A Review on Durability Enhancement of Fly Ash Based Geopolymer Concrete at Different Curing Temperatures-LCA

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Abstract: In the Production of cement heating of limestone releases CO2 into atmosphere as well as the large amount of waste coming out from thermal power plants in the form of Fly ash, which contain minerals (aluminosilicate) and creates ecological problems. In early years, it has been found that utilization of fly ash for making of Geopolymer Resin is considered as an Eco-friendly and alternative to OPC (Ordinary Portland Cement). This paper reviews summary on geopolymer Resin concrete like mixing process of all materials is carried, as well as chemical composition for the alkali activator to calculate the optimum composition ratio based on the suggested molarity ratio and Properties of mortars/concrete made from geopolymer binders. The potential of Alkali activated fly ash binder to produce geopolymer concrete durability studies such as high temperature and curing conditions of geopolymer concrete is referred as LCA (Life Cycle Analysis) are examined.

***Index Terms* - Geopolymer, Fly Ash, Ordinary Portland cement, Durability, Life Cycle Analysis.**

I. INTRODUCTION

Cement – the largest source of emissions from decomposition of carbonates – is a binding material that has been used since ancient times. The production of cement conserving material and energy resources, as well as releases greenhouse gas emissions both directly and indirectly: the heating of limestone releases CO2 directly, while the burning of fossil fuels to heat the kiln indirectly results in CO2 emissions [1]. On average, each year, three tons of concrete are consumed by every person on the planet. Total emissions from the cement industry could therefore contribute as much as 8% of global CO2 emissions.

Society faces the challenge of reducing the environmental impact of concrete without compromising people's need for housing and infrastructure [3, 5]. The use of Alternative Fuels and Raw materials (AFR) for cement production is certainly of high importance for the cement manufacturer but also for society as a whole [2]. To protect Global warming issues several researchers have found an alternative resin instead of Ordinary Portland Cement with less emission of green house gasses, utilization of less amount of energy and raw materials. The alternative resin using now a days is a geopolymer cement/binder/resin. These geopolymer binding materials are quite different from ordinary Portland cement and prepared by activating source materials or by products (which contains silica and alumina) from industries like fly ash, silica fume, GGBS (Ground Granulated Blast Furnace Slag) with Na2SiO3 and alkali solutions [5]. The usage of geopolymer binders are increases day by day because of utilization of waste materials from industries. Out of the source materials mentions above, one of the important materials is fly ash, which has widely utilizing in the production of geopolymer concrete with enhanced thermal, chemical, mechanical and durability properties compared with conventional concrete [4]. Table: 1 indicates some of the properties like density, specific surface area and size distribution range of OPC and industrial wastes/byproducts.

Table: 1 Density, Surface Area, and Particle Size Distribution Data of Starting Materials [38]

Material	Density (g/cm^3)	BET Specific Surface Area (m^2/g)	Size Distribution Range (mm)
OPC (type I) (I33)	3.12	0.85	1.1-50
Class F fly ash (G-05)	2.45	0.7	2.0-40
Granulated blast-furnace slag (G42)	2.9	0.75	0.70-40
Silica fume (G-15)	2.05	18.02	0.1-5.0

II. MATERIAL PROPERTIES

2.1 Fly ash

Fly ash is a fine residual particle formed during combustion of powdered coal. Fly-ash mainly contains silica, alumina and minor amounts of oxides such as iron (Fe), sodium (Na), calcium (Ca), magnesium (Mg) and potassium (K). But major chemical constituents in class-F fly ash are alumina and silica, both together occupies more than 90% of fly ash [5-7, 13]. The Fly ash (Class-F) based geopolymers; the raw material mixture should be appropriately tailored. In particular, the Si/Al ratio, Fly ash activated by an alkaline reagent affected significantly the compressive strength in both geopolymer paste and mortar with 20 – 40 wt% sand [12]. The strength achieved (23.7 – 26.4 MPa after 28 d aging) indicate that these materials may be used in construction applications. Fineness of fly ash particles, which are increases the workability of geopolymer concrete [36].

