

DEVELOPMENT OF ENVIRONMENTAL FRIENDLY GEO-POLYMER CONCRETE WITH COAL FLY ASH AND SILICA FUME

Yasir Ali¹, Dr. Manthar Ali Keerio², Jawad Akhter Siddique³, Jabir Ali Keryio⁴,
Dr. Narain Das Bheel⁵, Noor Hussain⁶

^{1,2,3,4}Department of Civil Engineering Technology, Benazir Bhutto Shaheed University of Technology & Skill Development (BBSUTSD) Khairpur Mirs, Sindh, Pakistan

⁵Department of Civil Engineering Technology, Aror University of Art, Architecture, Design and Heritage, Sukkur, Sindh, Pakistan

⁶Bachelor Student Department of Civil Engineering, Quaid-e-Awam University of Engineering, Science & Technology (QUEST), Nawabshah, Sindh, Pakistan

¹yasirali@bbsutsd.edu.pk

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Corresponding Author: *

Yasir Ali

Abstract

The ordinary Portland cement is associated with carbon dioxide productions, which makes environment unsafe. The concept of by-product as supportable material is important alternative. This research focuses on the geo-polymer concrete (GPC) with silica fume and coal fly ash with alkaline solutions of (NaOH) and (Na₂SiO₃). The basic objective of this research is to study alkaline molarity influence, activator solution along with solid-to-liquid ratios on compressive strength with compressive strength of Goe-polymer concrete. The 18 mix designs prepared by (NaOH) molarity with different levels as (10 M, 12 M, and 14 M) with activator ratio (1.5, 2.0 and 3.0) and solid-to liquid ratios respectively. During process of constant binder composition of 50% silica fume and 50% coal fly ash. Standard cube for specimens (100 mm × 100 mm × 100 mm) casted, oven-cured at 60–70°C, and experimented compressive strength and compressive strength with open fire exposure for 7 days. The output revealed compressive strength of GPC in incremental pattern when NaOH molarity and activator ratio rapidly increased. The highest compressive strength of 4300 psi (≈29.65 MPa) was achieved for (GPC-14) with 14 M NaOH, activator ratio 2:1, and solid-to-liquid ratio of 1.5. However, mixes with higher silica fume content retained better strength due to enhanced polymerization and dense matrix formation. At open fire exposure the maximum compressive strength compressive strength recorded was 2500 psi (≈17.24 MPa). Finally, this study proposed the optimum mix design with significant potential for eco-friendly and sustainable construction, offering aviable substitute to Ordinary Portland Cement-based concrete while reducing emissions of CO₂ through waste utilization., providing a promising solution for sustainable and reliable power generation in remote and off-grid areas.

INTRODUCTION

The extensive construction industry depends on concrete but its manufacturing process produces environmental problems. The global emission of Co₂ increased from 2% to 8% due to the emission of cement industry which causes climate change and environmental destruction [1].

The Geo-polymer production concrete occurs by combination with industrial by-products includes fly ash, along slag together. This increase in addition with alkaline activator result. The manufacturing process gives better mechanical performance while decreasing CO₂ output [1].

The construction industry becomes a serious concern due to increased harmful environment factors. The old and outdated portland cement, although widely used, considered as important part of carbon dioxide global emission. As in contrast the geo-polymer comes in category of environment friendly source. The Goe-polymer synthesized from the industrial by-product and waste materials in aluminosilicates. The material like fly ash, bottom ash, and metakaolin, react together NaOH and Na₂SiO₃ activators. GPC is not depended on silicate hydration for the material strength as traditional concrete. Instead, it forms through a polycondensation reaction that results in an amorphous to semi-crystalline network of aluminosilicate gels. This binder system reduces the carbon footprint, additionally it enhances the strength with mechanical performance related to the concrete, especially in aggressive environments [3].

