GEOPOLYMER CONCRETE WITH FLYASH AND GGBS

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***Abstract*:-**Construction has been most important human activity since ancient time. Concrete is widely used and reliable material for construction. Some of challenges in industry are global warming and insufficiency of construction material. One of the methods for replacing concrete constituents is the use of geo-polymer which helps in using very less quantity of cement in concrete. This project represents study on the mechanical properties of geopolymer concrete with various mixes.

In this study, Geopolymer concrete is produced with fly ash and sodium hydroxide and sodium silicate is used as a binder. Fly ash is replaced by GGBS in proportions of 25%, 50% and 75% to enhance various properties of concrete. For this project, the mix design is carried out for 11M and 13M concentration of sodium hydroxide. Alkaline activator solution ratio of 2.5 and alkaline liquid to fly ash ratio 0.40 is selected for this investigation.

The specimen of size 150x150x150mm cubes, 150x300mm cylinders and 500x100x100mm prisms were casted and the specimens of geo-polymer concrete are cured at ambient temperature for 7 days and 28 days. The cured specimens were then tested for compressive strength, split tensile strength and flexural strength respectively.

Keywords-Fly Ash, Ground Granulated Blast Slag, Geopolymer concrete, Sodium Hydroxide, Sodium Silicate, Molarity.

1. INTRODUCTION

Geopolymer is an inorganic alumina-silicate polymer synthesized predominantly from silicon and aluminum material such as fly ash and GGBS (Ground granulated blast furnace slag). The binders could be produced by a polymeric reaction of alkaline solutions with materials containing silicon and aluminum by geological origin or by- product materials such as fly ash and GGBS.

The major component in ordinary Portland cement (OPC) is calcium silicate hydrate (C–S–H). The crystalline form of (C–S–H) consists of a layered structure where chains of silicon oxide tetrahedral sandwich a CaO layer and alternate with water interlayer. Calcium preferentially binds with silicate during the reaction of SiO_2, CaO, and water to quickly and easily form the stable C–S–H product, which allows OPC to be a quick-setting material. However, OPC production is considered environmentally unfriendly, because it requires large quantities of raw materials and fuel and it releases dusts and CO_2(a greenhouse gas). In addition, OPC is not chemically stable, deteriorating through carbonation and dehydration.

Geopolymers (GPs) are amorphous to semi-crystalline alumino silicates with short range, local ordering similar to that of zeolites. Silicon and aluminum oxide tetrahedral are linked together to create a negatively charged, three- dimensional, porous framework where the pores are filled with counter-balancing cations, Group I or II, and water molecules. GPs are considered environmental friendly products because they can use waste materials such as fly ash (FA) for their production and reduce greenhouse gas emissions. In addition, they exhibit high mechanical strength and stability and they are acid and fire resistant. However, GPs do not always set-up as quickly as OPCs.

While there are many differences between OPCs and GPs, the main difference is the absence of calcium within the geopolymer structure. Thus, many researchers have investigated the effects of adding calcium into their geopolymer syntheses through various forms such as ground granulated blast furnace slag (a high-calcium source), high- calcium Class C FA, calcium salt solutions, $Ca(OH)_2$, and CaO. Incorporation of such various forms of calcium into a traditional geopolymer synthesis will lead to different reaction pathways and the formation of multiple reaction products such as C–S–H, calcium aluminates hydrate (CAH), calcium alumino silicate hydrate (CASH), various calcium silicate phases, and Ca-geopolymer in addition to the expected Group I geopolymer product. Yip and coworkers, for example, incorporated slag into their metakaolin (MK) GPs. Under certain conditions and alkaline-ities, distinct geopolymer and C–S–H phases coexisting within the sample were observed. However, at high slag concentrations, only C–S–H,CAH, and CASH formed. Increased concentrations of slag led to increased sample compressive strengths. Several other research groups making GPs using either Class C FA, FA with slag, or metakaolin with slag also saw geopolymer and C–S–H phases coexisting within the products, in addition to strength increases, due to calcium incorporation. Lee and van Deventer observed accelerated set-times and increased sample strengths resulting from the addition of calcium salt solutions to their FA/kaolin GPs. Palomo and coworkers investigated the addition of $Ca(OH)_2$ to their MK GPs under various conditions. Addition of calcium resulted in a stronger product due to greater MK dissolution and degree of reaction. While higher alkaline solutions produced geopolymer framework as the main product phase with C–S–H as a secondary phase, lower alkalinities formed only C–S–H. According to Dombrowski et al., FA GPs synthesized with increasing $Ca(OH)_2$ content showed increased reaction degree and reaction product with a more compact, dense matrix, and increased strength. Although the main reaction product was geopolymer framework, some C–S–H phases were also present. Similarly, Temuujin et al. observed increased reagent dissolution and reaction degree, increased strength, and accelerated set-up time for FA GPs which were substituted with CaO and $Ca(OH)_2$ and cured at 20 °C. Although C–S–H phase was not detected within the geo-polymer binder, it was suggested that its formation may have increased the extent of the geopolymerization reaction.

The goal of this research effort was to combine the positive attributes from GPs and Ca-based cements in order to create strong, stable, quick-setting materials for potential use in rapid repair of OPC-based pavements including air- craft operating surfaces, e.g., runways. This was accomplished by incorporating calcium into the geopolymer synthesis through use of a high-calcium FA in order to accelerate set-up time. High-calcium Class C/F Performance Pozzolana (PP) FA was blended with low-calcium Class F Boral FA for use in this geopolymer synthesis. Samples were analyzed for mechanical strength and characterized using infrared spectroscopy (IR), X-ray diffraction (XRD),

Thermal gravimetric analysis / differential scanning calorimetry (TGA/DSC), and ion exchange. Finally, dissolution of the FA blends was investigated in an effort to understand the role of calcium in these geopolymer samples.

A) OBJECTIVE OF STUDY

1. The fly ash from Neyveli thermal power station is collected as high calcium fly ash and it is sieved with 90mm micron. The properties of 90micron passing fly ash is carried out in the laboratory for the particle size distribution, void content and specific gravity
2. The river sand, foundry waste sand, Neyveli bottom ash, Ennore bottom ash passing 4.75mm to 150 micron retaining are collected and the study is conducted in respect of geopolymer mortar and the properties such as fineness modulus, void content, specific gravity are studied in the laboratory.
3. The hard broken granite material as coarse aggregate passing 20 to 4.75mm are collected and the properties such as fineness modulus, and specific gravity is also studied in the laboratory.
4. The chemicals such as sodium silicate solution and sodium hydroxide pellets 98% purity is purchased from the manufacturer and the chemical and physical properties obtained from the manufacturer.
5. In this study it is proposed to use the fly ash passing 90 micron as a source material for the activation in alkaline medium such as sodium silicate and sodium hydroxide. The chemical composition of fly ash as class F is also available for the study.
6. The mix proportion for the Geopolymer paste is prepared based on the void content of the fly ash to alkaline activator ratio is selected so as to bring the water to solid ratio is less than 0.4
7. The solution of NaoH is prepared according to 10, 12, 14, 16, 18 M with this variable the sodium silicate to NaoH ratio is also selected as 1, 1.5, 2, 2.5, 3.0. Based on the above the geopolymer paste is prepared and casted in the cube of size 7.06x7.06x7.06cm. For the ambient curing condition the ground granulated blast furnace slag (GGBS) is substituted 10%, 20% in respect of fly ash and the cubes are tested in the UTM at the end of seventh day.
8. The geopolymer mortar is prepared using the river sand, foundry waste sand, Neyveli bottom ash and Ennore bottom ash with different molarity as 10, 12, 14, 16, and 18. The fine aggregate to paste ratio is fixed based on the workable mix. The cubes of 7.06x7.06x7.06cm are casted and the compressive strength is also tested at the end of seventh day in room temperature curing.
9. The geopolymer concrete is prepared using coarse aggregate with four types of fine aggregate in respect of optimum proportion of paste and mortar, the mix design is prepared accordingly based on the water solid ratio for workable mix. The cubes of 10x10x10cm cubes are casted and

the compressive strength is also obtained at the end of seventh day in room temperature curing

10. Based on the optimum mix the bricks of size 200x100x100mm, 200x100x75mm is casted and tested for the suitability of the brick for housing purpose.

B) SCOPE OF STUDY

1. To find alternate material instead of cement which liberate CO_2 during the production and also depletion of source material such as calcium oxide.
2. To control the pollution by the production of fly ash and also effective utilization of waste material for the construction purpose.
3. Based on the result, there is a scope of using these bricks for building construction purpose and also safeguard the climate due to the elimination of CO_2
4. To utilize the waste material such as fly ash foundry waste sand, glass waste and inert material to safeguard the environment from pollution.To control the CO_2 emission by utilizing these materials instead of cement because 1 ton of cement production releases 1 ton of CO_2 into the atmosphere.
5. To safeguard the natural resources such as river sand by substituting the waste material

2. LITERATURE REVIEW

The background of general geopolymer mechanism in respect of paste as a binding material, geopolymer mortar and geopolymer concrete are discussed and brief review of work already carried out with different alkaline activator and fly ash ratio for the paste, using different fraction of fine aggregate for mortar and concrete are respectively provided.

A) GEOPOLYMER

Davidovits (1988-1994) proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product material such as fly ash and rice husk ash to produced binders. Because the chemical reaction that takes place in this case is polymerization process, he coined the term geopolymer to represent this binder. Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolite materials, but the micro structure is amorphous. The polymerization process involved substantial fast chemical reaction under alkaline condition on Si-Al minerals that result in a three dimensional polymer chain and ring structure consisting of Si-O-Al-O bonds. To date, the exact mechanism of setting and hardening of the polymer material is not clear as well as the last term in reveals that water is released during chemical reaction that occur in the formation of geopolymer. This water expelled from the geopolymer matrix during the curing and further drying period, leaves behind discontinuous Nano pores in the matrix, which provide benefits to the performance of the geopolymer. The water in the geopolymer mixture there for, places no role in the chemical reaction that takes place it merely provides to workability to the mixture dueling handling. This is in contrast to the chemical reaction of water in the Portland cement concrete mixture during the hydration process.

