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Experimental Investigation of Alkali Activated Slag and Fly Ash based Geopolymer Concrete

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***Abstract:-* This thesis report is about experimental investigation done on various strength and durability parameters of Alkali Activated Slag (AAS) And Fly ash(FA) Based Geopolymer Concrete and comparing it with nominal mix conventional concrete of grade M40. The durability properties namely Rapid Chloride Permeability Test (RCPT) and Sorpitivity have been investigated. The alkali activators are attained by combination of Sodium Hydroxide (Naoh) and Sodium Silicate (Nacl) in the ratio of 2.5 and of molarities 12M and 16M, and by varying curing Regime namely Open Air Curing and Dry Curing. Totally nine mixes were prepared with Naoh concentration of 12M and 16M and Open Air Cured in ambient temperature; and Dry cured for 24hrs at 100°c in Hot Air Oven and then left to ambient temperature until day of testing, including one nominal control mix..Split tensile and flexural strength and durability tests were conducted on each of nine mixes at 56days and 90days. Compressive strength tests are carried out on 14days,28days,56days and 90days. The investigation results shows that there is a increase in compressive and flexural strength with the increase in concentration of NaOH solution, and also noted that there is an increase in tensile strength with decrease in concentration of Naoh solution. However, with regards to the Durability properties such as water Sorptivity and Rapid Chloride Penetration Test; the AAS-FA based Geopolymer concrete was found to not perform well as a result of surface cracking dominating these characteristics. When compared with control mix results with AAS-FA based geopolymer concrete mix it shows a greater improvement of strength parameters in Geopolymer concrete than in conventional concrete. and the cost in present rate seems to be cheaper in case of preparing geopolymer concrete than conventional concrete. Hence AAS and FA based geopolymer concrete has great potential for utilization in construction field as it is Eco-Friendly and also facilitates use of Fly ash and GGBS which is a waste product of thermal power plant and coal burning industries.**

CHAPTER1
INTRODUCTION

1.1 GENERAL

Ordinary Portland cement (OPC) is the most important and widely used one among building materials popularly.the application of concrete in the area of infrastructure ,habitation,and transportation have greatly prompted the development of civilization, economicprogress, and the stability and of the quality of life. However
The utilization of cement causes pollution to the environment and reduction of raw material (limestone). The production of cement is increasingly about 3% annually, among the green gases CO2 contributes about 65% of global warming. The production of one ton of cement liberates about one ton of CO2 to atmosphere. Furthermore, it has been reported that the durability of ordinary Portland cement is under examination, as many concrete structures; especially those built in corrosive environments start to deteriorate after 20 to 30 years,even though they have been designed for more than 50years of service life.

One possible alternative is the use of alkali-activated binder using industrial byproductscontaining silicate materials (Gjorv, 1989; Philleo, 1989). The most common industrial by-products used as binder materials are fly ash (FA) and ground granulated blast furnace slag (GGBS). GGBS has been widely used as a cement replacement material due to its latent hydraulic properties, while fly ash has been used as a pozzolanic material to enhance the physical, chemical and mechanical properties of cements and concretes (Swamy, 1986).

GGBS is a latent hydraulic material which can react directly with water, but requires an alkali activator. In concrete, this is the $Ca(OH)_2$released from the hydration of Portland cement. While fly ash is a pozzolanic material which reactswith Ca(OH)2from Portland cement hydration forming calcium silicate hydrate (C-S-H) as the hydration product. This delay causes the blended cements to develop strength more slowly at early ages compared to the normal Portland cement.Geopolymer concrete is synthesized from geological origin and by products such as Fly ash , Silica fume, GGBS , Rice husk ash , metakolin etc…Recent research has shown that it is possible to use 100% fly ash or slag as thebinder in mortar by activating them with an alkali component, such as; caustic alkalis, silicate salts, and non silicate salts of weak acids (Bakharev, Sanjayan, &Cheng, 1999a; Talling&Brandstetr, 1989). There are two models of alkali activation. Activation by low to mild alkali of a material containing primarily silicate and calcium will produce calcium silicate hydrate gel (C-S-H), similar to that formed in Portland cements, but with a lower Ca/Si ratio (Brough& Atkinson, 2002; Deja, 2002). The second mechanism involves the activation of material containing primarily silicate and aluminates using a highly alkaline solution. This reaction will form an inorganic binder through a polymerization process (Barbosa,MacKenzie,

