https://doi.org/10.48047/AFJBS.6.12.2024.6627-6645

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper **Open Access**

AN EXPERIMENTAL STUDY ON COMPRESSIVE STRENGTH CHARACTERISTICS OF FLY ASH AND GGBS BASED GEOPOLYMER CONCRETE (FGGC) WITH VARYING ALKALINE BINDER RATIOS

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Volume 6, Issue 12, June 2024
Received: 15 Apr 2024
Accepted: 05 May 2024
Published: 03 June 2024
doi:10.48047/AFJBS.6.12.2024.6627-6645

ABSTRACT: This study examines use of geopolymer concrete (GPC) as a sustainable alternative to Portland cement-based concrete by investigating the influence of varying proportions of ground granulated blast furnace slag (GGBS) and fly ash (FA) on the compressive strength of GPC 8M alkaline solutions. Mix designs were formulated with GGBS-to-FA ratios of 80:20, 60:40, 50:50, 40:60, and 20:80. Additionally, alkaline-to-binder ratios of 0.30, 0.34, 0.38, 0.42, 0.46, and 0.50 were also considered to study their effect on compressive strength, along with aggregate proportions of 1080 kg/m^3 (67%) and 1174 kg/m (70%). Compressive strength test was conducted on 100 mm x 100 mm cube specimens after 7 and 28 days of ambient curing. Results showed that increasing alkaline-to-binder ratio enhanced workability, leading to improved compressive strength. Mixes with higher GGBS content exhibited greater compressive strength due to high calcium content in GGBS, which accelerated geo-polymerization. However, higher GGBS proportions reduced workability due to the material's rapid reaction rate. The findings of the study revealed that the compressive strength of GPC is significantly influenced by GGBS-to-FA proportion and the alkaline-to-binder ratio. An alkaline-to-binder ratio of 0.38 was found to provide optimal performance, balancing workability and compressive strength. Further, the results of the study underscore the potential of GPC as a high-strength, eco-friendly construction material due to the effective utilization of industrial by-products such as fly ash and GGBS. In this paper, a Parameter called Binder Index is proposed to quantify the effect of GGBS, fly ash and molarity on the Compressive strength of Geo-polymer concrete developed at ambient room temperature.

Keywords: Geopolymer Concrete, Fly Ash, GGBS, Alkaline-to-Binder Ratio, Compressive Strength, Ambient Curing.

1. INTRODUCTION

The production of Portland cement is a major contributor to global carbon emissions, highlighting the need for more sustainable construction materials [1]. Geopolymer concrete (GPC) is a viable alternative for Portland cement-based concrete to reduce global carbon emission, by utilizing industrial by-products such as ground granulated blast furnace slag (GGBS) and fly ash (FA) as primary binders, for sustainable construction This study explores the compressive strength properties of GPC, emphasizing mix design optimization to develop various concrete grades while promoting environmental sustainability.

1.1 NEED OF PRESENT RESEARCH

Concrete is the most widely used construction material globally due to its versatility and strength properties. However, its extensive production significantly contributes to environmental degradation, particularly through high carbon emissions associated with the production of Portland cement. The urgent need to reduce the carbon footprint in the construction sector has driven the search for sustainable alternatives. Geopolymer concrete (GPC) emerges as a promising solution by utilising industrial by-products such as fly ash (FA) and ground granulated blast furnace slag (GGBS) as binders, eliminating the need for conventional cement. The use of alkaline activators initiates the geopolymerization process, forming a strong and durable matrix.

This research focuses on optimising GPC properties by exploring various alkaline-to-binder ratios combined with different aggregate volumes. The study aims to identify the optimal binder ratios that enhance the mechanical strength, durability, and workability of GPC while promoting eco-friendly construction practices. By investigating the influence of these parameters, the research intends to contribute to a deeper understanding of GPC mix designs, paving the way for its broader adoption in the construction industry.

1.2 RESEARCH METHODOLOGY

This study investigates geopolymer concrete (GPC) with GGBS-to-FA ratios of 80:20, 60:40, 50:50, 40:60, and 20:80, and alkaline binder ratios of 0.30, 0.34, 0.38, 0.42, 0.46, and 0.50. A fixed sodium silicate to sodium hydroxide ratio of 2.5 and 8M NaOH solution were used, with aggregate content at 67% and 70%. Concrete cubes (100mm) were cast and cured under ambient conditions. Compressive strength tests at 7 and 28 days helped determine the optimal mix for strength and workability.

2.0 LITRATURE REVIEW

A comprehensive study was conducted on geopolymer concrete, reviewing existing literature on its properties, mix designs, and performance. The review focused on various aspects of geopolymer concrete, including the use of industrial by-products like fly ash and GGBS, alkaline activator ratios, and the impact of these factors on strength, durability, and sustainability. Anuradha et al. [2] In order to develop a mix design for GPC, a trial-and-error approach was used in miscellaneous research. Annapurna et al. [3], The materials used for making fly ash-based geo polymer concrete specimens are dry fly ash as the source material, aggregates, alkaline liquids, water, and super plasticizer. Amirtharaj Praveen et al. [4] The effect of sodium oxide dosage and activator modulus on the compressive strength of concrete specimens was explored and the results used to design suitable AAS and Geopolymer concrete mixes. Krishna Rao et al. [5] The commonly used combination of alkaline activator solution is NaOH and Na2SiO3. The silica byproducts form with alkaline solution a binder matrix to bind aggregate in the mixture and to produce the hardened concrete. Adil Ahmed et al. [6] with the increase in GGBS content, there was a reduction in setting time, and the mix set faster, with more GGBS, greater strength was achieved at a relatively milder alkali activator solution. Krishna Rao et al. [7-8] & Radhika et al. [9] by increasing the NaOH concentration, there is a decreased in the workability and improvement in the mechanical properties with ambient curing.

3. MATERIALS AND METHODS

3.1.0 MATERIALS

3.1.1 FLYASH: Fly ash, a fine powder by-product from coal combustion in thermal power plants, is a pozzolanic material rich in silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). It is classified into Class F and Class C based on chemical composition. High silica and alumina content are essential for geopolymerization, while calcium oxide (CaO) influences setting time and strength. Fly ash-based GPC is an eco-friendly, high-performance alternative to traditional concrete, reducing carbon emissions and efficiently utilizing industrial waste [10].

3.1.2 GGBS: GGBS, a by-product of iron production in blast furnaces, is formed by rapidly cooling molten slag and grinding it into a fine powder. Rich in CaO, SiO_2, and Al_2O_3, it acts as a reactive SCM with pozzolanic and cementitious properties. Its high calcium content accelerates geopolymerization, enhancing strength and durability against sulfate and chloride attacks. GGBS also reduces Portland cement use, supporting sustainable construction. [11].