General properties

Previous study have reported that geopolymers possess high earlier strength, low shrinkage, freeze-thaw resistant, sulphate resistance, corrosion resistance, acid resistance, fire resistance and dangerous alkali-aggregate reaction. Base on laboratory test, Davidovits (1988b) reported that geopolymer cement can harden rapidly at room temperature and gain the compressive strength in the Range of 20Mpa after only four hours at 20° C and about 70-1'00 Mpa after 28 days. comire et.al.(1988) conducted test on geopolymer mortar and reported that most of the 7 day strength was gained during the first 2 days of curing.

Geopolymeric cement was superior to Portland cement in terms of heat and fire resistance, as the Portland cement experience a rapid deterioration in expensive strength at 300°C, whereas the geopolymer cement where stable up to 600°C. It has also been shown that compare to Portland cement geopolymer cement has extremely low shrinkage. The presence of alkalis in the normal Portland cement are concrete could generate dangerous alkalis-aggregate reaction. However the geopolymer system is safe from that phenomenon even with higher alkali content. As demonstrated by davidovits (1994 b), based on ASTM C227 bar explanation yet, geopolymer cement with much higher alkali content compare to Portland cement did not generate any dangerous alkali aggregate reaction where the Portland cement.

Geopolymer cement is also acid-resistant, because unlike a Portland cement geopolymer cement do not rely lime and are not dissolved by acidic solutions. As shown by the tests of exposing the specimens in 5% of sulphuric acid and chloric acid geopolymer cements were relatively stable with the weight lose in the range of 5-8% while the portland based cements were destroyed and the calcium alumina cement lost weight about 30-60% (davidovits, 1994).

Step1: Alkalization and formation of tetravalent Al in the side group sialate-Si-0-A-$(OH)_3$-Na+.

Step2: Alkaline dissolution starts with the attachment of the base 011-to the silicon atom.

Step3: Cleavage of the oxygen in Si-O-Si through trunkers of the electron from Si to O.

Step4: Further formation of sianol Si-OH group and solution of the orthosilate molecule. The primary unit in geopolymerization.

Step5: Reaction of the basic si16xo Si-O-with the sodium caution Na+ and formation of Si-O-Na terminal bond.

Step6: Condensation between reactive group Si-O-Na and aluminum hydroxyl OH-Al, with production of NaoH, creation of cyclo-tri-silate structure, and further polycondensation into Na-poly (silate) nepheline frame work.

Step7: In the presence of soluble Na-poly siloxonate one gets creation of ortho-silicate-disiloxo cyclic structure, where by the alkali NaOH is liberated and reacts again.

Step8: Further polycondensation into Na-poly (silicate-disiloxo) albite framework with its typical feldspar crankshaft chain structure.

B) GEOPOLYMER PASTE

The alkaline liquid could be used to react with the silicon (Si) and aluminum (Al)in a source material of natural mineral or in by product material, such as fly ash and rise husk ash, to produce binder. The alkaline activation of material can be define as a chemical process that provides a rapid change of specific structures partial or completely amorphous into compact cemented frameworks. The alkaline activation of FA is process that different widely on Portland cement (PC) hydration and it very similar to the chemistry involve d in the synthesis of large group of zeolites. Some researchers have describe alkaline activity and stored at mild temperature 1000C for a short period of time to produce a material with good binding properties at the end of this process an amorphous alkaline alumina-silicate gel is formed as the main reaction produce. In addition, Na-herschelite type zeolites and hydroxy sodality are formed as secondary reaction products.

The most used alkaline activators are a mixture of sodium or potassium hydroxide (NaOH or KOH) with sodium water glass (SiO_2Na_2) or potassium water glass (SiO_2K_2O) one of the factor that influence the compressive strength of geopolymer is the Na_2Si0_3/NaOH ratio. The ratio of 1.0 produce a product with a compressive strength as high as 70MPa a study conducted by hardjito et al.showed that the use of an Na_2Si0_3/NaOH ratio of 2.5 gave the highest compressive strength of 56. 8 MPa, where a ratio of 0.4 resulted in a lower compressive strength of 17. 3MPa.

The concentration of NaOH solution that can be used are in the range of 8 to 16M. some researchers have studied the effect of different molarities of NaOH on the geopolymer. Stated that at 28days of reaction, a mixture of equal parts FA and stage activated with 10M NaOH and cured at 25°c develops a compressive strength of approximately 50MPa. Rattanasak and chindaprasirt concluded that geopolymer mortar strength of up to 70MPa is obtained when the mixture is formulated with 10M NaoH and Na_2Si0_3/NaoH ratio of 1.0 Reported that an 12M activator concentration leads to better result than an 18M concentration.

C) GEOPOLYMER MORTAR

Geopolymer technology is one of the new technologies attempted to reduce the use of portland cement in concrete. Fly ash reacts with alkaline solutions to form a cementations material; fly ash based geopolymer which does not emit carbon dioxide into the atmosphere. In this project, bottom ash is considered as partial-or full-replacement for sand as fine aggregate in the geopolymer mortar. To date, bottom ash from Sejingkat Coal Fired Power Station in Kuching, Sarawak, Malaysia, has not been utilized yet.

Fly ash and bottom ash are residues from the combustion of coal. Fly ash is captured in the chimney while bottom ash is collected from the bottom of the furnace from the coal fired power plant. Furthermore, the particles of fly ash are very fine whereas bottom ash has much larger particle size, which is about the size of sand but more porous. In Sejingkat Coal Fired Power Station, fly ash and bottom ash are disposed off into an 81, 000 m2 area, 2. 4 m deep ash pond situated beside the power station (Tsen, 2008). In fact, currently there are two ash ponds with one of them has been fully utilized.

Fly ash based geopolymer with bottom ash gives emphasis in reducing carbon dioxide emission and in recycling fly ash and bottom ash. Since fly ash and bottom ash are the waste products of coal fired power plant, this research can lead to the awareness of sustainable development to the society. This is very advisable in sustainable developments to reduce $C0_2$ emission and to recycle the waste materials. At present time, there is limited information on the influence of parameters on geopolymer available, especially geopolymer with bottom ash as the fine aggregate. As a result, study on the effect of different parameters on the fly ash based geopolymer with bottom ash as sand replacement is needed. In addition, this research can provide additional information and to further introduce geopolymer to concrete industry.

D) GEOPOLYMER CONCRETE

Geopolymer have been introducing to replace the utilization of ordinary Portland cement (OPC) in the concrete industry. This material was introduced due to the extensive consumption of energy during the manufacture of (OPC), which releases a large amount of greenhouse gases into the atmosphere. It has been reported that 13, 500 million tons of (OPC) are produced from this process worldwide, accounting for approximately 7% of greenhouse gases annually produced. The silica and alumina in the GGBD are activated by an alkaline activator that consists of sodium silicate and sodium hydroxide to produce aluminous silicate gel that acts as a binder.

The term geopolymer was introduced by Davidovits to represent the mineral polymer resulting from geochemistry. It has been reported that geopolymer material does not suffer on alkali-aggregate reaction even in the presence of high alkalinity and possesses excellent fire resistant. He termed these binder as geopolymers. Geopolymer is an inorganic aluminous-silicate polymer synthesized from predominantly silicon (Si) and aluminum (AI) material of geological origin or byproduct material like fly ash, metakaolin, granulated blast furnace slag etc. Sine GGBS is the source of silica and alumina required for geopolymer and is excessively available worldwide, the use of GGBS will reduced problem with dumping sites for these waste materials. The polymerization process involved a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three dimensional polymeric chain and ring structure consisting of Si-O-A1-0 bonds. The chemical reaction comprises the following steps

1. Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
2. Orientation or condensation of precursor ions into monomers.
3. Setting or poly-condensation or polymerization of monomers into polymeric structure

E) GEOPOLYMER WITH GGBS

During the manufacture of iron, blast furnace slag is produced as a by-product. This material is rapidly cooled to form a granulate and then ground to a fine white powder (GGBS), which has many similar characteristics to portland cement. When GGBS is blended with portland cement further recognized cementations materials such as portland-slag cement and blast furnace cement are produced. In the UK, GGBS is manufactured and generally sold as a separate powder which is then batched and blended within the mixer. It is used extensively in the construction industry to produce concretes, grouts and mortars.

F) OVER VIEW OF EARLIER STUDIES

In this research already carried out in respect of geopolymer paste, mortar and concrete are discussed. The useful literature on demolition waste as coarse aggregate in conventional concrete is also discussed. Based on the above research available its propose to extern the demolition waste particularly brick work, concrete as fine aggregate and also the coarse aggregate for geopolymer application.

*Gina M. Canfield. (2014)*In this research effort, the role of calcium in geopolymers was investigated through a series of syntheses where a high-calcium fly ash was blended with a low- calcium fly ash. Potassium silicate solution (Kasil 6, 26.5 % (w/w) SiO2 and 12.7 % (w/w) K2O) was obtained from PQ Corporation and reagent grade potassium hydroxide flakes were obtained from Aldrich. Boral Class F (low-calcium) and PP Class C/F (high-calcium) FA were obtained from Head- waters Resources Increased calcium content led to accelerated set-up times, increased compressive strength, and increased product formation. Powder X-ray diffraction results showed the majority of that product to be geo- polymer framework with only minor contributions from calcium silicate phases. Thermal analysis confirmed the absence of a calcium silicate hydrate phase. Analysis of fly ash dissolution showed that calcium aided in alumino silicate dissolution and therefore the geopolymer ejection reaction. While aiding in this reaction, calcium became incorporated into the pore structure of the geopolymer as a counter-balancing action, according to ion exchange experiments. Thus, geopolymer synthesis with increased calcium content through the use of a high-calcium fly ash under these experimental conditions produced a quick-setting, strong, calcium incorporated geopolymer material.

