Water Treatment Technology Using Geopolymer Concrete: A Review

Monika Verma[1], Dr. Ashutosh Sharma[2], Aravind Kumar K S[3], Krishna Das[4], Allen Abraham[5], Abhishek Verma[6]

Assistant Professor[1,2]
UG Student[3,4,5,6]
School of Civil Engineering, Lovely Professional University-Jalandhar (Punjab)

Abstract

Sewage disposal and treatment is a multi-disciplinary concept, that is gaining wider importance today owing to gigantic amount of waste produced every second. It is important to ensure that the sewage and other waste are effectively removed or else it will result in the contamination of land and water. Although there are many sewage treatment methodologies and techniques in existence most of them lack proper efficiency and exerts a greater ecological footprint. The idea of this project is to develop a water treatment technology using a sustainable material; 'Geopolymer Concrete'. The cement industries are one largest producers of CO_2, producing up to 8% worldwide man-made emissions of CO_2, in which 50% from the chemical process and 40% from burning fuel. Conventional cement concrete also fuels the depletion of natural resources as it uses natural materials as aggregates. Owing to the increasing trends in construction field it is important to find a viable and sustainable replacement for conventional PCC. Geopolymer concrete is a cement free concrete and extensive researches today prove that GPC serves as a green replacement option. It also exhibits good engineering properties similar to that of PCC at the same time being greener. This paper discusses about geopolymer concrete and its engineering properties and hence thereby explains that it can serve as a viable replacement for concrete and at the same time urging the world to shift towards a greener construction method.

Keywords: *Geopolymer, copper slag, PCC, Cement, Concrete.*

Introduction

This project focuses to create a drainage system which is smart, green and sustainable to treat waste water. This includes developing of a pervious concrete panel utilizing geopolymer concrete as the core material. As discussed, earlier geopolymer concrete is a green and sustainable concrete which is cement free and utilizes waste materials and industrial byproducts for its production. We will be utilizing materials such as rice husk ash, agro waste, copper slag, recycled rubber and chemical solutions. As you can see most of the materials mentioned are industrial waste or byproducts that are either dumped or treated improperly. The binder material used is a combination of rice husk ash and agro waste as it has similar particle size and microstructural property to that of cement. However, the carbon emission here is reduced drastically. Aggregate used here will be copper slag, which also is an industrial byproduct. By replacing the normal coarse aggregate with copper slag, it reduces the ecological footprint of the concrete because as for normal coarse aggregates, they are natural resources and it requires cutting down and crushing of quarries and mountains. Owning to the complexity of the project we plan to execute the same in two phases. In the current term, we have solely focused on learning in depth about geopolymer concrete and also have a brief exposure to IoT and programming. The implementation of IOT and automated monitoring system makes this project smart as well as different from the normal filter system. IOT (Internet of Things) is a mechanism of interrelated computing devices, digital, mechanical machines, objects, animals or people which are provided with UIDs (unique identifiers) & ability to exchanging data over a network without requiring interaction between human-to-human or human-to-computer. In this project a raspberry pi or arduino with sensor is implemented in the concrete panels so as to avoid the blockage of filter. Thus, the filter works more efficiently.

In the coming modules we will be further explaining about geopolymer concrete and its engineering properties that include fresh properties, hardened properties, durability, rheology and fracture properties.

GPC

The technology of Geopolymer was first introduced in 1978 by Davidovits. GPC is a concrete in which no Portland cement is used. Here the reaction in between source material which is rich in silica, alumina, & alkaline liquid produces the binder. Unlike cement geopolymer concrete offers a wider range of materials to be used as the binder material which includes fly ash, GGBFS, silica fume etc. Another factor that makes GPC unique is the use of recycled aggregates. This promote the reuse of construction and demolition waste. Recycled rubber is also used as an aggregate in GPC; this can be a viable solution to solve the treatment and dumping of tons of rubber waste developed. Extensive researches are being done to use GPC as replacement for cement concrete and it has proven geopolymer concrete mixture shows better thermal resistance, acid resistance, chloride and sulphate resistance and excellent durability properties. Further the properties and behavior of geopolymer concrete is discussed.