Table 1. Chemical Composition of Fly Ash and GGBS percentage by mass.

Material	SiO_2	Al_2O_3	Fe_2O_3	SO_3	CaO	MgO	Na_2O	Ti	K_2O	LOI
Fly ash	58.5	22.3	8.2	1.6	1.08	1.05	0.12	1.52	5.13	0.3
GGBS	35.25	20.12	0.85	0.82	32.9	7.82	-	-	-	-

Table 2. Materials used for NaOH solution preparation.

	8 moles/L
Sodium hydroxide pellets, (grams)	262
Potable Water (grams)	738

3.1.3 Alkaline Solution: Geopolymer concrete (GPC) is an eco-friendly alternative to traditional Portland cement concrete, using industrial by-products like fly ash or slag, activated by an alkaline solution. The alkaline solution plays a crucial role in dissolving the aluminosilicate materials and forming the geopolymer gel, which provides strength and durability. The alkaline solution used in GPC typically consists of Sodium Hydroxide (NaOH) or Potassium Hydroxide (KOH) Provides the necessary alkalinity for activation. Sodium Silicate (Na_2SiO_3) or Potassium Silicate (K_2SiO_3) Enhances the polymerization process and improves strength development. In the present research study Alkaline solution of 8M is used. The ratio of sodium silicate to sodium hydroxide was maintained at 2.5 for all mixes [12].

3.1.4 AGGREGATES: Aggregates play a crucial role in geopolymer concrete (GPC) by providing strength, stability, and volume to the mix. They occupy about 70–80% of the total concrete volume and significantly influence its mechanical properties and durability. Locally available Fine and coarse aggregates were chosen in accordance with IS:383-2016, with an optimized aggregate content of 1174 kg/m^3 (70%) to achieve maximum compressive strength [13].

4.0 MIX PROPORTIONS: Various GGBS-to-Fly ash ratios, including 80:20, 60:40, 50:50, 40:60, and 20:80, were analysed. Additionally, alkaline-to-binder ratios of 0.30, 0.34, 0.38, 0.42, 0.46 and 0.50 were tested to assess their effect on workability and compressive strength. The unit weight of Geopolymer concrete is 2400 Kg/m^3 [14].

Table 3 Geopolymer Concrete mix proportions (Kg/m^3) for various Binder ratios at 67% of Aggregates

Alk/fly ash	Coarse Aggregate	Fine Aggregate	Fly Ash+GGBS	Alkaline Solution	Super Plasticizer	Additional Water
0.30	1080	531.94	606.2	181.86	12.12	45.46
0.34	1080	531.94	588.1	199.96	11.76	44.1
0.38	1080	531.94	571.05	217.01	11.42	42.83
0.42	1080	531.94	554.97	233.09	11.09	41.6
0.46	1080	531.94	539.76	248.3	10.76	40.48
0.50	1080	531.94	525.37	262.69	10.5	39.4

Table 4 Geopolymer Concrete mix proportions (Kg/m^3) at 0.38 Binder Ratio.

GGBS:FA	Molarity(M)	Coarse Aggregate	Fine Aggregate	NaoH Solution	Fly Ash in (kgs)	GGBS (kgs)	Super Plasticizer (2% of the Binder)	Extra Water (7.5% of the Binder)
80:20	8M	1080	531.94	216.12	456.8	114.3	11.42	42.83
60:40	8M	1080	531.94	216.12	342.7	228.4	11.42	42.83
50:50	8M	1080	531.94	216.12	285.6	285.6	11.42	42.83
40:60	8M	1080	531.94	216.12	228.4	342.7	11.42	42.83
20:80	8M	1080	531.94	216.12	114.3	456.8	11.42	42.83

Table 5 Geopolymer Concrete mix proportions (Kg/m^3) for various Binder ratios at 70% of Aggregates

Alk/fly ash	Coarse Aggregate	Fine Aggregate	Fly Ash+GGBS	Alkaline Solution	Super Plasticizer (2% of the Binder)	Extra Water (7.5% of the Binder)
0.30	1174	503.2	556	166.8	11.12	41.7
0.34	1174	503.2	539.4	184.4	10.78	40.45
0.38	1174	503.2	523.76	199.04	10.47	39.28
0.42	1174	503.2	509	213.8	10.18	38.17
0.46	1174	503.2	495	227.8	9.9	37.13
0.50	1174	503.2	481.7	240.94	9.63	36.12

Table 6 Geopolymer Concrete mix proportions (Kg/m^3) at 0.38 Binder Ratio.

GGBS:FA	Molarity(M)	Coarse Aggregate	Fine Aggregate	NaoH Solution	Fly Ash in (kgs)	GGBS (kgs)	Super Plasticizer (2% of the Binder)	Extra Water (7.5% of the Binder)
80:20	8M	1174	503.2	199.04	419	104.8	10.47	39.28
60:40	8M	1174	503.2	199.04	314.3	209.5	10.47	39.28
50:50	8M	1174	503.2	199.04	261.9	261.9	10.47	39.28
40:60	8M	1174	503.2	199.04	209.5	314.3	10.47	39.28
20:80	8M	1174	503.2	199.04	104.8	419	10.47	39.28

5.0 EXPERIMENTAL PROGRAM: The experimental program involved evaluating the compressive strength of GPC by casting and testing 100 x 100 x 100 mm cubes after 7 and 28 days of ambient curing, following the guidelines of IS: 516-1959. Workability was measured using the flow table test as per IS: 1199-1959 [15].

5.1 CASTING OF GEOPOLYMER CONCRETE SPECIMENS: The preparation of Geopolymer Concrete (GPC) involved initially dry mixing the solid constituents, including aggregates, fly ash, and GGBS, for approximately three minutes. Meanwhile, the liquid components, consisting of the alkaline solution, added water, and superplasticizer, were premixed before being incorporated into the dry mix. Wet mixing continued for an additional four minutes, resulting in a fresh concrete mixture that appeared dark in colour, shiny, and highly cohesive.

The workability of the fresh GPC was assessed using the conventional slump test. The concrete was then placed into cube moulds in three equal layers, with each layer compacted using a vibration table for ten seconds. After 24 hours, the specimens were demoulded and subjected to ambient curing **[16]**. For compressive strength testing, the GPC specimens were evaluated using a Universal Testing Machine (UTM) with a capacity of 1000 kN. The load was applied gradually at a constant rate until failure, and the maximum load sustained by each specimen was recorded in accordance with IS 516-1959. Three identical specimens were cast and tested for each variation after 7 and 28 days of ambient curing. The test results are presented in Table 4.

