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Review on Durability Performance of Fly Ash and GGBFS Based Alkali Activated Concrete

[1]ALFIYA A, [2]INDU SUSAN RAJ
*[*1]PG Scholar, Department of Civil Engineering, Mar Athanasius College of Engineering, Kothamangalam*
[2]Assistant Professor, Department of Civil Engineering, Mar Athanasius College of Engineering, Kothamangalam

Abstract
Lot of industrial waste by-products such as fly ash, GGBS, silica fume, paper pulp etc. are generated all over the world leading to environmental degradation and pollution. Utilization of the industrial waste by-products in construction industry will at least reduce the quantity of these wastes that are being dumped in landfills leading to wastage of useful land area. The increased demand for cement as a construction material led to its humongous production and hence the emission of carbon dioxide. The geopolymer binder is an alternate binder which make use of aluminosilicate surplus industrial and agricultural waste and hence completely devoid of cement. The current study primarily aims at investigating the durability performance of fly ash and GGBFS based Alkali Activated Concrete. The durability characteristics of the optimum mix in terms of Water absorption, sorptivity, acid attack resistance (H_2SO_4*), permeability and carbonation also the mechanical property (Compressive strength) were analyzed.*

Keywords: *Durability, Fly ash and GGBFS, Alkali Activated Concrete*

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I. INTRODUCTION

Nowadays, the increase in the people's attention on the conservation of natural resources and minimization of environment depletion has led to look at the alternatives to accustomed construction materials. Currently, ordinary Portland cement-based concrete is the leading construction material all across the world, with the cement usage being 4.0 billion tons per annum and growth rate being 4% per annum. The major problems associated with the Portland cement are its production, which is energy consuming and more significantly it releases very high volume of carbon dioxide in to the atmosphere. At the same time the disposal of industrial wastes such as fly ash, ground granulated blast furnace slag, mine waste, red mud etc., has become a big problem, it requires large areas of useful land and also has huge impact on the environment. Therefore, the need is emanated from further investigation into safe waste disposal and investigation into alternative to cement products with reduced environmental impacts. In these circumstances geopolymer concrete is found to be one of the better alternatives in terms of reducing the global warming, as it can reduce the CO2 emissions caused by cement industries by about 80%. Geopolymer concrete (GPC) is a sustainable material which not only utilizes industrial wastes such as fly ash effectively but also serve as a better alternative to ordinary Portland cement concrete. From the past decade or so geopolymer concrete is certainly emerged as a novel construction material and has a huge potential to become a prominent construction product of good environmental sustainability. Geopolymer concrete is a new form of concrete which is produced by the alkali activation of material rich in aluminosilicates. Geopolymers binders can be produced from variety of natural materials and industrial by-products like metakaolin, fly ash, ground granulated blast furnace slag, red mud, mine waste etc.

Fly ash is a widely used source material due to its low cost, abundance availability and greater potential for making geopolymers. Fly ash was chosen as the basic material to be activated by the geopolymerization process to be the concrete binder, to totally replace the use of Portland cement. The binder is the only difference to the ordinary Portland cement concrete. To activate the Silicon and Aluminium content in fly ash, a combination of sodium hydroxide solution and sodium silicate solution was used. Naphthalene-based superplasticizer was found to be ii useful to improve the workability of fresh fly ash-based geopolymer concrete, as well as the addition of extra water. The main parameters affecting the compressive strength of hardened fly ash-based geopolymer concrete are the curing temperature and curing time, the molar H_2O-to-Na_2O ratio, and mixing time. Fresh fly ash-based geopolymer concrete has been able to remain workable up to at least 120 minutes without any sign of setting and without any degradation in the compressive strength. Providing a rest period for fresh concrete after casting before the start of curing up to five days increased the compressive strength of hardened concrete. The elastic properties of hardened fly ash-based geopolymer concrete, i.e. the modulus of elasticity, the Poisson's ratio, and the indirect tensile strength, are similar to those of ordinary Portland cement concrete. The stress-strain relations of fly ash-based geopolymer concrete fit well with the expression developed for ordinary Portland cement concrete.