Fresh Properties

Setting Time: Setting time of geopolymer concrete was measured using the Vicat apparatus. Setting time increases with increase in the concentration of KOH. It is also found that setting time of geopolymer is more rapid at 60º C than at room temperature. Metakaolinite also affects setting time i.e. the more metakaolinite is added, slower is the setting time. Sodium silicate also has a similar influence on setting time. From the results obtained from researches, it is evaluated that setting time for geopolymer was very less approx. 15-45 min at 60º C, because of water loss increasing the rate. The setting time is directly influenced by content of potassium oxide (K_2O) [1]. Laboratory experiments also prove that fresh GPC could be handled up to 120 minutes after mixing without any signs of setting [2]. According to tests conducted at controlled temperatures 21-23º C where GGBFS was added as a binder. However, when GGBFS was added along with fly ash there was a significant setting time improvement. GPC with GGBFS content of 10%, 20%, 30% as binder showed initial setting times of 290, 94, 41 minutes respectively. Difference of initial and final setting time also decreased supporting the fact that slag as a part of binder effectively accelerates setting time of GPC at ambient conditions [3]. The setting time in this case was also influenced by the amount of alkaline activator solution. Mixes thus needed a time of 220, 290, 388, minutes to set having 35%, 40%, 45% of alkaline liquid content respectively.

A phenomenon of flash setting was observed among GPC mixtures during the 2006-07 researches. It is a phenomenon in which the mixtures undergo hardening within the minutes of alkaline liquids mixing with fly ash & aggregates leaving mixture in unworkable condition. [4]. However recent researches prove usage of GGBS as complete replacement of fly ash provide better synthesis of geopolymer [5]. Addition of borax by 0%-3% by the weight of GGBS altered the flash setting process (Table 1.0). It can be concluded that the settiing time increases with Borax content increment. It also increases lag between the initial and final setting time.

Table 1.0

SL No. Setting Time	**Geopolymer Paste with Content of Borax (%)**			
	0	**1**	**2**	**3**
Initial (min)	15.	18.	19.5.	22.5.
Final (min)	17.	22.	24.	28.
Difference	2.	4.	4.5.	5.5.

Workability: Similar to the conventional concrete testing methods, the slump test serves as the basis of determining the workability of geopolymer concrete and it was found that GPC mixtures were more workable than Ordinary Portland cement concrete [6].

Fig 1.0

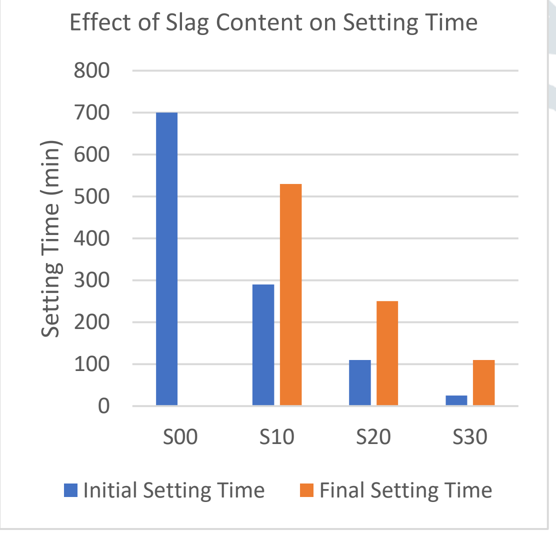
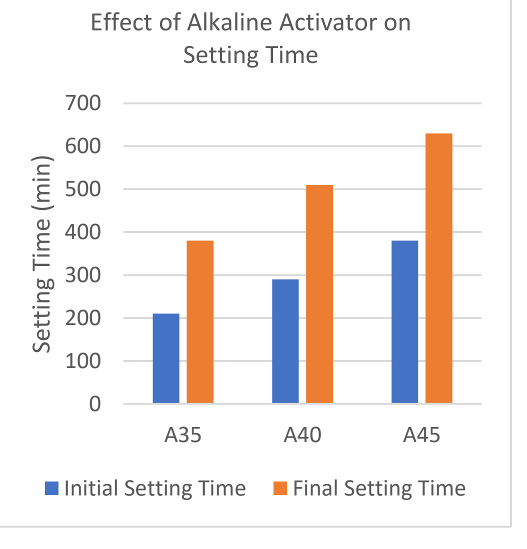


