Influence of calcium and alumina-based pozzolanas on the strength properties of low calcium fly ash geopolymer concrete

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Abstract. This work presents the effect of Ground granulated blast furnace slag (GGBS), fly ash (FA) and metakaolin (MK) on the strength properties of geopolymer concrete (GPC). Geopolymer concrete made with FA produces calcium aluminosilicate hydrate (C-A-S-H) product due to presence of alumina and sodium aluminosilicate hydrate (N-A-S-H) gel as main reaction product of polymerization. Geopolymer concrete made with FA and GGBS, calcium silicate hydrate (C-S-H) also gets produced additionally with calcium aluminosilicate hydrate (C-A-S-H) gel and sodium aluminosilicate hydrate (N-A-S-H) gel due to presence of high content of CaO in GGBS. This additional product imparts more strength performance in GPC. In geopolymer concrete made with FA and MK, the more amount of calcium aluminosilicate hydrate (C-A-S-H) is produced due to presence of high amount of alumina in metakaolin along with sodium aluminosilicate hydrates (N-A-S-H) giving more strength to GPC. Metakaolin is recommended to be used for the development of GPC because it has high amount of alumina.

1 Introduction

The processing of one ton of cement releases one ton of "CO₂" carbon dioxide into the atmosphere contributing to global warming [1]. A prerequisite for the current situation is that we create additional cement production facilities or look for alternative binder systems to manufacture concrete? In the other case, a large amount of fly ash is generated from thermal power plants around the world and is typically used as filler in low-level zones [2]. "Geopolymer concrete" is an alternative binding system with fly ash for concrete removal. Geopolymer has the optimal characteristics of rock shaping materials¹, i.e. toughness, chemical inertness, and durability as a type of amorphous aluminium hydroxide substance [3]. In combination with Geopolymer binding aggregates, Geopolymer composites are made. Ideologies as they have very strong early strength, they are suitable for the design,

repair, and pre-casting of infrastructure, they can monitor their set times and stay intact very long without any repair [4]. Geo-polymer properties involve low shrinkage, freeze thaw resistance, high early strength, corrosion & sulphate resistance [5]. These greater-alkaline additives do not cause an aggregate alkaline reaction. The binder is a controversial substance of low carbon dioxide. It's doesn't depend on the limestone calcinations that emits carbon dioxide. This innovation will save 80 percent of the production of carbon dioxide from the cement and concrete sectors. This work presents the effect of Ground granulated blast furnace slag (GGBS), fly ash (FA) and metakaolin (MK) on the strength properties of geopolymer concrete (GPC)

2 Mix proportions

2.1 Geopolymer Concrete

The mix ingredients of geopolymer concrete are-

1. 16M NaOH
2. SiO₂/Na₂O = 2.0

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3. $\text{Na}_2\text{SiO}_3/\text{NaOH} = 2.5$
4. Fly Ash = 450 kg/m^3
5. Alkali Activator solution (AAS) / Fly ash = 0.50
6. Fine aggregate = 505 kg/m^3
7. 20mm Coarse aggregate = 1246 kg/m^3
8. 60°C temperature oven heat cured for 24h period
9. Rest period = 0 days (casted cubes are immediately sealed and kept in oven with moulds on)

2.2 Conventional Concrete

The mix proportions for conventional concrete are-

1. Cement = 450 kg/m^3
2. Water/cement ratio = 0.50
3. Fine aggregate = 505 kg/m^3
4. 20mm Coarse aggregate = 1246 kg/m^3
5. Water = 225 l/m^3

2 Compressive Strength

This investigation is carried out to study the compressive strength of conventional and Geopolymer concrete. The compression test on cubes and cylinders were conducted according to Indian

Standard specifications (IS: 516 – 1959). For the given mixture proportion casted concrete cubes of $150\text{mm} \times 150\text{mm} \times 150\text{mm}$ and Cylinder of 150mm Diameter and 300mm Height provided with oven curing temperature and ambient temperature.

3 Split tensile Strength

The split tensile strength test was carried out on the compression testing machine. The casting and testing of the specimens were done as per IS 5816: 1999. This investigation was carried out to study the split tensile strength of conventional and Geopolymer concrete. Cylinders of size $150 \times 300 \text{ mm}$ are cast and tested to study the split tensile strength as per IS:5816 – 1999. From the following table it can be observed that the GGBS has high CaO and Silica content and moderate amount of alumina oxide whereas FA has high amount of silica and alumina oxides. Metakaolin has very high amount of silica and Alumina. Silica and alumina are the major requirements for polymerization. Table 2-4 present the ingredients of GPC made with FA, FA+GGBS and FA+MK

Table 1. Chemical composition of GGBS, FA and MK

Chemical composition	GGBS % by mass	FA % by mass	MK % by mass
SiO_2	43.4	62.10	53.20
Al_2O_3	12.5	27.44	43.90
Fe_2O_3	0.3	4.57	0.38
CaO	40.0	0.83	0.02
MgO	1.5	0.55	0.05
SO_3	-	0.40	-
Na_2O	0.9	0.04	0.17
K_2O	0.6	1.17	0.10

Table 2. Ingredients of GPC made with Fly ash

GPC Mix Designation	NaOH Molarity	$\text{Na}_2\text{SiO}_3/\text{NaOH}$ ratio	$\text{SiO}_2/\text{Na}_2\text{O}$ ratio	AAS / Fly ash
GP1	8M	2.5	2.0	0.5
GP2	10M	2.5	2.0	0.5
GP3	12M	2.5	2.0	0.5
GP4	14M	2.5	2.0	0.5
GP5	16M	2.5	2.0	0.5
GP6	18M	2.5	2.0	0.5

