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Binder index as criteria for assessing the strength of geopolymer concrete

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Geopolymer is being developed as new the binder, instead of cement paste, to produce concrete. The geopolymer paste binds with coarse aggregates, fine aggregates together to form the Geopolymer Concrete (GPC). Several investigators used the industrial bye products such as Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS) in combination with alkaline activator solutions in producing the Geopolymer binders. The published literature has revealed several variables that are affecting the strength of GPC. This paper presents a new parameter called 'Binder Index' which combines the effect of different parameters and it may be considered as unique parameter influencing the compressive strength of GPC and thereby help in development of binder index based criteria for mix design of GPC.

KEYWORDS: Binder index; geopolymer concrete; GGBS, fly ash; alkaline activator.

In the development of new age construction materials the key factors are 'sustainability' and 'energy efficiency'. The long-term view is to reduce the impact of unwanted industrial by-products by lowering the rate of material consumption. In this direction the geopolymers have emerged as environmental friendly substitutes for Portland cement which in many applications not only reduce greenhouse gas emissions but also consume large volumes of industrial wastes such as fly ash, mine tailings and metallurgical slag. Geopolymer Concrete (GPC) is recently being developed as an alternative to the Ordinary Portland Cement (OPC). GPC is obtained by stimulating the source materials such as Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS) which are rich in Silicon (Si) and Aluminum (Al) using high alkaline liquids such as NaOH and/or Sodium silicate solution. These alkaline liquids act as an activator and produce the binder required to manufacture the concrete with no cement. In the recent past several investigations[1-8] reported various parameters affecting the strength of GPC. These parameters include quantity of source material, activator to binder ratio, molarities of activator solution. The published literature indicates that several variables were affecting the strength of GPC. However when taken the effect of different parameters individually on the strength of GPC the scatter in the results is high[9]. The combined effect of different parameters on the strength of GGBS and Fly ash based Geopolymer concrete was presented by proposing a parameter called 'Binder Index[10] (Bi)'. However the binder index proposed earlier did not account for variation of alkaline to binder ratio. Hence in this paper the binder index proposed earlier is modified so that it takes into account the major parameters affecting the strength of Geopolymer concrete.

FACTORS AFFECTING THE STRENGTH OF GPC

Based on the previous studies in the literature, the parameters affecting the production of alkali activated fly ash and/or GGBS-based geopolymer paste are the

concentration of the sodium hydroxide solution, the curing temperature, the Na_2SiO_3/NaOH ratio and the alkaline activator / binder (GGBS and FA together) ratio[9-11]. The chemical composition of the source material is also an important parameter affecting the mechanical properties of the GPC[2,6]. Previous studies also shown that using an alkaline activator composed of sodium hydroxide solution (NaOH solution) and sodium silicate solution (Na_2SiO_3 solution) leads to better mechanical properties (including compressive strengths) than using only NaOH solution as an activator[2]. The Na_2SiO_3 solution percentage in the alkaline activator also has an important effect since the solution favors the polymerization process adding more silicon (Si) atoms to the product and thus resulting better mechanical strength[4]. It was reported[11] that GPC achieved maximum strength for Na_2SiO_3/NaOH ratio of 2.5. The compressivestrength of GPC was observed to increase with increase in GGBS to FA ratio for a particular molarity of activator used[12]. The rate of increase of compressive strength is more for GGBS to FA ratios less than 1.0.

BINDER INDEX OF GEOPOLYMER CONCRETE

To study the combined effect of different parameters on the strength of GGBS and FA based GPC a new parameter called 'Binder Index (Bi)' is proposed[10]. However the binder index proposed earlier did not account for variation of alkaline to binder ratio. Hence in this paper the binder index proposed earlier is modified so that it takes into account the major parameters affecting the strength of GPC. The proposed binder index is based on the reported findings related to the strength of GPC[9]. The major observations include the increase in strength of GPC with increase in molarity, alkaline to binder ratio and GGBS to FA ratio for constant ratio of Na_2SiO_3/NaOH. Keeping in view of the above observations the strength of GPC is considered to be proportional to the molarity of alkaline solution, alkaline to binder (GGBS + FA) ratio and GGBS to FA ratio. All these identified parameters are grouped in to a single parameter called 'Binder Index (Bi) to which the strength of GPC can be related. Hence the proposed binder index (Bi) is:

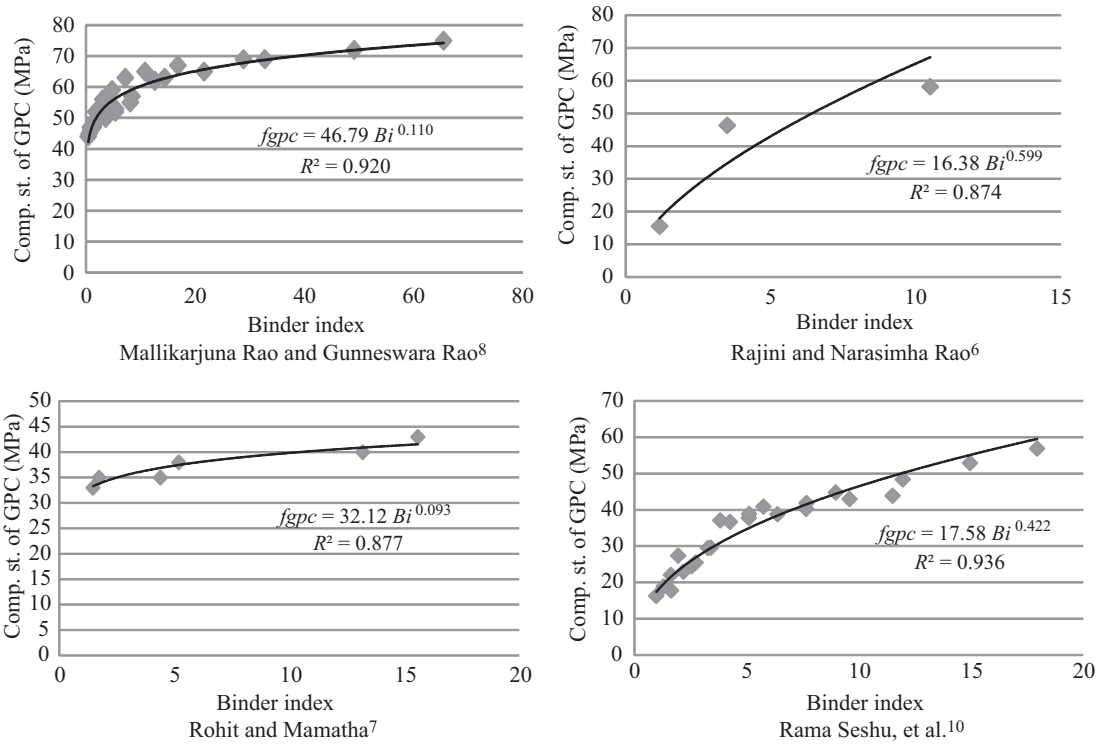

Fig. 1 Variation of compressive strength of GPC (f_{gpc}) with the proposed binder index (Bi) for the experimental results reported inliterature

$$Bi = \frac{MA}{G+F}\left[\frac{G}{F}\right]$$

where, M = molarity of NaOH; A = alkaline activator (both NaOH and Na_2SiO_3 together) content; G = GGBS content; F = fly ash content

Figure 1 shows the variation of compressive strength of GPC (f_{gpc}) with binder index (Bi) for the compressive strength test results of GPC mixes reported by different investigators. The best fit equation and corresponding R^2 value obtained are given in Table 2. It is observed from the Fig.1 that there is an increase in compressive strength of GPC with increase of binder index. The observed variation of compressive strength of GPC (f_{gpc}) with binder index (Bi) indicates that the proposed form of binder index which combines the effects of alkaline to binder ratios, GGBS to fly as ratio and molarity, can be considered as single unique parameter influencing the compressive strength of GPC mixes. The variation of compressive strength of GPC (f_{gpc}) with binder index (Bi) can be represented by a simple power equation of the following form.