Binder Index = Molarity x [GGBS / (GGBS + Fly Ash)] [17]

Table 7. Compressive strength values of Fly ash and GGBS based GPC (For 67% of Total Aggregate case) with constant alkaline molarity (8M)

For 67% Of Total Aggregate							7 Days		28 Days		
Sl.No	Designation	MIX TYPE	GGBS:Flyash	GGBS/Flyash	Binder Index	Alk/Binder	Load(kN)	Compressive Strength(MPa)	Load(kN)	Compressive Strength(MPa)	7D/28D ratio
1	8A	X1	20:80	0.25	1.6	0.3	65	6.5	95	9.5	0.68
2	8B	X2	40:60	0.67	3.2	0.3	110	11	205	20.5	0.53
3	8C	X3	50:50	1	4	0.3	148	14.8	268	26.8	0.55

4	8D	X4	60:40	1.5	4.8	0.3	312	31.2	400	40	0.78
5	8E	X5	80:20	4	6.4	0.3	403	40.3	490	49	0.82
6	8A	X6	20:80	0.25	1.6	0.34	70	7	135	13.5	0.51
7	8B	X7	40:60	0.67	3.2	0.34	210	21	350	35	0.6
8	8C	X8	50:50	1	4	0.34	315	31.5	424	42.4	0.74
9	8D	X9	60:40	1.5	4.8	0.34	386	38.6	485	48.5	0.79
10	8E	X10	80:20	4	6.4	0.34	412	41.2	515	51.5	0.8
11	8A	X11	20:80	0.25	1.6	0.38	95	9.5	160	16	0.59
12	8B	X12	40:60	0.67	3.2	0.38	275	27.5	360	36	0.76
13	8C	X13	50:50	1	4	0.38	382	38.2	440	44	0.86
14	8D	X14	60:40	1.5	4.8	0.38	41	41	495	49.5	0.82
15	8E	X15	80:20	4	6.4	0.38	465	46.5	540	54	0.86
16	8A	X16	20:80	0.25	1.6	0.42	125	12.5	195	19.5	0.64
17	8B	X17	40:60	0.67	3.2	0.42	290	29	380	38	0.76
18	8C	X18	50:50	1	4	0.42	425	42.5	490	49	0.86
19	8D	X19	60:40	1.5	4.8	0.42	440	44	540	54	0.81
20	8E	X20	80:20	4	6.4	0.42	525	52.5	595	59.5	0.88
21	8A	X21	20:80	0.25	1.6	0.46	145	14.5	205	20.5	0.7
22	8B	X22	40:60	0.67	3.2	0.46	315	31.5	415	41.5	0.75
23	8C	X23	50:50	1	4	0.46	450	45	525	52.5	0.85
24	8D	X24	60:40	1.5	4.8	0.46	470	47	565	56.5	0.83
25	8E	X25	80:20	4	6.4	0.46	585	58.5	655	65.5	0.89
26	8A	X26	20:80	0.25	1.6	0.5	215	21.5	270	27	0.79
27	8B	X27	40:60	0.67	3.2	0.5	327	32.7	420	42	0.77
28	8C	X28	50:50	1	4	0.5	465	46.6	540	54	0.86
29	8D	X29	60:40	1.5	4.8	0.5	480	48	570	57	0.84
30	8E	X30	80:20	4	6.4	0.5	600	60	670	67	0.89

Table 8. Compressive strength values of Fly ash and GGBS based GPC (For 70% of Total Aggregate case) with constant alkaline molarity (8M)

For 70% Of Total Aggregate							7 Days		28 Days		
Sl.No	**Designation**	**NaoH molarity**	**GGBS:Flyash**	**GGBS/Flyash**	**Binder Index**	**Alk/Binder**	**Load(kN)**	**Compressive Strength(MPa)**	**Load(kN)**	**Compressive Strength(MPa)**	**7D/28D ratio**
1	8A	Y1	20:80	0.25	1.6	0.3	84	8.4	148	14.8	0.57
2	8B	Y2	40:60	0.67	3.2	0.3	206	20.6	325	32.5	0.63
3	8C	Y3	50:50	1	4	0.3	260	26	380	38	0.68
4	8D	Y4	60:40	1.5	4.8	0.3	357	35.7	476	47.6	0.75
5	8E	Y5	80:20	4	6.4	0.3	415	41.5	535	53.5	0.77
6	8A	Y6	20:80	0.25	1.6	0.34	91	9.1	176	17.6	0.51
7	8B	Y7	40:60	0.67	3.2	0.34	240	24	395	39.5	0.6
8	8C	Y8	50:50	1	4	0.34	325	32.5	443	44.3	0.73

9	8D	Y9	60:40	1.5	4.8	0.34	420	42	515	51.5	0.81
10	8E	Y10	80:20	4	6.4	0.34	478	47.8	595	59.5	0.8
11	8A	Y11	20:80	0.25	1.6	0.38	115	11.5	210	21	0.54
12	8B	Y12	40:60	0.67	3.2	0.38	295	29.5	420	42	0.7
13	8C	Y13	50:50	1	4	0.38	400	40	460	46	0.86
14	8D	Y14	60:40	1.5	4.8	0.38	437	43.7	585	58.5	0.74
15	8E	Y15	80:20	4	6.4	0.38	490	49	615	61.5	0.79
16	8A	Y16	20:80	0.25	1.6	0.42	154	15.4	242	24.2	0.63
17	8B	Y17	40:60	0.67	3.2	0.42	345	34.5	425	42.5	0.81
18	8C	Y18	50:50	1	4	0.42	430	43	520	52	0.82
19	8D	Y19	60:40	1.5	4.8	0.42	535	53.5	656	65.6	0.81
20	8E	Y20	80:20	4	6.4	0.42	568	56.8	693	69.3	0.82
21	8A	Y21	20:80	0.25	1.6	0.46	205	20.5	278	27.8	0.74
22	8B	Y22	40:60	0.67	3.2	0.46	365	36.5	465	46.5	0.78
23	8C	Y23	50:50	1	4	0.46	450	45	530	53.5	0.84
24	8D	Y24	60:40	1.5	4.8	0.46	545	54.5	660	66	0.81
25	8E	Y25	80:20	4	6.4	0.46	620	62	710	71	0.87
26	8A	Y26	20:80	0.25	1.6	0.5	230	23	325	32.5	0.7
27	8B	Y27	40:60	0.67	3.2	0.5	380	38	505	50.5	0.75
28	8C	Y28	50:50	1	4	0.5	460	46	545	54.5	0.84
29	8D	Y29	60:40	1.5	4.8	0.5	550	55	668	66.8	0.82
30	8E	Y30	80:20	4	6.4	0.5	630	63	760	76	0.82

