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The Structural Performance of Externally Strengthened RCC Beams Made With GPC

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Abstract: ***Cement is one of the prime ingredients in construction but at the same time a source of CO2 emission during its manufacture. In order to create a sustainable building material, Geopolymer concrete (GPC) was proposed by Davidovits in 1988 which could be viable substitute for conventional concrete production. In this study, totally 21 beam specimens were prepared with GPC of M30 grade which were externally strengthened by two systems of strengthening namely Externally Bonded Reinforcement System (EBR) and Near Surface Mounted System (NSM). Strengthening of existing beams will enhance the service life and service loading conditions of beams. In EBR system, 2 numbers of 6, 8 and 10mm diameter bars are bonded at the bottom face of RCC beams and in NSM system, different types of polymer sheets are attached at the bottom face of the beam such as Carbon, Glass and Aramid. Results show that, the beam specimens made with Carbon Fiber Reinforced Polymer (CFRP) sheets perform better than the other strengthening methods, and have 67% better load-carrying capacity than the control beam (beams without strengthening applications).***

Keywords: GPC, Strengthening Methods, EBR, NSM.

I. INTRODUCTION

Around the world, 5% of CO_2 emission was incorporated by Global cement production and $1m^3$ of CO_2 was released into the environment while an equal amount of cement was produced [1]. Fly ash is an industrial byproduct obtained from Thermal Power Plants and the source of wide range of problems to the environment while being disposed ofas landfills. In order to rectify these problems, a new method of concreting was proposed by Davidovits in the late90's. Generally, GPC is neither a method nor a technique.

GPC uses pozzolanic materials as the preparation-binding agent in concrete in place of Ordinary Portland Cement [2]. In GPC, the binders are formed by the reaction of alkaline liquids with a material that has high composition of silica and alumina. The production of RCC beams with GPC would be a little costlier than that of beams with conventional method, because there is additional auxiliary equipment required for curing. This because the GPC samples cannot be polymerized under regular curing techniques; the curing of GPC will be done either by oven or steam [5] [6]. The strength of GPC samples depends on various factors such as type of curing, curing duration, type of alkaline activators and the concentration of alkaline activators [7]. In this study, three parameters were considered as constants which were mentioned in the third section of this article.

Many researchers around the world, made a wide range of investigations on the strength and durability aspects of only fly-ash-based GPC with oven curing. It is possible to make RCC beams with different curing methods, and investigations are made on the strengthened GPC beams to predict the structural performance of beams under two point loading.

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II. MATERIALS USED

The list of materials used in this study are:

- Fly ash
- Manufactured Sand
- Coarse aggregate (Gravel)
- Alkaline Solution (NaOH& Na_2SiO_3)
- Water

a. Fly Ash

The properties of fly ash are listed in Tables 1 and 2.

Table- 1: Physical Properties of Fly Ash

Parameter	Value	As per IS 3812
Class	F	-
Color	Light Grey	-
Residue on 45µ sieve (%)	67.5	$\ngtr$ 34
Specific Surface Area (m^2/kg)	352	320
Specific Gravity	2.35	-
Moisture content	0.4	$\ngtr$ 2

Table- 2: Chemical Properties of Fly Ash

Composition	Value		As per IS 3812	
CaO	0.07		$\ngtr$ 5	
Na_2O	0.79		$\nless$ 1.5	
SO_3	1.32		$\nless$ 2.75	
MgO	1.47		$\ngtr$ 5	
LOI	2.03		$\nless$ 12	
Fe_2O_3	8.19	91.57	-	$\nless$ 70
Al_2O_3	26.98		-	
SiO_2	56.4		$\nless$ 35	

b. Manufactured Sand (M-Sand)

Crushed rock deposits to create fine aggregate which is a lot more angular in shape and has rougher surface texture than river sand particles. It was replaced with natural sand from 0 – 100% at an interval of 20% [1] [7].

c. Coarse Aggregate

Generally available crushed rock granites of 20mm were used in this study conforming to IS 383 specifications.

