of Input Parameters

Factor	Input Parameter	Units	Minimum	Maximum	Mean	Standard Deviation
a	GGBFS	%	20	40	30	9.13
B	RCA	%	0	80	40	30.55
C	BF	%	0.3	0.9	0.6	0.23

Table 11 Design Matrix and Responses

Std	Group	Run	Input Factors (%)			Response: Compressive Strength (MPa)
			a: GGBFS	B: RCA	C: BF	
1	5	13	20	0	0.3	43.6
2	5	15	20	80	0.3	40
3	5	14	20	0	0.9	38.4
4	5	16	20	80	0.9	35.3
5	7	21	40	0	0.3	42.2
6	7	23	40	80	0.3	37.9
7	7	22	40	0	0.9	37.2
8	7	20	40	80	0.9	33.4
9	2	4	30	40	0.6	53.9
10	2	5	30	40	0.6	52.7
11	2	3	30	40	0.6	53.1
12	8	25	12.6795	40	0.6	48
13	8	24	12.6795	40	0.6	48.4
14	1	2	47.3205	40	0.6	48.3
15	1	1	47.3205	40	0.6	49.1
16	3	9	30	-29.282	0.6	31.1
17	3	7	30	109.282	0.6	33.7
18	3	6	30	40	0.0803848	48.8
19	3	8	30	40	1.11962	46.2
20	6	19	30	40	0.6	52.4
21	6	17	30	40	0.6	53.8
22	6	18	30	40	0.6	52.7
23	4	10	30	40	0.6	52.5
24	4	11	30	40	0.6	53.6
25	4	12	30	40	0.6	53

The response function representing any of the process parameters can be expressed as: CS = F (a, B, C), the relationship selected being a 2nd degree response surface is expressed as: $CS = b_0 + b_1a + b_2B + b_3C + b_4aB + b_5aC + b_6BC + b_7a^2 + b_8B^2 + b_9C^2$. Equation 1 and 2 gives the details of regression coefficients on coded equation and final equation with actual factors respectively.

$$CS = 53.08 - 0.1259a - 0.7355B - 1.71C - 0.175aB + 0.05aC + 0.125BC - 1.82a^2 - 7.84B^2 - 2.8C^2 \quad (1)$$

$$CS = 21.20358 + 1.17924a + 0.378205B + 30.20558C - 0.000438aB + 0.016667aC + 0.010417BC - 0.019935a^2 - 0.004871B^2 - 30.67793C^2 \quad (2)$$

The RSM delivers the models for response surface to replicate the outcome of factors. The model of 2nd order is more accurate than the 1st order model due to the ability to find the optimum number of each factor precisely. Figure 10 and 11 shows the 3D surface diagrams of the output responses along with the input parameters.