&Thaumaturgo, 2000; Sindhunata, 2006a; Xu, 2002). The term “Geopolymeric” is used to characterise this type of reaction from the previous one, and accordingly, the name geopolymer has been adopted for this type of binder (Davidovits, 1994). The geopolymeric reaction differentiates geopolymerfrom other types of alkali activated materials (such as; alkali activated slag) since the product is a polymer rather than C-S-H gel.

1.2 NEED FOR ALTERNATIVE MATERIAL

In order to address environmental effects and pollution due to manufacture of cement there is need for an alternative cementitious material , the newly developed geopolymer concrete has no IS standards. High cost is the dominating factor of convectional construction material which is affecting thehousing system. As an alternative method to overcome this drawback which is decreasing the strength of building, it is necessary to make research on any alternating materials which will decrease the cost and increase the strength of concrete. Fine aggregate and coarse aggregate are the important ingredients in concrete. Due to demand of cementitious materials there is a need of alternative materials. Lot of materials are available that can be used as an alternative material in concrete. Some of the materials are copper slag, natural fibers, carbon fiber, steel fiber, ceramic tiles, and plastics. Waste materials from industries also used as an alternative material in concrete. Materials such as GGBS, flyash, silica fumes, quartz RHA (rice husk), coconut fiber ash also used**.**

1.3 NEED FOR THE STUDY

Buildings are considered to be durable for long time without showing any failure. In the recent revision of IS: 456-2000, one of major points discussed is the durability.

Use of geopolymers not only helps in getting them utilized in concrete, it helps in reducing the cost of concrete making when purchased in bulk amount, numerous indirect benefits such as reduction landfill cost, saving energy, and protecting the environmentfrom possible pollution effects..Every concrete structure requires proper maintenance to have long designed life with proper concrete material usage.

At a time when landfill space is becoming almost impossible due to increasing land value, then recycling and reuse of wastes as beneficial products should be strongly encouraged and examined. A concrete using cement alone as a binder requires high paste volume, which often leads to excessive shrinkage and large evolution of heat of hydration, besides increased cost. An attempt is made to replace cement by a mineral admixture like ground granulated blast furnace slag (GGBS) and silica fume in concrete mixes to overcome these problems. Increasing the performance of concrete with the partial replacement of mineral admixture using GGBS along with chemical admixture eliminates the drawbacks besides enhancing durability characteristics.

1.4 ORGANISATION OF REPORT

Chapter1 discusses the introduction of the whole thesis report.

Chapter2 discusses about the aim, scope and objective of the present investigation.

Chapter3 briefly explains about the experimental program ,materials collection , mix design, casting progresses.

Chapter4 is the discussions about the results of testing processes.

Finally the summary and conclusion of the thesis is briefly concluded in **Chapter 5**.

CHAPTER 2

AIMSCOPE AND LITERATURE REVIEW

2.1 AIM

The aim of the research is to evaluate the performance and suitability of fly ashbased geopolymer and alkali activated slag (AAS) as an alternative to the use of ordinary Portland cement (OPC) in the production of concrete. The individual objectives will include;

1)Optimization of the mix design for alkali activated slag(AAS) and fly ash based geopolymer concrete.

2) Evaluation of the strength development of alkali activated slag (AAS) and flyash based geopolymer concrete comparing with nominal control mix of M40 grade concrete.

3) Evaluation of the performance of AAS and FA-based Geopolymerconcrete with respect to the strength and durability properties for long time period of upto 90days.