The fly ash and GGBS are best source material for geopolymeric system to get satisfactory strength in geopolymer concrete. The alkaline activator solutions help to activate fly ash, GGBS in concrete. Ground granulated blast-furnace slag (GGBFS) is a by-product of iron in blast-furnace. It mainly consists of silicate and aluminosilicate of melted calcium that periodically needed to be removed from the blast furnace. Similar to fly ash, the chemical compositions of GGBFS depend on the row materials used in the production of iron while the physical properties depend on the cooling process used to cool down the molten materials. GGBFS was in use as a chief supplementary cementing material for more than a century. It possesses both cementitious and pozzolanic properties. There are too many investigations on the effect of GGBFS on the strength of different types of concretes and mortars. Replacement of PC with GGBFS ultimately leads to a significant increase in the compressive strength of the mix.

GGBS is one of the by-products of iron and steel-making. It is economical in large quantities, so it is suitable for premixed concrete, bulk on-site concrete production, and precast product manufacturing. GGBS produces lower heat during the hydration process, enhances resistance from chloride and sulfate attack compared with OPC.

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

- 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.

II. LITERATURE REVIEW

2.1 FLYASH

Positive impacts of Fly ash in the production of a recyclable, sustainable and ecofriendly GPC and it contributes in setting a safe, sustainable, clean, and healthy-environment. However, fly ash is deemed as one of the alternative supplemental cementing materials in concrete, several further research investigations are recommended for the production of a renewable and green concrete composites [1]

The flow of coarse lignite high calcium fly ash geopolymer mortar depended on the concentration of NaOH and sodium silicate. Increases in NaOH and sodium silicate concentrations reduced the flow of mortar. Improvements in the workability of the mortar could be achieved with addition of water or superplasticizer. However, the use of superplasticizer had an adverse effect on the strength of geopolymer.[2]

The incorporation of up to 40 % RACA (Recycled asphaltic concrete aggregate), the compressive strength of HFGC (high calcium fly ash geopolymer concrete) was reduced to an acceptable level. However, the surface abrasion and sulfuric acid resistances and thermal conductivity were improved. The RACA could thus be beneficially utilized to improve the properties of geopolymer concrete.[3]

Pervious fly ash geopolymer concrete is a promising material to make use of the fly ash from coal-fired power plants. The compressive strength of pervious geopolymer concrete is in the range 5.7–8.3 MPa, conforming to the requirements for pervious concrete as permeable bases and edge drains in pavement applications.[4]

Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of fly ash-based geopolymer concrete. Higher the ratio of sodium silicate-to-sodium hydroxide ratio by mass, higher is the compressive strength of fly ash-based geopolymer concrete. As the curing temperature in the range of 30^0C to 90^0C increases, the compressive strength of fly ash-based geopolymer concrete also increases. Longer curing time, in the range of 4 to 96 hours (4 days), produces higher compressive strength of fly ash-based geopolymer concrete.[14]

The design of fly ash based geopolymer concrete of ordinary and standard grade on the basis of quantity and fineness of fly ash, quantity of water and grading of fine aggregate by maintaining water- to-geopolymer binder ratio of 0.40, solution-to-fly ash ratio of 0.35, and sodium silicate-to-sodium hydroxide ratio of 2 with concentration of sodium hydroxide as 13 M. Heat curing was done at 60 °C for duration of 24 h and tested after 7 days after oven heating. Experimental results of M20, M25, M30, M35 and M40 grades of geopolymer concrete mixes using proposed method of mix design shows promising results of workability and compressive strength. So, these guidelines help in design of fly ash based geopolymer concrete of Ordinary and Standard Grades as mentioned in IS 456: 2000.[26]

The optimal percentage of addition that maximizes compressive strength for NC (Nanoclay) is 1 %, and 1.25 % for nano TiO_2 by weight of FA. The addition of nanoparticles improved the compressive strength of produced geopolymer concrete up to 38 % for NC, and 24 % for TiO_2 respectively in the binary blends. Meanwhile, the increase reaches 55 % in the ternary blends. The splitting tensile strength results proved that both: NC and NT are essential elements in developing the strength of geopolymer concrete. Nevertheless; NC shows more strength than NT. [16]