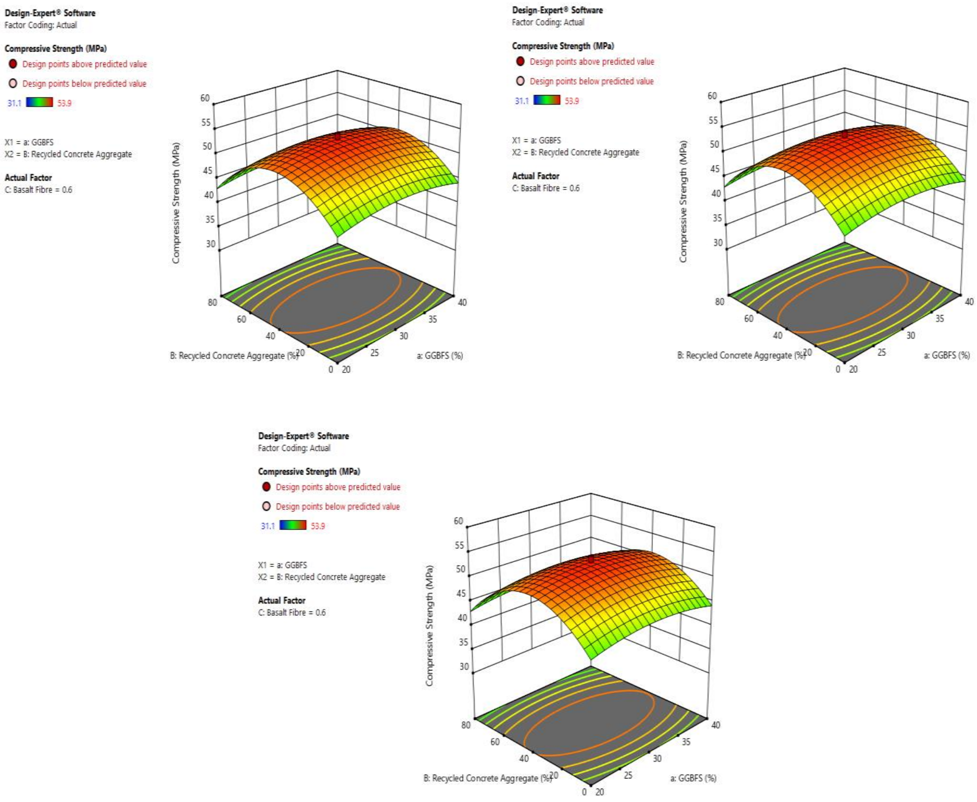

Figure 10 3D Response Surface Diagrams for Strength vs Input Parameters

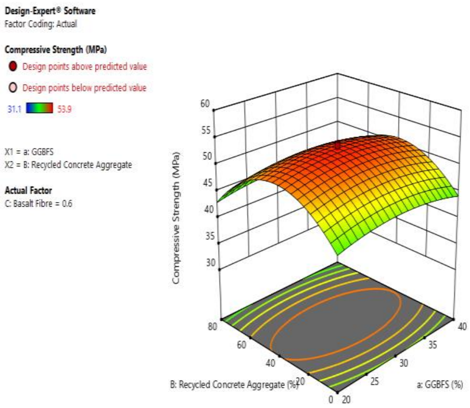

Figure 11 3D Cubical Diagram with all input parameters vs output response

After optimization process of each individual parameters with its agreeing response value, a validation study has been implemented with the optimized constraints. The compressive strength values obtained from the validation study have been narrowly related to the results obtained from optimization desirability by using CCD. In this study, M30 grade BFRC mixes were tested under different parameters and optimized constraints were taken at 53MPa of CS. Out of 100 solutions, one solution was taken for the experimental validation process by considering the strength of 53MPa, the optimized parameters obtained from Design Expert software such as % of GGBFS, RCA and BF are 34.032%, 37.495% and 0.493% respectively. For the obtained parameters, specimens were cast and strength values are validated with the experimental results.

Table 12 Experimental Validation

Input Parameters	Optimized Parameters	Predicted Results by Design Expert (P_{DE})	Actual Results by Experiments (P_{Exp})	P_{DE} / P_{Exp}
GGBFS (%)	34.032	53	53.84	0.984
RCA (%)	37.495			
BF (%)	0.493			

This work would be useful in determining the CS of M30 grade BFRC mixes without performing the experiments. The empirical relationships developed can be used as a quick decision-making tool in the preparation of BFRC mixes for predicting the responses. In conclusion, RSM technique proved to be a useful tool in establishing the optimum input parameters for the desired properties as responses.

6. CONCLUSIONS

The following are the conclusions are drawn from the experimental investigation done on BFRC with varying proportions of GGBFS, RCA and BF.

- It is possible to a concrete with waste materials like GGBFS and CD and they can act as a better substitute material for Cement and Coarse Aggregate.
- Addition of fibres enhances the strength properties of concrete whereas the addition of GGBFS and CD enhances the strength, but reduces the quality of concrete.
- It is observed that, around 53MPa strength can be achieved with different proportions of GGBFS, RCA and BF.
- Based on experiments, Optimum results on strength properties of concrete were obtained at 30% GGBFS, 40% RCA and 0.6% of BF.
- RSM could be better alternative technique to perform optimization process on different variables without performing the experiments.
- Based on RSM, Optimized input parameters to produce 53MPa strength were observed as 34.032% GGBFS, 37.495% RCA and 0.493% of BF.

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