M. Albitar, P. Visintin, M.S. Mohamed Ali, and M. Drechsler (2015). This paper presents an experimental study into the behavior of geopolymer concrete in both its wet and hardened states using Class fly ash. The experimental program included 15 mix designs to investigate the influence of water-to-binder and super plasticizer-to-binder ratios on the workability and strength of fly ash-based geopolymer concrete. The results show that the addition of naphthalene sulphonate polymer-based super plasticizer has little to no influence on workability and a detrimental effect on strength. Furthermore, the indirect tensile strength, flexural tensile strength and elastic modulus of fly ash-based geopolymer concrete were recorded in this experimental program and have been added to a database of available tests in the open literature. The experimentally determined results are subsequently compared with prediction models developed for OPC-based concrete. The comparison suggests that existing OPC models provide reasonably accurate predictions of the elastic module and stress-strain relationships, whereas they slightly underestimate flexural and splitting tensile strengths. *GUO Xiaolu (2013).* The feasibility of high calcium fly ash (CFA)-based geopolymers to fix heavy metals were studied. The CFA-based geopolymers were prepared from CFA, flue gas desulfurization gypsum (FGDG), and water treatment residual (WTR). The static leaching showed that heavy metals concentrations from CFA- based geopolymers were lower than their maximum concentration limits according to the U.S. environmental protection law. And the encapsulated and fixed ratios of heavy metals by the CFA-based geopolymers were 96.02%-99.88%. The dynamic real-time leaching experiment showed that concentration of Pb (II) was less than 1.1 μg / L, Cr (VI) less than 3.25 mg / L, while Hg (II) less than 4.0 μg / L. Additionally, dynamic accumulated leaching concentrations were increased at the beginning of leaching process then kept stable. During the dynamic leaching process, heavy metals migrated and accumulated in an area near to the solid-solution interface. When small part of heavy metals in "the accumulated area" breached through the threshold value of physical encapsulation and chemical fixation they migrated into solution. The dynamic leaching ratios and effective diffusion coefficients of heavy metals from CFA-based geopolymer were very low and the long-term security of heavy metals in CFA-based geopolymer was safe.

Tanakorn Phoo-ngernkham (2013). The effect of Portland cement (OPC) addition on the properties of high calcium fly ash geopolymer pastes was investigated in the paper. OPC partially replaced fly ash (FA) at the dosages of 0, 5%, 10%, and 15% by mass of binder. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions were used as the liquid portion in the mixture: NaOH 10 mol/L, Na_2SiO_3/NaOH with a mass ratio of 2.0, and alkaline liquid/binder (L/B) with a mass ratio of 0.6. The curing at 60°C for 24 h was used to accelerate the geopolymerization. The setting time of all fresh pastes, porosity, and compressive strength of the pastes at the stages of 1, 7, 28, and 90 d were tested. The elastic modulus and strain capacity of the pastes at the stage of 7 d were determined. It is revealed that the use of OPC as an additive to replace part of FA results in the decreases in the setting time, porosity, and strain capacity of the paste specimens, while the compressive strength and elastic modulus seem to increase.

KeNanFeng(2014). The effect of strain rate on the compressive behaviors of geopolymer concrete and mortar is reported. Split Hopkinson pressure bar was adopted for the high strain rate testing's. The dynamic increase factors for compressive strength (DIF_{f_c}) and critical strain (DIF_{e_c}) were measured and compared with Concrete "Comite Euro-international du Beton" (CEB) recommendations. The results show that alkaline activators have significant influence on the quasi- static compressive strength of geopolymer concrete. with high strain rate loading, the DIF_{f_c} of geopolymer concrete and mortar mixes increase with respect to increasing strain rates and in agreement with CEB recommendations. In addition, the coarse aggregates in geopolymer concrete mixes play important role in the increase of compressive strength. However, CEB recommendations underestimate the DIF_{e_c} of critical strain for geopolymer concrete in the high strain rate loading. It is found that for the quasi-static loading and low strain rate loading, cracks propagate along interface transition zone (ITZ) and matrix of geopolymer concrete specimens whereas cracks occur at both the aggregates and ITZ under high strain rateloading.

G.Mallikarjuna Rao(2015). Geopolymer binders are attracting the attention of researchers as substitution to cement binder in conventional concrete. In manufacturing 1 ton of cement, 1 ton of CO_2 is released into the atmosphere. Thus, replacement of cement by geopolymer material in construction industry reduces pollution by two ways: reduction in carbon dioxide emission into atmosphere by reducing the consumption of cement and utilization of fly ash, which is another waste product piling in huge quantities in thermal power plants. To examine the use of geopolymer as a replacement to cement, it is essential to investigate normal consistency, final setting time and compressive strength of geopolymer which are routine tests generally conducted for cement. The procedure adopted for determining the normal consistency, final set- ting time and compressive strength of geopolymer is same as the procedure adopted for cement. In these tests, cement is replaced by geopolymer material and water is replaced by alkaline activator solution. The parameters considered in this investigation are geopolymer source material (fly ash and GGBS) and alkaline activator consisting of sodium meta silicate and sodium hydroxide of different molarities (8, 12, 16 M). The ratio of sodium meta silicate to sodium hydroxide considered in this study is 2.5. The test results indicated that combination of fly ash and GGBS results in decreased final setting time and increased compressive strength. It was also observed that increase in sodium hydroxide increases compressive strength of geopolymer mortar.

Thamer Alomayr (2014). Geopolymer composites containing woven cotton fabric (0–8.3 wt%) were fabricated using the hand lay-up technique, and were exposed to elevated temperatures of 200°C, 400°C, 600 °C, 800 °C and 1000 °C. With an increase in temperature, the geopolymer composites exhibited a reduction in compressive strength, flexural strength and fracture toughness. When heated above 600 °C, the composites exhibited a significant reduction in mechanical properties. They also exhibited brittle behavior due to severe degradation of cotton fibers and the creation of additional porosity in the composites.

G) OBSERVATION ON LITERATURE SURVEY

Based on extensive literature reviewed on the various investigation carried out so far by the several investigators, the following observations has been made, which are relevant to the present work.

Geopolymer concrete made with fly ash and GGBS showed improved compressive strength, split tensile strength, resistance to acid attack and water absorption.

Fly ash based geo polymer concrete improved resistance against aggressive environment and elevated temperatures and increased compressive strength and reduced porosity.

Strength and modulus of elasticity increased with increase in concentration of NaOH.

Bond strength significantly increased than those given by current design codes.

Strength increased with increase in percentage of M-sand.

20% replacement with E-waste gave good results.

50 % replacement with M-Sand gave good results.

Addition of polypropylene fiber improves the durability properties.

Increase in compressive strength with increase in molarity of sodium hydroxide.

Oven cured specimens gave higher strengths.

3. MATERIAL PROPERTIES

The material such as Sodium Silicate (Na_2SiO_3), Sodium hydroxide (NaOH)is to be purchased from the manufacturer, Fly ash (FA),ground granulated Blast furnace slag , waste material are obtained from the respective industries. The physical and chemical properties are listed in this chapter .The coarse aggregate (20-12.5mm) and fine aggregate (Below 4.75mm) are used for this study. The physical properties are also carried out in the laboratory.

A) MATERIAL USED:

1. Sodium Silicate (Na_2SiO_3)

Generally the Sodium Silicate is also known as water glass or liquid glass, available in liquid (gel) form. In the present investigation sodium silicate (ratio between Na_2O to SiO_3) is used .As per the manufacture, silicate were supplied to the detergent company and textile industry as bonding agent. Same Sodium Silicate is used for making of geopolymer concrete. The Chemical and Physical Properties of Sodium Silicate is listed table 1

Table 1 Chemical and Physical Properties of Sodium Silicate(Na_2SiO_3)

Chemical formula	Na_2SiO_3 ,colorless
Na_2O	15.9%
SiO_2	31.4%
H_2O	52.7%
Appearance	Liquid(gel)
Color	Light yellow liquid(gel)
Boiling point	102ºC for 40%, aqueous solution
Molecular weight	184.04
Specific gravity	1.6

2. Sodium Hydroxide (NaOH)

Generally the sodium hydroxides are available in solid state by means of pellets and flakes. The cost of sodium hydroxide is mainly varied according to the purity of substance. Geopolymer concrete is homogeneous material and its main process to activate the sodium silicate. so it is recommended to use the lowest cost up to 94-96% purity. The chemical and physical properties of sodium hydroxide are listed in table 2.

Table 2 Chemical and Physical Properties of Sodium Hydroxide (NaOH)

Appearance /color	Light yellow liquid (gel)
Boiling point	102ºC for 40%, aqueous solution
Molecular weight	184.04
Specific gravity	1.6
Assay	97%
Carbonate (Na2CO3)	2%
Chloride(Cl)	0.01%
Sulphate SO2	0.05%
Lead (Pb)	0.001%
Iron (Fe)	0.001
Potassium(K)	0.1%
Zinc(Zn)	0.02%

3. Fly Ash/ GGBS

Low calcium class F fly ash is to be used in the entire experimental work. The fly ash was procured from Neyveli and Ennore Thermal power plant near Chennai. Ground granulated blast furnace slag (GGBS) a by-product of iron smelting industry was used in the present study. The physical and chemical characteristics are table 3.

Table 3 Physical and Chemical properties of LCFA/HCFA/GGBS

Compound	HCFA	LCFA	GGBS
Physical state	Micronized power	Micronized power	Micronized power
Odour	Odourless	Odourless	Odourless
Appearance	Grey color powder	Grey color powder	White color powder
Void content %	35.5	48.8	48.8
Void ratio	0.55	0.95	0.95
Bulk density gm/cc	0.86	0.66	0.95
Grain size distribution	0.0248	0.0301	0.0223
Specific gravity	2.40	2.00	2.67
Fineness (Kg/m^3)	421	419	400
SiO_2	50	52.52	35
Al_2O_3	31.2	32.63	10
Fe_2O_3	57.4	60.16	-
CaO	22.03	6.2	40.3
MgO	0.5	0.55	8
Na_2O	0.01	0.02	0.9
K_2O	1.14	1.17	0.6
TiO_2	1.05	1.09	-
Mn_2O_3	0.06	0.04	-
SO_3	4.31	4.95	-
LOI	1.03	1.08	4.1

Table 4. Physical properties of High calcium fly ash and GGBS Passing 90micron

Aggregate	Void content	Void ratio	Specific gravity
Fly ash	54.86	1.23	2.6
GGBS	37.5	0.6	2.6

4. Fine Aggregate

The properties such as specific gravity, fineness modules, void content for the natural sand and waste passing through 4.75mm are to be performed the laboratory.