2.2 GGBFS (GROUND GRANULATED BLAST-FURNACE SLAG)

The Fly ash based geopolymer modified with GGBFS is found to be a suitable binder for low to moderate strength concrete production at ambient curing condition, as it eliminates the necessity of heat curing. The mixture proportioning of fly ash based geopolymer using GGBFS as a blend requires optimum balance in the amount of slag content, activator content and activator ratio to achieve desired setting time and compressive strength. Among the mixtures of this study, the mixtures having 10% slag, 40% alkaline activator and SS/SH ratio 1.5–2.5 with no extra water can be considered as the optimum mixture for reasonable compressive strength in ambient curing condition with a setting time comparable to that of OPC concrete. [4]

The increase of GGBFS content in geopolymer pastes, the compressive strength increased significantly but the setting times and workability reduced sharply. Also, increasing the GGBFS content led to faster decrease rate of the mini-slump base area. The increase of alkaline solution to binder (Al/Bi) mass ratio resulted in a decrease of the compressive strength, but increases of workability and setting times. When the sodium silicate solution to sodium hydroxide solution (SS/SH) mass ratio increased from 1.0 to 2, the compressive strength increased. However, when the SS/SH ratio increased from 2.0 to 2.5, the compressive strength decreased.[5]

The geopolymer concrete with a binder content of 450 kg/m^3, Al/Bi ratio of 0.35, SS/SH ratio of 2.5, and SH concentration of 14 M achieved the highest 7-day compressive strength (60.4 MPa) at ambient curing conditions. The inclusion of FA, MK, and SF as partial replacement of GGBFS reduces the compressive strength of geopolymer concrete. Replacement of the GGBFS with FA, MK, and SF increases the initial and final setting time of the geopolymer paste and increases the slump of the fresh concrete as well. To increase the setting time of geopolymer concrete under ambient curing conditions, a combination of GGBFS with FA can be a possible solution, as the blend of GGBFS with FA achieved longer setting time compared with the blend of GGBFS with MK and SF. The inclusion of FA in the GGBFS-based geopolymer mixture is found to be a suitable binder of geopolymer concrete for in situ construction, in addition to the precast construction, under ambient curing conditions, thus eliminating the necessity for heat curing.[6]

Using sources material like FA, MK, and GGBS as fillers or replacements based on GPC has a significant environmental, engineering, and economy over conventional Portland cement concrete. The presence of GGBS improves the hardening properties of GPC, such as compressive strength, flexural strength, and splitting tensile strength. However, the workability of the GPC mix is reduced with an increased percentage of GGBS replacement. [11]

Considerable progress has been made during the last two decades in the investigation of geopolymer concrete and information available is summarized in this paper. Fundamental knowledge on compressive strength and microstructure of GPC has already been obtained by the research carried out so far. However, intensive research is required to get optimum mix of geopolymer concrete with and without fibers, durability and microstructure of geopolymer concrete. While a larger focus has been on investigating mix design and workability of GPC mixes, studies are still required to get a good workable GPC, durability aspects and microstructure of GPC. Authors are pursuing the research in this subject area. [18]

Water absorption property is lesser than the nominal concrete. The compressive strength and split tensile strength, flexural strength of geopolymer concrete higher than the normal concrete. For a given proportion of a mix, the compressive strength and split tensile strength increase with age. The rate of gain in compressive strength and split tensile strength of geopolymer concrete is very fast at 7 days curing period and the rate gets reduces with age. Geo polymer concrete can be recommended as an innovative construction material for the use of construction. Apart from less energy intensiveness, the GPCs utilize the industrial wastes for producing the binding system in concrete. There are both environmental and economic benefits of using GGBS. [19]

2.3 FLYASH AND GGBFS

The slump and slump flow of almost all the mixes were in the range of 100–220 and 305–595 mm, respectively. The mix design, however, satisfied the fresh property requirement of GC. Lightweight geopolymer concrete containing 50 % of fly ash and 50 % of GBSF achieved the best compressive strength test results. [8]

One of the major findings of the study is that ACI strength versus water to cement ratio concept, which is adopted in this study, holds good for developing geopolymer concrete as well. The study further demonstrates that medium to high compressive strengths, in the range from 32 to 66 MPa, can be attained even when ambient temperature curing conditions are practiced. Results reveal that for the same liquid content, geopolymer concretes found to yield higher compressive strengths than the normal concretes. [3]

