Chapter

Geopolymer Concrete under Ambient Curing

M. Indhumathi Anbarasan, S.R. Sanjaiyan and S. Nagan Soundarapandiyan

Abstract

Geopolymer concrete (GPC) has significant potential as a more sustainable alternative for ordinary Portland cement concrete. GPC had been introduced to reduce carbon footprints and thereby safeguarding environment. This emerging eco friendly construction product finds majority of its application in precast and prefabricated structures due to the special curing conditions required. Sustained research efforts are being taken to make the product suitable for in situ applications. The developed technology will certainly address the issues of huge energy consumption as well reduce water use which is becoming scarce nowadays. Ground Granulated Blast Furnace Slag (GGBS) a by-product of iron industries in combination with fly ash has proved to give enhanced strength, durability as well reduced setting time. This study investigates the effect of GGBS as partial replacement of fly ash in the manufacture of GPC. Cube and cylindrical specimens were cast and subjected to ambient curing as well to alternate wetting-drying cycles. The 28 day compressive strength, split tensile strength, flexural strength and density of GPC specimens were found. The study revealed increase in compressive strength, split tensile strength, density as well flexural strength up to 40 percent replacement of fly ash by GGBS.

Keywords: geopolymer concrete, ambient curing, Flyash, GGBS, Setting time

1. Introduction

It is well known that concrete is one of the most widely used reliable and effective construction material all over the World [1, 2]. Rapid urban growth development leads to the usage of concrete in construction industry increase day by day which further increases the demand of ordinary Portland cement. In order to meet the huge demand, the production of ordinary Portland cement (OPC) increases every year. During the production of OPC, an enormous amount of greenhouse gas such as carbon dioxide (CO_2) will be emitted giving rise to global warming issues [3]. As such invention of alternative binding materials evolved. Geopolymer concrete proved itself to address the issues by reduced carbon footprints. Further, the enormous energy required in the production of OPC could be avoided leading to energy conservation.

Geopolymer had proved further superior to OPC in terms of acid resistance, sulphate resistance, withstanding heat [4], fire and possessing corrosion resistance. Geopolymerization involves a heterogeneous chemical reaction between silicon and aluminium in a source of geological origin or industrial by products such as flyash and GGBS (binder) with high alkaline solution of sodium hydroxide and sodium silicate resulting in the form of three-dimensional amorphous to semi crystalline polymeric and ring structure comprising Si-O-Al and Si-O-Si bonds.

There exist some limitations in practical usage of geopolymer concrete in construction industry. Usage of alkaline solution in geopolymer concrete contributes to cost aspect. Further, requirement of specialized curing namely heat curing or steam curing makes it difficult for in situ applications.

Due to the heavy need of electricity, numerous thermal power stations have been installed throughout the country which gives rise to fly ash generation. Flyash is a heterogeneous by-product material produced in the combustion process of coal used in power stations. Fly ash particles are almost spherical in shape which allows them to flow and blend freely in mixtures. This characteristic makes fly ash a desirable binder for concrete. Further, control of high thermal gradients, pore refinement, depletion of cement alkalis, resistance to chloride [5] and sulphate penetration and continued micro structural development through a long-term hydration and pozzolanic reaction contributes to added durability aspects. Also, the magnitude of reinforcement steel production is also enormous so as to meet the present day needs of multistoreyed structures. The by product of iron manufacturing by heating iron ore, lime stone and coke at very high temperature of 1500 degree celcisus is GGBS.

GGBS posseses good mobility characteristics arising from consistent fineness, unique particle shape and from lower relative density. Also, workability gets improved due to the smoother surface texture and glassy surface of GGBS. Also, efflorescence and staining of concrete shall be prevented by the use of GGBS. It is evident that due to its superior performance, it replaces Sulphate Resisting Portland Cement (SRPC) and useful against severe chloride attack in reinforced concrete in marine environment.

In this work, an attempt was made to study the performance of GGBS admixed geopolymer concrete under ambient curing condition. The optimum percentage replacement of fly ash by GGBS had been determined by conducting compressive strength and split tensile strength tests. The results obtained would help resolve the issues addressed above.

2. Experimental procedure

2.1 Materials

In this study, Class F fly ash with specific gravity 2.3 and GGBS having specific gravity 2.1 was used. River sand was used as fine aggregate as per standards [6].

Coarse aggregate of different sizes 7 mm, 14 mm and 20 mm was graded using sieve analyser with specific gravity 2.717, 2.81, 2.76 has determined using pycnometer. The water absorption was found as 0.26%, 0.15%, 0.42% respectively while the aggregates are immersed in water for 24 hours. Sodium hydroxide (NaOH) having 14 M molarity with 97–98% purity in the form of pellets was used [7]. Sodium silicate available in the form of gel was used. Both chemicals have brought from the local supplier (Thirumala Nadar and Sons, Madurai, India-625001).

2.2 Concrete mix proportions and specimen preparation

The geopolymer concrete comprises binder, fine aggregate, coarse aggregate and alkaline solution. The materials were quantified before mixing using standard guidelines as per Rangan and Hardjito method [8]. Sodium hydroxide was mixed with water and then sodium silicate was added to the diluted sodium hydroxide to make alkaline solution. The alkaline solution was prepared one day before concrete mix to facilitate polymerization process.

The percentage replacement of fly ash by GGBS was varied from 0–50%. Including the control mix, six mix proportions were used for both ambient curing and for wetting-drying cycles. Due to the reason that quick setting developed [9], percentage replacement was not done above 50%.

It is a usual procedure to first mix the binder materials, fine aggregate and coarse aggregate using mixer machine [10] for about three to four minutes. Then the prepared alkaline liquid should be poured over the dry mix concrete and mixing to be continued for about four to five minutes to initiate geopolymerisation process.

After getting an intimate mix, they were cast using moulds. The cast specimens were cured under ambient curing for 28 days while another set of specimens were subjected to wetting for 2 days in curing tank and drying for 2 days in ambient condition. These wetting and drying cycles were continued upto 28 days. The cast cube and cylinder specimens subjected to ambient curing are shown in **Figures 1** and **2** respectively.