Table 5. Properties of Fine Aggregate Passing 4.75 mm and retaining 150micron

Aggregate	Void content	Void ratio	Specific gravity	Fineness Modulus
River sand	35.17	0.544	2.6	3.0
Foundry sand	35.17	0.54	2.5	1.62
Neyveli bottom ash	44.2	0.792	2.5	1.83
Ennore bottom ash	66.64	2.00	1.82	1.95

5. Coarse Aggregate

Aggregate	Void content	Void ratio	Specific gravity	F.M.
Ordinary HBG metal	46.5 %	0.869	2.71	3.18

Table 6. Properties of Coarse Aggregate Passing 20mm and retaining4.75mm

4. EXPERIMENTAL INVESTIGATION

The geo polymer paste is prepared based on the physical properties of fly ash obtained from Neyveli Lignite Corporation. The mix proportion for the geo polymer paste using high calcium fly ash is calculated based on the properties of the fly ash. The fly ash to alkaline activator ratio is modified based on the water solid ratio which is less than 0.4. The alkaline activator is the solution of sodium silicate and sodium hydroxide and the ratio is 1.0, 1.5, 2.0, 2.5, 3.0.The solution of sodium hydroxide for the molarity 10, 12, 14, 16, 18 is prepared according to Mr. Rajamane N.P. [1].For the room temperature curing the fly ash is replaced with Ground Granulated Glass Furnace Slag (GGBS) at 10% and 20%.

A) MIX PROPORTION

The mix design for geo polymer paste is calculated based on the void content and the weight proportion is listed in table 4.2, wherein the FA/AA is 1.38 which is more liquid so this is adjusted as 1.2 for the water/solid ratio is 0.3724.

The mix design for geo polymer mortar using different fine aggregates is calculated based on the minimum void approach using the powers formula and the weight proportions are listed in table 9.

The mix design for geo polymer concrete using HBG metal as coarse aggregate and river sand as fine aggregate is calculated based on the minimum void approach using the powers formula and the weight proportions are listed in tab12

Table 7. Mix Proportion of Paste by Volume

Name	Void Content	Void Ratio
Fly ash	54.86	1.23
GGBS	37.5	0.6

Table 8. Mix Proportion of Paste by Weight

Name	FA	AA	FA/AA
Fly ash	58	42	1.38

Table 9. Mix Proportion of Geo Polymer Mortar using different

Name fine aggregate	Fag	FA	Void Content	Void Ratio
River sand	80.50	19.50	19.43	0.2412
Foundry waste sand	80.50	19.50	19.34	0.2398
Neyveli bottom ash	73.79	26.21	24.37	0.3223
Ennore bottom ash	29.08	70.92	36.77	0.5816

Fine Aggregate and HCFA by Volume

Table 10. Mix Proportion of Geo polymer Mortar using different Fine Aggregate and HCFA by Volume taking into the Volume of Void Content

Name fine aggregate	Fag	FA	Void Content	Void Ratio
River sand	64.86	15.71	19.43	0.2412
Foundry waste sand	64.93	15.73	19.34	0.2398
Neyveli bottom ash	55.81	19.82	24.37	0.3223
Ennore bottom ash	18.39	44.84	36.77	0.5816

Table 11. Mix Proportion of Geo polymer mortar using different fine aggregate and HCFA by weight

Name fine aggregate	Fag	FA	AA	Fag/Paste
River sand	70.0	17.0	13.0	2.33
Foundry waste sand	69.7	17.6	12.7	3.97
Neyveli bottom ash	61.1	22.57	16.3	1.57
Ennore bottom ash	16.22	56.51	27.27	0.19

Table 12. Mix Proportion of Geo Polymer Concrete using River Sand and HCFA by volume

Name fine aggregate	CA	FAg	Void Content	Void Ratio
River sand	53.51	30.10	16.39	0.196
Foundry waste sand	64.0	36.0	16.3	0.1948
Neyveli bottom ash	67.34	32.66	20.54	0.2585
Ennore bottom ash	76.44	23.56	30.00	0.4287

Table 13. Mix Proportion of Geo Polymer Concrete using River Sand and HCFA by volume taking into the account of void content

Name fine aggregate	CA	FAg	Void Content	Void Ratio
River sand	64.0	36.0	16.39	0.196
Foundry waste sand	53.5	30.1	16.3	0.1948
Neyveli bottom ash	53.51	25.95	20.54	0.2585
Ennore bottom ash	53.51	16.49	30.00	0.4287

Table 14. Mix Proportion of Geo Polymer Concrete using River Sand and HCFA by weight

Name fine aggregate	CA	FAg	CA/FA
River sand	65.0	35.0	1.86
Foundry waste sand	66.0	34.0	1.94
Neyveli bottom ash	69.0	31.0	2.23
Ennore bottom ash	83.0	17.0	4.88

B) SPECIMEN AND TEST

Various paste specimen of size 70.6x70.6x70.6mm are casted for the molarity 10, 12, 14, 16 and 18 in respect of Na_2SiO_3/NaOH ratio 1.0, 1.5, 2.0, 2.5 and 3.0. The mix proportion obtained by minimum void approach is based on water. The geo polymer paste based on the void content the FA/AA arrived is 1.38 which is less workable due to the water solid ratio is 0.34 so that FA/AA ratio is reduced to 1.2 for workable mix of water/solid ratio of 0.37.The mix proportion for the molarity wise is listed in table 15 to 24. The compressive strength is tested in CTM at the end of seventh day.

Table 15. Mix Proportion for Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio FA/AA =1.2 Molarity 10

S.No	Na_2SiO_3/NaOH	FA	AA	Na_2SiO_3		NaOH		Total Water	Total Solids	Water /Solid
				Solid	Water	Solid	Water			
1	1.0	381.82	318.18	79.55	79.55	48.68	110.41	189.95	510.05	0.3724
2	1.0	381.82	318.18	79.55	79.55	48.68	110.41	189.95	510.05	0.3724
3	1.5	381.82	318.18	95.45	95.45	38.95	88.33	183.78	516.22	0.3560
4	1.5	381.82	318.18	95.45	95.45	38.95	88.33	183.78	516.22	0.3560
5	2.0	387.27	322.73	107.58	107.58	32.92	74.66	182.23	527.77	0.3453
6	2.0	387.27	322.73	107.58	107.58	32.92	74.66	182.23	527.77	0.3453
7	2.5	387.27	322.73	115.26	115.26	28.22	63.99	179.25	530.75	0.3377
8	2.5	387.27	322.73	115.26	115.26	28.22	63.99	179.25	530.75	0.3377
9	3.0	387.27	322.73	121.02	121.02	24.69	55.99	177.02	532.98	0.3321
10	3.0	387.27	322.73	121.02	121.02	24.69	55.99	177.02	532.98	0.3321

Table 16. Mix Proportion for Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio FA/AA =1.2 Molarity 10

S.No	Na_2SiO_3/NaOH	FA	AA	Na_2SiO_3		NaOH		Total Water	Total Solids	Water /Solid
				Solid	Water	Solid	Water			
1	1.0	381.82	318.18	79.55	79.55	56.32	102.77	182.32	517.68	0.3522
2	1.0	381.82	318.18	79.55	79.55	56.32	102.77	182.32	517.68	0.3522
3	1.5	381.82	318.18	95.45	95.45	45.05	82.22	177.67	522.33	0.3402
4	1.5	381.82	318.18	95.45	95.45	45.05	82.22	177.67	522.33	0.3402
5	2.0	381.82	318.18	106.06	106.06	37.55	68.52	174.58	525.42	0.3323
6	2.0	381.82	318.18	106.06	106.06	37.55	68.52	174.58	525.42	0.3323
7	2.5	381.82	318.18	113.64	113.64	32.18	58.73	172.36	527.64	0.3267
8	2.5	381.82	318.18	113.64	113.64	32.18	58.73	172.36	527.64	0.3267
9	3.0	381.82	318.18	119.32	119.32	28.16	51.39	170.70	529.30	0.3225
10	3.0	381.82	318.18	119.32	119.32	28.16	51.39	170.70	529.30	0.3225

Table 17. Mix Proportion for Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio FA/AA =1.2 Molarity 12

Sl. No.	Na_2SiO_3/NaOH	GGBS (%)	Fly Ash(FA)		Alkaline activator(AA)		Total	W/S
			Fly Ash	GGBS	Na_2SiO_3	NaOH		
1	1.0	10	343.64	38.18	159.09	159.09	700.00	0.3724
2	1.0	20	305.45	76.36	159.09	159.09	700.00	0.3724
3	1.5	10	343.64	38.18	190.91	127.27	700.00	0.3560
4	1.5	20	305.45	76.36	190.91	127.27	700.00	0.3560
5	2.0	10	348.55	38.18	215.15	107.58	710.00	0.3453
6	2.0	20	309.82	77.45	215.15	107.58	710.00	0.3453
7	2.5	10	348.55	38.18	230.52	92.21	710.00	0.3377
8	2.5	20	309.82	77.45	230.52	92.21	710.00	0.3377
9	3.0	10	348.55	38.18	242.05	80.68	710.00	0.3321
10	3.0	20	309.82	77.45	242.05	80.68	710.00	0.3321

Table 18. Mix Proportion for Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio.FA/AA =1.2 Molarity 12

Sl. No.	Na_2SiO_3/NaOH	GGBS (%)	Fly Ash(FA)		Alkaline activator(AA)		Total	W/S
			Fly Ash	GGBS	Na_2SiO_3	NaOH		
1	1.0	10	343.64	38.18	159.09	159.09	700.00	0.3724
2	1.0	20	305.45	76.36	159.09	159.09	700.00	0.3724
3	1.5	10	343.64	38.18	190.91	127.27	700.00	0.3560
4	1.5	20	305.45	76.36	190.91	127.27	700.00	0.3560
5	2.0	10	348.55	38.18	215.15	107.58	710.00	0.3453
6	2.0	20	309.82	77.45	215.15	107.58	710.00	0.3453
7	2.5	10	348.55	38.18	230.52	92.21	710.00	0.3377
8	2.5	20	309.82	77.45	230.52	92.21	710.00	0.3377
9	3.0	10	348.55	38.18	242.05	80.68	710.00	0.3321
10	3.0	20	309.82	77.45	242.05	80.68	710.00	0.3321

Table 19. Mix Proportion for Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio FA/AA =1.2 Molarity 14