Table- 3: Properties of Aggregates

Property	M-Sand	Coarse aggregate
Type	Crushed	Crushed
Shape	Spherical	Angular
Maximum size	4.75 mm	20 mm
Specific gravity	2.89	2.75
Water absorption	1.54	0.89 %
Crushing value	-	14 %
Impact value	-	10.25 %
Fineness modulus	2.90	6.49
Bulk density (kg/m^3)	1790	1604

d. Alkaline Solution

A combination of NaOH and Na_2SiO_3 solutions were utilized for the activation of fly ash [5].

e. Water

Potable drinking water was used in the preparation of alkaline solution, and excess water was added to the concrete mix if low workability was experienced.

III. MIX PROPORTIONS

Mix design for GPC was done as per Indian Standard Code of Practice [2]. Following are the parameters kept constant in the preparation of mix design:

- Type of fly ash: Class F fly ash
- Characteristic compressive strength (f_{ck}): 30MPa
- Sodium Hydroxide Concentration: 16M
- Solution-to-fly ash ratio by mass: 0.35
- Na_2SiO_3 to NaOH ratio by mass: 2.5
- Type of curing: Membrane Curing
- Curing Temperature: 120^{0}C
- Time of Curing: 16 Hours
- Testing Age: 7 Days

Table - 4: Mix Proportion for GPC

Material description	Quantity (kg/m^3)		Proportion	Total Weight of GPC (kg/m^3)
Flyash	404		1	2528
NaOH	101	2.5	0.35	
Na_2SiO_3	40.4			
Fine aggregate	658.39		1.63	
Coarse aggregate	1257.99		3.11	
Water	66.22		0.16	

IV. MECHANICAL STRENGTH PROPERTIES

The mechanical strength properties of M30 grade fly-ash-based GPC was tested after a curing period of 3, 14, 28, 56 and 90 days [7] [12]. The strength of properties of GPC with varying percentage of fine aggregate by M-Sand is shown in Tables 5 to 7.

Table -5: Compressive Strength

Specimen ID	Average Compressive strength (N/mm^2)				
	3	14	28	56	90
GC0MS	16.46	34.65	39.56	46.51	49.11
GC20MS	16.23	35.72	40.69	48.93	51.16
GC40MS	17.09	37.56	42.86	50.83	53.87
GC60MS	17.47	38.31	43.6	52.42	55
GC80MS	17.66	38.73	44.19	53.11	55.56
GC100MS	18.1	39.72	45.38	54.55	57.29

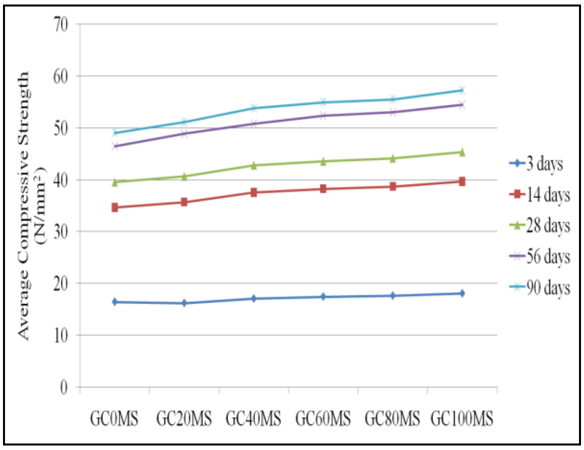

Fig. 1: Compressive Strength

Table- 6: Split Tensile Strength

Specimen ID	Average Split Tensile strength (N/mm^2)				
	3	14	28	56	90
GC0MS	1.82	3.24	4.05	4.48	4.72
GC20MS	1.79	3.28	4.11	4.56	4.86
GC40MS	1.84	3.36	4.26	4.69	5.01
GC60MS	1.87	3.49	4.31	4.76	5.08
GC80MS	1.95	3.58	4.48	4.86	5.29
GC100MS	2.02	3.76	4.69	4.93	5.51