2.2 SCOPE

The study builds on and contributes to the development of new ECO-Friendly binders in concrete. Although there are numerous studies that assess thesuitability of AAS and fly ash based geopolymer to replace OPC as a binder inconcrete, many of these studies have focused on the strength properties anddurability in terms of sorpitivity and RCPT. Only limited research conducted on the chloride penetration and there has not been an extended study. Comparing the two types of materials. As such, this study provides additional insight into the difference in strength development and durability in terms of chloride resistance.

2.3 OBJECTIVE

In order to address environmental effects associated with OPC , there is need to develop alternative binders to make concrete which gave rise to development of Geopolymer concrete.

- To develop the concrete that can be cured at ambient temperature by using industrial by products such as Fly Ash and GGBS.
- To obtain optimal values for mix constituents to maximize product performance.
- Evaluation of the performance of Fly Ash and GGBS based AAS concrete with respect to workability, strength and durability for two different morality (12M & 16M) of alkali solution.

- Main scope of this Experimental investigation on geopolymer concrete is to show the strength characteristics on specific periods namely 14 days , 28 days, 56 days , 90 days .
- The curing regims of AAS specimens are namely , Dry curing (oven curing) & ambient temperature curing (open air curing).
- And also to investigate the specimens for SORPITIVITY & RCPT durability tests on 56 & 90 days .
- As geopolymer concrete strength results increase as days longer the parameters are tested for long terms.

2.4 LITERATURE REVIEW

A.A. Adam, et al ., (2010),studied that alkali activated binders can achieve similar strengths to bothordinary Portland cement (OPC) and blended cements. However, to date little research has been undertaken ontheir durability properties. This study investigated the influence of activators concentration and alkali modulus onstrength, sorptivity and carbonation of alkali activated slag (AAS) and fly ash (FA) based geopolymer concrete.The same testswere also conducted on blended concrete with 30%, 50%, and 70% OPC replacement with groundgranulated blast-furnace slag (GGBS) along with control concrete. Results indicate that the alkali modulus hasa major effect on sorptivity of both AAS and geopolymer, however no significant effects of the alkali moduluson carbonation was observed on AAS concrete. The phenolphthalein indicator gave no clear indication betweencarbonated and non-carbonated area in geopolymer specimens. The sorptivity of blended concrete reduced butthe carbonation increased as the replacement level increased.

AmmarMotorwala,et al ., (2013), , discussed about thefeasibility of alkali activated geo-polymer concrete, as afuture construction material. Considering the increasing demand fordeveloping alternative construction materials, due to thegrowing environmental concerns.The main objective of thisstudy involves observation of structural behaviors of thefresh fly ash-based geo-polymer concrete, understandingthe basic mixture proportioning of fly ash-based geopolymerconcrete and evaluating various economic considerations.

AndiArham Adam,et al ., (2009),Experimentally studied in detail about the strength and durability properties of alkali activatedslag (AAS) and fly ash based geopolymer concrete. This studyprovides new insight into the strength development and the durabilityperformance in terms of chloride and carbonation resistance.The effect of sodium oxide dosage and activator modulus on the compressivestrength of mortar specimens was explored and the results used to designsuitable AAS and geopolymer concrete mixes. It is concluded that AAS and fly ash based geopolymer concretes can exhibitcomparable strength to OPC and slag-blended OPC concretes. However, withregards to the durability properties such as water sorptivity, chloride andcarbonation resistance; the AAS concrete was found to not perform well as aresult of surface cracking dominating these characteristics. The fly ash basedgeopolymer concrete performed better in water sorptivity and chloride penetrationtests than the OPC concrete, the slag-blended OPC concrete, and the AASconcrete. It was found that the fly ash based geopolymer concretes exhibitedhigh charge and high conductivity in the accelerated chloride diffusion tests.However it was concluded that this is a reflection of the concentration andcomposition of the free ions present rather than the ability to resist the diffusion of chloride ions.