Fig 1.1



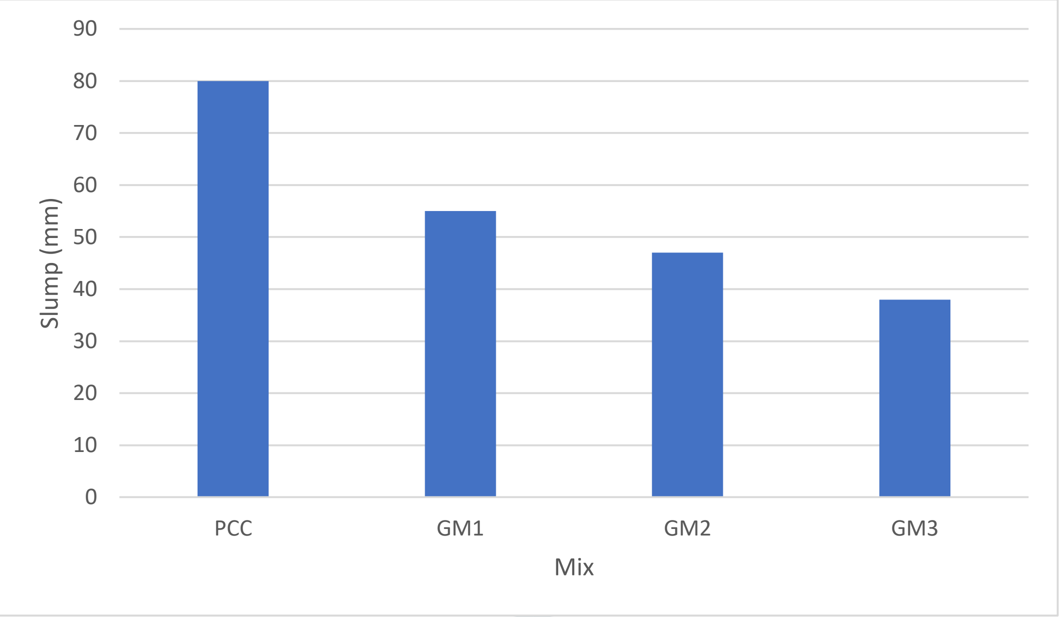


Fig 1.2

Workability is determined immediately after mixing according to ASTM: C 143-12. Binders like fly ash and the lubricating effect of alkaline activators makes GPC more flowable. However, presence if solutions of SS (sodium silicate) and SH (sodium hydroxide) makes the paste more, cohesive and stickier as compared to OPC concrete because of their higher viscosity. A higher slump indicates less stickiness and more workable nature. Further adding on, workability of GPC mixtures showed reduction Mixes with alkaline liquid content about 35% exhibited bad (poor) workability when than the latter. When more water (8 kg/m^3) and superplasticizer (6 kg/m^3) was added, same mixture showed improved workability; slump value 215mm – 245mm [7]. According to Lloyd and Rangan [4], the best performed superplasticizer where GA30:1 and VC16-1. However, in these mixtures' workability showed reduction the amounts of superplasticizer and water remained same while the content of slag increased and SS by SH ratio was decreased. Geopolymer concrete mixes showed greater cohesiveness when compared to OPC concrete mixes. The range of slump value exhibited by the mixtures was found to be suitable for the construction of members like beams, columns, slabs and footings [7]. A typical example in which ferrochrome slag replaced partially with normal coarse aggregate, the geopolymer concrete mixture showed an increased value of slump. This can be possibly because of the possible greater water absorption capability of FS than NCA [8]. Mixture in which GGBFS was used as partial replacement for normal C.A (coarse aggregates), the values of slumps and flow values are reduced as the concrete mixture became stiffened & lesser workable. Additionally, diminished workability is accompanied with reduced handling time. [3]. Workability showed reducing trend while the geopolymer concrete grade increased. This is due to the increase in the molarity of NaOH and decrease in water content. Hence the mix becomes more stiff as the grade increases[9] .

Table 1.1 Slump values for different grades OF GPC [9]

Grade of concrete	**$Na_2SiO_3/NaOH$**	**Slump (mm)**	**Grade**	**$Na_2SiO_3/NaOH$**	**Slump value (mm)**
M30	2.5.	135.	M-30	3.5.	145
M40	2.5.	130.	M-40	3.5.	140
M50	2.5.	110.	M-50	3.5.	130
M60	2.5.	95.	M-60	3.5.	110

Table1.2.Values of Slump and Slump Flow Testing on GPC [10]

Testing	**Retarder Variance percentage (%)**	**Result value (cm)**	**Standard used**	**Note**
Concrete Slump	0	0 cm	ASTM C 143/C 143M-03	Not Passed.
	0.2	2.7 cm	Do	Passed.
	0.4	3.8 cm	Do	Passed.
	0.6	8.8 cm	Do	Passed.
	0	20 cm	Ghosh & Ghosh (2012)	Passed.
	0.2	20 cm	Do	Passed.
	0.4	21 cm	Do	Passed.

