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Flexural Behaviour of FA and GGBS based RGPC Slabs

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Abstract:

Research on RGPC structural elements is still in the early stages. A small number of studies on the flexural behaviour of RGPC slabs are available. In this study, the efficacy of fly-ash and GGBS in RGPC flexural components is investigated. The RGPC flexural components are investigated in this study. RGPC slabs with a 50:50 percentage of fly-ash and GGBS with reinforcement, varying molarity of NaOH, and cured at ambient room temperature and water curing. All slabs were subjected to uniformly distributed loading conditions with all four sides being fixed and simply supported edge conditions. To compute and calculate the load vs deflections and moments carrying capacities as per IS 456 and yield line theory. The flexural behaviour of RGPC slabs is found similar and concluded that 50:50 proportion of FA: GGBS is used for structural applications.

Keywords: Flexural behaviour of slabs, Moment's, type of curing, Fixed and Simply supported edges

Introduction:

At present, the construction industry is trying to move towards sustainable development and improving the usage of environmentally eco-friendly materials to control global warming. Construction projects are the fastest growing and emerging economies to meet their demands, 4.2 billion tons of concrete are made per year. During the manufacturing process of cement, around 5 to 10% of CO_2 emissions are released into the environment, from these cement industries causing tremendous damage to the ecology, deteriorating air quality, and human health [1]. CO_2 emissions can be reduced by 12 % using various efficiency improvement techniques, using low carbon fuel content like coal to natural gas, using chemical absorption process, the strategy of changing clinker manufacturing process [2]. Incorporation of various sustainable cementitious materials like GGBFS, FA, SF, MK, RHA moreover, these materials show a positive impact on concrete in terms of their mechanical and durability properties, which in turn to lead environmental benefits of low CO_2 [3]. Nevertheless, in construction most feasible alternative is cement, gaining, the knowledge in construction, advancement in concrete technology many researchers are focused on viable solutions to replace and reduce the emissions of cement production. Davidovits describe a new mineral binder with chemical composition, i.e. Geopolymer Concrete. It is an inorganic aluminosilicate polymeric gel resulting from the reaction of amorphous aluminosilicates with alkali hydroxide and silicate solutions. By utilizing the polycondensation of silica and alumina precursors to achieve the required strength [4]. Different names were distinguished in their works such as Alkali-Activated Cement (AAC), Inorganic polymer concrete (IPC), and Geocement which are used to describe materials synthesized using the same chemistry [5]. Generally, the volume of concrete contains nearly 70 to 80 percent of Natural Coarse Aggregate, which influences the freshness and hardness of the concrete. Every industrialized country is dependent on aggregate resources like Sand, Gravel, and Stones to build and maintain infrastructural needs. These materials have been recorded due to scarcity of resources, increasing the risk of their availability compared to the alleged needs. To meet these societal needs depends on aggregate mining, which causes a serious impact on the environment [6]. One of the developing concerns about the hereafter of our planet, is to bring in the concept of sustainability in the construction industry. Alexander Vasquez et.al used Concrete Demolition Waste as a precursor to producing GPC, they obtain 25 MPa of strength with 100 % CDW when the addition of 10% of MK and 30% of Portland cement there is an increase in strength 76 % and 31.7 % respectively at 28 days of curing. [7]. F. U. Ahmed Shaikh has observed the mechanical properties of GPC decrease and durability properties show better results with the inclusion of 50 % of RCA at 7 and 28 days of curing [8]. Madheswaran C.K. et.al describes the flexural behavior of RGPC beams using LWA they obtained ultimate load capacities ranging from 53.3 to 64.85KN, 24 to 36.6 KN at 100 % and 50% of reinforcement respectively [9]. Another author O. M. Omar is used local steel slag as a coarse aggregate they observed 6 % higher compressive strength with 100 % substitute of local steel slag [10]. Kaim Mermerdas et.al evaluated the effects, by using different types of aggregates in GM in terms of strength, flowability, unit weight, absorption. They observed that grading of aggregate influences the flow properties, higher flowability with the coarse grading result of a lower specific surface, obtained better strength with crushed limestone and having low water absorption, sorptivity using combined natural sand and crushed limestone [11]. Peem Nuaklone et.al obtained 30.6-38.4 MPa of compressive strength with HCFA Geopolymer Concrete containing RCA these values are slightly lower if concrete contains crushed limestone. At 12 and 16 molarity gives better performance in terms of volume of voids, sorptivity, and absorption [12]. V. Sathish Kumar et.al studied by using three types of blended source materials in various % of replacement levels of fly ash they observed that oven-cured samples achieved higher strength than the steam type of curing [13]. B.V.Rangan et.al identified several financial benefits of usage of fly ash-based GPC and also represents suitable for housing applications, elastic properties in hardened GPC and shows excellent strength and durability properties including reinforced structural elements and those are similar to Portland cement [14]. J. Guru Jawahar et.al observed better results in ultimate loading, moment carrying capacities of GPC slabs and deflection is 89.22 mm for 28 days of room temperature, at 20 % replacement of natural sand with silica sand [15]. Mahantesh B .et.al experimentally studied the flexural behavior of various sizes of slab panels using FA, Slag, and M. sand under two types of loading and different edge condition they get displacement ductility is around 2.10 for RGPC and flexural behaviour is similar compared to ROPC slab panels [16]. Another author K. Amarnath et.al. studied the rectangular reinforced slabs and stated that having a close relationship in both GPC and OPC under different edges and loading conditions [17].M.C.Kumain et.al studied the impact load of GPC slabs having with and without fibers, they observed that the highest impact load is 45.31 in height of fall of 55 cm and appurtenance of cracks on above the surface of GPC slabs is less compared to OPC slabs [18].