Anuar K.A,et al ., (2011),Investigated about the Geopolymer concrete incorporating with recycle concrete aggregate (RCA) is one of the method. Waste Paper Sludge Ash (WPSA) and alkaline liquid as a binder are being used to replaced the Portland cement to produce geopolymer concrete. The alkaline liquid that been used in geopolymerisation is the combination of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3). In the present study, two (2) series of geopolymer concrete specimens composing two (2) different molar of sodium hydroxide (NaOH) which are 8M and 14M were adopted. There are 30 cube specimens at size 100mm x 100mm x 100mm were prepared which is 15 cubes for 8M and another 15 cubes for 14M. The compressive strength of the geopolymer concrete specimens is tested at the age of 3, 7, 14, 21 and 28 days after cured in local laboratory ambient condition. The result shows that the strength of geopolymer concrete based Waste Paper Sludge Ash (WPSA) incorporating with recycle concrete aggregate (RCA) increase by increasing the molarities of sodium hydroxide (NaOH).

Anurag Mishra,et al ., (2008),Conducted experiments on fly ash based geopolymer concrete by varying the concentration of NaOH and curing time. Total nine mixes were prepared with NaOH concentration as 8M, 12M, 16M and curing time as 24hrs, 48hrs, and 72hrs. Compressive strength, water absorption and tensile strength tests were conducted on each of the nine mixes. Results of the investigation indicated that there was an increase in compressive strength with increase in NaOH concentration. Strength was also increased with increase in curing time, although the increase in compressive strength after 48hrs curing time was not significant. Compressive strength up to 46 MPa was obtained with curing at 60^{o}C. The results of water absorption test indicated that % water absorption of cubes decreased with increase in NaOH concentration and curing time. Hence, geopolymar concrete has a great potential for utilization in construction industry as it is environmental friendly and also facilitates the use of fly ash, which is a waste product from coal burning industries.

D.Hardjito and B.V.Rangan,et al ., (2006),conducted an experimental work involved conduct of long-term tests on low-calcium fly ashbasedgeopolymer concrete. The tests currently available for Portland cementconcrete were used. In the experimental work, only one source of dry low-calciumfly ash (ASTM Class F) from a local power station was used. Analytical methodsavailable for Portland cement concrete were used to predict the test results.Based on the test results, the following conclusions are drawn, There is no substantial gain in the compressive strength of heat-cured fly ashbasedgeopolymer concrete with age. Fly ash-based geopolymer concrete cured in the laboratory ambient conditionsgains compressive strength with age. The 7th day compressive strength ofambient-cured specimens depends on the average ambient temperature during thefirst week after casting; higher the average ambient temperature higher is thecompressive strength.

Dr.JosephDavidovits,et al ., (2002),presented a powerpoint presentation of 30 slides describing following geopolymer applications developed since 1972 in France, Europe and USA. The Geopolymer chemistry concept was invented in1979 with the creation of a non-for profit scientific organization, the Institut de RecherchesurlesGéopolymères (Geopolymer Institute). Fire resistant wood panels,Insulated panels and walls, Decorative stone artifacts,Foamed (expanded) geopolymer panels for thermal insulation,Low-tech building materials,Energy low ceramic tiles,Refractory items,thermal shock refractory, Aluminum foundry application, Geopolymer cement and concrete, Fire resistant and fire proof composite for infrastructures repair and strengthening, Fireproof high-tech applications, aircraft interior, automobile,High-tech resin systems.The applications are based on 30 patents filed and issued in several countries. Several patents arenow in the public domain, but others are still valid. The applications show genuine geopolymerproducts having brilliantly withstood 25 years of use and that are continuously commercialized.