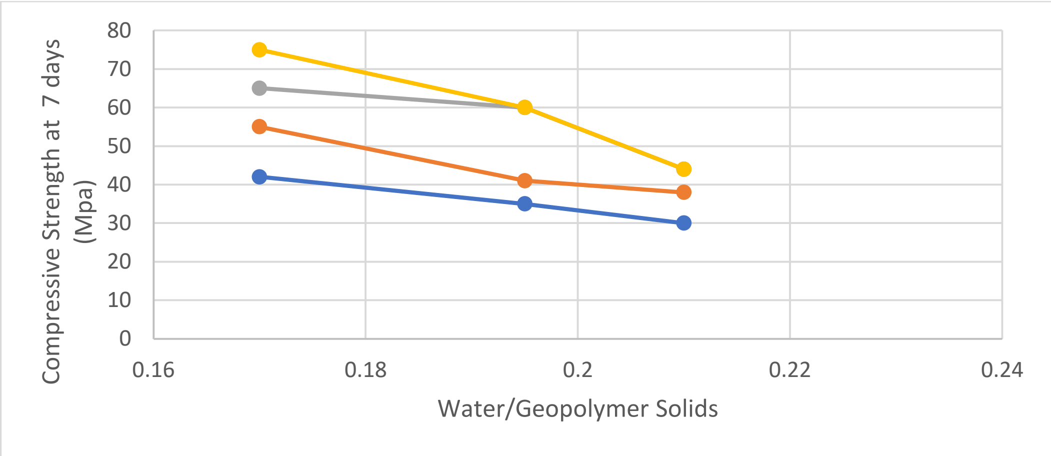
Concrete Slump flow	0.6	24 cm	Do	Passed.

Segregation: Due to natural difference in the matrix of GPC to that of OPC concrete [11], segregation, bleeding was not observed for the concrete during the stage of mixing, compaction and finishing [7].

Water to Solids Ratio: As discussed earlier, various parameters interaction on workability is very complex. To aid the low calcium fly ash geopolymer mixes design, main factor known as 'water-geo polymer solid ratio' is formulated. Water mass used for making the sodium hydroxide & extra water if any. Whereas the geopolymer solids mass is sum of the binder material mass, sodium hydroxide solids, and solids mass. [12].

The result values shown that compressive strength of geopolymer concrete reduces with increase in water-to-geopolymer solids ratio by mass [13].

Fig1.3



Hardened Properties

Compressive Strength: A vast number of studies have been conducted on geopolymer concrete in the past years. Fly ash was used in most of these tests as the binding material, while in some studies it was replaced by some other alumina silicate-rich materials. Compatibility of materials like rice husk, saw dust, and coir fibre were evaluated.

Recent investigation shown the usage of sodium hydroxide and sodium silicate as main alkali activator, excluding the ones [14] where a difference of acid-alkali medium was evaluated. Alkali solution of molarity range in 8 and 14 was used in most of the research.[15] The compressive strength of the various geopolymer concrete with these different materials were constituents were recorded as in Table.

Table 2.0

Type	Material	Molarity. (M)	Compressive Strength (MPa)	Curiing Time, &Temp.
Paste	F.A,	12	65.0	60°C for one day
	F.A and SD,	10	67.0	40°C for one day
	F.A and IOT,	10	36.0	7 thermal cycle at 200°C
	R.H.A and WTS,	10	24.0	60°C for one day
	F.A and coir fibre,	8	31.4	75°C for one day
Mortar	M.K and C.G,	N/A	97.0	22°C for one day
	G.GBS, M.K and R.H.A,	14	47.9	65°C for one day
	F.A,	16	56.0	65°C for one day
	BOT and Slag.	-	50.0	95°C for one day

Investigaions conducted by Hardjito and Rangan[16] in 2005 have evaluated the results:

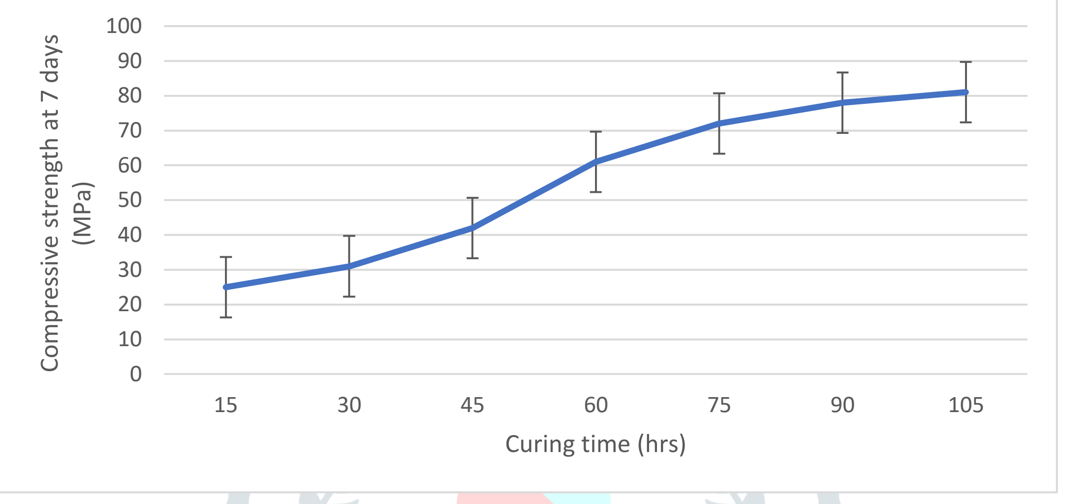
- Sodium hydroxide solution in higher concentration (in molar terms) results in higher compressive strength of geo polymer concrete.