Figure 1.
Cube specimens under ambient curing.

Figure 2.
Cylinder specimens under ambient curing.

Prisms of size 500 mm x 100 mm x100mm were cast to study the flexural behaviour of GPC using fly ash and GGBS combination. Prisms exposed to ambient curing for 28 days are shown in **Figure 3**.

The nomenclature of GPC specimens is presented in **Table 1**.

2.3 Test methods

To ascertain mechanical behavior of geopolymer concrete under ambient curing, compressive strength, split tensile strength and flexural strength tests were carried out. SEM analysis was done to study the microstructure, particles and formation of specimen [11].

2.3.1 Compressive strength test

Cube specimens were subjected to compressive axial load applied at the rate of 1.2 N/mm^2 to 2.4 N/mm^2 in accordance with IS code 5816:1999 [12] (**Figure 4**). The load was applied in such a way that the fracture plane crosses the trowel surface.

2.3.2 Split tensile strength test

To measure the tensile strength of concrete, cylinder specimens are placed centrally between the plates and the load is gradually applied in such a way that fracture plane will pass along its vertical diameter of specimen (**Figure 5**). The test was carried out as per IS code 5816:1999 [12] speficications.

Figure 3.
Ambient cured prism specimens.

Specimen (Indication)	Description
G	GGBS
0,10.20,30, 40,50	Percentage of GGBS in Fly ash
A	Ambient curing
A'	Wetting Drying Cycles

Table 1.
Nomenclature of GPC specimens.

Figure 4.
Compressive strength test of GPC.

Figure 5.
Split tensile strength test of GPC.

2.3.3 Flexural strength test

The flexural strength test set up is shown in **Figure 6**. Load is applied to the uppermost surface as cast along two lines 150 mm apart. The load was increased continuously till the specimen failed recording the failure load.

2.3.4 Microstructural analysis

To ascertain the morphological features of geopolymer concrete made with new combination of fine aggregates, micro structural analysis becomes essential.

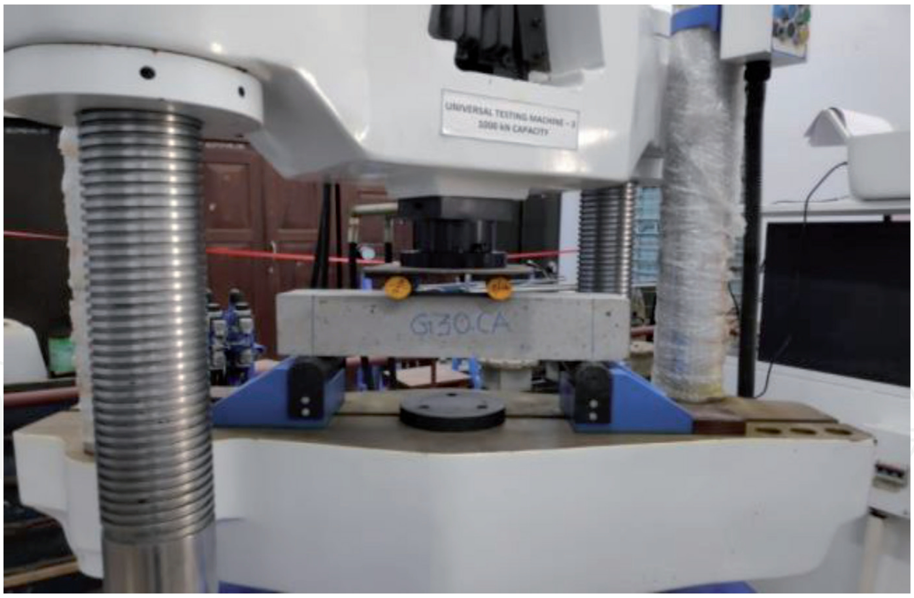

Figure 6.
Flexural strength test of Prisms.

The test results would reveal the factors affecting the mechanical properties. Presently available micro structural analysis include Scanning Electron Microscope (SEM), X Ray Diffraction Analysis (XRD), Energy Dispersive Spectroscopy (EDS) or Energy Dispersive X-Ray Analysis (EDAX) etc. In the present investigation, SEM and EDAX were used for the purpose for all mixes.

2.3.4.1 Energy dispersive X-ray analysis (EDAX)

EDAX shall very well be utilised to obtain the elemental composition or chemical characterisation of an area of interest on a specimen. The EDX or EDAX spectrum displays spectra showing peaks corresponding to the energy levels of elements making up the true composition of samples being analysed as received by X-rays. An excitation source, X-ray detector, pulse processor and the analyser constitute the primary components of EDAX. It is also possible to get elemental mapping of a sample as well image analysis. Samples of all proportions were made ready in powder form for analysis. For better accuracy, quantitative correction procedures are need to be applied.

2.3.4.2 Scanning electron microscopy (SEM)

In SEM, the surface of specimens will be scanned with a focused beam of electrons and images would be produced. The atoms in the sample will be interacted by the electrons and produce signals giving information regarding the topography of surface and composition of the sample. Resolution in the range of even 1 nanometer shall be achieved with the help of SEM.

A scanning electron microscope within built energy dispersive X-ray analysis (SEM- EDX) serves as good supplement to the optical microscope in examining new, old and deteriorated concrete. SEM analysis was done both for the samples having combination of fine aggregates (DMS and M-Sand) as well for samples with DMS alone. Samples for SEM analysis were collected from destructed pieces.

Thus, various tests as discussed above were conducted on geopolymer mortar as well on geopolymer concrete specimens conforming to relevant codal provisions.

3. Results and discussion

3.1 Compressive strength

The obtained compressive strength values for mixes G10A, G20A, G30A, G40A, G50A and G0A are respectively 30.88, 34.22, 37.78, 41.78, 36.22 and 26.5 MPa and the compressive strength values for mixes G10A', G20A', G30A', G40A', G50A'and G0A' are 30.56, 33.85, 36.65, 41.52, 38.5 and 27.76 MPa respectively. The values are plotted in **Figures** 7 and **8**.