Table: 2 Chemical Composition of Fly Ash (Class-F)

Elements	Fly ash component (wt. %)				
	T. Bakharev [11]	Faiz Uddin Ahmed Shaikh [14]	Shima Pilehvar Thokchom et al [19]	Aiken, T. A et al [20]	Kushal Ghosh and Dr. Partha Ghosh [57]
Al_2O_3	28	25.56	25.71	22.52	30.85
SiO_2	50	51.11	52.65	46.78	55.1
CaO	6.5	4.3	6.236	2.24	2.45
Fe_2O_3	12	12.48	5.307	9.15	3.15
K_2O	0.7	0.7	1.981	4.09	0.8
MgO	1.3	1.45	1.402	1.33	0.35
Na_2O	0.2	0.77	1.1	0.89	0.65
P_2O_5	1.2	0.885	1.01	1.43	-
TiO_2	1.3	1.32	1.2	1.05	1.85
MnO	-	0.15	-	0.05	-
SrO	-	-	0.19	-	-
SO_3	-	0.24	0.935	0.9	-
ZrO_2	-	-	-	-	-
LOI	-	0.57	1.74	3.57	-

The chemical composition and Loss on Ignition (LOI) of fly ash can be determined using XRF (X-ray Fluorescence), some of the chemical composition values of Fly ash class-F are tabulated in **table:2** [26, 26 and 36].

2.2 Alkaline Solutions

The alkaline activators required to synthesise geopolymers include potassium silicate, sodium silicate, potassium hydroxide and sodium hydroxide [11, 15, and 27]. Concentrated aqueous alkali solutions, which are corrosive, viscous, and, as such, difficult to handle and not user friendly [48]. Alkali activation technology also allows a waste beneficiation route for utilizing several industrial by-products. Alkali-activated Fly ash cements and concretes are among the most prominent AAMs (Alkali-activated Materials), for their manufacture emits less GHGs than Portland cement and consumes less energy and water [17, 21].

2.2.1 Sodium Hydroxide& Sodium Silicate

The alkaline activator was prepared by incorporation of sodium silicate and NaOH solution with different molarities. The ratio of fly ash to alkaline activator (Na_2SiO_3/NaOH) can be used either 1, 1.5, 2, 2.5 etc. the fly ash was mixed with these solutions with either any ratio of Na_2SiO_3/NaOH to prepare a geopolymer resin in wet mix and geopolymer cement in dry mix. Geopolymer concrete is produced by adding aggregates (fine and course) to this geopolymer resin. The Mortar resulting from mixing the fly ash with sand and alkaline solution was poured in to metallic prismatic molds which were later kept in an oven or ambient curing.

2.3 Admixtures

Generally Super plasticizer is used to improve workability properties at fresh stage of geo polymer concrete [51]. The super plasticizers work poorly with geopolymer pastes due to the extremely alkaline conditions and subsequent degradation of super plasticizer [48]. Super plasticizer (Reo-build) by wt% of binder is generally of different percentages, by taking 3.5% the workability of fresh geopolymer concrete is increased [43]. Conplast-SP-430 grade super plasticizer is used as admixture for mix in the solutions to get the better result [53]. **Figure: 1** says about the increase workability depending on dosage of chemical. At 4% of super plasticizer workability is high compare to other [57].

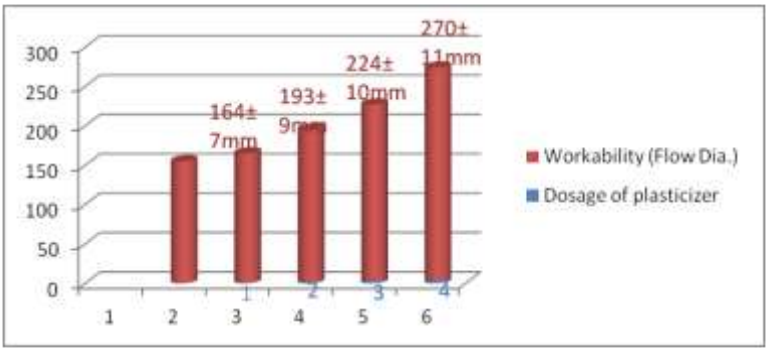

Figure: 1 Effect of dosage of super plasticizer on flow diameter of Geopolymer mortar [57]