1.1 COAL FLY ASH-BASED GEOPOLYMER CONCRETE

Coal fly ash (CFA) comes in the category of waste in the form of solid which is normally produced by coal-fired used in the huge thermal power plants. Traditionally, this material is

underutilized, often disposed of in landfills, leading to environmental pollution. However, its rich silica and alumina content produces it a potential binder material [4].

In context of GPC concrete, bottom ash undergoes alkaline activation through NaOH and Na₂SiO₃, which triggers major dissolution in reactive components for formation of geopolymeric gels. The approach used as Bottom ash-based geopolymer concrete offers effective and durable compressive strength with durability properties, feasible for the applications of structural design in Civil engineering. In addition, it is used to promote the durable, sustainable and firm construction by applying recycling of waste of industrial constraints, which reduced the dependency on cement [5].

1.2 SILICA FUME-BASED GEOPOLYMER CONCRETE

The silicone and ferrosilicon alloy industry is major source of production of silica fume by product which usually contain amorphous silicon dioxide particles. It is commonly used in cementitious systems to improve strength and reduce permeability due to its pozzolanic activity. The important supplementary binder material termed as silica fume serves a major part to enhance the polymerization reaction in geopolymer concrete [6].

Incorporating silica fume into the geopolymer matrix refining process of the pore which increases the concrete density leading to improved mechanical strength, chemical resistance, and durability. Its combination with other binder materials like bottom ash results in a synergistic effect, further improving the performance of the concrete mix.



Figure 1 Material used in Geopolymer

Research significance

Energy crises increase due to industrial application uses different sources of energy and produces carbon dioxide in huge amount. This causes many challenges like global warming and arises the energy consumption issues. As matter of fact one tone cement emits the 0.8 tons of CO₂.

This contributes about 5–8% of all worldwide CO₂ emission. The cement is being produced and used extensively in the country, and huge energy (1600 to 19000 °C) is required on production of cement. Since last two decades Pakistan is facing energy crises and the construction material especially cement cost are increasing day by day [7]. Although the individual usage of silica fume and CFA studied, but their combined result of silica fume along coal fly ash in Thar coal power plant on mechanical strength, durability, remains unexplored, creating a gap in the development of optimized geopolymer mixes for sustainable construction. In this regard, the current research is an approach to investigate the utilization Coal fly ash (CFA) at Thar coal power plant along with silica fume (SF) as binary

Addition to check density of geopolymer concrete additionally ultimate compressive strength which were not studied yet in previous literature review.

MATERIALS

Silica Fume (SF)

Silica Fume considered as important ultrafine pozzolanic by-product of silicon and ferrosilicon alloy production [9]. The Silica fume primarily consist amorphous SiO₂, strength and durability enhancement in concrete. In this research, locally procured silica fume is filtered through a #325 sieve for uniform fineness and used as 50% of the total binder. Its inclusion improves compressive strength, reduces permeability, and refines the microstructure of the GPC matrix.

Coal Fly Ash (CFA)

Coal Fly Ash considered as fine, non-combustible residue produced from combustion process of pulverized coal thermal plants [10].

In this study, CFA collected from the Power Plant, sieved through a #325 sieve, and used as 50% of the total binder alongside silica fume. The CFA used to contribute for sustainability,

eco-friendly utilization of industrial waste, and enhanced pozzolanic reactivity when stimulated with alkaline solutions.