Dr.S.P.Rajesh,et al ., (2013), investigated the potential of alkali activated slag as a sole binder in producing concrete.The performance of alkali-activated slag concrete with sodium silicate, sodium hydroxide, sodium carbonate asactivator are used at 4% Na2O(by weight of slag) and 4% of hydrated lime by total weight of solid binder content ifused as a retarder. The scope of the work covered four mixes: - Normal OPC mix and three alkali activated slag mixesof the same binder content and the same water binder ratio. The fresh concrete properties studied were setting time and

workability and the Engineering properties studied are compressive strength was measured in 1,7,28 days, split tensilestrength was measured in 7,28 days and flexure, punching shear strength was compared in 12 days only. The AASconcrete with different activators investigated was found to achieve good workability comparable with that of OPC.Sodium silicate, sodium hydroxide activated slag mixes sets very quickly. AAS concrete is much more sensitive tocuring where if there is no addition of retarder (hydrated lime) to the mix. Among AAS mix sodium silicate was thebest; sodium carbonate was the second; and sodium hydroxide was third in terms of compressive, split tensile strengthsand in terms of flexure strength and punching shear strength sodium hydroxide was best; sodium carbonate was second;sodium silicate (water glass) was third.

Fareed Ahmed Memom,et al ., (2011),reported the results of an experimental workconducted to investigate the effect of curing conditions on thecompressive strength of self-compacting geopolymer concreteprepared by using fly ash as base material and combination of sodiumhydroxide and sodium silicate as alkaline activator. The experimentswere conducted by varying the curing time and curing temperature inthe range of 24-96 hours and 60-90°C respectively. The essentialworkability properties of freshly prepared Self-compactingGeopolymer concrete such as filling ability, passing ability andsegregation resistance were evaluated by using Slump flow,V-funnel, L-box and J-ring test methods. The fundamentalrequirements of high flowability and resistance to segregation asspecified by guidelines on Self-compacting Concrete by EFNARCwere satisfied. Test results indicate that longer curing time and curingthe concrete specimens at higher temperatures result in higher

compressive strength. There was increase in compressive strengthwith the increase in curing time; however increase in compressivestrength after 48 hours was not significant. Concrete specimens curedat 70°C produced the highest compressive strength as compared tospecimens cured at 60°C, 80°C and 90°C.

FranstisekSkvana,et al ., (2006),reported about Geopolymer prepared by brown coal fly ash alkali activation contains mainly structures of the types AlQ4(4Si)and SiQ4(3Al)and SiQ4(2-3Al). Any presence of the temporary phase with different composition was not found between geopolymer andaggregate as it is at the concretes from Portland cement. Geopolymer composition is almost the same in the close nearnesseven in the geopolymer matrix. Elastic modulus evaluated for the mixed geopolymeric and C–S–H phase by means of nanoindentationwas found to be E= 36.1 ± 5.1 GPa. Such result is comparable (a little bit higher) to ordinary Porland cement pastes.

G.Saravanan,et al ., (2013),reviewed about theConcrete usage around the world is second only to water. Ordinary Portland Cement (OPC) is conventionally used as theprimary binder to produce concrete. But the amount of carbon dioxide released during the manufacture of OPC due tothe calcinations of lime stone and combustion of fossil fuel is in the order of 600 kg for every ton of OPC produced. Inaddition, the extent of energy requires to produce OPC is only next to steel and aluminum. On the other hand, theabundant availability of fly ash worldwide creates opportunity to utilize (by – product of burning coal, regarded as awaste material) as substitute for OPC to manufacture concrete. Binders could be produced by polymeric reaction ofalkali liquids with the silicon and the aluminum in the source materials such as fly ash and rice husk ash and thesebinders are termed as Geopolymer. In Geopolymer Concrete, fly ash and aggregates are mixed with alkaline liquids suchas a combination of Sodium Silicate and Sodium Hydroxide. United Nation’s Intergovernmental panel on ClimateChange (IPCC) prepared a report on global warming during April 2007 which enlists various methods of reduction ofCO2 emissions into atmosphere. As per that report, unmindful pumping of CO2 into the atmosphere is the main culpritfor the climate change. Large volume of fly ash is being produced by thermal power stations and part of the fly ashproduced is used in concrete industry, low laying area fill, roads and embankment, brick manufacturing etc. The balanceamount of fly ash is being stored in fly ash ponds. Hence it is imperative on the part of Scientists and Engineers to devisesuitable methodologies for the disposal of fly ash. Disposal of fly ash has the objective of saving vast amount of landmeant for ash pond to store fly ash. Further, use of fly ash as a value added material as in the case of geopolymerconcrete, reduces the consumption of cement. Reduction of cement usage will reduce the production of cement which inturn cut the CO2 emissions. Many researchers have worked on the development of geopolymer cement and concrete forthe past ten years. The time has come for the review of progress made in the field of development of geopolymerconcrete. Consequently 102 papers pertaining to the ingredients and technology of geopolymer concrete have beenreviewed in this state of the art paper.