GGBS blended FA based GPC mixes attained enhanced mechanical properties at ambient room temperature curing itself without the need of heat curing as in the case of only FA based GPC mixes. Fly ash-based GPC mixes have attained comparable values of mechanical properties at ambient room temperature curing at all ages to normal Strength. Keeping in view of savings in natural resources, sustainability, environment, production cost, maintenance cost and all other GPC properties, it can be recommended as an innovative construction material at low cost for the use of constructions. Though 100% Fly ash exhibited decrease in strength, it maintains the strength. The cost is also low compared to the 50% GGBS& 50% Fly ash [15]

Fresh properties results showed that the geopolymer concrete based on slag with 500 kg/m^3 showed 225 mm slump. [21]

Geopolymer concrete is approximately 11–50% and 30–52% more sustainable than PCC. At a 40% substitution of GGBFS with CCA, the economic efficiency of GPC was better than PCC.[24]

2.4 RUBBERIZED GPC

This review concluded that RGPC is long-lasting, eco-friendly and has good resistance to acid attack, chloride penetration, and water permeability compared to OPCC. Steel fibers and/micro silica could be added to RGPC for enhancing its mechanical properties. This was accomplished by reinforcing fibers and extremely small silica pore-blocking particles in RGPC, which prevented propagation of cracks. There was an increase in RGPC's compressive strength as a result of increasing the concentration of alkaline solution, while increasing alkaline to FA ratio caused a decrease in the compressive strength. Moreover, compressive strength of 2.5 NaOH/ Na_2SiO_3 ratio increased, but it then decreased as the ratio of NaOH/ Na_2SiO_3 increased.[10]

2.5 FIBRE REINFORCED GPC

The compressive strength of the FRG (1.5 vol % and age 7 days) cured at 50 ◦C for 24 h followed by room temperature curing became approximately 1.9 times that cured at room temperature only. Also, the addition of GNa (sodium gluconate) improved the compressive strength, and differences in the mixing procedure affected the compressive strength. [12]

The increased expansion of urban areas and construction of chemical plants have caused the large-scale production of chemicals which includes different kind of acidic solutions. This situation led to sever deterioration of concrete structures made from OPC. As per the authors current understanding, lots of researches are carried out for replacing cement with some other supplementary cementitious materials. However, there are a limited number of researches in the application of various fibres in these areas to solve the above-mentioned concrete durability related problems. The matrix for fly-ash based geopolymer concrete shows better results with 6% nano silica additions compared to geopolymer mortar without nanomaterials and conventional mortar due to the transformation of amorphous to crystalline compound.[13]

2.6 STEEL FIBER – GGBFS GPC

The compressive strength of the geopolymer concrete made with steel fibers are higher than the geopolymer concrete made without steel fibers. It was clear that as the NaOH concentration increases the compressive strength also increases. The tensile strength of the geopolymer concrete made with steel fibers shows good results. Flexural test on prisms with steel fibers under two-point loading had shown higher values than geopolymer made without steel fibers. It was clear in all tests, as the age of curing increases the strength of the GPC increases. The load vs deflection on 8 M and 10 M beam with steel fiber are more than the beam without steel fibers. The load carrying capacity of the beams made with steel fibers is higher.[17]

2.7 MOLARITY OF GPC

The maximum strength for mechanical properties for molarity was in the range of 16–18 M but depending upon the molarity changes controlling factor. The addition of an activator agent could increase the Si/Al ratio. The ratio Si/Al in the range of 2–3 in the total matrix of GPC can be attained from different combinations of binder (material rich in Si and Al) or activator that enhances better structural performances of GPC. Industrial waste rich in Si and Al acts as a better binder in GPC. The increase in the number of reactive particles proposes a fusion of the alkali resulting in Physio-chemical changes such as the disruption of crystalline phases and proclamation of silica and alumina, which leads to an increase in the reactivity in the polymerization process. Activator with high molarity improves accelerate the polycondensation leading to the rapid rate of chemical reaction in the polymer matrix.[20]