$$f_{gpc} = N[Bi]^L$$

TABLE 1
THE BINDER PROPORTIONS AND STRENGTH OF GEOPOLYMER CONCRETE

S.No	Authors and reference	FA (Kg) (F)	GGBS (Kg) (G)	Alkaline activator (A)		Molarity (M)	Comp. Strength (N/mm^2)	Bi (calculated)
				Na_2SiO_3	(Kg)	NaOH (Kg)		
1.	Mallikarjuna Rao and Gunneswara Rao[8]	808.24	89.8	289.74	115.5	8	44	0.401
		718.43	179.61	289.74	115.5	8	46	0.902
		628.63	269.41	289.74	115.5	8	49	1.547
		538.82	359.22	289.74	115.5	8	50	2.406
		449.02	449.02	289.74	115.5	8	50	3.609
		359.22	538.82	289.74	115.5	8	52	5.414
		269.41	628.83	289.74	115.5	8	57	8.424
		179.61	718.43	289.74	115.5	8	63	14.439
		89.08	808.24	289.74	115.5	8	69	32.780
		808.24	89.8	289.74	115.5	12	45	0.601
		718.43	179.61	289.74	115.5	12	47	1.353
		628.63	269.41	289.74	115.5	12	50	2.320
		538.82	359.22	289.74	115.5	12	52	3.610
		449.02	449.02	289.74	115.5	12	53	5.414
		359.22	538.82	289.74	115.5	12	55	8.122
		269.41	628.83	289.74	115.5	12	62	12.636
		179.61	718.43	289.74	115.5	12	65	21.659
		89.08	808.24	289.74	115.5	12	72	49.170
		808.24	89.8	289.74	115.5	16	47	0.802
		718.43	179.61	289.74	115.5	16	52	1.805
		628.63	269.41	289.74	115.5	16	56	3.094
		538.82	359.22	289.74	115.5	16	59	4.813
		449.02	449.02	289.74	115.5	16	63	7.219
		359.22	538.82	289.74	115.5	16	65	10.829
		269.41	628.83	289.74	115.5	16	67	16.848
		179.61	718.43	289.74	115.5	16	69	28.879
		89.08	808.24	289.74	115.5	16	75	65.560

2.	Rajini and Narasimha Rao[6]	102.2	306.7	102	41	10	58.12	10.494
		204.5	204.5	102	41	10	46.32	3.496
		306.7	102.2	102	41	10	15.55	1.165
3.	Rohit and Mamatha[11]	295.71	98.57	112.65	45.06	11	33	1.466
		197.14	197.14	112.65	45.06	11	35	4.399
		98.57	295.71	112.65	45.06	11	40	13.199
		295.71	98.57	112.65	45.06	13	35	1.733
		197.14	197.14	112.65	45.06	13	38	5.199
		98.57	295.71	112.65	45.06	13	43	15.599
4.	Rama Seshu, et al.[10]	7.85	2	4.5	1.8	6	16.3	0.977
		6.9	2.95	4.5	1.8	6	17.8	1.640
		5.91	3.94	4.5	1.8	6	24.5	2.558
		4.93	4.92	4.5	1.8	6	37.1	3.829
		3.94	5.91	4.5	1.8	6	40.9	5.756
		2.95	6.9	4.5	1.8	6	44.8	8.975
		7.85	2	4.5	1.8	8	18.9	1.303
		6.9	2.95	4.5	1.8	8	23	2.187
		5.91	3.94	4.5	1.8	8	29.6	3.411
		4.93	4.92	4.5	1.8	8	37.8	5.106
		3.94	5.91	4.5	1.8	8	41.9	7.675
		2.95	6.9	4.5	1.8	8	48.4	11.967
		7.85	2	4.5	1.8	10	22.1	1.629
		6.9	2.95	4.5	1.8	10	25.5	2.734
		5.91	3.94	4.5	1.8	10	36.7	4.263
		4.93	4.92	4.5	1.8	10	38.8	6.382
		3.94	5.91	4.5	1.8	10	43	9.593
		2.95	6.9	4.5	1.8	10	52.9	14.959
		7.85	2	4.5	1.8	12	27.4	1.955
		6.9	2.95	4.5	1.8	12	29.5	3.281
		5.91	3.94	4.5	1.8	12	38.9	5.116
		4.93	4.92	4.5	1.8	12	40.3	7.659
		3.94	5.91	4.5	1.8	12	43.9	11.512
		2.95	6.9	4.5	1.8	12	56.9	17.951

The N and L are the constants. The above form of equation forms the basis for the initial estimation of strength in the mix design of GPC.

CONCLUSIONS

The following are the conclusions arrived at after the study of different variables affecting the compressive strength of GPC mixes reported in published literature.

The new proposed parameter called binder index which combines the effects of alkaline to binder ratio, GGBS to FA ratio and molar concentration of activator solution can be used as single unique parameter to control the compressive strength of GPC.

The relation between the compressive strength and binder index of GPC is a non-linear and can be represented by a power equation: $f_{gpc} = N[Bi]^L$, where N and L are the constants

TABLE 2
RRELATIONSHIP FOR THE COMPRESSIVE STRENGTH AND BINDER INDEX

Authors and reference	Equation	R^2
Mallikarjuna Rao and Gunneswara Rao[8]	$f_{gpc} = 46.79\ Bi^{0.110}$	$R^2 = 0.920$
Rajini and Narasimha Rao[6]	$f_{gpc} = 16.38\ Bi^{0.599}$	$R^2 = 0.874$
Rohit and Mamatha[7]	$f_{gpc} = 32.12\ Bi^{0.093}$	$R^2 = 0.877$
Rama Seshu, et al.[10]	$f_{gpc} = 17.48\ Bi^{0.422}$	$R^2 = 0.936$

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