Sl. No.	Na_2SiO_3/NaOH	GGBS (%)	Fly Ash (FA)		Alkaline activator(AA)		Total	W/S
			Fly Ash	GGBS	Na_2SiO_3	NaOH		
1	1.0	10	343.64	38.18	159.09	159.09	700	0.3333
2	1.0	20	305.45	76.36	159.09	159.09	700	0.3333
3	1.5	10	343.64	38.18	190.91	127.27	700	0.3253
4	1.5	20	305.45	76.36	190.91	127.27	700	0.3253
5	2.0	10	343.64	38.18	212.12	106.06	700	0.3200
6	2.0	20	305.45	76.36	212.12	106.06	700	0.3200
7	2.5	10	343.64	38.18	227.27	90.91	700	0.3162
8	2.5	20	305.45	76.36	227.27	90.91	700	0.3162
9	3.0	10	343.64	38.18	238.64	79.55	700	0.3134
10	3.0	20	305.45	76.36	238.64	79.55	700	0.3134

Table 20. Mix Proportion for Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio FA/AA =1.2 Molarity 14

S.No	Na_2SiO_3/NaOH	FA	AA	Na_2SiO_3		NaOH		Total Water	Total Solids	Water /Solid
				Solid	Water	Solid	Water			
1	1.0	381.82	318.18	79.55	79.55	63.64	95.45	175.00	525.00	0.3333
2	1.0	381.82	318.18	79.55	79.55	63.64	95.45	175.00	525.00	0.3333
3	1.5	381.82	318.18	95.45	95.45	50.91	76.36	171.82	528.18	0.3253
4	1.5	381.82	318.18	95.45	95.45	50.91	76.36	171.82	528.18	0.3253
5	2.0	381.82	318.18	106.06	106.06	42.42	63.64	169.70	530.30	0.3200
6	2.0	381.82	318.18	106.06	106.06	42.42	63.64	169.70	530.30	0.3200
7	2.5	381.82	318.18	113.64	113.64	36.36	54.55	168.18	531.82	0.3162
8	2.5	381.82	318.18	113.64	113.64	36.36	54.55	168.18	531.82	0.3162
9	3.0	381.82	318.18	119.32	119.32	31.82	47.73	167.05	532.95	0.3134
10	3.0	381.82	318.18	119.32	119.32	31.82	47.73	167.05	532.95	0.3134

Table 21. Mix Proportion for Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio FA/AA =1.2 Molarity 16

Sl. No.	Na2SiO3/ NaOH	GGBS (%)	FA		Alkaline activator(AA)		Total	W/S
			Fly Ash	GGBS	Na_2SiO_3	NaOH		
1	1.0	10	343.64	38.18	159.09	159.09	700	0.3522
2	1.0	20	305.45	76.36	159.09	159.09	700	0.3522
3	1.5	10	343.64	38.18	190.91	127.27	700	0.3402
4	1.5	20	305.45	76.36	190.91	127.27	700	0.3402
5	2.0	10	343.64	38.18	212.12	106.06	700	0.3323
6	2.0	20	305.45	76.36	212.12	106.06	700	0.3323
7	2.5	10	343.64	38.18	227.27	90.91	700	0.3267
8	2.5	20	305.45	76.36	227.27	90.91	700	0.3267
9	3.0	10	343.64	38.18	238.64	79.55	700	0.3225
10	3.0	20	305.45	76.36	238.64	79.55	700	0.3225

Table 22. Mix Proportion for Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2sio_3 to NaOH Ratio FA/AA =1.2 Molarity 16

S.No	Na_2SiO_3 /NaOH	FA	AA	Na_2SiO_3		NaOH		Total Water	Total Solids	Water /Solid
				Solid	Water	Solid	Water			
1	1.0	381.82	318.18	82.73	76.36	70.48	88.61	164.98	535.02	0.3084
2	1.0	381.82	318.18	82.73	76.36	70.48	88.61	164.98	535.02	0.3084
3	1.5	381.82	318.18	99.27	91.64	56.38	70.89	162.53	537.47	0.3024
4	1.5	381.82	318.18	99.27	91.64	56.38	70.89	162.53	537.47	0.3024
5	2.0	381.82	318.18	110.30	101.82	46.98	59.08	160.89	539.11	0.2984
6	2.0	381.82	318.18	110.30	101.82	46.98	59.08	160.89	539.11	0.2984
7	2.5	381.82	318.18	118.18	109.09	40.27	50.64	159.73	540.27	0.2956
8	2.5	381.82	318.18	118.18	109.09	40.27	50.64	159.73	540.27	0.2956
9	3.0	381.82	318.18	124.09	114.55	35.24	44.31	158.85	541.15	0.2935
10	3.0	381.82	318.18	124.09	114.55	35.24	44.31	158.85	541.15	0.2935

Table 23. Mix Proportion for Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio FA/AA =1.2 Molarity 18

Sl. No.	Na_2SiO_3/ NaOH	GGBS (%)	Fly ash(FA)		Alkaline activator(AA)		Total	W/S
			Fly Ash	GGBS	Na_2SiO_3	NaOH		
1	1.0	10	343.64	38.18	159.09	159.09	700	0.2922
2	1.0	20	305.45	76.36	159.09	159.09	700	0.2922
3	1.5	10	343.64	38.18	190.91	127.27	700	0.2896
4	1.5	20	305.45	76.36	190.91	127.27	700	0.2896
5	2.0	10	343.64	38.18	212.12	106.06	700	0.2878
6	2.0	20	305.45	76.36	212.12	106.06	700	0.2878
7	2.5	10	343.64	38.18	227.27	90.91	700	0.2865
8	2.5	20	305.45	76.36	227.27	90.91	700	0.2865
9	3.0	10	343.64	38.18	238.64	79.55	700	0.2856
10	3.0	20	305.45	76.36	238.64	79.55	700	0.2856

Table 24. Mix Proportion for Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2sio_3 to NaOH Ratio.FA/AA =1.2 Molarity 18

S.No	Na_2SiO_3 /NaOH	FA	AA	Na_2SiO_3		NaOH		Total Water	Total Solids	Water /Solid
				Solid	Water	Solid	Water			
1	1.0	381.82	318.18	82.73	76.36	77.16	81.93	158.30	541.70	0.2922
2	1.0	381.82	318.18	82.73	76.36	77.16	81.93	158.30	541.70	0.2922
3	1.5	381.82	318.18	99.27	91.64	61.73	65.55	157.18	542.82	0.2896
4	1.5	381.82	318.18	99.27	91.64	61.73	65.55	157.18	542.82	0.2896
5	2.0	381.82	318.18	110.30	101.82	51.44	54.62	156.44	543.56	0.2878
6	2.0	381.82	318.18	110.30	101.82	51.44	54.62	156.44	543.56	0.2878
7	2.5	381.82	318.18	118.18	109.09	44.09	46.82	155.91	544.09	0.2865
8	2.5	381.82	318.18	118.18	109.09	44.09	46.82	155.91	544.09	0.2865
9	3.0	381.82	318.18	124.09	114.55	38.58	40.97	155.51	544.49	0.2856
10	3.0	381.82	318.18	124.09	114.55	38.58	40.97	155.51	544.49	0.2856

The Geo polymer mortar specimen of size 70.6x70.6x70.6mm are casted for the different fine aggregates with the FA/AA as 1.2 and the varying Fag/paste ratio for different fine aggregate and the molarity, Na2SiO3/NaOH ratio is selected based on the maximum strength obtained in the paste specimen which is listed in table 25 to 32.

Fag/paste ratio for River sand is calculated as per mix design is 2.33 but for the sake of workable mix it is reduced to 1.8. Fag/paste ratio for Foundry waste sand is calculated as per mix design is 3.97 but for the sake of workable mix it is reduced to 1.2. Fag/paste ratio for Neyveli Bottom ash is calculated as per mix design is 1.57 but for the sake of workable mix it is reduced to 1.4. Fag/paste ratio for Ennore Bottom ash is calculated as per mix design is 0.19 due to less ratio of Fag/Paste for Ennore Bottom ash the same ratio of 0.19 is adopted.

Table 25. Mix Proportion for Geo polymer Mortar Using River Sand as Fine Aggregate for Different Molarity and Na_2SiO_3 to NaOH ratio. FA/AA=1.2 F.Ag/Paste=1.64

Sl. No.	Mole	Fine Aggregate	Fly Ash (FA)		Alkaline activator(AA)		Total	W/S	FA/ AA	Na_2SiO_3/ NaOH
			Fly Ash	GGBS	Na_2SiO_3	NaOH				
1	10	505.25	134.43	33.61(20%)	100.03	40.01	813.33	0.3614	1.2	2.5
2	12	505.25	134.43	33.61(20%)	84.02	56.01	813.33	0.3600	1.2	1.5
3	14	505.25	134.43	33.61(20%)	84.02	56.01	813.33	0.3447	1.2	1.5
4	16	505.25	134.43	33.61(20%)	100.03	40.01	813.33	0.3292	1.2	2.5
5	18	505.25	151.24	16.80(10%)	84.02	56.01	813.33	0.3174	1.2	1.5
6	18	505.25	134.43	33.61(20%)	84.02	56.01	813.33	0.3174	1.2	1.5

Table 26. Mix Proportion For Geo polymer Mortar Using River Sand as Fine Aggregate for Different Molarity and Na_2SiO_3

S.No	Paste	FA	AA	Na2SiO3		NaOH		Total Water	Total Solids	Water /Solid
				Solid	Water	Solid	Water			
1	308.08	168.04	140.04	46.01	54.01	12.24	27.77	81.78	226.30	0.3614
2	308.08	168.04	140.04	38.65	45.37	19.83	36.19	81.56	226.52	0.3600
3	308.08	168.04	140.04	38.65	45.37	22.41	33.61	78.98	229.10	0.3447
4	308.08	168.04	140.04	46.01	54.01	17.72	22.29	76.30	231.78	0.3292
5	308.08	168.04	140.04	38.65	45.37	27.17	28.85	74.22	233.86	0.3174
6	308.08	168.04	140.04	38.65	45.37	27.17	28.85	74.22	233.86	0.3174

Table 27. Mix Proportion for Geo polymer Mortar Using Foundry Sand as Fine Aggregate for Different Molarity and Na_2SiO_3 to NaOH ratio. FA/AA=1.2F.Ag/Paste=1.2

Sl. No.	Mole	Fine Aggregate	FA		Alkaline activator(AA)		Total	W/S	FA/AA	Na2SiO3 /NaOH
			Fly Ash	GGBS	Na_2SiO_3	NaOH				
1	10	420.00	130.91	32.73	97.40	38.96	720	0.3614	1.2	2.5
2	12	420.00	130.91	32.73	81.82	54.55	720	0.3600	1.2	1.5
3	14	420.00	130.91	32.73	81.82	54.55	720	0.3447	1.2	1.5
4	16	420.00	130.91	32.73	97.40	38.96	720	0.3292	1.2	2.5
5	18	420.00	130.91	32.73	81.82	54.55	720	0.3174	1.2	1.5