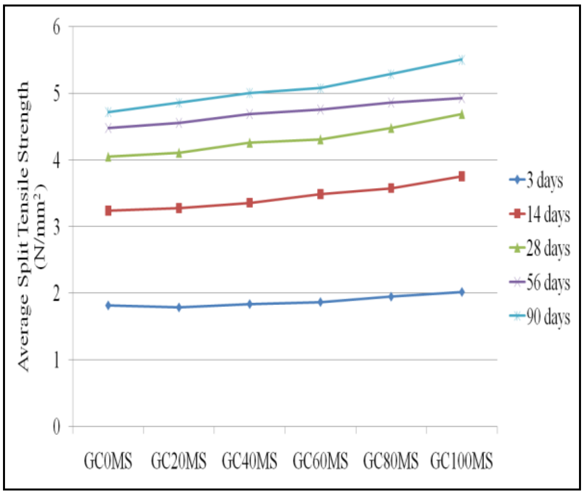

Fig. 2: Split Tensile Strength

Table 7: Flexural Strength

Specimen ID	Average Flexural strength (N/mm^2)				
	3	14	28	56	90
GC0MS	3.01	6.36	7.44	8.18	8.72
GC20MS	3.12	6.64	7.71	8.52	9.06
GC40MS	3.18	6.81	7.95	8.95	9.33

GC60MS	3.26	7.08	8.25	9.28	9.69
GC80MS	3.41	7.37	8.59	9.49	10.08
GC100MS	3.59	7.52	8.75	9.81	10.23

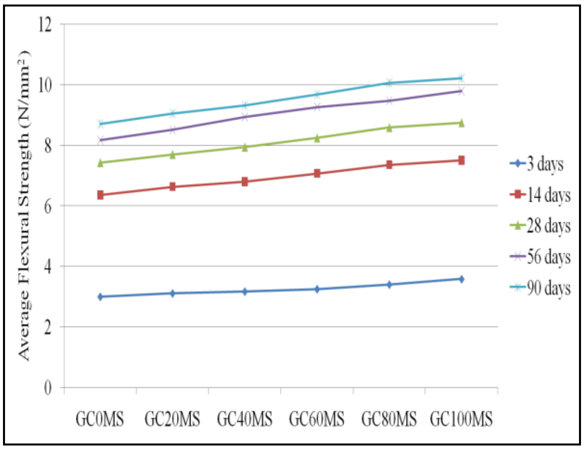

Fig. 3: Flexural Strength

V.THE STRUCTURAL BEHAVIOR OF STRENGTHENED RCC BEAMS

In this study, RCC beams of size 125 x 200 x 1500mm were inspected as simple supported beams subjected to two-point loading over an effective length of 1200mm. The beam was reinforced with 2 numbers of 16mm and12mm diameter bars at bottom and top respectively. Shear reinforcement of 8mm diameter bars at 150mm was used. The loads were applied at a distance of 200mm on both sides of the mid span of the beam. Mid span and L/3 deflections; initial cracking and ultimate load of the specimens were noted.

The values of deflections due to corresponding loads were recorded. Three flexure control beams were tested until failure and the remaining beams for 70% preloaded ultimate load capacity, and the deflections were measured [14] [20]. As per the NSM technique proposed, the wrapping and HYSD bars were used at the bottom face of the RCC beams [13]. When the beams were preloaded, the bottom face of the beam throughout the entire length was strengthened with varying diameter bars and varying polymer sheets. The test plan followed in this study is tabulated in Table 8. Tables 9 and 10 show the different properties of reinforcing steel and FRP laminates which were used in the investigation.

Table 8: Test Plan

Strengthening System	Specimen ID	Comment
	CB	Control beam (Un-strengthen)
Strengthening by NSM System with HYSD bars	SB1	2# 6mm dia bar
	SB2	2# 8mm dia bar
	SB3	2# 10mm dia bar
FRP Composites	CFRP	Carbon Fiber Reinforced Polymer Sheets
	GFRP	Glass Fiber Reinforced Polymer Sheets
	AFRP	Aramid Fiber Reinforced Polymer Sheets

Table 9: Properties of Reinforcing Steel used

Properties of steel reinforcements used	HYSD bar			Mild steel bar	
	10mm	12mm	16mm	6mm	8mm
Yield strength (MPa)	532	550	596	318	324
Ultimate strength (MPa)	647	690	712	421	425
Modulus of Elasticity (GPa)	200				