The variation of Compressive strength with GGBS to fly ash ratio are shown in fig 1 to fig 2. The variation of Compressive strength with Binder index is shown in fig 4 to fig

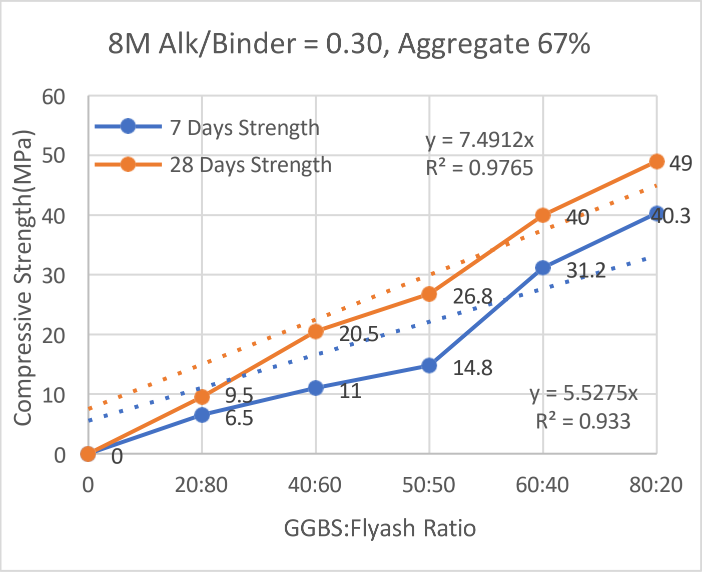


Fig 1 : Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.30 & Agg: 67%)

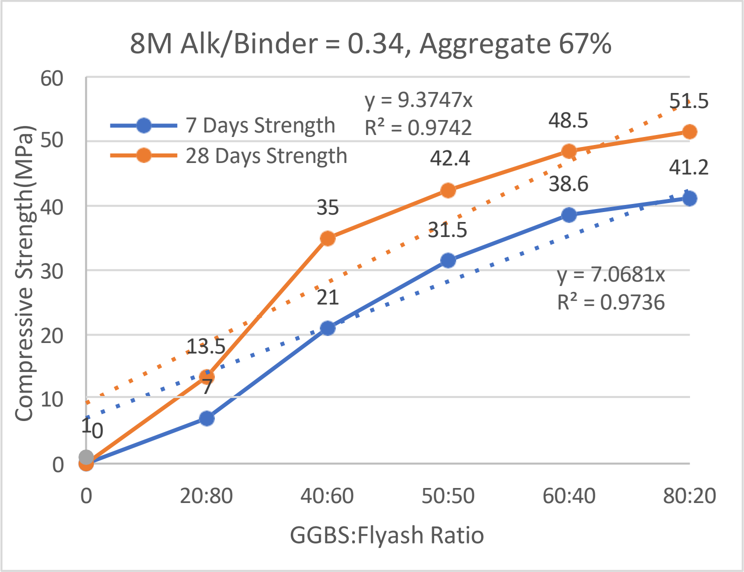


Fig 2 : Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.34 & Agg: 67%)

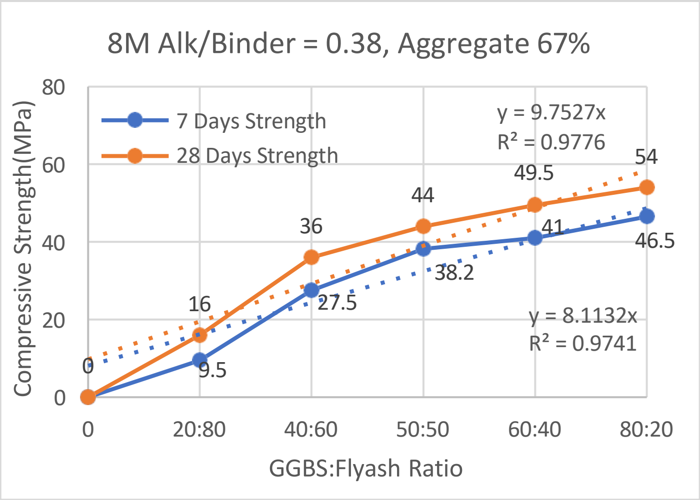


Fig 3 : Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.38 & Agg: 67%))

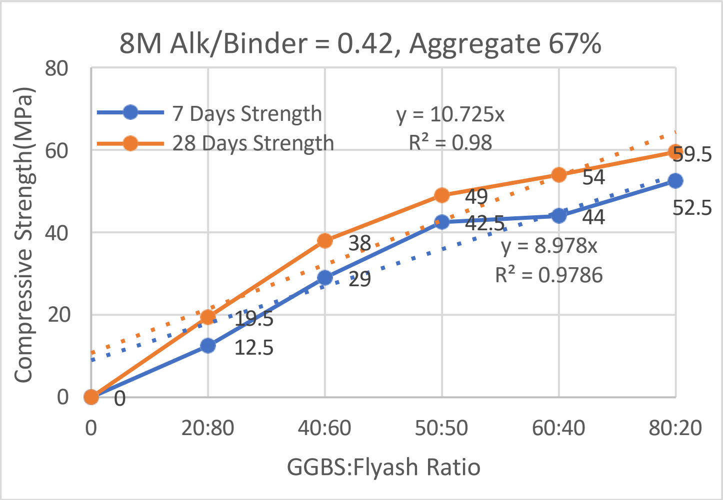
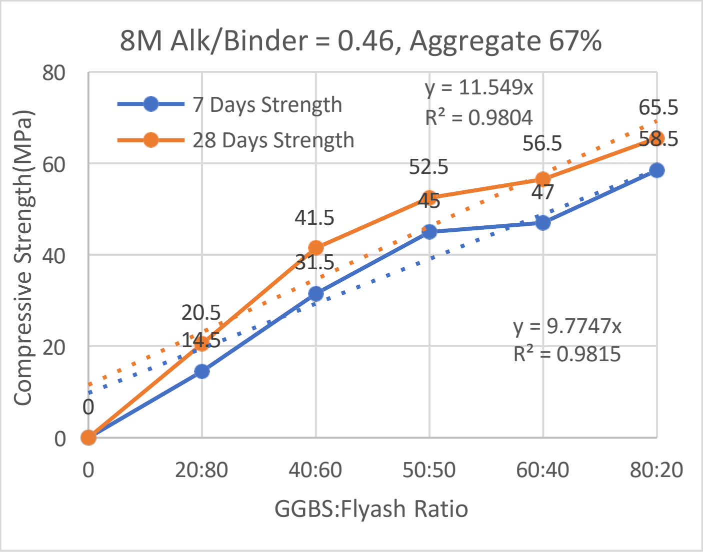


Fig 4 : Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.42 & Agg: 67%)



