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Influence of Type of Alkaline Activators on Performance of Fly-ash based Geopolymer Concrete-A Critical Review

R.S.V.V.L. Kumar Raju[1], Potharaju Malasani[2],V.Sai Kumar[3]

[1] Research scholar,[2] Professor,[3] Asst. Professor

Department of Civil Engineering., GITAM-Deemed to be University,

Visakhapatnam-530045, Andhra Pradesh, INDIA.

Abstract - Geopolymer concrete (GPC) has the capacity to lower carbon emission, which in result leads to ecological sustainability and growth of the concrete industry. This technology has the potential to lower CO2 emissions from the cement industry by up to 80%. GPC (Geo Polymer Concrete) is a material that does not require OPCcement as a binder. Instead of cement, supplementary binding products like fly ash (FA), GGBS etcwith Silicon and Aluminiumcontents in abundant are stimulated by alkali solution to form the binder. The researchers use alkaline liquids NaOH (Sodium Hydroxide) ,KOH (Potassium hydroxide) etc., for activating the base materials to produce geopolymers. In this paper, the authors attempted to present a critical review of the use different activators and their effect on mechanical and durability properties of GPC. Moreover, the advantages by using combination of alkali activators (NaOH and KOH) is highlighted.

Keywords: Geopolymer concrete, Fly ash, Alkaline activators, Sodium Hydroxide, Potassium Hydroxide.

INTRODUCTION

This paper is a review on advancements in geopolymers produced by alkaline activation of alumino silicates and their influence on the characteristics of GPC. The strength qualities of GPC are influenced by a wide range of factors. They include the source material utilised, and also the concentration and type of alkali activator used. The precise selection of all these factors can result in high performance characteristics[2].

According to the French Professor Davidovits, the FA geopolymer paste binds fine and coarse aggregates with several other unreacted products together to make GPC, which can be made with or without admixtures. The traditional concrete technology procedures are used to make GPC[6]. D. Hardjito and B. V. Rangan (2005) presented stated in OPC , aggregates make up about 75-80% of the mass, while in GPC also aggregates make up about 75% to 80% of the material. The Si and Al in low-calcium FA react with an alkaline liquid made up of Na_2SiO_3 and NaOH solutions to create a geopolymer paste which binds the aggregates and unreacted components.

Geopolymerization & Reaction mechanism

Usually, concrete begins to develop strength by forming of hydrates (CSH) which is generated by the hydration process. OPC cement generally used as a binder. Geopolymerization is the process of hardening a Geopolymer by disintegrating the Alumina and Silica ingredients of the FA with alkaline solution [7]. Davidovits developed the geopolymerization process in 1978, suggesting a chemical interaction between Al-Si oxides that creates the 3-D polymer chain Si-O-Al-O. Polysialate[-Si-O-Al-O-], polysialatesiloxo[Si-O-Al-O-Si-O], and polysialatedisiloxo [Si-O-Al-O-Si-O-Si-O] are the three forms of these structures. The polycondensation of hydrolyzed aluminate and silicate species is thought to be the source of the geopolymer's hardening. The general formula forpolymer composition is nM2O.Al2O3.xSiO2.yH2O, here M denotes alkali metal, MOH is type of caustic alkalis and [R2O.(n)SiO2] is type of silicatesthatare the most extensively utilised alkaline activators, which can be employed separately or in combination. M is typically NaOH,KOH, sodium carbonate or sodium sulphate which contains alkaline metal ions and serves as an accelerator by activating Al and Si with the binder. The dissolving of water is shown in the 2nd chemical reaction. It is known that curing during geopolymerization accelerates the dissolution of water, resulting in discontinuous gel nanopores in the paste, which improves the paste's performance even more. The hardening method by geopolymerization is depicted in Figure 1[8]. The Al2O3/Na_2O ratio and the SiO2/Al2O3 ratio are both important in alkali-activated FA-based concrete. However, the main hardening process of alkali-activated flyash-based concrete's geopolymerization is unclear.