Table 10: Properties of FRP Laminates used

Properties		CFRP	GFRP	AFRP
Young's Modulus (MPa)	**E_x**	165000	21100	13600
	E_y	9650	7000	1485
	E_z	9650	7000	1485
Modulus of Rigidity (MPa)	**G_{xy}**	5200	1520	550
	G_{yz}	5200	2650	547
	G_{zx}	3400	1520	550
Poisson's Ratio	**μ_{xy}**	0.3	0.26	0.32
	μ_{yz}	0.3	0.3	0.35
	μ_{zx}	0.45	0.26	0.35
Density (g/cm^3)		100	125	85

Sikadur 30 was an epoxy adhesive used to bond the strengthening materials to the concrete surface. It had two segments which were mixed at a ratio of 3:1 until a grey color was obtained [16].

Table 11: Properties of Adhesive Material

Property	Curing time (Days)	Strength (MPa)
Compressive strength	7	92
Tensile strength		35
Shear strength		21

Load was applied on the beam specimens at an interval of 5kN until the beams failed. Loads and the corresponding mid span deflections are noted down in Table 13.

Table 12: Structural Behavior of Un-strengthened Control Beams

Sample	CB1	CB2	CB3
Initial Crack Load (kN)	20	21	17
Ultimate Load (kN)	60	59	62
Load kN	**Mid Span Deflection (mm)**		
0	0	0	0
5	0.24	0.26	0.28
10	0.59	0.59	0.50
15	0.95	1.28	0.70
20	1.15	1.92	1.24
25	2.15	2.62	1.79
30	2.67	3.27	2.39
35	3.28	3.92	2.83
40	3.75	4.54	3.59
45	4.39	5.17	4.22
50	5.79	8.35	5.66
55	8.66	11.27	7.94
60	14.92	18.23	12.61

58	15.37	19.90	14.70
55	15.55	20.89	15.79
50	15.62	22.18	16.33

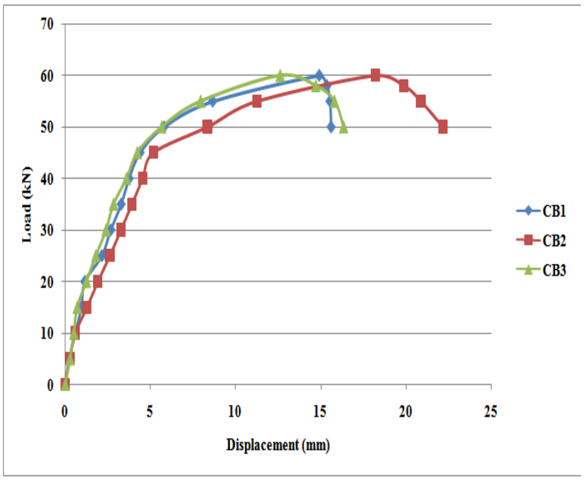

Fig. 4: Load vs Deflection Behavior of Control Beams

For the strengthening of RCC beams, the remaining beams were preloaded with 70% average ultimate load carried by control beams. That means that the beams were tested up to 42kN which was 70% of ultimate load of 60 kN. After the application of 42kN, the beams were strengthened by EBR and NSM System of strengthening methods. Load vs deflection behavior of RCC beams with EBR and NSM strengthened systems is tabulated in Table 13.

Table 13 a): Load vs Deflection Behavior of NSM System

S. ID*	**NSM-2-6**			**S. ID***	**NSM-2-8**		
	1	**2**	**3**		**1**	**2**	**3**
P*	**D***			**P***	**D***		
0	0	0	0	0	0	0	0
5	0.49	0.26	0.6	5	0.45	0.22	0.57
10	0.72	0.65	0.99	10	0.70	0.58	0.99
15	0.98	1.25	1.22	15	0.95	1.15	1.38
20	1.48	1.71	1.72	20	1.46	1.79	2.03
25	1.93	2.28	2.28	25	1.98	2.44	2.82
30	2.7	2.93	2.86	30	2.87	3.22	3.65
35	3.26	3.54	3.42	35	3.50	3.86	4.28
40	3.79	3.67	3.98	40	4.33	4.31	4.98
45	4.32	4.21	4.33	45	4.72	4.94	5.23
50	4.45	4.58	4.64	50	5.09	5.47	5.94
55	4.99	5.31	5.11	55	5.64	6.05	6.55
60	5.91	5.8	5.64	60	6.18	6.62	7.18
63	6.12	6.22	5.91	65	6.74	7.21	7.80
70	6.56	6.65	6.54	67	6.93	7.42	7.98
65	7.18	7.63	6.99	70	7.83	8.40	9.04
-	-	-	-	65	8.91	8.98	9.65