K.Parthiban,et al ., (2013),in this paper the influence of the various proportions of GGBS (0-100%) on Fly Ash based GPC; the effect of the amount of Alkaline Activated Solution (AAS) in themixture of GPC on their compressive strength is studied under ambient temperature conditions. Fromthe experimental results, it was observed that the compressive strength of the GPC is increased with theincrease in the percentage of GGBS and also with the increase in the amount of the sodium silicatesolution in which the concentration of sodium hydroxide in the aqueous solution is fixed at a constantvalue of 10M.

Mohd.NadeemQuershi,et al ., (2013), presented a paper where the effect of curing method on the strength development of alkali- activated blast furnace slag paste. In this study, alkali activation was done using a combination of potassium hydroxide and sodium silicate. The test parameters include the curing methods (water curing at 270C, heat curing at 500C and controlled curing with relative humidity 50%, 70% and 90 % at 270 C), alkali content with 6.41 %, 8.41 %, 10.41% and 12.41 % of the mass of GGBS. The compressive strength results showed that there is an increase in compressive strength with the increase in age of water curing and controlled curing specimens. A comparison of hot cured specimens, the increase in compressive strength with age was less. Further heat curing has shown to adversely affect compressive strength and to create internal micro cracking as well as surface cracks. The higher compressive strengths were obtained from water cured specimens.

Ravindra.N.Thakur,et al ., (2009),reported the results of an experimentalstudy on development of compressive strength and microstructure of geopolymer paste and mortar specimens prepared bythermal activation of Indian fly ash with sodium hydroxide and sodium silicate solution. The effect of main synthesisparameters such as alkali content(NaB2BO/AlB2BOB3B), silica content (SiOB2B/AlB2BOB3B), water to geopolymer solid ratio and sand to flyash ratio of geopolymer mixture and processing parameters such as curing time and curing temperature on development ofcompressive strength and microstructure of fly ash based geopolymer paste and mortar were studied. The compressivestrength of 48.20MPa was obtained for geopolymer mixture cured at 85P0PC for 48 hours with alkali content of 0.62 and silica content of 4.0. The mineralogical and microstructure studies on hardened geopolymer performed by means Scanningelectron microscope (SEM) and X-ray diffraction (XRD), showed formation of a new amorphous alumino-silicate phasesuch as hydroxysodalite and herschelite, which influenced development of compressive strength. The results obtained inthe current research will be useful for developing of mix design guidelines for commercial exploitation of the new bindingmaterial.

S.Vaidya,et al ., (2011), here he studied about the polymerization reaction temperatures involved with the formation of geopolymer were studied. Thermocouples were embedded in the fresh geopolymer concrete to record temperatures generated by the exothermic polymerization reaction. A preliminary study conducted on a cylindrical concrete specimen demonstrated that the temperature profile of fresh geopolymer concrete was casted with embedded thermocouples, and the temperature data was collected over a period of two weeks. Test data suggest that temperatures induced during the curing of geopolymer concrete are a function of a volume mixed. By trapping heat generated by the exothermic reaction within the geopolymer massthe need for external heat to ensure curing of the geopolymer concrete is eliminated. Compressive strength tests revealed that even when cured under heat generated from its own exothermic polymerization reaction, geopolymer concrete can reach compressive strengths of upto 43Mpa, eliminating the need for externally applied heat, a major constraint in field cast applications of geopolymer concrete.