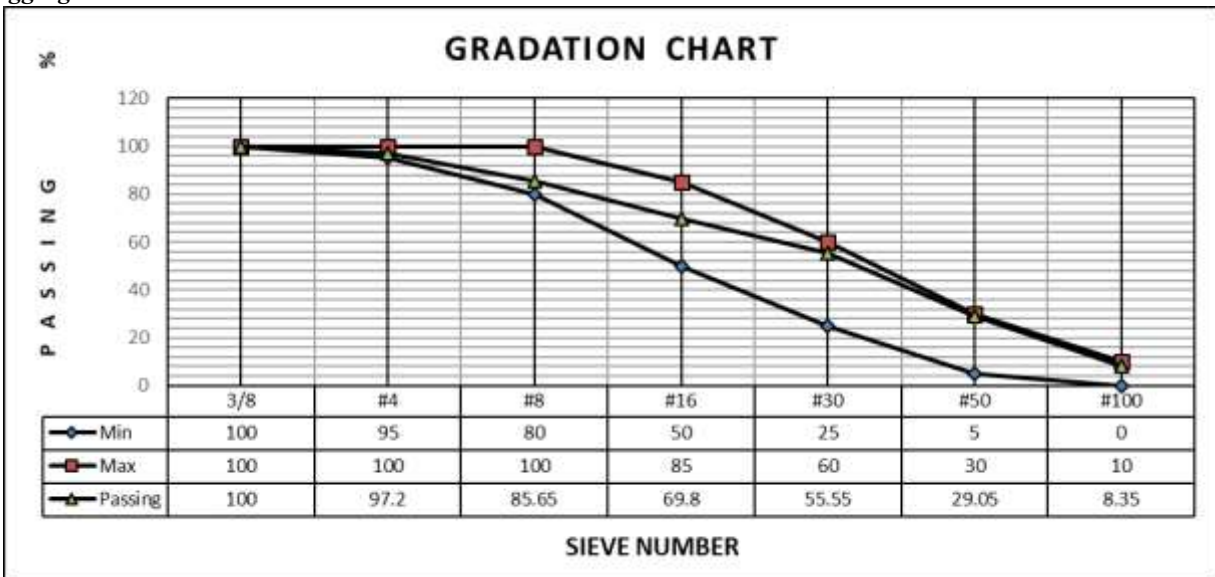
Alkaline Activators

The alkaline activator solution produced by mixing NaOH with Na₂SiO₃ in different ratios [11]. The activator plays a decisive role for dissolving aluminosilicate materials which is initiating the polymerization process.

Aggregates were used as the inert phase in the geopolymer concrete to provide bulk, strength, and dimensional stability.

- **Coarse Aggregate:** Locally available crushed stone obtained from the Kot Banglow source, passing through a 12.7 mm sieve and reserved on a 4.75 mm sieve, was used.
- **Fine Aggregate:** Hill sand from Bholari source passing via 4.75 mm sieve used as fine combined aggregate.

Aggregates



Superplasticizer

This research presented, a high-range water-reducing admixture, PRONAPHT F-1100, considered as a superplasticizer to enhance the workability of geopolymer concrete without increasing water content. PRONAPHT F-1100 is a dark brown liquid admixture specifically designed for producing with high early strength and excellent workability characteristics.

Mix Design Procedure

The mix design approach developed including 18 different geo-polymer concrete mixes (GPC1-GPC18). Each mix consisted of a constant binder content of 400 kg/m³, divided equally between Silica Fume (50%) and Coal fly ash (50%). The Discrepancy constraints involved in process of formation of the material are given below:

- NaOH Molarity: 10 M, 12 M, and 14 M
- Activator Ratio (Na₂SiO₃/NaOH): 1.5, 2.0, 2.5, 3.0
- Solid-to-Liquid Ratio: 1.5 and 2.0

The mixture is designed to involve the fine Aggregate of amount 800 kg/m³ with coarse aggregate of 1200 kg/m³. In order to go further with other step the binder-to-liquid ration along with content adjusted as activator are maintained for the consistent workability.

The total 18 mixes are used to prepare as termed as GPC1-GPC18. The three cubes specimen were casted to prepare each mix respectively. The labeling is used for the each specimen with crossponding Mix ID for the further identification and also the data in which casting is performed before the demolding.