[S. ID* – Sample ID; P* - Load in kN; D* - Mid span Deflection in mm]

Table 13 b): Load vs Deflection Behavior of NSM and EBR System

S. ID*	**NSM-2-10**			**S. ID***	**CFRP**		
	1	**2**	**3**		**1**	**2**	**3**
P*	**D***			**P***	**D***		
0	0	0	0	0	0	0	0
5	0.57	0.25	0.59	5	0.83	0.34	0.90
10	0.90	0.66	1.01	10	1.28	0.90	1.61
15	1.22	1.31	1.42	15	1.74	1.76	2.25
20	1.89	2.05	2.09	20	2.69	2.78	3.31
25	2.52	2.80	2.91	25	3.60	3.77	4.63
30	3.68	3.71	3.76	30	5.27	4.99	5.98
35	4.31	4.26	4.41	35	6.43	5.96	7.30
40	5.34	4.76	5.14	40	7.94	6.65	8.49
45	5.80	5.46	5.39	45	8.63	7.64	8.91
50	6.26	6.05	6.14	50	9.32	8.44	10.14
55	6.94	6.70	6.76	55	10.31	9.35	11.19
60	7.61	7.34	7.41	60	11.32	10.25	12.23
65	8.30	7.98	8.05	65	12.34	11.14	13.31
70	8.96	8.63	8.69	70	13.32	12.06	14.36
74	9.31	8.98	9.05	75	14.33	12.95	15.54
75	10.98	9.93	9.96	80	16.31	13.86	16.47
70	11.13	10.58	10.61	85	17.57	15.67	18.58
65	11.81	11.23	11.25	90	18.59	16.57	19.66
-	-	-	-	95	19.12	17.48	20.71
-	-	-	-	100	19.56	17.96	21.30
-	-	-	-	102	20.21	18.91	22.40
-	-	-	-	100	22.27	19.85	23.49
-	-	-	-	95	23.33	20.78	24.58

Table 13 c): Load vs Deflection Behavior of EBR System

S. ID*	**GFRP**			**S. ID***	**AFRP**		
	1	**2**	**3**		**1**	**2**	**3**
P*	**D***			**P***	**D***		
0	0	0	0	0	0	0	0
5	0.77	0.33	0.33	5	0.68	0.29	0.68
10	1.20	0.87	0.84	10	1.04	0.77	1.17
15	1.61	1.73	1.79	15	1.40	1.51	1.65
20	2.50	2.69	2.74	20	2.17	2.38	2.43
25	3.35	3.67	3.67	25	2.90	3.22	3.38
30	4.91	4.86	4.86	30	4.24	4.26	4.37
35	5.98	5.80	5.90	35	5.04	4.98	5.23
40	7.40	6.46	6.66	40	6.22	5.56	6.07
45	8.05	7.42	7.47	45	6.77	6.39	6.38
50	8.70	8.20	8.40	50	7.32	7.06	7.26
55	9.62	9.09	9.19	55	8.09	7.82	8.00
60	10.54	9.97	9.93	60	8.89	8.56	8.75
65	11.51	10.83	10.93	65	9.68	9.31	9.51
70	12.43	11.73	11.79	70	10.45	10.07	10.26
75	13.36	12.60	12.65	75	11.25	10.82	11.11
80	15.21	13.47	13.47	80	12.80	11.60	11.79
86	16.37	15.24	15.44	81	12.98	12.34	12.55
80	17.33	16.11	16.31	80	13.79	13.09	13.28
75	18.28	16.99	17.49	75	14.58	13.84	14.06
-	-	-	-	70	15.39	14.61	14.81