Table 28. Mix Proportion for Geo polymer Mortar Using Foundry Sand as Fine Aggregate for Different Molarity and Na_2SiO_3 to NaOH ratio.FA/AA=1.2 F.Ag/Paste=1.2

Sl.No	Paste	FA	AA	Na2SiO3		NaOH		Total Water	Total Solids	Water /Solid
				Solid	Water	Solid	Water			
1	350.00	190.91	159.09	56.82	56.82	13.91	31.55	88.36	261.64	0.3377
2	350.00	190.91	159.09	47.73	47.73	22.53	41.11	88.84	261.16	0.3402
3	350.00	190.91	159.09	47.73	47.73	25.45	38.18	85.91	264.09	0.3253
4	350.00	190.91	159.09	56.82	56.82	20.14	25.32	82.14	267.86	0.3066
5	350.00	190.91	159.09	47.73	47.73	30.86	32.77	80.50	269.50	0.2987
6	350.00	190.91	159.09	47.73	47.73	30.86	32.77	80.50	269.50	0.2987

Table 29. Mix Proportion for Geo polymer Mortar Using Neyveli Bottom Ash as Fine Aggregate for different Molarity and Na_2SiO_3 to NaOH ratio FA/AA=1.2 F.Ag/Paste=1.4

Sl. No.	Mole	Fine Aggregate	FA		Alkaline activator(AA)		Total	W/S	FA/AA	Na_2SiO_3/NaOH
			Fly Ash	GGBS	Na_2SiO_3	NaOH				
1	10	420.00	152.73	38.18	113.64	45.45	770.00	0.3377	1.2	2.5
2	12	420.00	152.73	38.18	95.45	63.64	770.00	0.3402	1.2	1.5
3	14	420.00	152.73	38.18	95.45	63.64	770.00	0.3253	1.2	1.5
4	16	420.00	152.73	38.18	113.64	45.45	770.00	0.3066	1.2	2.5
5	18	420.00	171.82	19.09	95.45	63.64	770.00	0.2987	1.2	1.5
6	18	420.00	152.73	38.18	95.45	63.64	770.00	0.2987	1.2	1.5

Table 30. Mix Proportion for Geo polymer Mortar Using Neyveli Bottom Ash as Fine Aggregate for different Molarity and Na_2SiO_3 to NaOH ratio

Sl.No	Paste	FA	AA	Na_2SiO_3		NaOH		Total Water	Total Solids	Water /Solid
				Solid	Water	Solid	Water			
1	300.00	163.64	136.36	44.81	52.60	11.92	27.04	79.64	220.36	0.3614
2	300.00	163.64	136.36	37.64	44.18	19.31	35.24	79.42	220.58	0.3600
3	300.00	163.64	136.36	37.64	44.18	21.82	32.73	76.91	223.09	0.3447
4	300.00	163.64	136.36	44.81	52.60	17.26	21.70	74.30	225.70	0.3292
5	300.00	163.64	136.36	37.64	44.18	26.45	28.09	72.27	227.73	0.3174

Table 31. Mix Proportion for Geopolymer Mortar using Ennore Bottom Ash as Fine Aggregate for different Molarity and Na2SiO3 to NaOH ratioFA/AA=1.2 F.Ag/Paste=0.19

Sl. No.	Mole	Fine Aggregate	FA		Alkaline activator(AA)		Total	W/S	FA/A A	Na2SiO3 /NaOH
			Fly Ash	GGBS	Na_2SiO_3	NaOH				
1	10	108.57	249.35	62.34	185.53	74.21	680	0.3614	1.2	2.5
2	12	108.57	249.35	62.34	155.84	103.90	680	0.3600	1.2	1.5
3	14	108.57	249.35	62.34	155.84	103.90	680	0.3447	1.2	1.5
4	16	108.57	249.35	62.34	185.53	74.21	680	0.3292	1.2	2.5
5	18	108.57	249.35	62.34	155.84	103.90	680	0.3174	1.2	1.5

Table 32. Mix Proportion for Geopolymer Mortar using Ennore Bottom Ash as Fine Aggregate for different Molarity and Na2SiO3 to NaOH ratio FA/AA=1.2 F.Ag/Paste=0.19

S.No	Paste	FA	AA	Na_2SiO_3		NaOH		Total Water	Total Solids	Water /Solid
				Solid	Water	Solid	Water			
1	571.43	311.69	259.74	85.34	100.19	22.71	51.50	151.69	419.74	0.3614
2	571.43	311.69	259.74	71.69	84.16	36.78	67.12	151.27	420.16	0.3600
3	571.43	311.69	259.74	71.69	84.16	41.56	62.34	146.49	424.94	0.3447
4	571.43	311.69	259.74	85.34	100.19	32.88	41.34	141.52	429.91	0.3292
5	571.43	311.69	259.74	71.69	84.16	50.39	53.51	137.66	433.77	0.3174

The Geo Polymer concrete specimen of size 100x100x100mm cubes are casted using hard broken granite (HBG) metal as coarse aggregate and different fine aggregate the ratio of coarse aggregate and fine aggregate in respect of river sand, foundry waste sand, Neyveli bottom ash and Ennore bottom ash are 1.86, 1.94, 2.23 and 4.88.

The fine aggregate quantity is taken up for the calculation of Fag/Paste as in mortar specimen and the molarity, Na2SiO3/NaOH ratio is based on the optimum proportion obtained in the mortar specimen as listed in table 33.

Table 33. Mix Proportion for Geoploymer Concrete using Coarse aggregate as CA Fag/Fly ash=3.00/Fly ash/AA=1.2

Sl. No.	Types of Fine Agg	Mole	Coarse aggregate 20-4.75 mm	Fine Aggregate	Fly Ash (FA)		Alkaline activator(AA)		Total	W/S	FAg/Paste	Na_2SiO_3/NaOH
					Fly Ash	GGBS	Na_2SiO_3	NaOH				
1	River Sand	18	1449.5	780.50	233.63	25.96	216.33	86.33	2792.25	0.4022	1.64	2.5
2	Foundry Sand	14	1300.63	672.02	292.38	73.09	182.73	121.82	2642.67	0.3174	1.00	1.5
3	Neyveli Bottom Ash	14	1449.00	651.00	218.52	54.63	136.57	91.05	2600.77	0.3174	1.40	1.5
4	Ennore Bottom Ash	18	1452.5	297.50	683.26	170.81	427.03	284.69	3315.79	0.3174	0.19	1.5

5. RESULTS AND DISCUSSIONS

In this chapter, the results of the strength properties of Geo polymer paste, mortar and concrete are analyzed, discussed and inferences are presented. Based on the discussions, conclusions relevant to this study are drawn and scope for further work is given in topic 6.

The results of the specimen casted as in section 4.2 , (i) Geo polymer paste using high calcium fly ash passing 90 micron with FA/AA ratio 1.2 is selected based on the water solid ratio 0.3724 for 10 molarity and it is reduced to 0.2856 for molarity 18. (ii) The geo polymer mortar for the different fine aggregate with the above FA/AA ratio 1.2, the optimum Na2SiO3 and NaOH ratio, GGBS percentage is selected for the respective molarity of the paste. The Fag/Paste ratio obtained from the minimum void approach is reduced according to the workable mix. (iii) The geo polymer concrete using HBG metal as coarse aggregate and river sand as fine aggregate is also adjusted in respect of coarse aggregate and fine aggregate ratio for the workable mix.

The compressive strength for the paste, mortar and concrete are listed in the tables 34 to 38 respectively and the following inferences are drawn.

1. As mentioned in para 4.2 the FA/AA ratio adopted is 1.2 for the workable mix of water to solid ratio is 0.3724. For the paste of 10 molarity, varying Na_2SiO_3/NaOH ratio (1.0, 1.5, 2.0, 2.5, 3.0), the water to solid ratio starts from 0.3724 to 0.3321 similarly for molarity 12 the W/S ratio is from 0.3522 to 0.3225.For molarity 14 the W/S ratio is from 0.3333 to 0.3134 for molarity 16 the W/S ratio is from 0.3084 to 0.2935for molarity 18 the W/S ratio is from 0.2922 to 0.2856. The reduction in water solid ratio is due to the solid content increase in sodium hydroxide solution of higher molarity. Which is listed in table 5.1 to 5.5.
2. The compressive strength of geo polymer paste for 10 molarity maximum compressive strength of 38.59 N/mm^2 (Na2SiO3/NaOH=1, GGBS=10%) for 12 molarity maximum compressive strength of 42.59 N/mm^2 (Na2SiO3/NaOH=1.5, GGBS=20%)for 14 molarity maximum compressive strength of 46.76 N/mm^2 (Na2SiO3/NaOH=1.5, GGBS=20%) for 16 molarity maximum compressive strength of 45.26 N/mm^2 (Na2SiO3/NaOH=2.5, GGBS=20%)for 18 molarity maximum compressive strength of 42.95 N/mm^2 (Na2SiO3/NaOH=1.5, GGBS=10%).