III. GEOPOLYMER RESIN/BINDER

The major components of geopolymer cement can be broadly divided into two categories; they are alkaline liquids and the source materials. The source materials need to be alumino silicate materials like slag, rich husk ash, metakaolin, fly ash, red mud, activated betonies clay etc [18]. The alkaline activation on these source materials will result in formation of geopolymer cement. The source materials for geopolymers based alumino-silicate should be rich in silicon and aluminum such as natural pozzolana, like fly ash, blast furnace slag, and calcined kaolinite clays [24, 25]. Sodium or potassium based soluble alkali metals are used to make alkaline liquids. Normally sodium hydroxide with sodium silicate at liquid ratio of 2.5 is used as a alkaline liquids [37]. Sodium is preferred over potassium mainly because it is cheaper.

3.1 Geopolymerization

In the process of Geopolymerization different source materials such as fly ash, clays, zeolite, silica fume, red mud etc are used for synthesizing the geopolymers [42]. The commonly used binder in a geopolymer is NaOH/KOH & Na_2SiO3/K_2SIO_3. Fly ash is mixed with alkali solutions of definite proportion of concentration, to obtain geopolymer binder [5, 15]. Geopolymerization involves a chemical reaction between an alumino-silicate (Al-Si) material and a strong alkaline solution yielding amorphous to semi-crystalline three-dimensional polymeric structures, which consist of Si-O-Al bonds [10]. The process geopolymerization takes place with fly ash is indicated by **figure: 2**.

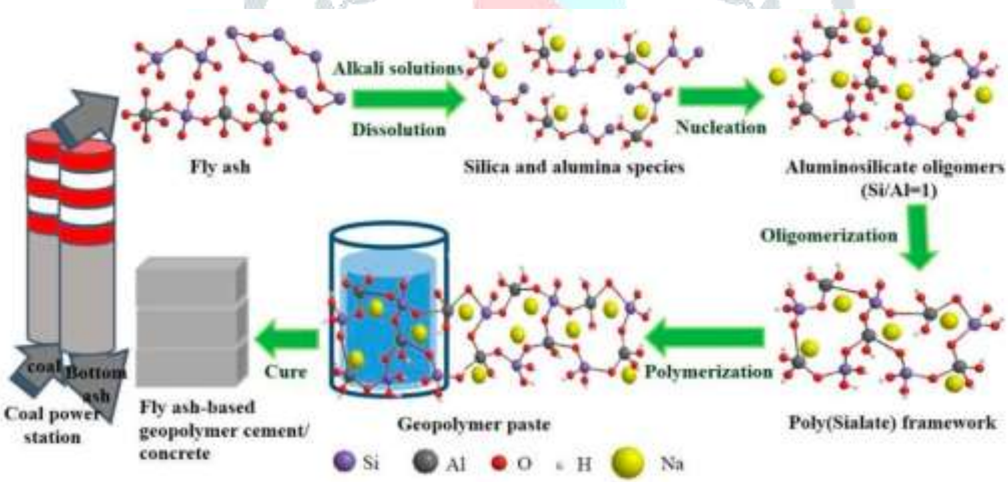

Figure 2: Processes of Geopolymerization from Fly ash

3.2 Properties of Geopolymer Concrete

Geopolymer concrete is new material to be developed for use in construction work which should be eco-friendly. The following are the properties of geopolymer concrete [58].

- Geopolymer concrete sets at room temperature
- It is non toxic
- It has long life
- It is impermeable
- It is a bad thermal conductor and possess high resistance to inorganic solvents
- It gives more strength

4. Mixing, Casting, Curing and Testing Procedures

The temperature and curing time significantly improves the compressive strength, although the increase in strength may not be significant for curing at more than 600ºC [9]. How the chemical composition and dissimilar molarities of NaOH solution will carry according to different authors are presented in **table: 3**.