Table 14: Summary of Load vs Deflection Behavior

Specimen ID		**Load at Initial Crack (kN)**	**Ultimate load (kN)**	**Mean Deflection at Ultimate load (mm)**
Control beams	CB1	20	60	14.92
	CB2	21	59	18.23
	CB3	17	62	12.61
Preloaded beams	PLB1	21	42	4.26
	PLB2	20	42	4.25
	PLB3	21	42	4.17
Strengthened by NSM system	NSM-2-6-1	28	63	6.12
	NSM-2-6-2	27	62	6.22
	NSM-2-6-3	27	64	5.91
	NSM-2-8-1	30	67	6.62
	NSM-2-8-2	31	67	6.47
	NSM-2-8-3	31	68	7.98
	NSM-2-10-1	36	73	9.31
	NSM-2-10-2	36	74	8.98
	NSM-2-10-3	35	72	9.05
FRP Laminates	CFRP1	40	102	20.21
	CFRP2	42	99	18.91
	CFRP3	41	101	22.40
	GFRP1	38	85	16.37
	GFRP2	37	86	15.24
	GFRP3	38	86	15.72
	AFRP1	31	81	12.98
	AFRP2	29	81	12.34
	AFRP3	30	82	12.58

Table 15: Summary of Strengthened RCC beams

Specimen Description		Mean Deflection at Ultimate Load (mm)	Mean load at Initial Crack (kN)	Mean Ultimate load (kN)	Percentage increase in Ultimate load
Control beams		15.25	19.3	60.3	-
NSM System	2#-6	6.08	27.3	63	4.48
	2#-8	7.02	30.7	67.3	11.61
	2#-10	9.11	35.7	73	21.06
EBR System	CFRP	20.51	41	100.7	67.00
	GFRP	15.78	37.7	85.7	42.12
	AFRP	12.63	30	81.3	34.83

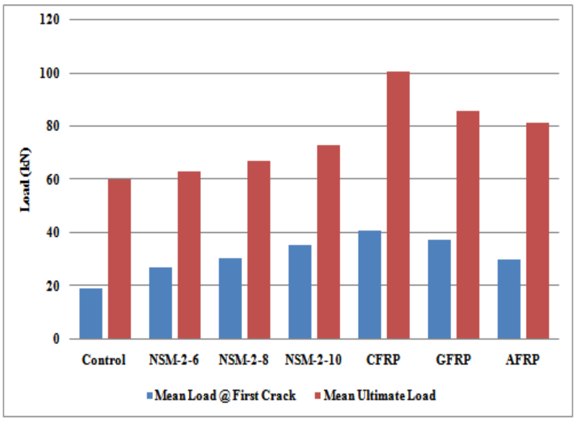

Figure 5: Structural Behavior of RCC Beams

RCC beams casted with GPC had low flexural strength and high deflection. It was concluded that the flexural strength capacity of the RCC beams made with GPC could be increased either with NSM technique or FRP wrapping technique.

VI. CONCLUSIONS

Following are the conclusions drawn from the investigations done on the RCC beams strengthened by NSM and EBR techniques:

- GPC made with fly ash can be effectively used instead of conventional concrete to minimize the global cement production, consumption.
- Full substitution of fine aggregate by M-Sand in GPC is feasible with increment in strength properties.
- After28 days, the strength properties of GC100MS are 14.99%, 18.02% and 20.03% than GC0MS.
- The deflection was reduced in all strengthened beams and the lowest deflection was observed in the strengthened beam when compared to control beams.
- The provision of NSM system with 6, 8 and 10mm diameter bars raised the ultimate load carrying capacity of beam by 4.48%, 11.61% and 21.06% respectively than control beams.
- The provision of EBR system with carbon, glass and aramid polymer sheets raised the ultimate load carrying capacity of beams by 67%, 42.12% and 34.83% respectively compared to control beams.
- Based on the obtained results CFRP wrapping provided better results than other types of wrappings and increased the load carrying capacity by 67% compared to conventional beams.

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