Table 1 Mix Proportions

MIX ID	Binder Content		NaOH Molarity (M)	Activator Ratio (Na ₂ SiO ₃ / NaOH)	Solid/Liquid Ratio	F.A %	C.A %	Binder Content		Alkaline Activator Solution (kg/m ³)	Alkaline Solution	Activator	Sodium Hydroxide	
	Silica Fume %	Coal bottom Ash %						Silica Fume (kg/m ³)	Coal Fly Ash (kg/m ³)		Sodium Silicate (Na ₂ SiO ₃) (kg/m ³)	Sodium Hydroxide Solution (NaOH) (kg/m ³)	NaOH Solid (kg/m ³)	Water (kg/m ³)
GPC 1	50	50	10	1.5 : 1	1.5	100	100	200	200	266.7	160.0	106.7	43	64
GPC 2	50	50	12	1.5 : 1	1.5	100	100	200	200	266.7	160.0	106.7	51	55
GPC 3	50	50	14	1.5 : 1	1.5	100	100	200	200	266.7	160.0	106.7	60	47
GPC 4	50	50	10	2 : 1	1.5	100	100	200	200	266.7	177.8	88.9	36	53
GPC 5	50	50	12	2 : 1	1.5	100	100	200	200	266.7	177.8	88.9	43	46
GPC 6	50	50	14	2 : 1	1.5	100	100	200	200	266.7	177.8	88.9	50	39
GPC 7	50	50	10	2.5 : 1	1.5	100	100	200	200	266.7	190.5	76.2	30	46
GPC 8	50	50	12	2.5 : 1	1.5	100	100	200	200	266.7	190.5	76.2	37	40
GPC 9	50	50	14	2.5 : 1	1.5	100	100	200	200	266.7	190.5	76.2	43	34
GPC 10	50	50	10	1.5 : 1	2	100	100	200	200	200.0	120.0	80.0	32	48
GPC 11	50	50	12	1.5 : 1	2	100	100	200	200	200.0	120.0	80.0	38	42
GPC 12	50	50	14	1.5 : 1	2	100	100	200	200	200.0	120.0	80.0	45	35
GPC 13	50	50	10	2 : 1	2	100	100	200	200	200.0	133.3	66.7	27	40
GPC 14	50	50	12	2 : 1	2	100	100	200	200	200.0	133.3	66.7	32	35
GPC 15	50	50	14	2 : 1	2	100	100	200	200	200.0	133.3	66.7	37	29
GPC 16	50	50	10	2.5 : 1	2	100	100	200	200	200.0	142.9	57.1	23	34
GPC 17	50	50	12	2.5 : 1	2	100	100	200	200	200.0	142.9	57.1	27	30
GPC 18	50	50	14	2.5 : 1	2	100	100	200	200	200.0	142.9	57.1	32	25

Casting of Specimens

After mixing, the fresh geo-polymer concrete was poured into steel cube molds of size (100 mm × 100 mm × 100 mm). The different layers are used for the mould, layers are filled with mold and each layer with 25 blows of tamping rod to compact for the removal of entrapped air and the proper consolidation assurance.

Results and Discussion

A total of 18 different mix combinations (GPC 1 to GPC 18) were prepared according to the experimental program. Each mix was cast into

(100 mm × 100 mm × 100 mm) cube specimens and oven-cured at 60–70 °C for 7 days. The average of three readings was considered for each mix.

Compressive strength of GPC at 7 days

Figure 4 show parameters details of geo-polymer concrete prepared with coal flay ash and silica fume:



Figure 3 Casting of Specimen

Compressive strength of GPC after open fire exposure

Figure 5 present the compressive strength of geopolymer concrete (GPC) specimens after exposure to open fire for 30 minutes, followed by

air cooling to room temperature. The results indicate the influence of fire exposure on the loss or retention of compressive strength compared with the normal 7-day cured specimens.