Ingredients and mix proportioning details: As per IS 3812 confining class F fly ash [19] and as per IS 12089 GGBS [20] are used, causing a specific gravity of 2.24 and 2.94, fineness is 360 m^2/kg and 400 m^2/kg respectively. A combination of Sodium hydroxide NaOH and sodium silicate Na_2SiO_3 are used as Alkaline Activators 8M, 10M, and 12M concentrations of NaOH were used in this study. This solution is blended together one day before the moulding of specimens. NCA is obtained from local stone crushing units and BMWA is dumped from slab polishing industries near Anantapur, facilitating and crushing into desired sizes, tested as per IS 2386 [21] specific gravity is 2.68 and 2.77, water absorption is 0.42 % and 0.50 % respectively. Fine aggregate is tested as per IS 383-1970 [22] confirming Zone-II and specific gravity 2.61 and bulk density 16.62 Kn/m^3 as per IS 2386. There is no standard mix design for preparation for GPC, based on the guidelines from past research [23, 24] of different mix proportions were taken and for constituent materials are presented in below table 1

Mix Proportions of Geopolymer Concrete Kg/m3									
Mixes	FA	GGBS	NaOH			Na_2SiO_3	Fine Aggregate	Coarse Aggregate	
			8 M	10 M	12 M			NCA	BMWA
Mix 1	205	205	41	41	41	102	555	1294	-
Mix 2	205	205	41	41	41	102	555	647	647
Mix 3	205	205	41	41	41	102	555	-	1294

Note: NCA Natural Coarse Aggregate, BMWA: Black Marble Waste Aggregate

Table: 1 Showing Mix proportions details

Experimental program: The test program has been contrived to obtain sufficient data to assess the flexural behavior of GPC slabs containing BMWA as NCA under simulated uniformly distributed load. Total 36 Nos of slabs having a dimension of 600 x 600 x 50mm was caste with the varying molarity of NaOH i.e 8M, 10M, and 12M. Two edge conditions are considered in the study are given as below:

1. Four edges are fixed condition
2. Four edges are simply supported

Experimental setup and application of loading: Structural loading frame with the platform is used to test square slab specimens having 600 x 600 x 50 mm dimensions. The loading platform consists of 4 welded steel beams of ISLB150 and is supported on 4 columns of ISLB150 placed at 4 corners. The loading platform and frame are stiff enough to support the loading without deformation. Loading platform as shown in figure 1. Application of load on the surface of the slab through a distribution system called "loading spreaders" consists of an iron plate with 50 mm diameter iron balls welded closely placed above the surface of the slab to simulate uniformly distributed loading conditions through I- Section placed above the plate. In the bottom face of the slab, deflectometer are placed at the center and along the diagonal direction to record the deflections, and also consist of a pre-calibrated proving ring and hydraulic jack. Loading frame, platform, and proving ring as shown in Figure 1

Figure: 1 Loading frame, platform, and proving ring

Test specimen details and casting: All the specimens have identical dimensions and reinforcement details. Fe 415 HYSD bars of 8 mm diameter steel bars are used to provide reinforcement in slabs with 150 mm center to center spacing in both directions. All specimens are cast in specially manufactured steel moulds with 2 L Shaped frames with a depth of 50 mm which are connected to a flat plate using nots and bolts and cross stiffeners are provided at the bottom to prevent deflections.

Figure: 2

Moment carrying capacity of the slab due to flexure:

Simply supported Edge condition: The slab is laid over the loading platform and the four edges are permitted for free rotation, thus simulating the simply supported edge condition, as shown in figure 3. To determine the moment carrying capacity of the slab at first crack and ultimate load by using IS Code method and yield line theory if the edge of the slabs is S.S with the variation of replacement of NCA, i.e (NCA, NCA+BMWA, BMWA) curing condition and 8M, 10M and 12M of NaOH. The values are tabulated in table 2 & 3.

Figure 3: Simply Supported Slab Condition

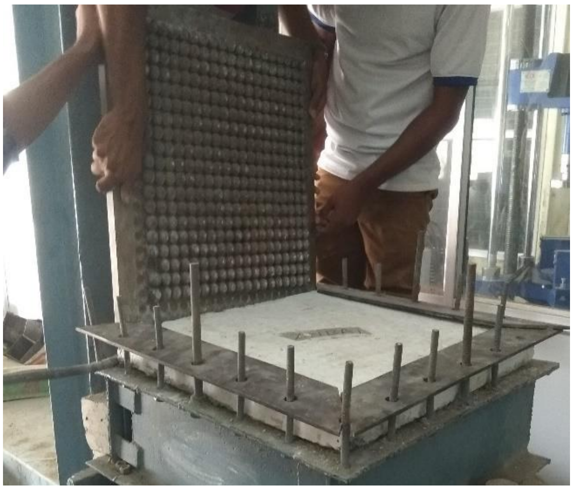

Figure 4: Fixed Edge Condition

Moment carrying capacity of the slab all the four sides of slab are simply supported Edge Condition

Mix	Molarity	At first crack				At ultimate load			
		Load (KN)	Load (KN/m)	Moments (KN-m)		Load (KN)	Load (KN/m)	Moments (KN-m)	
				IS method	Yield line theory			IS method	Yield line theory
Mix 1	8M	47.83	191.32	3.59	2.869	89.08	356.32	6.68	5.345
	10M	54.49	217.96	4.09	3.269	101.49	405.96	7.61	6.089
	12M	58.5	234	4.39	3.51	106.34	425.36	7.98	6.38
Mix 2	8M	40.21	160.84	3.02	2.412	83.68	334.72	6.28	5.02
	10M	46.51	186.04	3.49	2.79	94.23	376.92	7.07	5.65
	12M	51.51	204.6	3.84	3.06	101.25	405	7.6	6.075
Mix 3	8M	36.24	144.96	2.72	2.17	75.17	300.68	5.64	4.51
	10M	41.19	164.76	3.09	2.47	86.25	345	6.47	5.175
	12M	46.37	185.48	3.48	2.78	92.35	369.4	6.93	5.54