The test results yield an inference that addition of GGBS in fly ash increases the compressive strength upto 40% replacement [13, 14]. The presence of calcium content in GGBS seems to be a real contributor for increase in strength upto 40% after which microstructure gets altered causing decrease in compressive strength. The compressive strength of control mix was low compared to other mixes using GGBS.

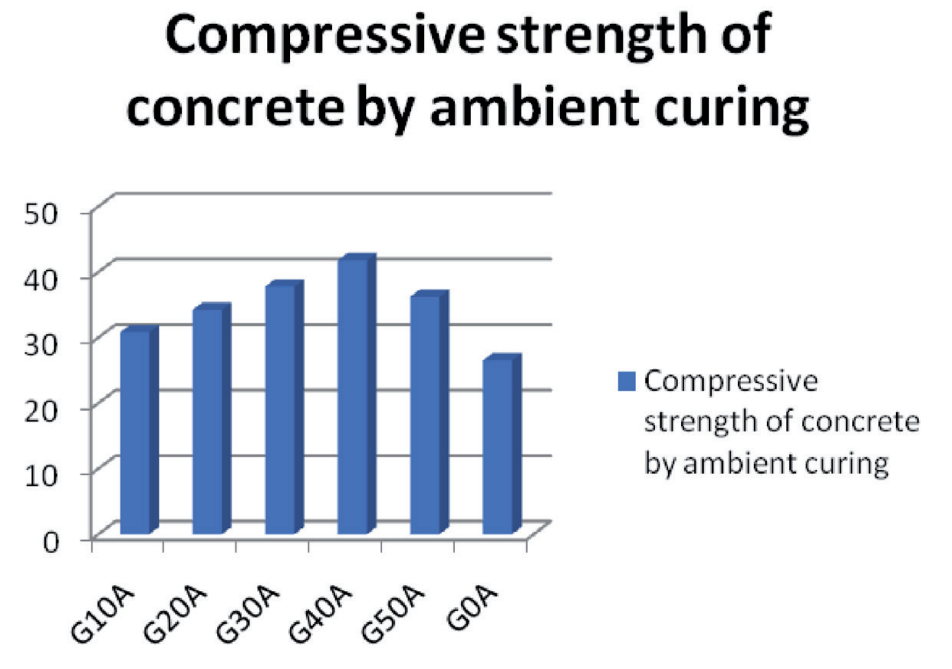

Figure 7.
Comparison of Compressive strength of GPC by ambient curing.

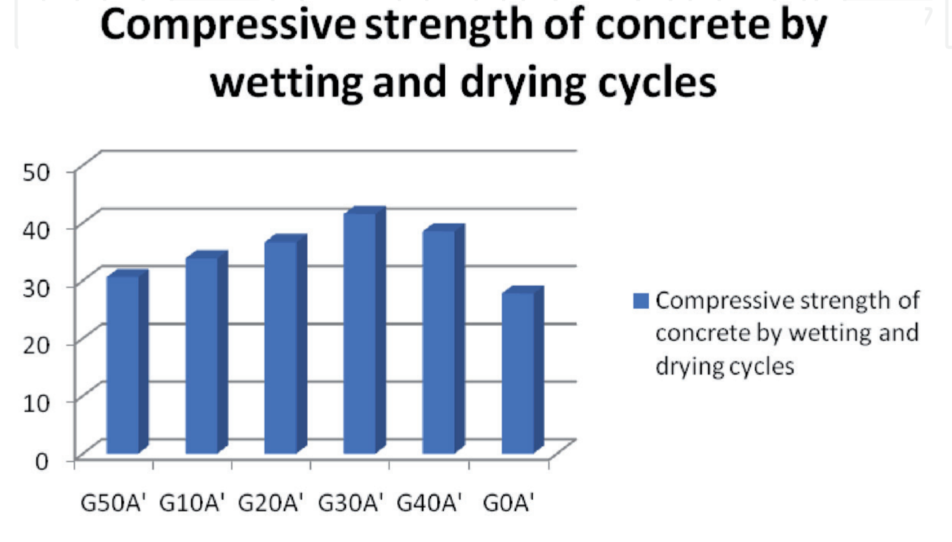

Figure 8.
Comparison of Compressive strength of GPC by Wetting and drying cycles.

3.2 Split tensile strength

The split tensile strength after 28 days for mixes G10A, G20A, G30A, G40A, G50A and G0A are 3.54, 3.96, 4.24, 4.81, 4.05 and 2.86 MPa respectively and these values are represented in **Figure 9**. The test results indicate that the maximum split tensile strength of 4.81 MPa is achieved for G40A mix. This may be due to the fact that addition of GGBS upto 40% increases the consistency, mortar phase and bond strength between mortar and aggregate. However, the split tensile strength of concrete decreased after 40% addition of GGBS which may be due to the glossy surface, surface texture and relatively low density reducing the bond strength and consistency (**Figure 10**).

3.3 Density

The measured density for the mixes G10A, G20A, G30A, G40A, G50A and G0A are respectively 2267, 2306, 2378, 2392, 2384 and 2240 kg/m^3 as shown in **Figure 10**.