- As the water content of the mix increases, the value of slump of fresh concrete (GPC) also increases. Super-plasticizers can help improve workability.
- As the molar ratio between H2O and Na2O increases, the GPC's compressive strength decreases.

Studies evaluated that the curing temperature in between 20 ℃ to 100 ℃. On thermal curing, the samples having lower mass ratio of sodium oxide-to-silica results in expansion [17]. Therefore, specimens curing below 70℃ is advantageous for gaining strength while decreasing the expansion. [18].

In general, the method of hot vulcanization of concrete fly ash geopolymer with low-calcium is suggested. The impact of the curing time is shown in Figure[19].

Fig 2.0



Characteristic Split Tensile Strength : The split tensile test divided by the cylindrical samples performed by K. Jeevanandan and V. Sreevidya[20] was done in accordance with Indian Standard 516-1964. Test performed by placing a cylindrical sample uniformly in b/w the stacking surfaces of test machine.

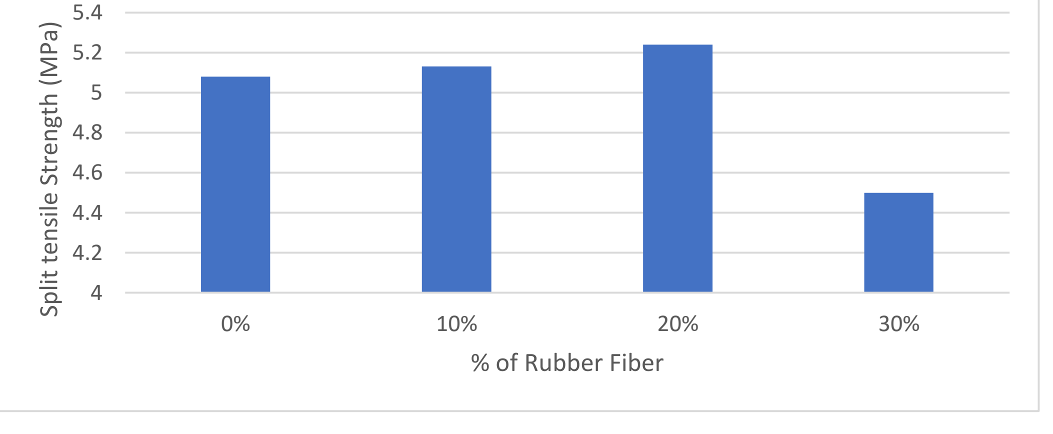
Split Tensile Strength (N/mm^2), $f_{cr} = 2P/\pi LD$ where,

P-Ultimate load (N); L-Length of cylinder (mm); D-Diameter of cylinder (mm)

In this experiment they compared the split tensile strength of conventional concrete to the split tensile strength of fly ash based geopolymer concrete till the 28th day from the initial day being the 7th day. The average split tensile strength of geopolymer was found out to be 2.12 MPa which was similar to the value of conventional concrete (2.16 MPa)[20].

Geopolymer concrete when combined with recycled rubber shows tremendous improvement in the split tensile strength as a result of the good bonding between the geopolymer waste and the aggregate[21]. Similar results have been provided in other studies as well.[22]–[24]. The following graph shows the split tensile strength recorded by Salmabanu Luhar, Sandeep Chaudhary, Ismail Luhar[21] in their experiment, which shoes the strength in different proportion of rubber fiber in the concrete at the end of the 28th day.