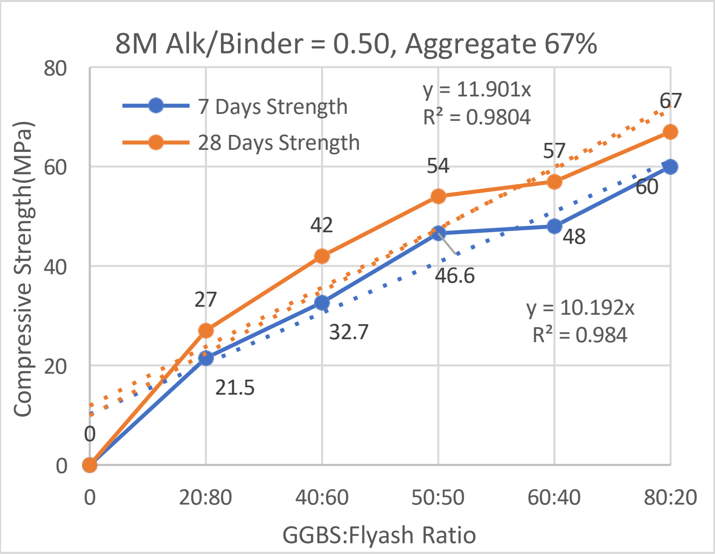


Fig 5 : Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.46 & Agg: 67%)

Fig 6 : Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.50 & Agg: 67%)

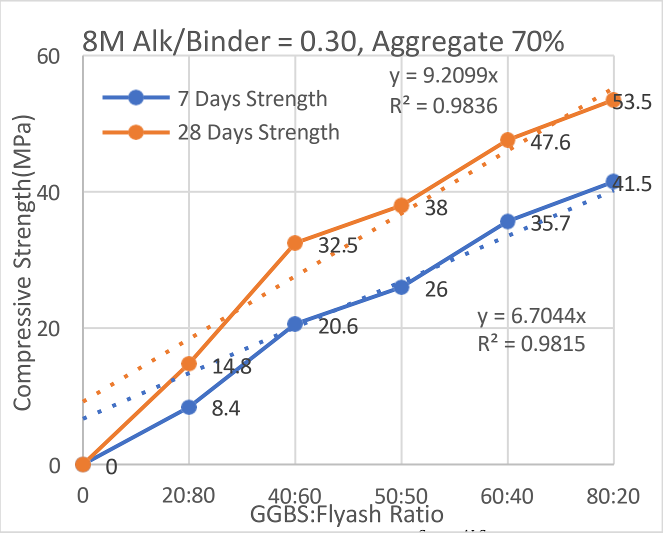


Fig 7 : Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.30 & Agg: 70%)

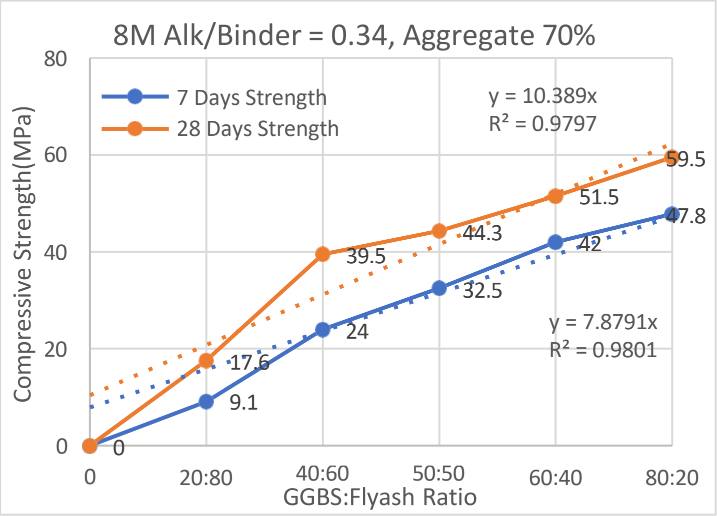


Fig8: Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.34 & Agg: 70%)

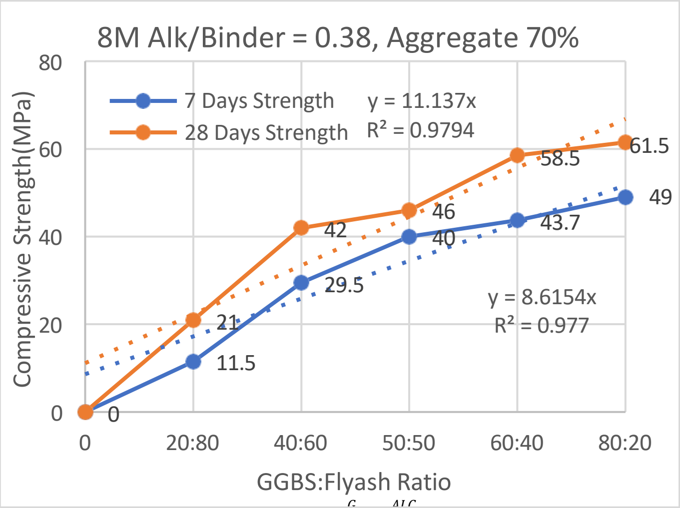


Fig9 : Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.38 & Agg: 70%)

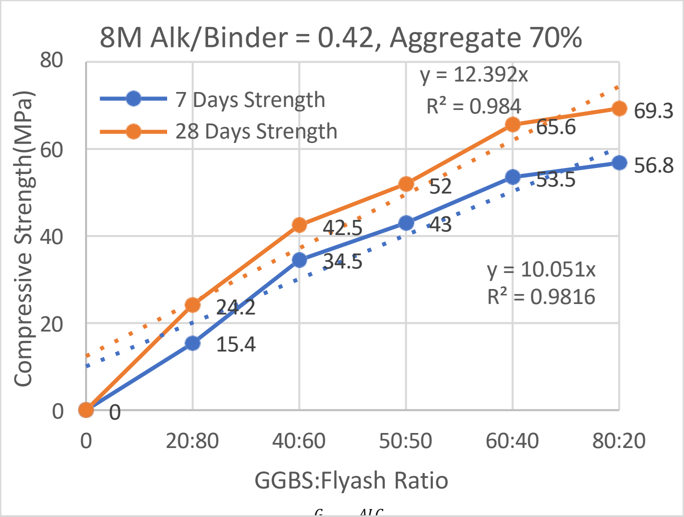


Fig10 : Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.42 & Agg: 70%)