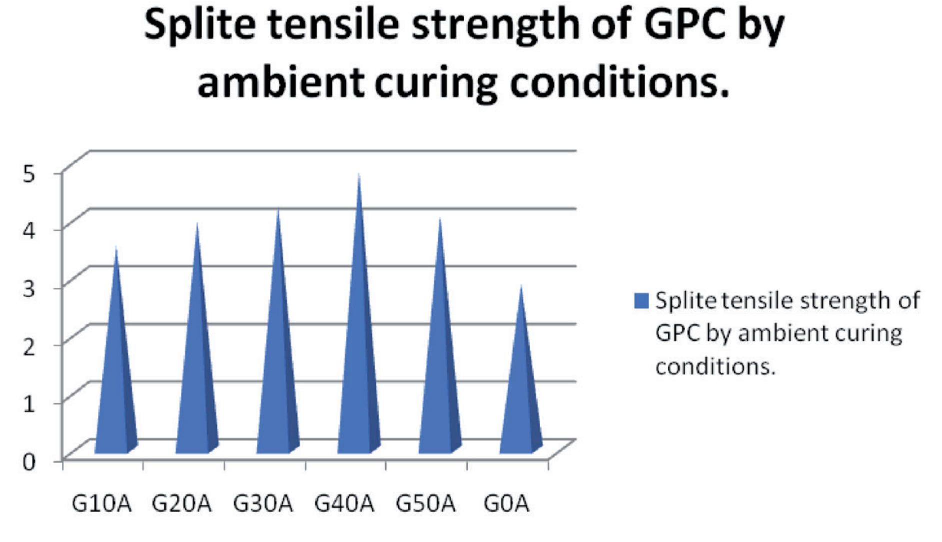

Figure 9.
Split tensile strength of GPC all combinations.

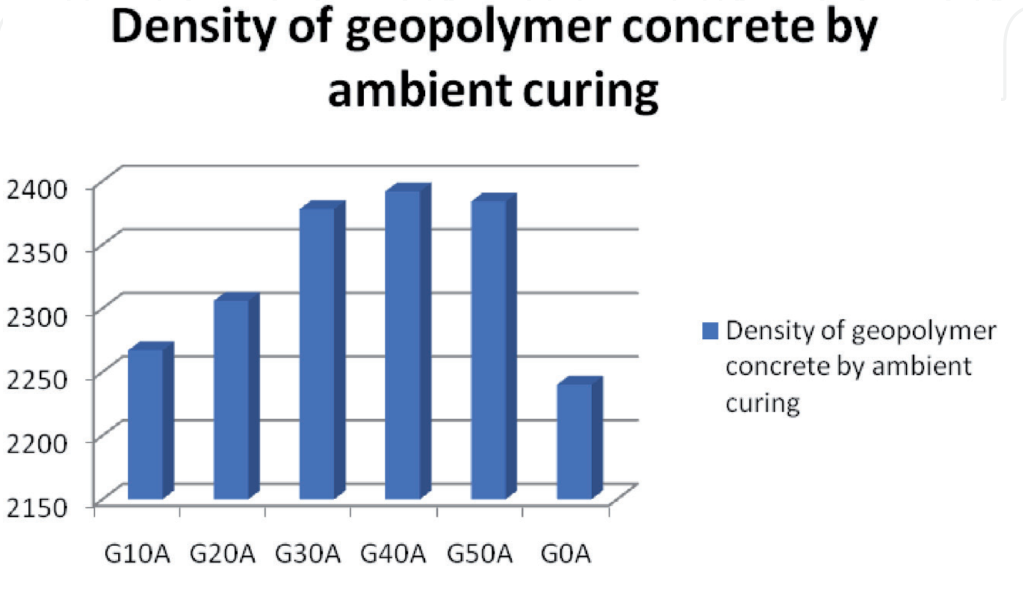

Figure 10.
Density of GPC for all combinations by ambient curing.

and the density values for mixes G10A', G20A', G30A', G40A', G50A' and G0A are 2254, 2258, 2327, 2385, 2346 and 2217 kg/m^3 as shown in **Figure 11**. Here again, upto 40% replacement, increase in density could be noticed.

3.4 Flexural strength

The flexural strength values of mixes G10A, G20A, G30A, G40A, G50A and G0A are 2.35, 3.59, 4.39, 6.5, 5.84 and 5.35 MPa respectively as shown in **Figure 12**. Flexural strength test also yields the same inference that increase in strength upto 40% replacement of flyash by GGBS and getting decreased after that.

3.5 Microstructural analysis

EDAX and SEM analysis were carried out on specimens as a part of microstructural analysis [15] to know the factors contributing to the behaviour of new combination of fine aggregates used in geopolymer concrete.

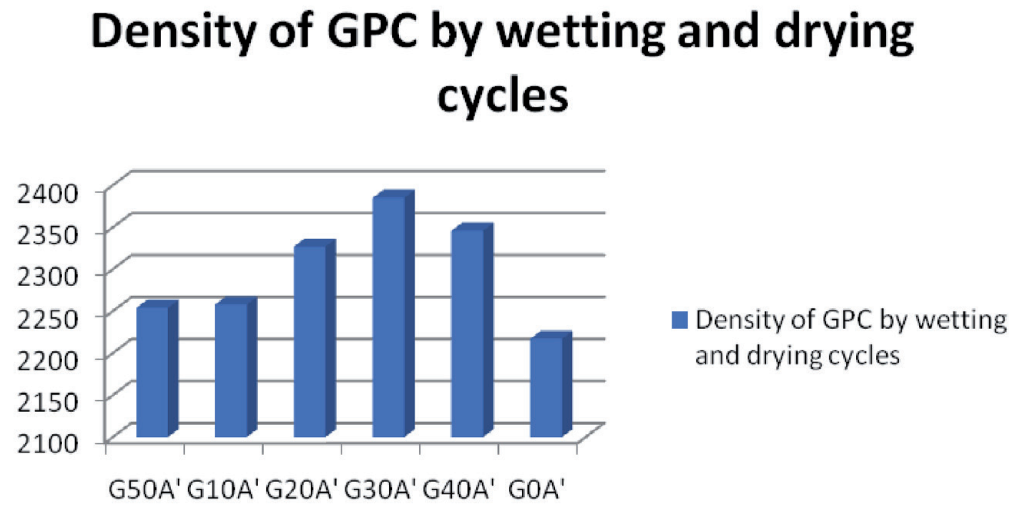

Figure 11.
Density of GPC for all combinations by wetting and drying cycles.