Table: 2 Moment carrying capacity of Slab specimens are at ambient temperature

Mix	Molarity	At first crack				At ultimate load			
		Load (KN)	Load (KN/m)	Moments (KN-m)		Load (KN)	Load (KN/m)	Moments (KN-m)	
				IS method	Yield line theory			IS method	Yield line theory
Mix 1	8M	40.25	161	3.02	2.415	79.09	316.36	5.93	4.745
	10M	46.09	184.36	3.46	2.765	90.56	362.24	6.79	5.434
	12M	47.73	190.92	3.58	2.864	93.78	375.12	7.04	5.627
Mix 2	8M	43.8	175.2	3.29	2.62	84.24	336.96	6.32	5.054
	10M	50.15	200.6	3.76	3	98.61	394.44	7.4	5.917
	12M	51.94	207.76	3.9	3.116	102.12	408.48	7.66	6.127
Mix 3	8M	50.86	203.44	3.82	3.052	91.2	364.8	6.84	5.472
	10M	58.23	232.92	4.37	3.494	106.68	426.72	8	6.401
	12M	60.3	241.2	4.52	3.618	110.48	441.92	8.29	6.629

Table: 3 Moment carrying capacity of Slab specimens are water cured

From the above tables, it is noticed that the 1st crack load increases from 47.83 Kn/m of 8M, 54.49 Kn/m of 10M, and 58.5 Kn/m of 12M in mix1. 40.21 Kn/m of 8M, 46.51 Kn/m of 10M, and 51.51 Kn/m of 12M in mix2. 36.24 Kn/m of 8M, 41.19 Kn/m of 10M, and 46.37 Kn/m of 12M in mix3 if the specimens are in ambient temperature. If the specimens are water cured 1st crack load increases from 40.25 Kn/m of 8M, 46.09 Kn/m of 10M, and 47.73 Kn/m of 12M in mix1. 43.8 Kn/m of 8M, 50.15 Kn/m of 10M, and 51.94 Kn/m of 12M in mix2. 50.86 Kn/m of 8M, 58.23 Kn/m of 10M, and 60.3 Kn/m of 12M in mix3.

Fixed Edge Conditions: The slabs were restrained on all four sides iron plates were all fixed on four sides of the slab through the nuts and bolts in order to prevent any rotation and any differential settlements. Set up and position of slab specimens are shown in figure 4. To determine the moment carrying capacity of the slab at first crack and ultimate load by using IS Code method and yield line theory if the edge of the slabs is fixed with the variation of replacement of NCA, i.e (NCA, NCA+BMWA, BMWA) curing condition and 8M, 10M and 12M of NaOH. The values are tabulated in tables 4 & 5.

Moment carrying capacity of the slab all the four sides of the slab are Fixed Edge Condition

Mix	Molarity	At first crack				At ultimate load			
		Load (KN)	Load (KN/m)	Moments (KN-m)		Load (KN)	Load (KN/m)	Moments (KN-m)	
				IS method	Yield line theory			IS method	Yield line theory
Mix 1	8M	66.32	265.28	4.49	1.989	12.14	492.56	8.34	3.694
	10M	74.23	296.92	5.03	2.22	139.52	558.08	9.45	4.186
	12M	80.14	320.56	5.43	2.404	146.26	585.04	9.91	4.388
Mix 2	8M	56.71	226.84	3.84	1.7	115.32	461.28	7.81	3.46
	10M	62.23	248.92	4.22	1.86	129.21	516.84	8.76	3.87
	12M	70.07	280.28	4.75	2.102	138.25	553	9.37	4.14
Mix 3	8M	53.13	212.52	3.6	1.593	106.42	425.68	7.21	3.193
	10M	57.25	229	3.88	1.718	120.11	480.44	8.14	3.6
	12M	63.53	254.12	4.3	1.906	126.3	505.2	8.56	3.786