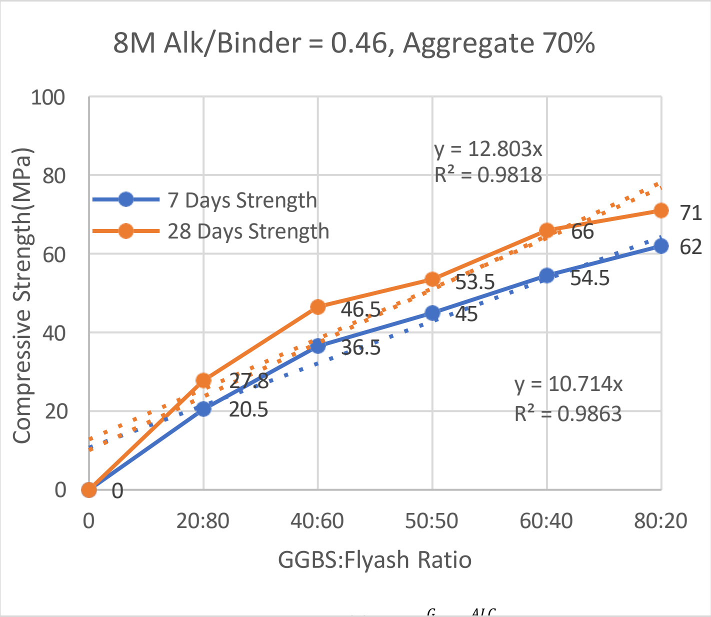


Fig11 : Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.46 & Agg: 70%)

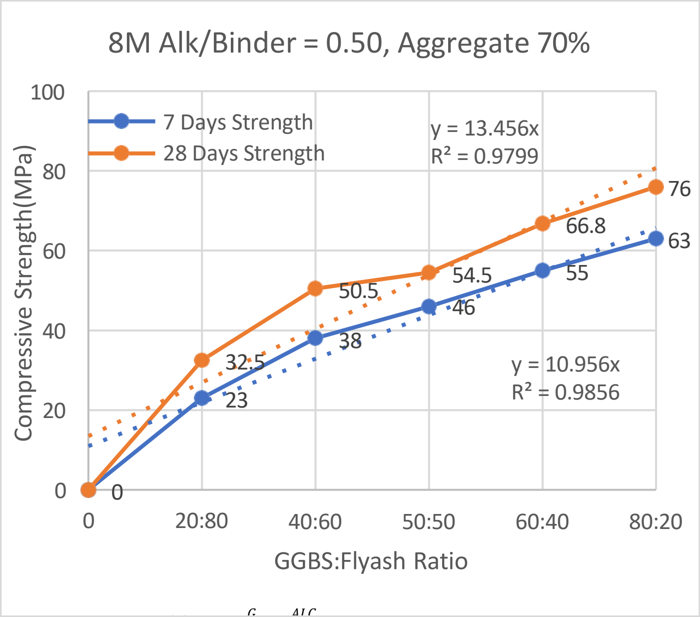


Fig12 : Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.50 & Agg: 70%)

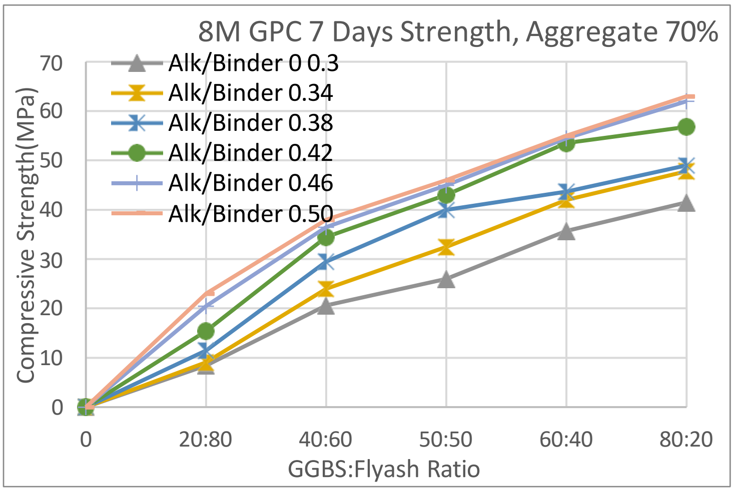


Fig13: Variation of 7days f_{ck} with $\frac{G}{F}$ & (Agg: 70%)

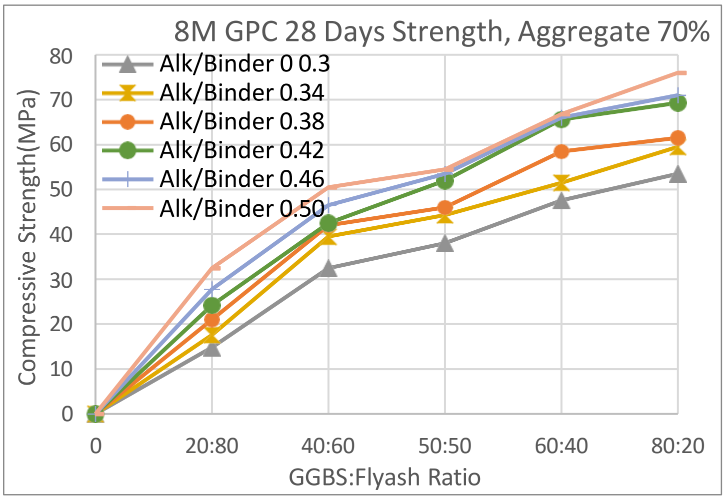


Fig14: Variation of 28days f_{ck} with $\frac{G}{F}$ & (Agg: 70%)

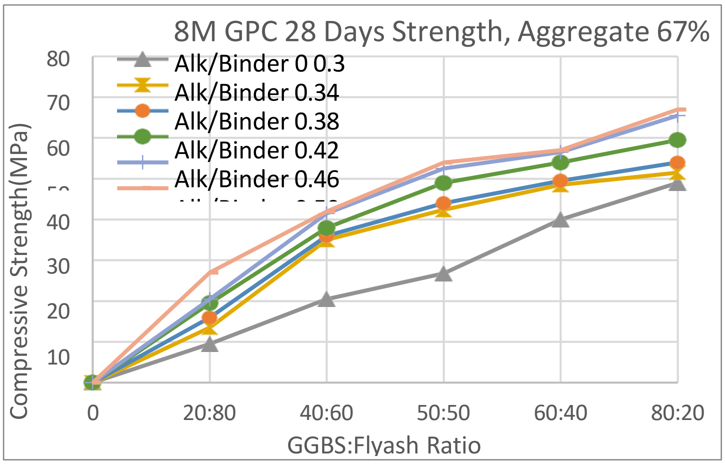


Fig15: Variation of 7days f_{ck} with ^{G} & (Agg: 67%)

Fig16: Variation of 28days f_{ck} with $\frac{G}{F}$ & (Agg: 67%)