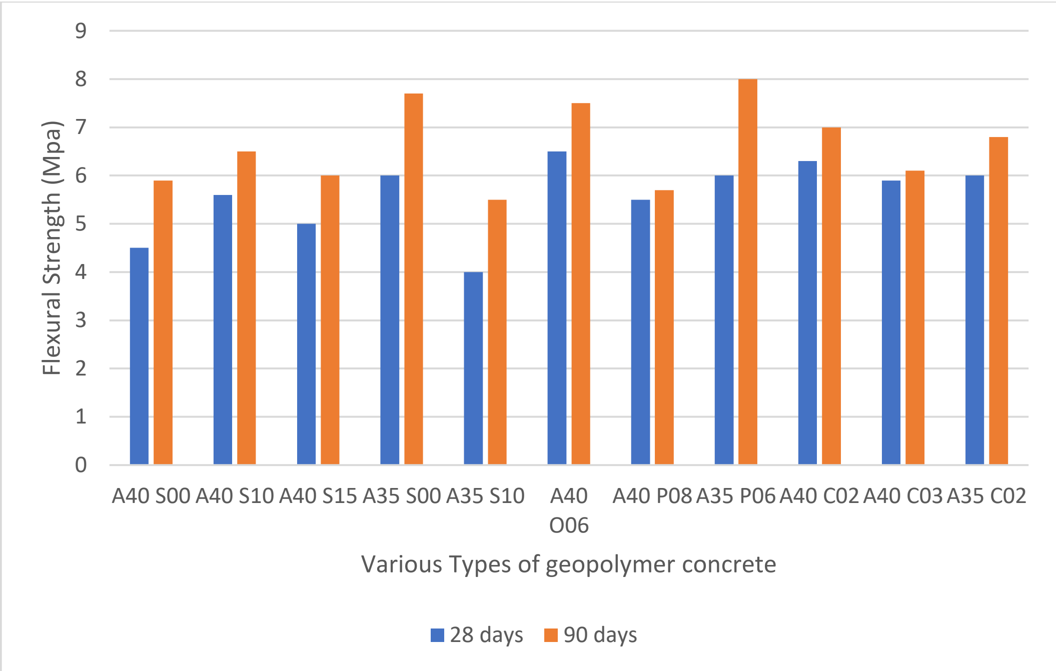
Fig 2.1



Flexural Strength: Generally, Flexural strength shows a greater value as compared to split tensile strength[25]. As the GGBFS or calcium hydroxide with fly ash used, the flexural strength increased. But as the additives proportion is increased, after a certain proportion, the strength started to decrease. [25].

As per Deb [26], concreting of geo polymer of fly-ash mixed by using GGBFS up to 20 percent shown greater tensile strength divided by the more proportion of GGBFS. An aggregate of size up to 20 mm were used in this mix, while in this investigation, used a 10mm maximum aggregate size. It can be observed that mixes that have OPC 6% and CH 2% and additional water in the mixes have reached a lower bending strength as compare to the control geo polymer (A35S00) in which no additional water. [27].

Fig 2.2



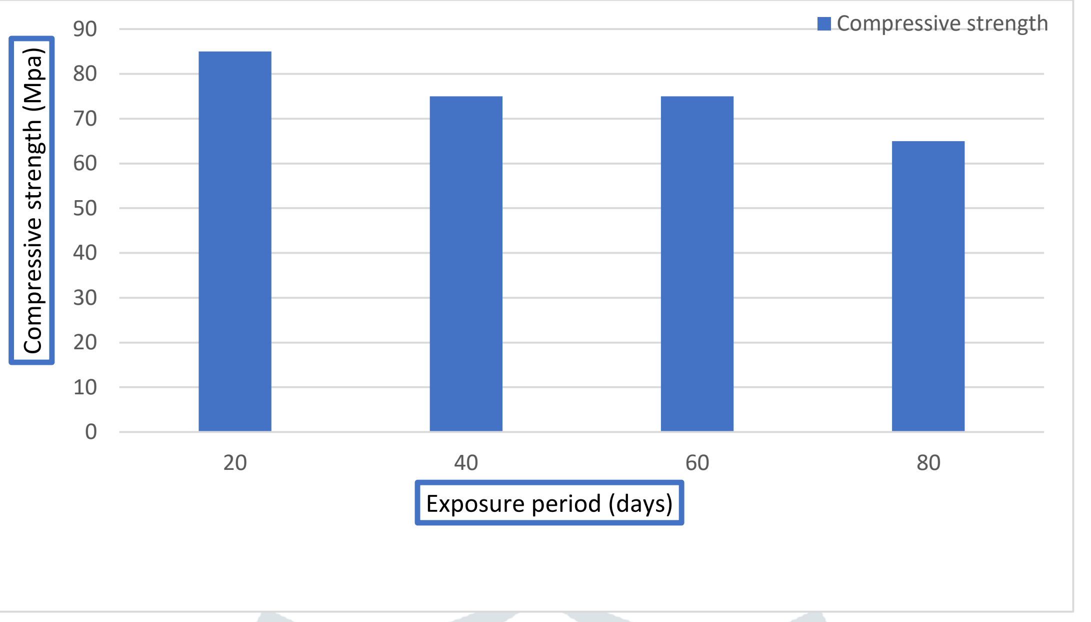
Geopolymer concrete cured at a high temperature generally has a lower modulus of elasticity as compared to conventional concrete [28], [29]. As per Olivia and Nikraz study [30], the heat cured geo polymer concretes rely on fly ash about 55 N/mm^2 compressive strength shown elastic modulus lower than 14.9-28.8% compared to conventional concrete.