Table: 4 Moment carrying capacity of Slab specimens are at ambient temperature

Mix	Molarity	At first crack				At ultimate load			
		Load (KN)	Load (KN/m)	Moments (KN-m)		Load (KN)	Load (KN/m)	Moments (KN-m)	
				IS method	Yield line theory			IS method	Yield line theory
Mix 1	8M	54.25	217	3.68	1.62	109.35	437.4	7.41	3.28
	10M	61.01	256.04	4.36	1.92	125.77	503.08	8.52	3.77
	12M	65.38	261.52	4.43	1.961	125.32	501.28	8.49	3.76
Mix 2	8M	60.25	241	4.08	1.8	119.24	476.96	8.08	3.57
	10M	69.66	278.64	4.72	2.09	134.52	538.08	9.12	4.036
	12M	71.15	284.6	4.82	2.135	136.24	544.96	9.23	4.08
Mix 3	8M	69.25	277	4.69	2.078	129.36	517.44	8.77	3.88
	10M	80.87	323.48	5.48	2.42	146.23	548.92	9.91	4.38
	12M	82.61	330.44	5.6	2.478	146.23	584.92	9.91	4.38

Table: 5 Moment carrying capacity of Slab specimens are water cured

From the above tables, it is noticed that the 1st crack load increases from 66.32 Kn/m of 8M, 74.23 Kn/m of 10M, and 80.14 Kn/m of 12M in mix1. 56.71 Kn/m of 8M, 62.23 Kn/m of 10M, and 70.07 Kn/m of 12M in mix2. 53.13 Kn/m of 8M, 57.25 Kn/m of 10M, and 63.53 Kn/m of 12M in mix3 if the specimens are in ambient temperature. If the specimens are water cured 1st crack load increases from 54.25 Kn/m of 8M, 61.01 Kn/m of 10M, and 65.38 Kn/m of 12M in mix1. 60.25 Kn/m of 8M, 69.66 Kn/m of 10M, and 71.15 Kn/m of 12M in mix2. 69.25 Kn/m of 8M, 80.87 Kn/m of 10M, and 82.61 Kn/m of 12M in mix3.

Load and Deformation Behaviour:

Figure 5 to 10 and figure 11 to 15 shows the Load Vs Deformation behaviour of slabs in simply supported and Fixed edge conditions both in ambient temperature and water curing methods respectively.