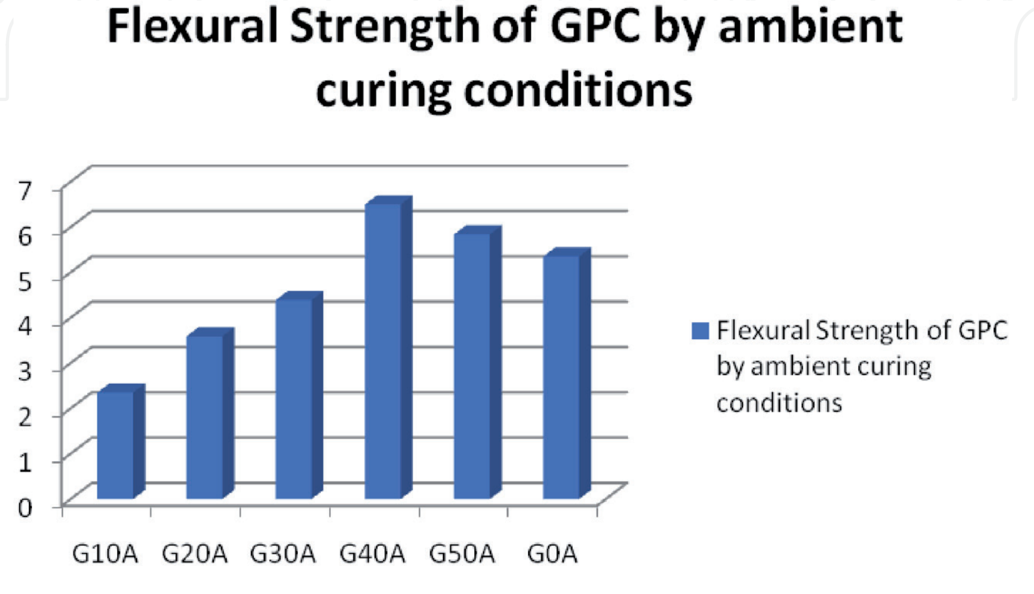

Figure 12.
Flexural strength of GPC under ambient curing conditions.

3.5.1 EDAX analysis

The elemental composition of D20, D40, D60, D80 and D100 specimens are shown in **Figures 13–17** which show the presence of Ca, Si, Al confirming the formation of geopolymeric gel as well the process of geopolymerisation. The presence of calcium in geopolymer concrete indicates that the setting time fastens during process. The rapid hardening process through solidification of gel frame work is found to be contributed by C-A-S-H gel. This would facilititate ambient curing conditions.

Elemental Weights obtained from EDAX analysis are given in **Table 2**. It shall be observed that oxides are present in larger extent in all mixes. Binding property could be weekened by the presence of oxides. The decrease in strength initially (after D20) and subsequent increase in strength (from D80) may be due to the

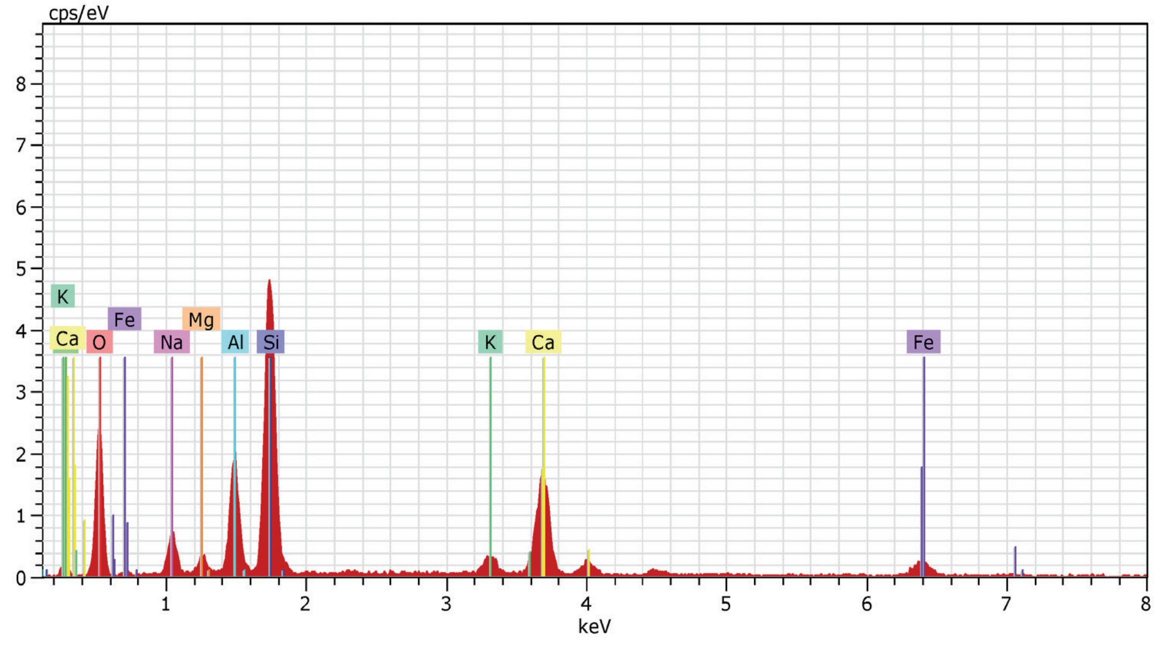

Figure 13.
Elemental composition of G10A.