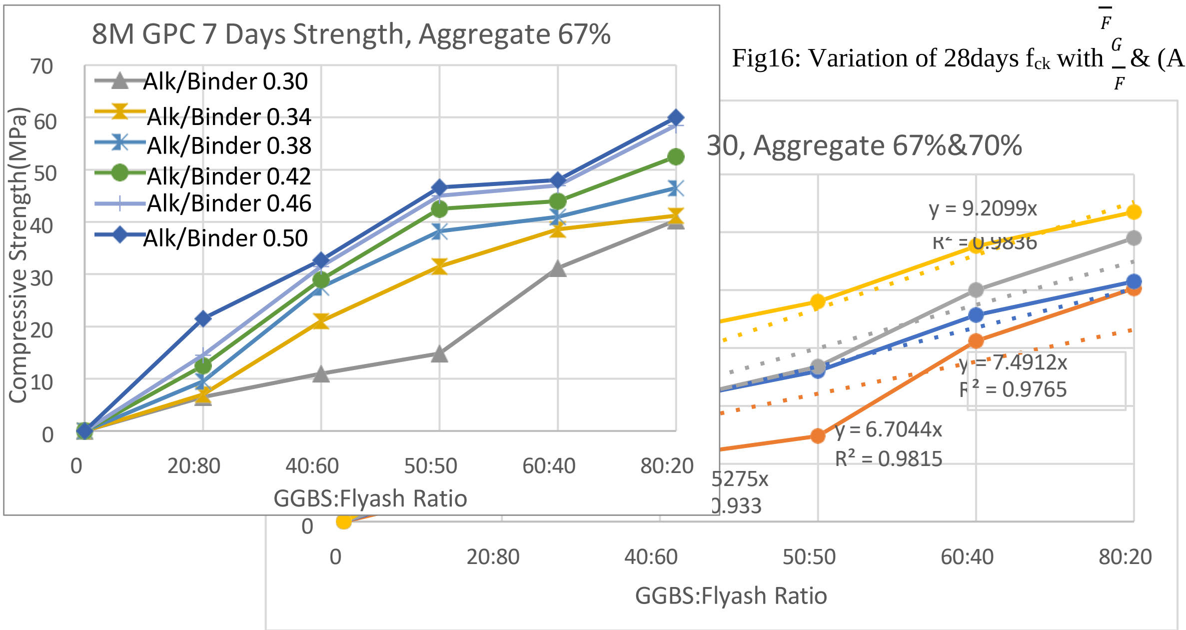


Fig17: Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.30, Agg: 67% & 70%)

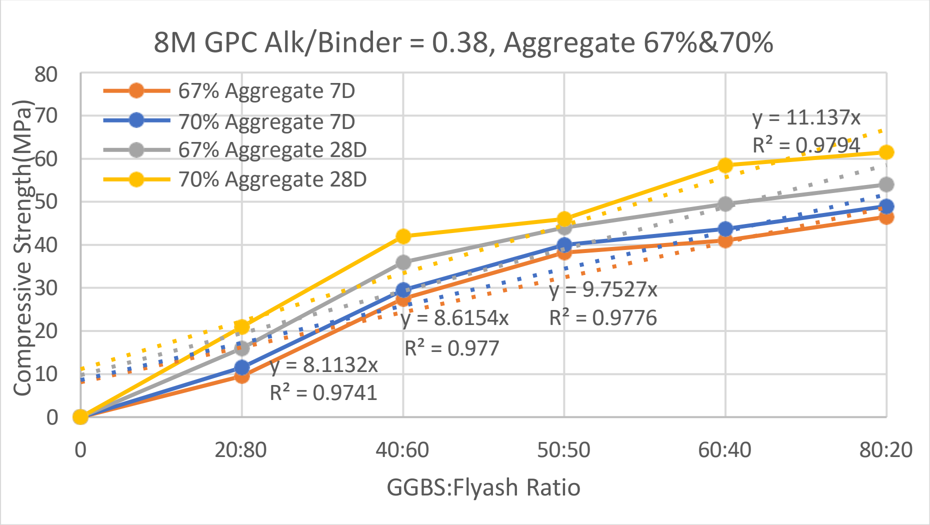


Fig18: Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.38, Agg: 67% & 70%)

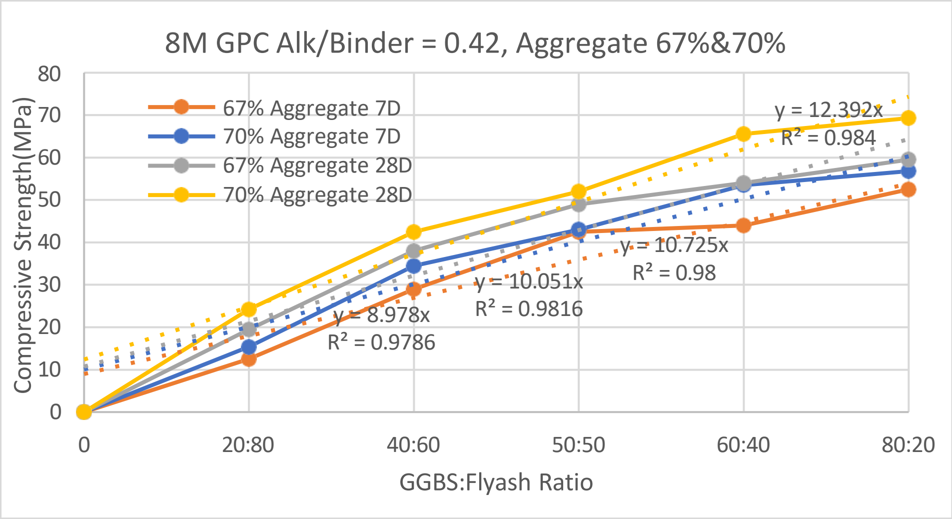


Fig19: Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.42, Agg: 67% & 70%)