Table 34. Compressive strength of Geo polymer Paste Using High calcium Fly ashbPassing 90micron with different Na_2Sio_3 to NaOH Ratio FA/AA=1.2 Molarity 10

Sl. No.	Na2SiO3/NaOH	GGBS (%)	Fly ash(FA)		Alkaline activator(AA)		Total	W/S	Density (gm/cc)	Compressive Strength (N/mm2)
			Fly Ash	GGBS	Na_2SiO_3	NaOH				
1	1.0	10	49.09	5.45	22.73	22.73	100	0.3724	1.81	38.59
2	1.0	20	43.64	10.91	22.73	22.73	100	0.3724	1.81	24.77
3	1.5	10	49.09	5.45	27.27	18.18	100	0.3560	1.73	15.92
4	1.5	20	43.64	10.91	27.27	18.18	100	0.3560	1.77	22.51
5	2.0	10	49.09	5.45	30.30	15.15	100	0.3453	1.60	17.12
6	2.0	20	43.64	10.91	30.30	15.15	100	0.3453	1.87	29.25
7	2.5	10	49.09	5.45	32.47	12.99	100	0.3377	1.83	25.32
8	2.5	20	43.64	10.91	32.47	12.99	100	0.3377	1.80	34.49
9	3.0	10	49.09	5.45	34.09	11.36	100	0.3321	1.80	22.00
10	3.0	20	43.64	10.91	34.09	11.36	100	0.3321	1.76	12.04

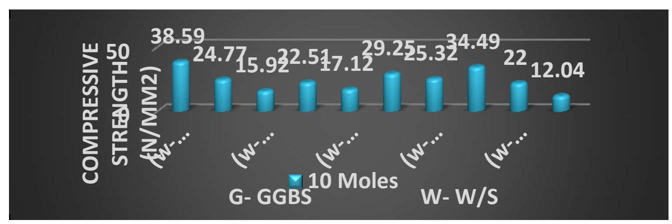

Fig 1:Compressive strength of Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio FA/AA =1.2 Molarity 10

Table 35. Compressive strength of Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio

FA/AA =1.2 Molarity 12

Sl. No.	Na_2SiO_3/NaOH	GGBS (%)	Fly ash(FA)		Alkaline activator(AA)		Total	W/S	Density (gm/cc)	Compressive strength (N/mm^2)
			Fly Ash	GGBS	Na_2SiO_3	NaOH				
1	1.0	10	49.09	5.45	22.73	22.73	100	0.3522	1.87	37.24
2	1.0	20	43.64	10.91	22.73	22.73	100	0.3522	1.94	41.72
3	1.5	10	49.09	5.45	27.27	18.18	100	0.3402	1.87	34.27
4	1.5	20	43.64	10.91	27.27	18.18	100	0.3402	1.87	42.59
5	2.0	10	49.09	5.45	30.30	15.15	100	0.3323	1.83	31.60
6	2.0	20	43.64	10.91	30.30	15.15	100	0.3323	1.80	20.02
7	2.5	10	49.09	5.45	32.47	12.99	100	0.3267	1.84	25.84
8	2.5	20	43.64	10.91	32.47	12.99	100	0.3267	1.80	16.66
9	3.0	10	49.09	5.45	34.09	11.36	100	0.3225	1.82	24.41
10	3.0	20	43.64	10.91	34.09	11.36	100	0.3225	1.73	23.79

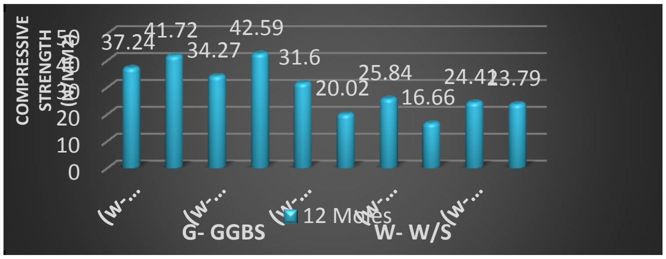

Fig 2: Compressive strength of Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH RatioFA/AA =1.2 Molarity 12

Table 36. Compressive strength of Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH RatioFA/AA =1.2 Molarity 14

Sl. No.	Na2SiO3 /NaOH	GGBS (%)	Fly Ash (FA)		Alkaline activator(AA)		Total	W/S	Density (gm/cc)	Compressive strength (N/mm^2)
			Fly Ash	GGBS	Na_2SiO_3	NaOH				
1	1.0	10	49.09	5.45	22.73	22.73	100	0.3333	1.92	11.88
2	1.0	20	43.64	10.91	22.73	22.73	100	0.3333	1.96	11.74
3	1.5	10	49.09	5.45	22.27	18.18	100	0.3253	1.89	41.66
4	1.5	20	43.64	10.91	22.27	18.18	100	0.3253	1.85	46.76
5	2.0	10	49.09	5.45	30.30	15.15	100	0.3200	1.79	23.93
6	2.0	20	43.64	10.91	30.30	15.15	100	0.3200	1.83	22.85
7	2.5	10	49.09	5.45	32.47	12.99	100	0.3162	1.79	27.32
8	2.5	20	43.64	10.91	32.47	12.99	100	0.3162	1.74	20.20
9	3.0	10	49.09	5.45	34.09	11.36	100	0.3134	1.79	31.70
10	3.0	20	43.64	10.91	34.09	11.36	100	0.3134	1.79	31.74

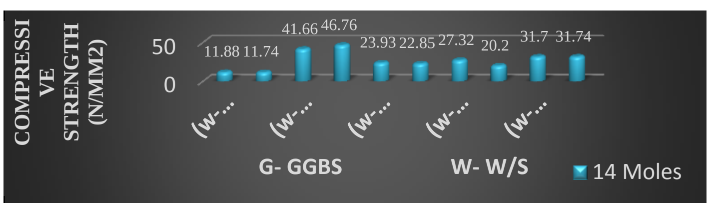

Fig 3: Compressive strength of Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio/FA/AA =1.2 Molarity 14

Table 37. Compressive strength of Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio FA/AA =1.2 Molarity 16

Sl. No.	Na_2SiO_3/ NaOH	GGBS (%)	Fly Ash (FA)		Alkaline activator(AA)		Total	W/S	Density (gm/cc)	Compressive strength (N/mm^2)
			Fly Ash	GGBS	Na_2SiO_3	NaOH				
1	1.0	10	49.09	5.45	22.73	22.73	100	0.3084	1.86	39.39
2	1.0	20	43.64	10.91	22.73	22.73	100	0.3084	1.84	24.69
3	1.5	10	49.09	5.45	27.27	18.18	100	0.3024	1.92	20.42
4	1.5	20	43.64	10.91	27.27	18.18	100	0.3024	1.94	36.86
5	2.0	10	49.09	5.45	30.30	15.15	100	0.2984	1.89	29.75
6	2.0	20	43.64	10.91	30.30	15.15	100	0.2984	1.88	36.48
7	2.5	10	49.09	5.45	32.47	12.99	100	0.2956	1.81	31.80
8	2.5	20	43.64	10.91	32.47	12.99	100	0.2956	1.87	45.26
9	3.0	10	49.09	5.45	34.09	11.36	100	0.2935	1.80	27.42
10	3.0	20	43.64	10.91	34.09	11.36	100	0.2935	1.80	10.22

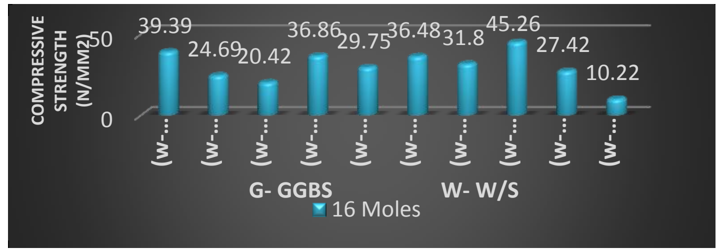

Fig 4: Compressive strength of Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio FA/AA =1.2 Molarity 16

Table 38. Compressive strength of Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na2Sio3 to NaOH Ratio

FA/AA =1.2 Molarity 18

Sl. No.	Na2SiO3/NaOH	GGBS (%)	Fly ash(FA)		Alkaline activator(AA)		Total	W/S	Density (gm/cc)	Compressive strength (N/mm^2)
			Fly Ash	GGBS	Na_2SiO_3	NaOH				
1	1.0	10	49.09	5.45	22.73	22.73	100	0.2922	1.88	34.85
2	1.0	20	43.64	10.91	22.73	22.73	100	0.2922	1.96	23.87
3	1.5	10	49.09	5.45	27.27	18.18	100	0.2896	1.92	42.95
4	1.5	20	43.64	10.91	27.27	18.18	100	0.2896	1.93	42.93
5	2.0	10	49.09	5.45	30.30	15.15	100	0.2878	1.88	38.09
6	2.0	20	43.64	10.91	30.30	15.15	100	0.2878	1.81	29.19
7	2.5	10	49.09	5.45	32.47	12.99	100	0.2865	1.87	30.68
8	2.5	20	43.64	10.91	32.47	12.99	100	0.2865	1.88	30.46
9	3.0	10	49.09	5.45	34.09	11.36	100	0.2856	1.88	35.68
10	3.0	20	43.64	10.91	34.09	11.36	100	0.2856	1.80	17.46

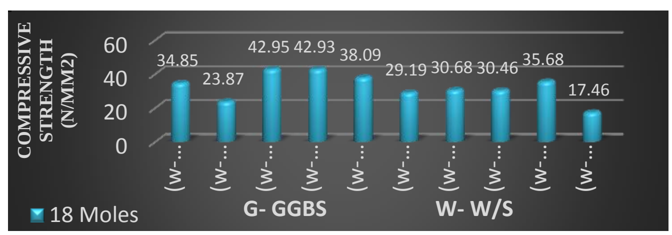

Fig 5: Compressive strength of Geo polymer Paste Using High calcium Fly ash Passing 90micron with different Na_2Sio_3 to NaOH Ratio/FA/AA =1.2 Molarity 16

3. The maximum compressive strength of geo polymer mortar using river sand is 43.81 N/mm2 for Fag/paste ratio 1.64, FA/AA 1.2 Na2SiO3/NaOH 1.5 water to solid ratio 0.3447 and the molarity 14 which is relevant to the combination of paste highest compressive strength.
4. The maximum compressive strength of geo polymer mortar using foundry waste sand is 24.17 N/mm2 for Fag/paste ratio 1.2, FA/AA 1.2 Na2SiO3/NaOH 1.5 water to solid ratio 0.3253 and the molarity 14 which is relevant to the combination of paste highest compressive strength.
5. The maximum compressive strength of geo polymer mortar using Neyveli bottom ash is 35.55 N/mm2 for

Fag/paste ratio 1.4, FA/AA 1.2 Na2SiO3/NaOH 1.5 water to solid ratio 0.3447 and the molarity 14 which is relevant to the combination of paste highest compressive strength.

6. The maximum compressive strength of geo polymer mortar using Ennore bottom ash is42.36 N/mm2 for Fag/paste ratio 0.19, FA/AA 1.2 Na2SiO3/NaOH 1.5 water to solid ratio 0.3174 and the molarity 18 which is relevant to the combination of paste highest compressive strength.
7. The compressive strength is 45.63 N/mm²of geo polymer concrete with river sand as fine aggregate, 27.64 N/mm2 with foundry sand as fine aggregate, 29.48 N/mm2 as Neyveli bottom ash as fine aggregate and 49.28 N/mm2 with Ennore bottom ash as fine aggregate was obtained and the proportion mentioned in chapter 4 is adopted particularly coarse aggregate to fine aggregate ratio is 1.84, 1.94, 2.23 and 4.88. All other combination of FA/AA, Fag/Paste is the optimum proportion obtained in respect of paste and mortar.