2.8 GEOPOLYMER CONCRETE

The use of geopolymer concrete as an alternative to the conventional Portland cement concrete would result in about an 80% reduction in carbon dioxide emissions associated with the production of concrete. In addition, the use of geopolymers would result in a reduction in the cost and use of raw materials. The term ‘‘geopolymer’’ is used to define an amorphous alkali aluminosilicate which is frequently used for alkali-activated cements, alkali-bonded ceramics, inorganic polymers geochemists, hydro ceramics, etc. The proposed Silica fume (SF) based geopolymers are appropriate for uses that require developed compressive strength values. SF has been considered one of the highest cementitious materials in great compressive strength OPC concrete and mortar technology. GGBS can be used for growing the long-term strength, alkali-silica and sulphate reaction resistance of concrete and refining the pores as well as for dropping the permeability, water demand and heat generation throughout the hydration process. [22]

The Geopolymer concrete showed high performance with respect to the strength. The Geopolymer concrete was a good workable mix. High early strength was obtained in the Geopolymer concrete mix. The increase in percentage of fine aggregates and coarse aggregates increased the compressive strength up to the optimum level. This may be due to the high bonding between the aggregates and alkaline solution. The compressive strength was found reduced beyond the optimum mix. This may be due to the increase in volume of voids between the aggregates. The optimum mix is- Fly ash: Fine aggregate: Coarse aggregate are 1:1.5:3.3 with a solution (NaOH & Na_2SiO_3 combined together) to fly ash ratio of 0.35.[23]

A rational mix design approach for fly ash-based GPC has been introduced. A review on the earlier proposed mix designs shows that they all depend mainly on the AAS (Alkaline Activator Solution) content. As AAS is the costliest ingredient of all, providing flexibility in fixing the AAS content is very advantageous from the economy point of view. The findings of this study suggest that, using the proposed method GPC can be produced for a specific strength by employing the corresponding AAS/FA ratio obtained from the modified ACI strength vs. w/c ratio curve. GPC can also be produced for a specific AAS/FA ratio to achieve the corresponding strength. Using the proposed methodology, fly ash-based GPC of strengths ranging from 23 to 53 MPa at varying activator solution to fly ash ratio can be developed. By strictly following the proposed steps the required GPCs can be produced effectively and efficiently. From the experimental investigations it has been found that, GPC follow similar trend to that of normal concrete in the strength aspect where the strength decreases with the increase in the fluid content.[25]

2.9 DURABILITY OF CONCRETE

The durability of concrete is defined as its ability to resist weathering action, chemical attack or any other process of deterioration. Durable concrete will retain its original form quality, and serviceability when exposed to environment. While interacting with its service cement concrete often undergoes significant alterations that often have significant adverse consequences on its engineering properties. It also includes the effects of quality and serviceability of concrete when exposed to sulphate and chloride attacks. As a result, the durability of hydrated cement systems and their constituent phases has received significant attention from scientists and engineers. A material is assumed to reach the end of service life when its properties under given conditions of use have deteriorated to an extent that the continuing use of the material is ruled either unsafe or uneconomical. Therefore, durability of concrete constructions is of a great major concern to the construction industry across the world.

III. CONCLUSION

In this project, the effect of 0.5 liquid to binder ratio at 100% replacement of cement on the durability property and mechanical property of Alkaline activated concrete was examined. The binders used in this study were GGBFS and fly ash. Also, the acid used in the study were sulphuric acid. The main aim of the concrete study was to investigate the workability, strength and durability of Flyash and GGBFS AAC. The same liquid binder ratio used for the fly ash and GGBFS based Alkali Activated Concrete but the compressive strength of GGBFS based AAC is 3 times higher than that of Fly ash based AAC. Water absorption rate and sorptivity rate of fly ash is higher than GGBFS at the age of 28 and 56 days. The sulphuric acid attack is adversely affecting the strength of both fly ash and GGBFS. The different types of curing that is Water curing and Ambient curing is examined in this study the water curing is slightly adverse effect on the compressive strength of AAC. Compared to Compressive strength, Water absorption, Water permeability, Carbonation, Acid attack resistance of fly ash and GGBFS based AAC better one is GGBFS based AAC.

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