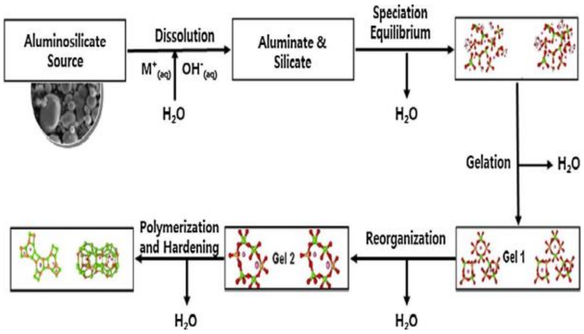

Figure.1 Reaction Mechanism of Low calcium FA based GPC

Review of Parameters.

A review of several studies related to the influence of alkali activator concentration and ratio on GPC strength and durability characteristics is addressed below.

Effect of the Alkali Activators

Curing time, strength properties and bond of FAbased GPC were examined by PV Sata et al. In this research, the concentration of NaOH solution was varied with 10, 15, and 20 molars. Heat curing at 60°C for a time period of24hrs and ambient curing at room temperature were employed as curing regimes. The strength properties and elastic modulus of GPC rise as the molarity increases, according to the findings. The influence of alkali hydroxide and its concentration on the development of compressive strength was hypothesised by G Nagalia and Y Park. Alkaline solutions such NaOH, KOH, Ba(OH)2, and LiOH were employed to evaluate geopolymers made by combining Class C (9.42 percent CaO) and Class F-FA in this study (1.29 percent CaO). X-ray diffraction and SEM were used to study the microstructure. The results revealed that NaOH was the only solution that produced a high level of activation. Sodium hydroxide used with variation in molarities from 8M to 14M. The compressive strength raised as the molarity increased, according to the study.

The influence of NaOH concentration of FAbased GPC was studied by R Hamidi and K Azizi in a study. An activator solution of Na_2SiO_3 and NaOH was utilised in the investigation. Heat curing took place at 60°C in oven for one day. The effect of NaOH concentrations varying from 4 molar to 18 molarwere investigated. To examine the morphology, researchers used a scanning electron microscope (SEM). The specimens' flexural strength was also tested. The optimum molarity was found to be 12M, which performed well in all experiments. M.Tagore et al presented a study on the qualities of GPC with GGBS as a Binder. The activators utilised in the experiment were Na_2SiO_3 ad NaOH. The molar concentration of the solution used by varying between 8 and 10molar, and the effect was studied in this work by determining flexural and compressive strength. The researchers discovered that as molarity increased, compressive strength also increased simultaneously.

S. Siddiraju and A.I Ahmed investigated the mechanical properties of FA based GPC withadmixtures. As an activator solution, Na_2SiO_3 and NaOH were utilised. The molarities of NaOH used in this study were 8M, 12M, and 16M. Curing regimes like oven curing and sunlight curing were used. The results depicted that when the molarity of sodium hydroxide rose, compressive strength improved in both modes of curing. Patankar S.V. et al.investigated the influence of various sodium hydroxide solution molarities at different solution to FA ratios (0.3, 0.35& 0.4). They concluded that the workability and compressive strength of geopolymer mortar increased as the molarity of NaOH solution increased, and 13 M NaOH is recommended for workability and compressive strength. Hariz Zain et al. evaluated the environmental impact of several types of geopolymer materials including FA, kaolin, MK and dolomite.In order to achieve sustainable growth, particularly in the building and construction sector, FA-based geopolymer material outperforms compared to remaining metakaolin, kaolin, POFA, and dolomitebased geopolymer materials in terms of SiO_2

Combined usage of Alkali activator

Sameer Ul Bashir evaluated the influence of activators on mechanical properties of GPC. The alkali activators used in this study are NaOH and KOH individually and also in combination. The molarity of the activators is varied from 8M to 14M and the parametes compressive, split tensile and flexural strength were studied and differentiated with OPC of same grade. The results projected by the author are as follows:

KOH as an activator: GPC has better compressive, split tensile, and flexural strength characteristics than OPC M25 grade. Additionally, as the molar concentration of KOH is raised from 8Molar to 14Molar, the strengths of samples raised. However, the increase in strengths from 12M to 14M is negligible. In this investigation, 12M was determined to be the optimal molarity in terms of economy.