Table 39 Compressive Strength for Geo polymer Mortar Using River Sand as Fine Aggregate for Different Molarity and Na_2SiO_3 to NaOH ratio.

Sl. No.	Mole	Fine Aggregate	Fly Ash(FA)		Alkaline activator(AA)		Total	W/S	Na_2SiO_3/NaOH	Density (gm / cc)	Compressive Strength (N/mm²)
			Fly Ash	GGBS	Na_2SiO_3	NaOH					
1	10	62.12	16.53	4.13	12.30	4.92	100.00	0.3614	2.50	2.23	38.79
2	12	62.12	16.53	4.13	10.33	6.89	100.00	0.3600	1.50	2.21	43.11
3	14	62.12	16.53	4.13	10.33	6.89	100.00	0.3447	1.50	2.25	43.81
4	16	62.12	16.53	4.13	12.30	4.92	100.00	0.3292	2.50	2.27	37.51
5	18	62.12	18.60	2.07	10.33	6.89	100.00	0.3174	1.50	2.27	46.36
6	18	62.12	16.53	4.13	10.33	6.89	100.00	0.3174	1.50	2.29	44.80

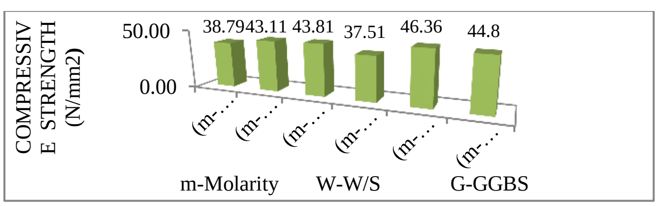

Fig 6: Compressive Strength for Geo polymer Mortar Using River Sand as Fine Aggregate for Different Molarity and Na_2SiO_3 to NaOH ratio.

FA/AA=1.2 F.Ag/Paste=1.64

Table 40 Compressive Strength for Geo polymer Mortar Using Foundry Sand as Fine Aggregate for Different Molarity and Na_2SiO_3 to NaOH ratio.FA/AA=1.2 F.Ag/Paste=1.2

Sl. No.	Mole	Fine Aggregate	Fly ash(FA)		Alkaline activator(AA)		Total	W/S	Na_2SiO_3/NaOH	Density (gm / cc)	Compressive Strength (N/mm²)
			Fly Ash	GGBS	Na_2SiO_3	NaOH					
1	10	54.55	19.83	4.96	14.76	5.90	100.00	0.3377	2.5	2.04	9.33
2	12	54.55	19.83	4.96	12.40	8.26	100.00	0.3402	1.5	2.11	19.35
3	14	54.55	19.83	4.96	12.40	8.26	100.00	0.3253	1.5	2.12	24.17
4	16	54.55	19.83	4.96	14.76	5.90	100.00	0.3066	2.5	2.11	20.86
5	18	54.55	22.31	2.48	12.40	8.26	100.00	0.2987	1.5	2.15	15.08
6	18	54.55	19.83	4.96	12.40	8.26	100.00	0.2987	1.5	2.14	16.26

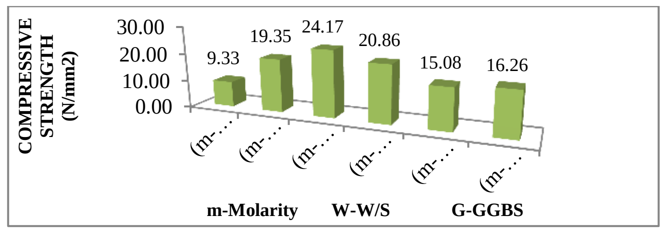

Fig 7: Compressive Strength for Geo polymer Mortar Using Foundry Sand as Fine Aggregate for Different Molarity and Na_2SiO_3 to NaOH ratio./FA/AA=1.2 F.Ag/Paste=1.2

Table 41.Compressive Strength for Geopolymer Mortar Using Neyveli Bottom Ash as Fine Aggregate for different Molarity and Na_2SiO_3 to NaOH ratio FA/AA=1.2 F.Ag/Paste=1.4

Sl. No.	Mole	Fine Aggregate	Fly ash(FA)		Alkaline activator(AA)		Total	W/S	Na_2SiO_3/NaOH	Density (gm / cc)	Compressive Strength (N/mm²)
			Fly Ash	GGBS	Na_2SiO_3	NaOH					
1	10	58.33	18.18	4.55	13.53	5.41	100.00	0.3614	2.5	1.95	25.20
2	12	58.33	18.18	4.55	11.36	7.58	100.00	0.3600	1.5	2.02	26.62
3	14	58.33	18.18	4.55	11.36	7.58	100.00	0.3447	1.5	2.01	35.55
4	16	58.33	18.18	4.55	13.53	5.41	100.00	0.3292	2.5	1.99	17.06
5	18	58.33	18.18	4.55	11.36	7.58	100.00	0.3174	1.5	1.92	24.21

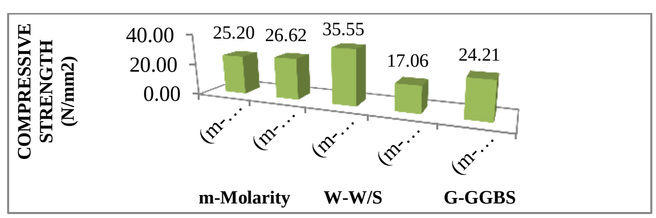

Fig 8: Compressive Strength for Geopolymer Mortar Using Neyveli Bottom Ash as Fine Aggregate for different Molarity and Na_2SiO_3 to NaOH ratio FA/AA=1.2 F.Ag/Paste=1.4

Table 42.Compressive Strength for Geo polymer Mortar Using Ennore Bottom Ash as Fine Aggregate for different Molarity and Na2SiO3 to NaOH ratio FA/AA=1.2 F.Ag/Paste=0.19

Sl. No.	Mole	Fine Aggregate	Fly ash(FA)		Alkaline activator (AA)		Total	W/S	Na_2SiO_3/NaOH	Density (gm / cc)	Compressive Strength (N/mm²)
			Fly Ash	GGBS	Na_2SiO_3	NaOH					
1	10	15.97	36.67	9.17	27.28	10.91	100.00	0.3614	2.50	1.75	24.41
2	12	15.97	36.67	9.17	22.92	15.28	100.00	0.3600	1.50	1.79	14.50
3	14	15.97	36.67	9.17	22.92	15.28	100.00	0.3447	1.50	1.82	31.24
4	16	15.97	36.67	9.17	27.28	10.91	100.00	0.3292	2.50	1.86	29.79
5	18	15.97	36.67	9.17	22.92	15.28	100.00	0.3174	1.50	1.89	42.36

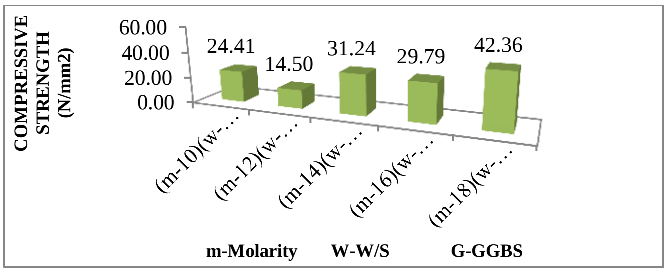

Fig 9: Compressive Strength for Geo polymer Mortar Using Ennore Bottom Ash as Fine Aggregate for different Molarity and Na2SiO3 to NaOH ratio FA/AA=1.2 F.Ag/Paste=0.19

6. CONCLUSIONS

A) OBSERVATION AND CRITICAL REMARKS

Based on the extensive observations and discussions made in topic 5, following are the salient conclusions.

1. The maximum compressive strength 46.76N/mm2 for FA/AA=1.2, molarity 14, Na_2SiO_3/NaOH 1.5 GGBS 20% and the water to solid ratio 0.3253. The maximum compressive strength of molarity 10, 12 mole the water to solid ratio is 0.3724, 0.3402 for 16 molarity the water solid ratio 0.2956 which is near to the above two moles for molarity 18 the water to solid ratio is 0.2896. From the above it is observed that for less molarity the water solid ratio needed is 0.3724 and higher moles of 18 the less water to solid ratio of 0.2896 gives the maximum compressive strength.
2. The maximum compressive strength of geo polymer mortar using river sand is 43.81 N/mm² with 14 molarity compared to all other fine aggregates. All other fine aggregates the maximum strength obtained is in different molarity based on the water solid ratio. The foundry sand water to solid ratio is 0.3447 molarity 14, Neyveli bottom ash water to solid ratio 0.3253 molarity 14. For the Ennore bottom ash water to solid ratio is 0.3174 molarity 18 from the above it is concluded that the for a particular fine aggregate the requirement of water to solid ratio is necessary to get the maximum strength.
3. The maximum Compressive strength of 49.28 N/mm² using bottom ash as fine aggregate and 45.63 N/mm² using river sand as fine aggregate is obtained which is relevant to the strength of geo polymer mortar in respective of the above two sands.
4. The bottom ash combination is very less compared to other sand in which fly ash is maximum of 20.61% compare to all other sand which is around 10%.

B) SCOPE FOR FURTHER STUDY

- In this study the high calcium fly ash passing 90 micron is taken up for the investigation. It is necessary to do experiment less than 90 micron fly ash.
- The chemical composition is also analyzed detail and the combination of silica, alumina and calcium oxide is also taken into account for the analysis.
- We have conducted the water solid ratio that is variable due to sodium hydroxide molarity starts from m10 to m18. It is necessary to conduct experiment of constant water to solid ratio that is 0.38 in all the cases by varying FA/AA ratio.
- Further investigation of tensile stress flexure strength is necessary in term of paste, motar and concrete is necessary.
- Application aspect such as precast material for housing, building blocks and roads pavements product such as inner locking blocks, kerb stones, center median is also to be studied in detail.
- Durability studied to be conducted.

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