Table No 3: Molarity and Compressive Strength Properties According to Different Articles.

S.No	Author	NAOH M	Na2SiO3 / NaOH	Water / Geopolymer Solids	Alkaline/ Binder	Compressive Strength
1	Sunil Kumar.R and Dr V.Ramesh [46]	8M	2.5	0.3,0.4	0.6,0.7,0.8(35%GGBS+65% flyash)	0.3 & 0.7 High Strength(M70)
2	Nisha Khamar and Resmi V Kumar [47]	10M, 12M, 14M	2.5	0.17	0.7(50%GGBS+50%Fly ash+Super Plasticizer 2%)	12M Increased
3	Eliyas Basha Shaik and Sreenivasulu Reddy [48]	8M	2.25	0.3	0.7(100% Fly ash+ 0-30%Granite Powder)	Increased at 15% replacement of granite powder
4	P.Vignesh et al [49]	16M	2.5	0.3	0.7(100%Fly ash+1%Glass fibres)	Increased in addition of 1% glass fibres
5	Rekha K P and Hazeena R [50]	10M	2.5	0.3	0.55(100%Fly ash+0-1%Steel fibres)	Increased due to fibre increased steel fibres0-1%

The compressive strength of geopolymer concrete is higher at longer curing time, in the range of 24 to 72 hours (4 days). However, the increase in strength beyond 48 hours is not significant [44, 45]. However, conventional Fly ash-based geopolymer requires elevated temperature curing (600C to 800C) for 24 hours to develop sufficient strength [16] and do not gain any significant strength at ambient curing. Compressive strengths of oven curing and atmospheric curing for 28 days were almost similar but the maximum strength was attained in oven curing within 48 hours but for atmospheric curing it took very long time(28 days) [49]. Fly ash based geopolymer concrete is achieved nearly 80% of the strength in 7days at ambient curing [41]. The **Figure: 3** indicate how the compressive strength varies according to curing temperatures and no of days.

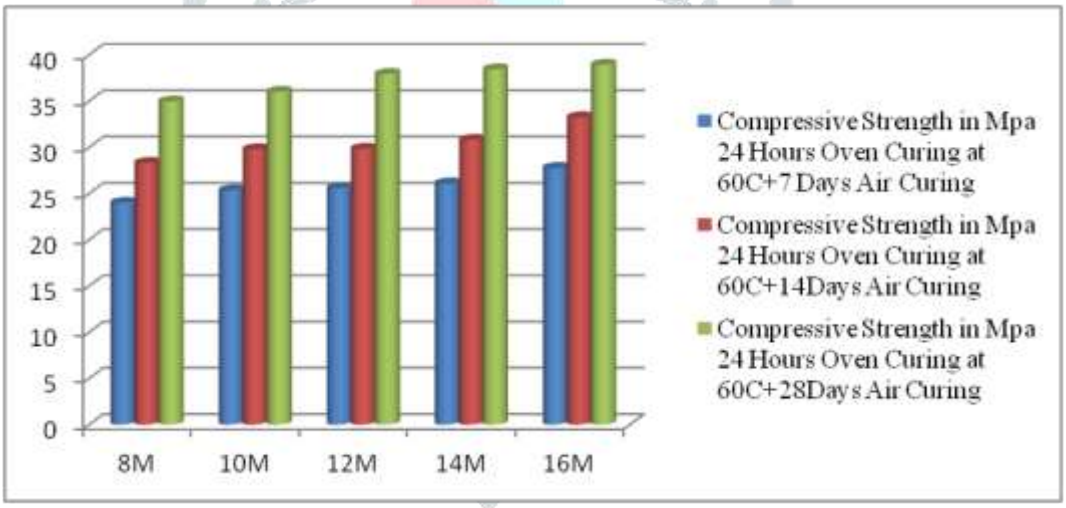

Figure: 3 Compressive Strength of GPC Specimens at Different Molarities of NaOH Solution [51]