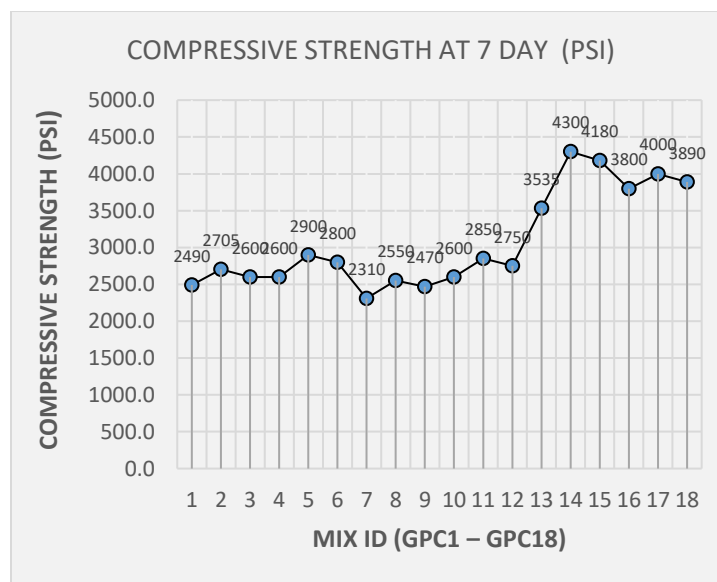


Figure 4 Compressive Strength at 7 days

This figure shows that maximum compressive strength at 7 days was observed at Mix ID 14 i.e

GPC 14 where the compressive strength was determined as 4300 psi.

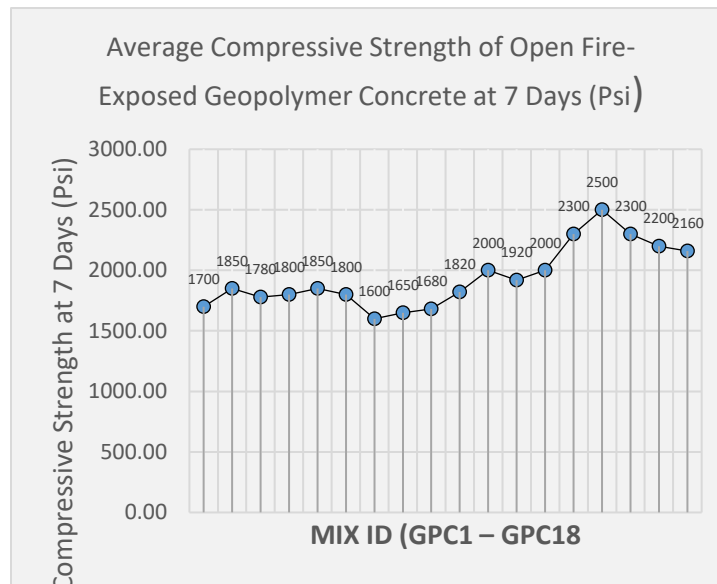


Figure 5 Fire Exposed Compressive Strength at 7 days

This figure shows that maximum compressive strength at 7 days was observed at Mix ID 15 i.e GPC 15 where the compressive strength was determined as 2500 psi.

Conclusions

On the whole this research focuses on the geopolymer eco-friendly concrete material for the Construction applications. The SF in addition with CFA as binary binder, which significantly reforms and improves reactivity, density and mechanical strength.

The strength of the alkalinity which is caused light gel disruption.

The 7 days CS: 4300 psi (≈ 29.65 MPa) was found optimum which is obtained by Mix GPC-14.

At open fire exposure the compressive strength decreases rapidly after achieving 2500 psi (≈ 17.24 MPa) i.e at MIX ID GPC 15.

Recommendations

For future studies and practical implementation, the following recommendations are proposed:

- The long-term Geopolymer concrete at the increase of days
- The tests like sulfate resistance, acid attacks and chloride penetration and freeze thaw cycles needs to conduct if someone want to assess the

performance of GPC in stern environmental conditions.

- The investigation of the microstructural methods like SEM, XRD, and FTIR analysis are included in this study recommendation. A comprehensive economic analysis comparing OPC concrete and geo-polymer concrete should be carried out to assess the feasibility of large-scale implementation in the construction industry of Pakistan.

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