NaOH as an activator: GPC's compressive, split tensile, and flexural strengths are all more or equal to those of OPC M25. Additionally, as the NaoHmolarity (similar to KOH solution) is raised from 8M to 14M, the trend in strengths increased.

GPC with (KOH + NaOH) as activator (12M) exhibits an increase in all three paramaters compressive, split tensile strength and flexural strength. Here, the ratios are (20%:80%-NaOH:KOH),(40%:60%-NaOH:KOH), (60%:40%NaOH:KOH) and (80% :20%- NaOH:KOH). At 12M, the optimal combination is 80 percent NaOH + 20% KOH.

D B Raijiwala et al studied the effect of alkali activator on mechanical properties ofGPC. In this study NaOH and KOH both were added in the proportion of 1:1 (50% NaOH+50%KOH)along withNa_2SiO_3 and cured at different temperatures Mixes with NaOH and KOHindividually were also casted for investigation. Mechanical and durability tests were performed on the above said combinations and differentiated. Results in this study projected the compressive strength, Flexural strength and Split tensile strength is higher for combination mix at 800c followed by 12M KOH and 12M NaOH.

Voraa, Prakash R., and Dave, Urmil V.

investigated Parametric Compressive Strength of GPC. The objective of this article was to describe the experimental work done to assess the influence of different factors on compressive strength. The alumino silicate material utilised was Class F FA. Two concrete mixes were cast with an alkaline liquid to FA ratio (0.35& 0.4). The activator solution's $Na_2SiO_3$and NaOH ratio was also changed. The molar concentrations of NaOH solution were varied from 8M to 14M. The ratios for alkaline solution to FA has no effect on the strength, according to the findings. The amount of NaOH in the solution improved the compressive strength.

B.VijayRangan et. al, stated that the mechanical properties of GPCare significantly morecompared to that of regular OPC concrete. For the same mix, the GPC compressive strength is approximately one and half times more than that of regular OPC concrete. Similarly to conventional Portland Cement Concrete, the GPC demonstrated excellent workability.Olivia et al.conducted a complete experimental examination on water penetrability properties of low calcium FAGPC, including water absorption, permeable voids, permeability, and sorptivity. GPC is produced from FA and an alkaline activator mixture of NaOH and Na_2SiO_3 in this study. In the steam curing chamber, seven mixtures were cast in 100 x 200 mm cylinders and cured for 24 hours at 60 C. The cylinders were sliced into slices after 28 days to assess permeability, sorptivity, and the volume of permeable voids. Scanning Electron Microscopy was also used to investigate a microstructure characteristic of GPC. The findings show that GPC has low water absorption, permeable void volume, and sorptivity. According to the water permeability value, the GPC might be characterised as a concrete of ordinary quality. Furthermore, a low water/binder ratio and well-graded aggregate are two key aspects in achieving low water penetrability in GPC.

Anurag Mishra et al. investigated the effect of NaOH content and curing duration FA-based GPC. Nine different mixtures were made, with NaOH concentrations of 8 M, 12 M, and 16 M and curing times of 24 hours, 48 hours, and 72 hours. Each of the nine cast mixtures was tested for compressive strength, water absorption, and tensile strength. The research found that when the concentration of NaOH increased, compressive strength increased as well. Compressive strength increased as curing time increased, but it was shown that the rise in compressive strength beyond 48 hours of curing time was not significant.Anuar et. al, explained that a greater concentration of sodium hydroxide solution in the GPC will result in increased compressive strength because NaOH will improve bonding between the aggregate and the concrete past

Table 1.0: GPC activator (KOH + NaOH) results at 12M

Mixes	Compressive strength		Split tensile strength		Flexural strength	
Age in days	7	28	7	28	7	28
20%NAOH+80%KOH	14.43	18.18	2.826	3.62	2.42	5.31
40%NAOH+60%KOH	16.30	20.43	2.852	3.63	3.48	5.33
60%NAOH+40%KOH	17.65	22.36	2.87	3.65	3.5	5.37
80%NAOH+20%KOH	19.178	24.54	2.90	3.67	3.52	5.46