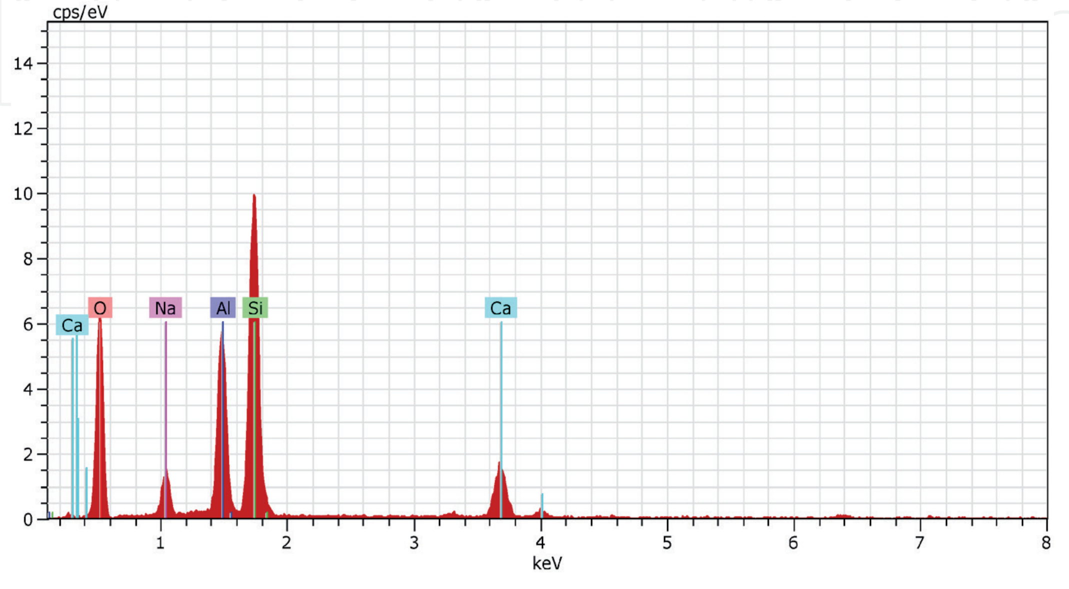

Figure 14.
Elemental composition of G20A.

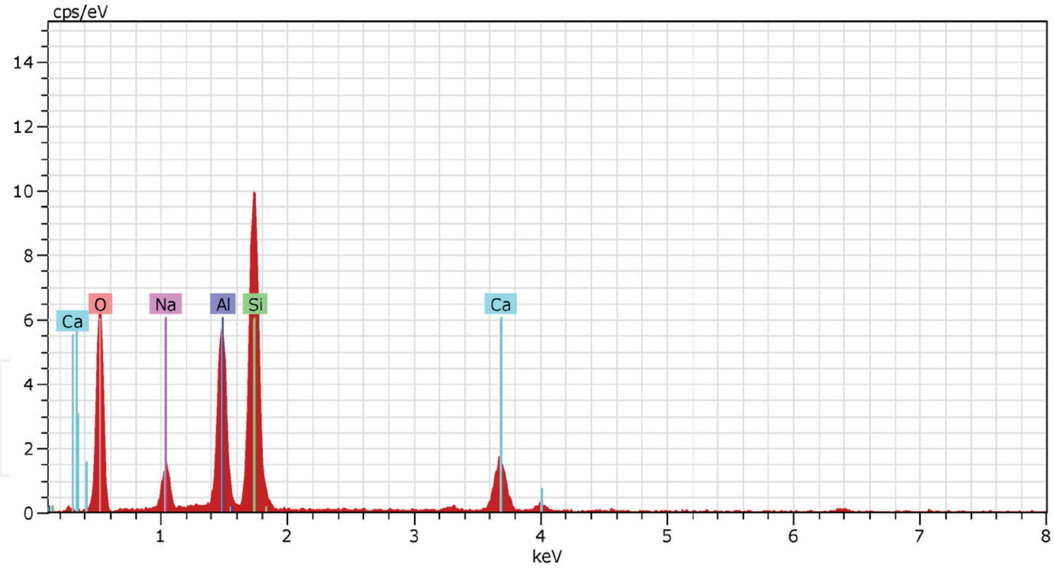

Figure 15.
Elemental composition of G30A.

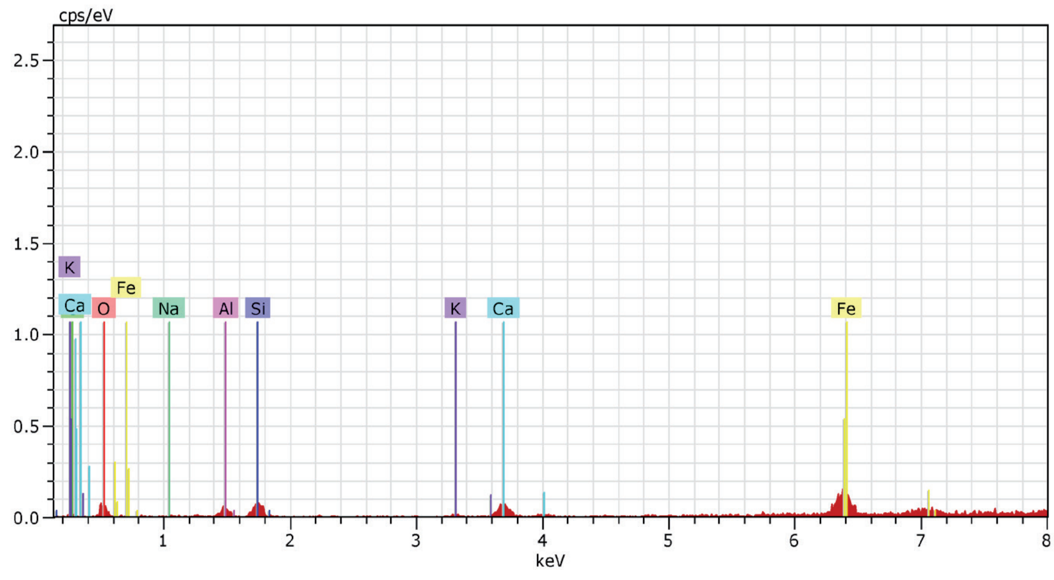

Figure 16.
Elemental composition of G40A.