Durability

Durability is considered as the major issues which is associated with OPC concrete. On the other hand, durability is claimed to be one of the major advantage of geopolymer concrete as it does not contain the presence of calcium compounds [31]. Generally, durability is assessed on the basis of sulphate attack, chloride induced corrosion, alkali aggregate reaction, permeability, frost action. To understand the properties of durability of geopolymer concrete various tests are being carried out.

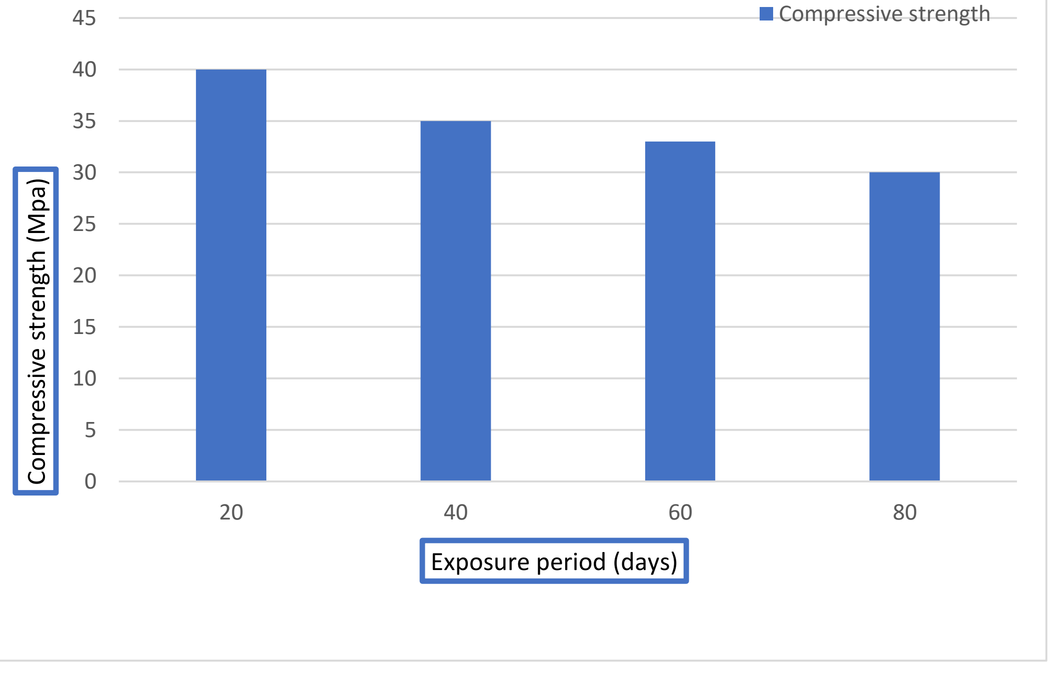
Sulphate Resistance: In soil, there may be presence of sulphate and ground-water when in contact with the concrete, can deteriorate it. So, it is important to know about the resistance of concrete against sulphate attack. From the studies, this is found, visual appearance of the geopolymer concrete specimen is somewhat similar to OPC concrete specimen after 45 days of exposure to magnesium sulphate solutions. There is a presence of efflorescence on the surface of specimen due to high calcium hydrated products [32]. It has been found that compressive strength is slightly decreasing after 28 days and some specimen shows no change as well. Very slight enhancement in specimen mass after exposure to sulphate solutions. Also the length of the specimen remains same in most of the tests [33].

Fig 3.0 Compressive strength values of geopolymer concrete after sulphate solution attack.