Table 2.0: Results for GPC (50%KOH +50% NaOH) and OPC

28 Days Results	M25	60^0c	80^0c	100^0c	12M NaOH	12M KOH
Compressive strength	30.33	50.42	55.26	52.18	39	42.44
Split tensile Strength	3.6	5.4	6.48	6	4.08	4.8
Flexural Strength	4.54	7.56	10.58	8.98	6	6.6
Pull out strength	5.66	0.84	0.60	0.76	0.92	0.88

DjwantoroHardjito et al studied the effect of different factors on the short-term engineering characteristics of fresh and hardened low-calcium fly-ash-based geopolymer mortars. The tests were carried out on 50X50X50 mm cube geopolymer specimens with varying parameters i.e concentration of NaOH 8M to 16M, curing temperature 650 C to 800 C, Ratio of activator to FA(0.35:0.45), ratio of water to geopolymer solids (0.27 to 0.33). They arrived at the conclusion that a greater NaOH solution concentration leads in a higher compressive strength of GPC. The highest compressive strength was reported with a mortar and activatortoFA ratio of 0.40 by mass. The temperature at which the geopolymerization takes place is crucial. The compressive strength of geopolymer mortar falls as the ratio of water to geopolymer particles by mass increases.

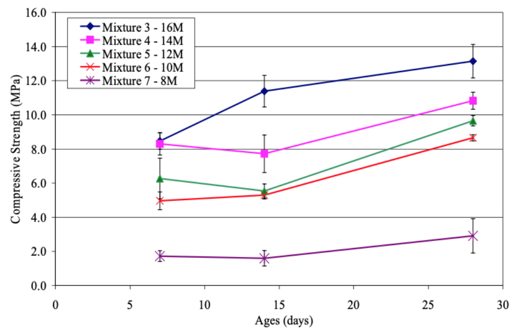

Figure 2. Effect of Concentration of Alkaline Activator on Compressive Strength

Fernandez-Jimenez et al evaluated the mechanical characteristics of alkali-activated FA concrete. Compressive and bending strengths, modulus of elasticity, pull-out bond strength, and mass shrinkage were all determined by experimental testing. The findings of flexural testing revealed that initial strength was gained gradually over time. The modulus of elasticity is a measurement of the elasticity of a material. The Portland cement-free specimens had lower elasticity values than the Portland cement control group, according to the results. Kannapiran et al compared the performance of geopolymer and conventional concretes in the presence of acid and sulphate. The durability tests were carried out using ASTM standards and mixture proportions of two classes M30 & M50 for conventional concretes and G30&G50 for GPCs. Visual appearance, mass change, and compressive strength change are all examples of qualities. According to the research, GPC has high compressive strength, sulphate resistance, and acid resistance. When GPC is exposed to unfavourable circumstances such as sulphate assault, acid attack, and water absorption, the change in mass and loss in compressive strength are very minimal, if not non-existent.

The effect of parameters on the characteristics of GPC was studied by Nguyen Van Chanh et al. They investigated at five different mixture proportions with different concentrations ranging from 14 to 18 M, additional water supplied ranging from 40 to 59 kg/m3, alkaline liquid to FA ratios ranging from 0.30-0.45, and curing temperatures varying from 60 to 900 C. They came to the conclusion that a prolonged curing period of 24 to 72 hours results in increased compressive strength, increase in strength beyond 48 hours is negligible. With the addition of more water to the combination, the slump value rises. They came to the conclusion that the compressive strength of heat cured FA based GPC is unaffected by its age. The compressive strength of the material increases as the curing temperature rises from 60°C to 90°C.

CONCLUSIONS:

After a critical review of the literature on GPC , it may be concluded that

- The alkali activated FA based GPC is a more environmental friendly and best alternative to OPC concrete.
- GPC exhibits better performance in terms of climate change.
- Fly ash is widely used as a base material in GPC.
- The optimum time of curing for FA based GPC is between 20 to 24 hours.
- The molarity ranging from 8M to 16M of NaOH solutions gave best results for GPC.
- The molarity ranging from 8M to 12M of Podium hydroxide solutions gave best results for GPC.
- The use of KOH as activator in GPC produced high compressive strength values compared to NaOH.
- The use of NaOH as activator in GPC resulted in enhanced durability properties compared to KOH.
- The combined usage of NaOH and KOH in GPC may result in enhanced mechanical and durability properties.

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