Table 3. Ingredients of GPC made with Fly ash and GGBS

GPC Mix Designation	NaOH Molarity	$\text{Na}_2\text{SiO}_3/\text{NaOH}$ ratio	$\text{SiO}_2/\text{Na}_2\text{O}$ ratio	AAS / (Fly ash + GGBS)
GP7	8M	2.5	2.0	0.5
GP8	10M	2.5	2.0	0.5
GP9	12M	2.5	2.0	0.5
GP10	14M	2.5	2.0	0.5

GP11	16M	2.5	2.0	0.5
GP12	18M	2.5	2.0	0.5

Table 4. Ingredients of GPC made with Fly ash and MK

GPC Mix Designation	NaOH Molarity	Na ₂ SiO ₃ /NaOH ratio	SiO ₂ /Na ₂ O ratio	AAS / (Fly ash +MK)
GP13	8M	2.5	2.0	0.5
GP14	10M	2.5	2.0	0.5
GP15	12M	2.5	2.0	0.5
GP16	14M	2.5	2.0	0.5
GP17	16M	2.5	2.0	0.5
GP18	18M	2.5	2.0	0.5

Table 5. NaOH flakes to be added to make One litre of NaOH solution

Molarity NaOH flakes	NaOH flakes to be added to make One litre of NaOH solution (grams)
8M	296
10M	364
12M	429
14M	491
16M	552
18M	610

Table 6. Mix quantities for GPC made with FA

GPC Mix	AAS (kg/m ³)		Fly ash (kg/m ³)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)	Curing type
	NaOH	Na ₂ SiO ₃				
GP1	64.29	160.71	450	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP2	64.29	160.71	450	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP3	64.29	160.71	450	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP4	64.29	160.71	450	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP5	64.29	160.71	450	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP6	64.29	160.71	450	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days

Table 7. Mix quantities for GPC made with FA and GGBS

GPC Mix	AAS (kg/m ³)		Fly ash (kg/m ³)	GGBS (kg/m ³)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)	Curing
	NaOH	Na ₂ SiO ₃					
GP7	64.29	160.71	350	100	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP8	64.29	160.71	350	100	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP9	64.29	160.71	350	100	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP10	64.29	160.71	350	100	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP11	64.29	160.71	350	100	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP12	64.29	160.71	350	100	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days

Table 6. Mix quantities for GPC made with FA

GPC Mix	AAS (kg/m ³)		Fly ash (kg/m ³)	MK (kg/m ³)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)	Curing
	NaOH	Na ₂ SiO ₃					
GP13	64.29	160.71	225	225	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP14	64.29	160.71	225	225	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP15	64.29	160.71	225	225	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP16	64.29	160.71	225	225	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP17	64.29	160.71	225	225	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days
GP18	64.29	160.71	225	225	505	1246	Heat @ 60 °C for 24 h exposure/ Sun dried for 28 days

Table 6. Strengths for GPC made with FA, FA+GGBS and FA+MK

GPC Mix	Heat @ 60 °C for 24 h exposure			Sun dried for 28 days		
	Compressive Strength (MPa)	Split-tensile Strength (MPa)	Flexural Strength (MPa)	Compressive Strength (MPa)	Split-tensile Strength (MPa)	Flexural Strength (MPa)
GP1	25.52	2.30	3.54	21.69	1.96	3.01
GP2	27.80	2.50	3.69	23.63	2.13	3.14
GP3	29.07	2.62	3.77	24.71	2.23	3.20
GP4	29.68	2.67	3.81	25.23	2.27	3.24
GP5	39.23	3.53	4.38	33.35	3.00	3.72
GP6	33.35	3.00	4.04	28.35	2.55	3.43
GP7	28.07	2.53	3.71	25.26	2.28	3.34
GP8	30.58	2.75	3.87	27.52	2.48	3.48
GP9	31.98	2.88	3.96	28.78	2.59	3.56
GP10	32.65	2.94	4.00	29.39	2.65	3.60
GP11	43.15	3.88	4.60	38.84	3.49	4.14
GP12	36.69	3.30	4.24	33.02	2.97	3.82
GP13	31.90	2.87	3.95	31.26	2.81	3.87
GP14	34.75	3.13	4.13	34.06	3.07	4.05
GP15	36.34	3.27	4.22	35.61	3.20	4.14
GP16	37.10	3.34	4.26	36.36	3.27	4.17
GP17	49.04	4.41	4.90	48.06	4.32	4.80
GP18	41.69	3.75	4.52	40.86	3.68	4.43

Fig.1. Compressive Strengths for GPC made with FA, FA+GGBS and FA+MK

Fig.2. Split-tensile Strengths for GPC made with FA, FA+GGBS and FA+MK

Fig.3. Flexural Strengths for GPC made with FA, FA+GGBS and FA+MK

Conclusions

1. Geopolymer concrete made with FA produces calcium aluminosilicate hydrate (C-A-S-H) product due to presence of alumina and sodium aluminosilicate hydrate (N-A-S-H) gel as main reaction product of polymerization
2. Geopolymer concrete made with FA and GGBS, calcium silicate hydrate (C-S-H) also gets produced additionally with calcium aluminosilicate hydrate (C-A-S-H) gel and sodium aluminosilicate hydrate (N-A-S-H) gel due to presence of high content of CaO in GGBS. This additional product imparts more strength performance in GPC
3. In geopolymer concrete made with FA and MK, the more amount of calcium aluminosilicate hydrate (C-A-S-H) is produced due to presence of high amount of alumina in metakaolin along with sodium aluminosilicate hydrates (N-A-S-H) giving more strength to GPC.
4. Metakaolin is recommended to be used for the development of GPC because it has high amount of alumina.

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