5.0 Effect on Temperature:

Thermal stability properties firing to around 800oC 1200oC of materials prepared by using Class F fly ash based geopolymer using potassium or sodium as activators [23]. The materials were prepared in the water binder ratio as 0.09- 0.35 using compaction pressures up to 10 MPa and curing temperatures 80oC to 100oC. Compared to sodium and potassium silicate, potassium silicate as activator was better in compressive strength on heating and deterioration was started at 1000oC [16]. The wetting–drying and heating–cooling cycles reflected service conditions in which the compressive strength fluctuated due to the imbalance in the internal stresses caused by the elevated temperature and penetrated chlorides and sulphates [22]. An electrically-heated furnace designed for a maximum temperature of 1200oC. Specimens were subjected to temperatures of up to 800oC at an incremental rate of 4.4oC per minute from room temperature. The temperature was sustained at 800oC for one hour before the specimens were allowed to cool naturally at room temperature inside the furnace. Meanwhile, the unexposed samples were left undisturbed at ambient temperature [26]. Different curing conditions like ambient and oven, figure: 4 shows, how the compressive strength differs.

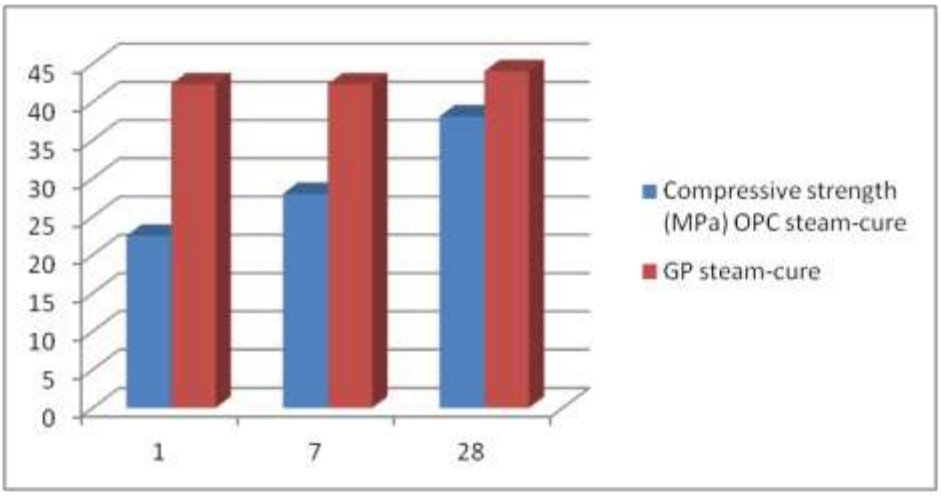

Figure No 4: Compressive Strength Development of Ambient Cured OPC and GP Concretes [31].

6. Life Cycle Analysis

The performance, including strength and durability of geopolymer concrete are significantly influenced by composition of blended binder, chemical composite of binder, alkali activator, water content and curing condition. It has been recognized for a long time that the use of mineral admixtures generally improves the durability of concrete [32, 33]. Many authors have concluded that pozzolanic cements or blends with slag, fly ash, or silica fume are best suited for applications where durability is a priority requirement. In such applications, a high resistance to chemical attack, freezing/thawing, and repressing alkali-aggregate reaction are of concern [38].

Geopolymer concrete has excellent properties within both acid and salt environments. Comparing to Portland cement, the production of geopolymer has a relative higher strength, excellent volume stability, better durability [45].

Conclusions

This paper has presented the detailed literature study that was undertaken to investigate the behavior geopolymer concretes exposed to high temperatures and the durability aspects. The following conclusions can be drawn based on the review and discussions reported in this paper:

- Fly ash based geopolymer resin/concrete are the best alternative to ordinary Portland cement/concrete to decreases the emission of green house gases and to utilize the less energy and raw materials as well as geopolymer concrete gives early high strength and durable compared to OPC.
- Fly ash-based (class-F) geopolymer is better than Conventional concrete in several aspects such as compressive strength, exposure to aggressive environment, workability and exposure to high temperature.
- The property of geopolymer concrete depends on various factors. However, the most important one is curing conditions (ambient or elevated temperatures), and duration.
- Geopolymer concrete possesses excellent mechanical properties and durability.

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