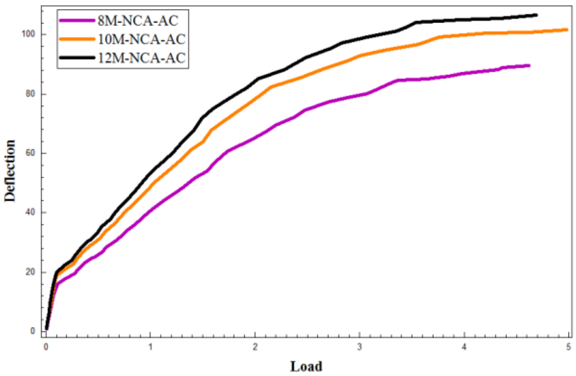

Fig.5 NCA-SSE-AC

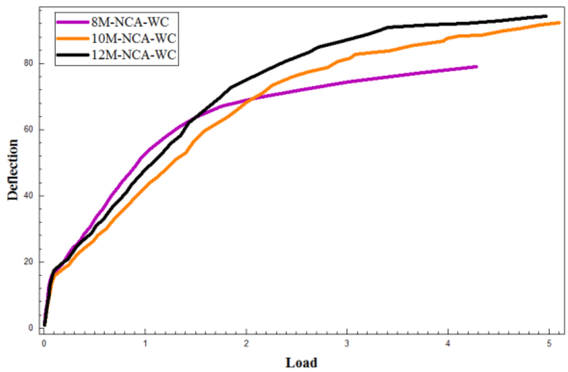

Fig.6 NCA-SSE-WC

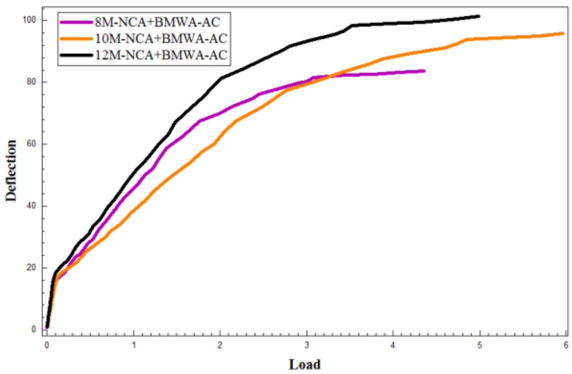

Fig.7 NCA+BMWA-SSE-AC

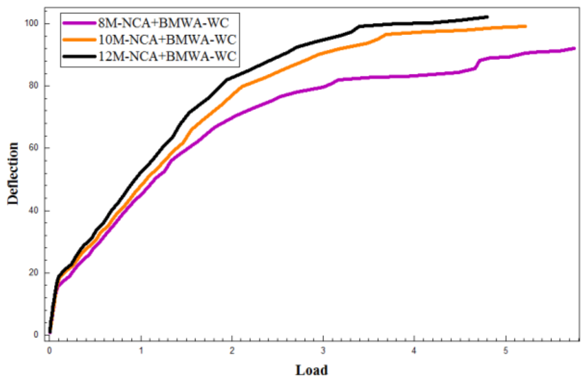

Fig.8 NCA+BMWA-SSE-WC

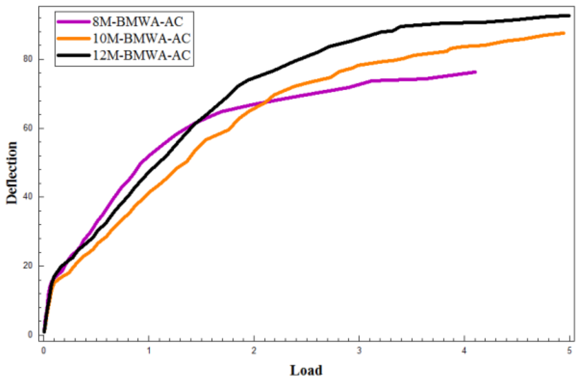

Fig.9 BMWA-SSE-AC

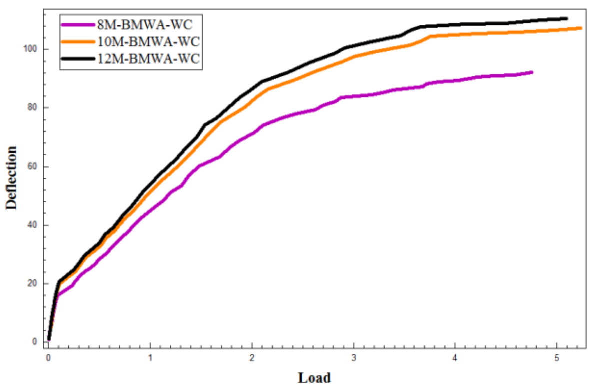

Fig.10 BMWA-SSE-WC

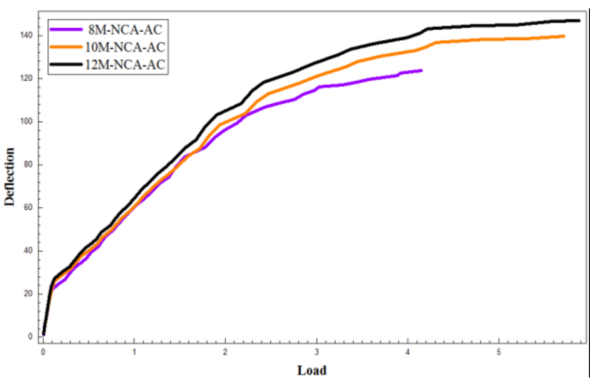

Fig.10 NCA-FE-AC

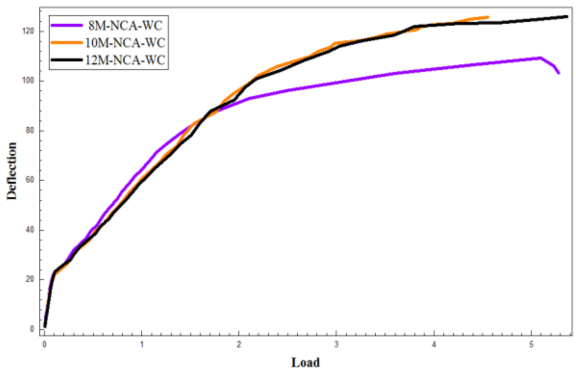

Fig.11 NCA-FE-WC

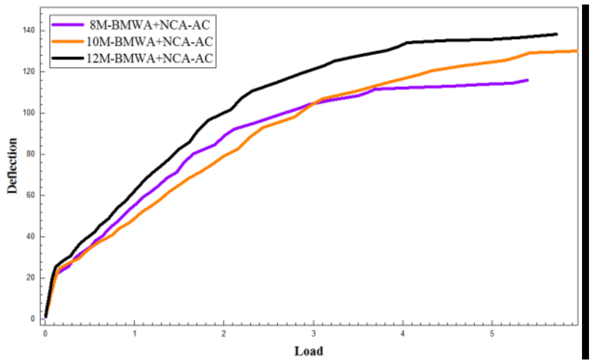

Fig.12 NCA+BMWA-FE-AC

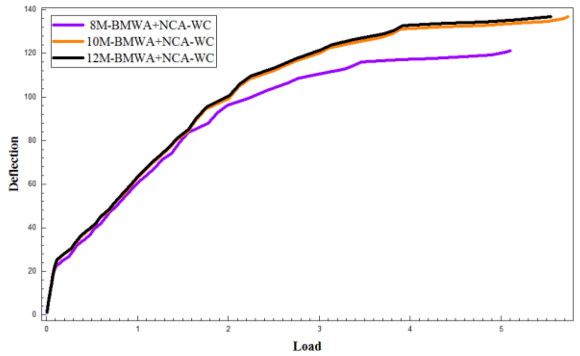

Fig.13 NCA+BMWA-FE-WC

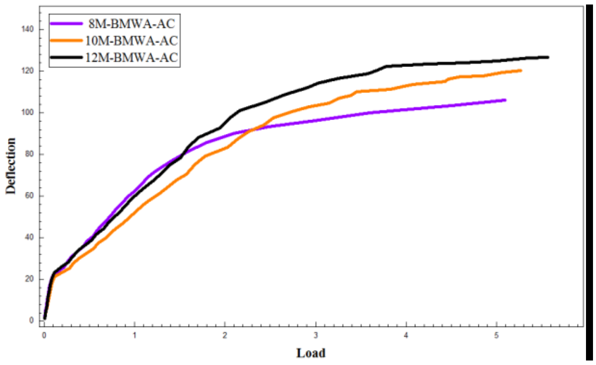

Fig.14 BMWA-FE-AC

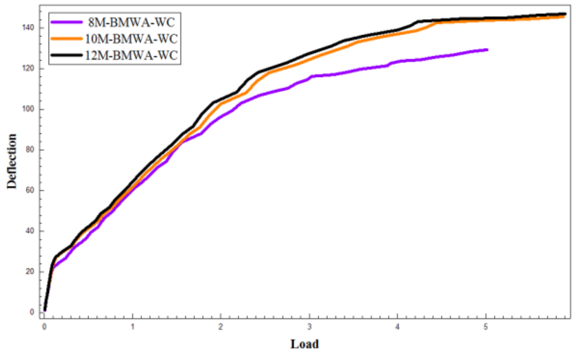

Fig.15 BMWA-FE-WC

Results and conclusions:

1. Manufacturing of GPC by using FA and GGBS as 50:50 percentage can be used as structural and in situ applications.
2. The moment carrying capacity of reinforced GPC slabs increases with the increase in the concentration of NaOH.
3. The values of moment carrying capacity of slabs decreases with increases the percentage replacement of NCA with BMWA in ambient temperature whereas in water curing it increases in both SS and fixed edge conditions under udl loading.
4. The ultimate load and moment of RGPC slab with fixed edge condition, were observed almost similar in both curing conditions in 12M of NaOH.

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