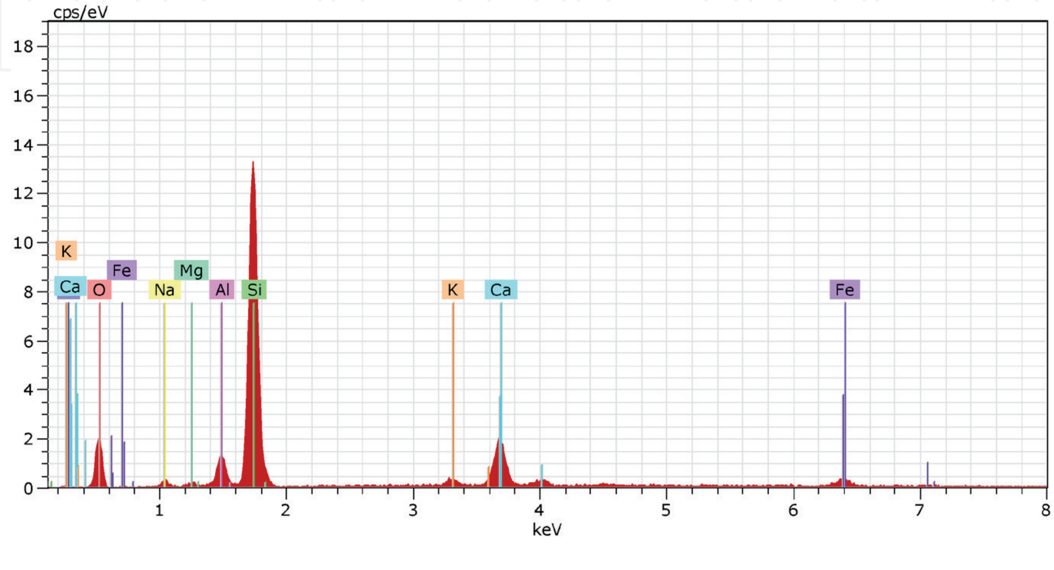

Figure 17.
Elemental composition of G50A.

S. No.	Elemental Composition	G10A	G20A	G30A	G40A	G50A
1.	Si	10.50	15.16	17.58	7.24	27.32
2.	Al	4.32	8.57	7.81	5.56	10.58
3.	Na	4.03	4.98	4.20	1.68	1.73
4.	Ca	3.16	4.31	7.90	4.93	3.94
5.	O	57.49	69.19	69.39	57.19	46.77
Si/Al		2.43	1.768	2.25	1.302	2.58
Na/Al		0.383	0.328	0.537	0.302	0.164

Table 2.
Elemental composition.

above reason. Si/Al ratio confirms the structure of sialate link as (Sialate- Di Silaxo-D20), (Silate Silaxo-D40), (Silate Tri Silaxo-D60), (Silate Silaxo-D80) and (Silate Tri Silaxo-D100). Si/Al ratio of 1 indicates that the structure is Sialate Silaxo, Si/Al ratio of 2 indicates that the structure is Silate Di Silaxo and Si/Al of 3 represents that it is Silate Tri Silaxo.

3.5.2 SEM analysis

SEM analysis was carried out for the samples having mixture of fine aggregates (DMS and M-Sand) and for sample with DMS only. The obtained SEM images are shown in **Figures 18** and **19**.

From **Figure 18**, it shall be observed that geopolymer matrix is well formed and the ITZ gap between the aggregates and matrix is less leading to greater compressive strength in case of D20 which confirms the inference obtained earlier that strength decreases after D20. Further, micro cracks are observed in case of D100. (**Figure 19**).

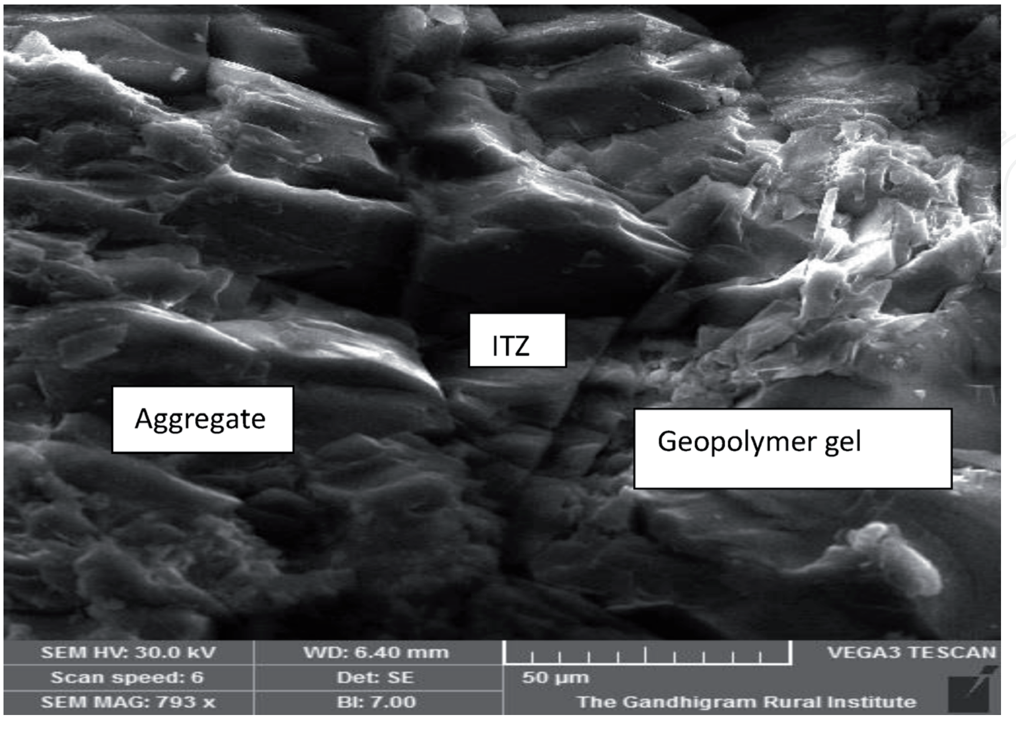

Figure 18.
SEM analysis of G40A.