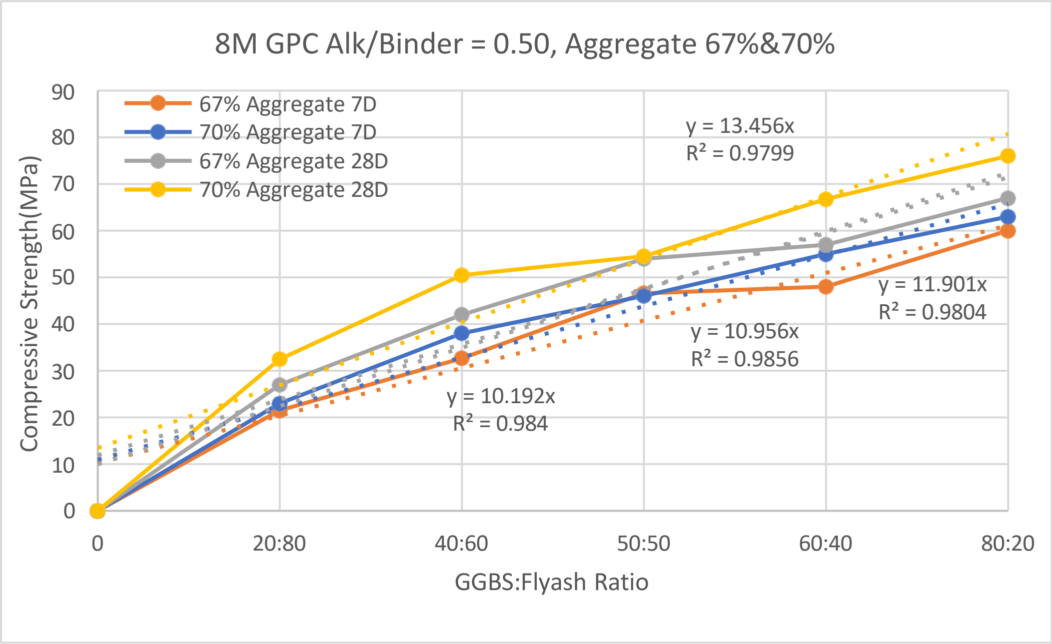


Fig20: Variation of f_{ck} with $\frac{G}{F}$ & ($\frac{ALC}{BIN}$=0.50, Agg: 67% & 70%)

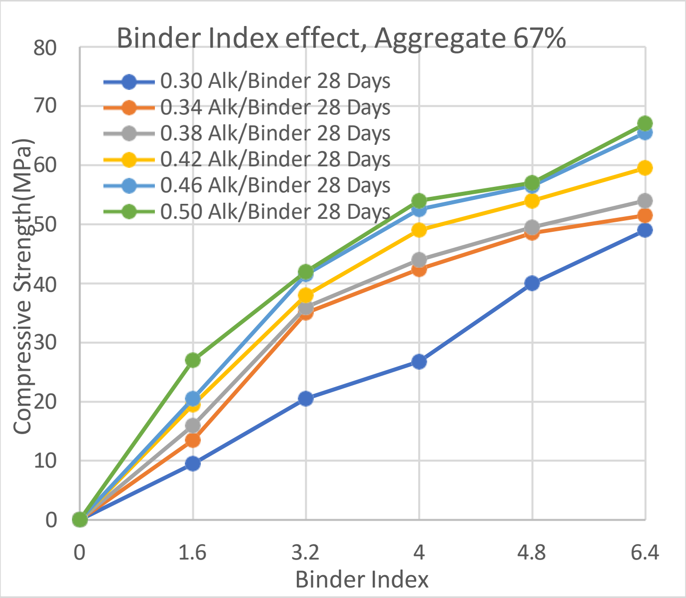


Fig21: Variation of strength with Binder Index

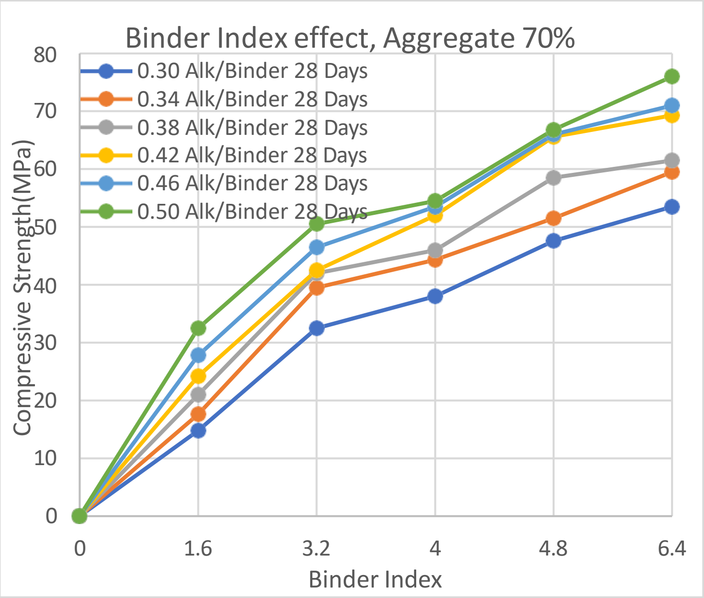


Fig21: Variation of strength with Binder Index

6.0 RESULTS & DISCUSSIONS

A. **Variation of Compressive strength (f_{ck}) with GGBS to Fly ash proportion:** From Fig.1 to Fig.12, it is observed that,

   1. The 7D and 28D compressive strength of GPC is increased with increase in GGBS to Fly ash proportion (from 20:80 to 80:20) for constant molarity 8M. It shows that, the fly ash a waste material, which us abundantly available can be used with addition of GGBS, which is a binder to avoid heat curing.

B. **Variation of Compressive strength (f_{ck}) with Aggregate ratio:** From Fig.1 to Fig.12, it is observed that, the 7D and 28D compressive strength of GPC is increased with increase in Aggregate ratio (67% to

70%) for constant molarity 8M. Aggregate ratio plays an vital role in developing the strength in concrete.

C. Variation of Compressive strength (f_{ck}) with Alkaline to Binder ratio:

From Fig.1 to Fig.12, it is observed that, the 7D and 28D compressive strength of GPC is increased with increase in Alkaline to Binder ratio (0.30 to 0.50) for constant molarity 8M. As alkaline activator is a chemical binder which plays a vital role in development of the polymerization process. As the increase in alkaline to binder ratio, there is a increase in the compressive strength. The combination of sodium hydroxide and sodium silicate solution forms a solution called, alkaline molar activator solution.

7.0 CONCLUSIONS:

1. Fly ash and GGBS can be used as source materials in making GPC.
2. As fly ash cannot set at a fast rate, GGBS is used for fast setting without heat curing.
3. Increase in the GGBS proportion, has shown increase in the compressive strength.
4. Workability and setting time of GPC decreases with increase in the GGBS proportion. The GPC mixes considered registered true slumps, in range of 100-150 mm, and were found to be adequately workable.
5. The compressive strength increased with the increase in the GGBS proportion with ambient curing. This results in higher strengths than heat curing, compared with other research works, due to acceleration of geo-polymerization reaction with increased GGBS proportion.

6. Increase in the Alkaline to binder ratio has also shown increase in the compressive strength.
7. With increase in aggregate ratio, compressive strength increased.

8. A unified parameter called Binder index is proposed to study the combined effect of all the source materials, fly ash, GGBS, alkaline molar activator. With increase in the Binder Index, compressive strength increased.

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