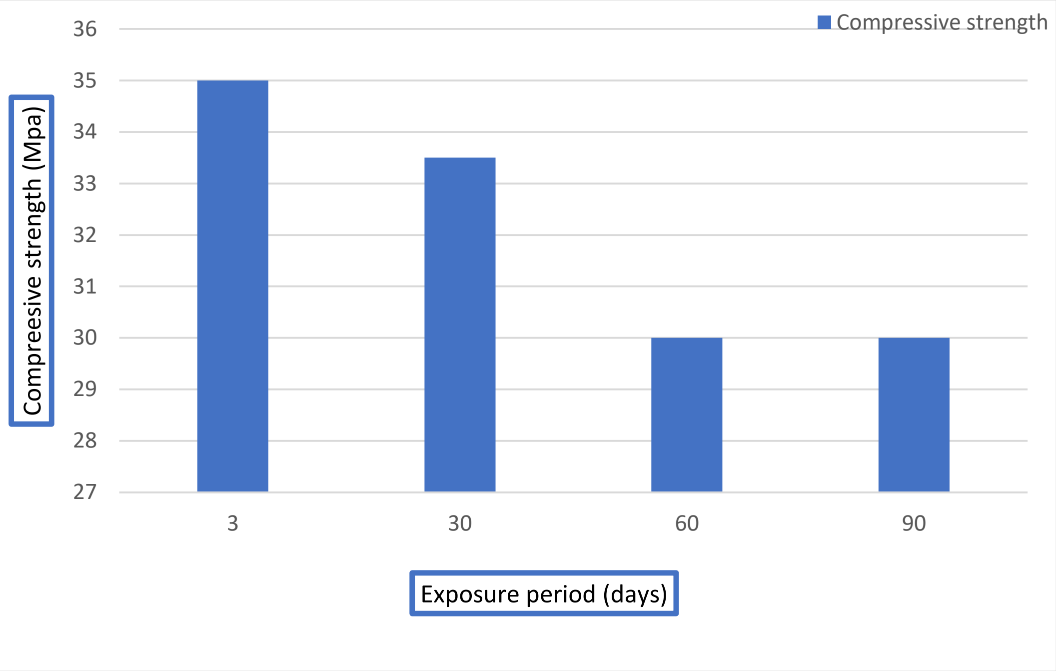
Acid Resistance: After casting and curing of specimen, it is submerged in solution of sulfuric acid. Deterioration of specimen is found to be increasing with time. In comparison with the unexposed specimen, the exposed specimen found to be soft in touch. The compressive strength of the sample is found to be decreasing with time increment. Results show that the change in mass of the specimen makes a noticeable change in the initial stages. This may be due to absorption of solution by the extra pores in the specimen due to oven curing [34].

Figure 3.1. Values of Compressive strength of GPC after attack of sulfuric acid.



Chloride Resistance: Visual appearance of the specimen when expose to chloride solution shows no deterioration or erosion on the surface in the initial stage. But later it shows little deterioration on top surface of specimens, less than 2mm, which had led to visibility of coarse aggregates [35]. The compressive strength of the specimen found to be decreasing with increase in time. The decrease in compressive strength of OPC was much more than geopolymer concrete. Thus it shows that geopolymer concrete exhibit high resistance to chloride attack [36]. The specimens retained their shape and size and there was no noticeable change in the weight after the exposure to chloride. It was observed that the change in weight of the specimen is more in OPC as compared to geopolymer concrete.

Figure 3.2. Compressive strength results of GPC after expose to chloride attack



Permeability: As compared to OPC, permeability coefficient is low for geopolymer concrete [37]. Generally, water permeability is influenced by pore connectivity in the concrete paste. Pore generated in the concrete is depend on parameters such as water content, binder material and the curing method. Thus the denser paste and smaller pore interconnectivity contributes to low permeability [38].

Conclusion

It can be seen from the above-mentioned data that geopolymer concrete exhibit good fresh and hardened properties and as well as have excellent durability characteristics.

- The setting time of GPC is influenced by various characteristics. This include alkaline solution content, alkaline activator content, admixture, slag content.
- Flash setting is a phenomenon that occurs during reaction between alkaline solution with aggregates and binder material, which render the mixture unworkable
- The workability of GPC is influenced by parameters like SS/SH ratio, alkaline activators, slag content and concrete grade.
- Water-geopolymer solids ratio is a deciding factor in deciding the setting time, workability, compressive strength and all other major properties of the GPC mixture. This is analogous to water-to-cement ratio in conventional PCC (Portland cement concrete).
- GPC gain Compressive strength more rapid than Portland cement concrete. It is influenced by slag content, binder material, poly-condensation of alumina, silica and alkaline content.
- Sulphate, chloride, acid resistance of GPC is found to be better than Portland cement concrete. In general GPC exhibits good resistance in aggressive or severe environmental conditions
- The permeability coefficient of GPC is lower than Portland Cement Concrete.

Hence it can be concluded that GPC can be hence used as a viable and sustainable replacement for conventional concrete as it exhibits good overall properties, resistance and also has a low ecological foot print. Its high time that we use GPC for all commercial and all other sorts of construction.

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