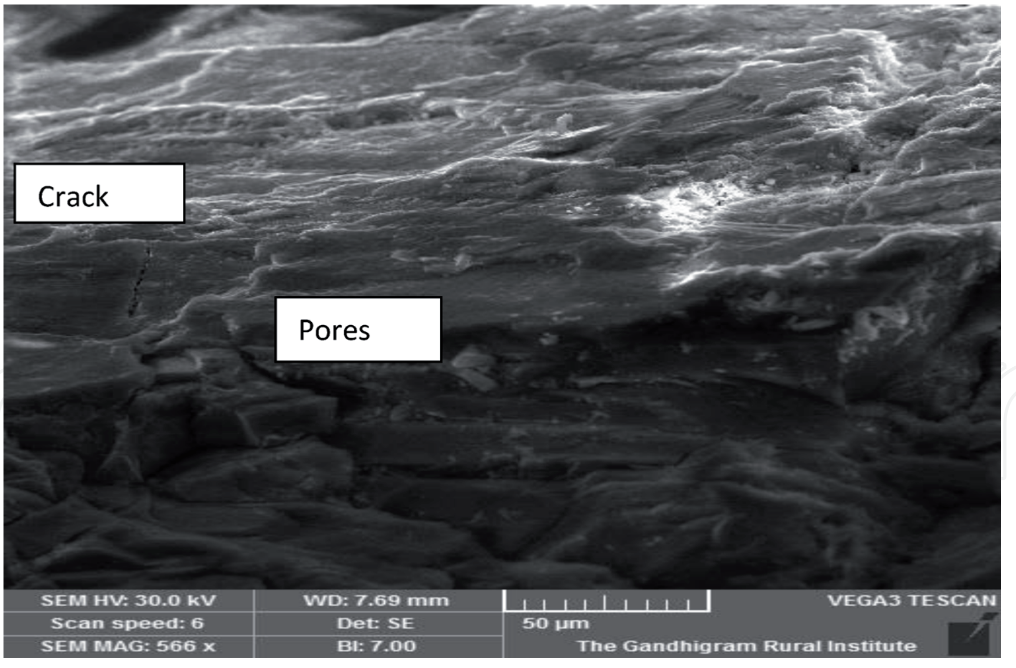

Figure 19.
SEM analysis of GOA.

4. Conclusion

This project mainly focused on arriving at the optimum percentage replacement of flyash by GGBS in geopolymer concrete. The following conclusions are derived from the investigations carried out on compressive strength, split tensile strength, density measurements and flexural strength:

- Compression, split tension as well flexure yielded the same inference that increase in strength was upto 40% replacement of fly ash by GGBS beyond which strength got decreased due to the fact that microstructure gets altered as evidenced by EDAX and SEM analysis.

- Workability was observed to be stiff upto 40% replacement requiring use of superplasticisers at the time of casting.

- Strength values of specimens subjected to alternate wetting drying conditions were slightly lower compared to ambient cured specimens.

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References

[1] T. VenuMadhav, I.V. Ramana Reddy, Vaishali G. Ghorpade and S. Jyothirmai, "Compressive strength study of geopolymer mortar using quarry rock dust" – Construction and Building Materials (2018).

[2] Khoa Tan Nguyen, Tuan Anh Le and Kihak Lee, "Evaluation of the mechanical properties of sea sand-based geopolymer concrete and the corrosion of embedded steelbar" - Construction and Building Materials (2018) 462-472.

[3] Marland, G., T.A. Boden, R.C. Griffin, S.F. Huang, P. Kanciruk and T.R. Nelson (1989),). Estimates of CO2 Emissions from Fossil Fuel Burning and Cement Manufacturing

[4] Dumitru Doru Burduhos Nergis et al. (20200, "XRD and TG-DTA Study of New Alkali Activated Materials Based on Fly Ash with Sand and Glass Powder", Materials, 13(2), 343

[5] M. Albitar, M.S. Mohamed Ali, P. Visintin and M. Drechsler, "Durability evaluation of geopolymer and conventional concretes" - Construction and Building Materials (2017) 374-385.

[6] IS 383: 1970, "Specification for coarse and fine aggregates from naturalsources for concrete".

[7] U.S. Agrawal, S.P. Wanjari, D.N. Naresh, "Impact of replacement of natural river sand with geopolymer fly ash sand on hardened properties of concrete" - Construction and Building Materials (2019) 499-507.

[8] N A Lloyd and B V Rangan "Geopolymer concrete with flyash" Main Prodeedings, Second International conference on Sustainable construction materials and technologies June 28-june 30, 2010.

[9] Muhammad N.S. Hadi, Haiqiu Zhang, Shelley Parkinson, "Optimum mix design of geopolymer pastes and concretes cured in ambient condition based on compressive strength, setting time and workability" - Journal of Building engineering (2019).

[10] K. Jeevanandan and V. Sreevidya, "Experimental investigation on concrete and geopolymer concrete" - Materials Today (2019).

[11] Aissa Bouaissi , Long-yuan Li, Mohd Mustafa Al Bakri Abdullah and Quoc-Bao Bui, "Mechanical properties and microstructure analysis of FA-GGBS-HMNS based geopolymer concrete" - Construction and Building Materials 210 (2019) 198-209.

[12] IS 5816:1999, "Compressive and Splitting tensile strength of concrete".

[13] Mithanthaya I.R. , Shriram Marathe, N B S Rao, VeenaBhat, "Influence of superplasticizer on the properties of geopolymer concrete using industrial wastes" - Materials Today (2017) 9803-9806.

[14] S. JeevaChithambaram, Sanjay Kumar and M.M. Prasad, "Thermo-mechanical characteristics of geopolymer mortar" - Construction and Building Materials 213 (2019) 100-108.

[15] Indhumathi Anbarasan and Nagan Soundarapandian, 2019,"Investigation of mechanical and microstructural properties of geopolymer concrete blended by Dredged Marine Sand and Manufactured Sand under ambient curing conditions", Structural Concrete, DOI 10.1002/SUCO 201900343, Vol.21, No.3, Nov 2019, pp 992-1003