Shankar.H.Sanni,et al ., (2012), experimentally investigated on performance of geopolymer concrete subjected to severe environmental conditions. The grades choosen for the investigation were M-30, M-40, M-50 and M-60, the mixes were designed for molarity of 8M and 12M. The alkaline solution used for present study is the combination of sodium silicate and sodium hydroxide solution with the ratio of 2.50 and 3.50.The test specimens were 150x150x150 mm cubes, 100x200 mm cylinders heat-cured at 60°C in an oven. The geopolymer concretes (GPCs) have inorganic polymer of alumino-silicates as the binder whereas the conventional concretes have Portland cement (P-C) generated C-S-H gel (beside freelime). It is well known that mechanisms of attack by sulphuric acid and magnesium sulphates are different. Conventional concretes are generally not resistant to prolonged exposure to very high concentrations of these solutions because decalcification of C-S-H will occur. As a result of this, OPC concrete surface becomes soft and could be removed, thus, exposing the interior concrete layers to deterioration. At the same time as the magnesium sulphate attack, causes decalcification of C-S-H to form magnesium silicate hydrate (M-S-H). It also destroys the binding capacity of C-S-H and leads to a loss of adhesion and strength in concrete. Durability of specimens were assessed by immersing GPC specimens in 10% sulphuric acid and 10% magnesium sulphate solutions separately, periodically monitoring surface deterioration and depth of dealkalization, changes in weight and strength over a period of 15, 30 and 45 days. The test results indicate that the heat-cured fly ash-based geopolymer concrete has an excellent resistance to acid and sulphate attack when compared to conventional concrete. Thus we can say that the production of geopolymers have a relative higher strength, excellent volume stability and better durability.

Suresh Thokchom,et al ., (2009),reported the experimental results of a study conducted to assess the resistance of fly ash based Geopolymer mortar specimens in sulfuric acid. The program consisted immersion of geopolymer mortar samples having percentage Na_2O ranging from 5% to 8% of fly ash in a 10% Sulfuric acid solution up to a period of 18 weeks and evaluation of its resistance in terms of visual appearance, residual alkalinity, changes in weight and compressive strength at regular intervals. Visual inspection of Geopolymer mortar samples did not reveal any recognizable change in colour and remained structurally intact though the exposed surface turned slightly softer. Through Optical microscope, corroded surface could be seen which increased with time of exposure. After exposure in the acid solution for 18 weeks, the Geopolymer samples almost lost its alkalinity and showed very low weight loss in the range from 0.41% to 1.23% of initial weight. Loss of weight was found higher for specimen with higher percent of Na_2O. Compressive strength loss at the end of test was 52% for specimen with 5% Na_2O and 28% for specimens with 8% Na_2O. Results obtained in the present study indicate that Geopolymers are highly resistant to sulfuric acid.

Wallah.S.E.,B.V.Rangan,et al ., (2006), Concrete is one of the most widely used construction materials; it is usuallyassociated with Portland cement as the main component for making concrete. Thedemand for concrete as a construction material is on the increase. It is estimated thatthe production of cement will increase from about from 1.5 billion tons in 1995 to2.2 billion tons in 2010 (Malhotra, 1999). The experimental work involved conduct of long-term tests on low-calcium fly ashbasedgeopolymer concrete. The tests currently available for Portland cementconcrete were used. In the experimental work, only one source of dry low-calciumfly ash (ASTM Class F) from a local power station was used. Analytical methodsavailable for Portland cement concrete were used to predict the test results.

CHAPTER 3
EXPERIMENTAL PROGRAM

3.1 MATERIALS USED

3.1.1 Cementitious Materials

The GGBS used to prepare alkali activated slag and fly ash based geopolymer concrete was supplied from Construction Chemicals Pvt.Ltd.,Vadapalani,Chennai.Thefly ash used for manufacturing of AAS geopolymer concrete is of Low Calcium Class-F was collected from Ennore thermal power plant,chennai.OPC used for manufacturing of nominal control mix of grade M40 is bought from local dealer of 53Grade. The Figure3.1,3.2 and 3.3 shows the pictures of used GGBS, Flyash and OPC respectively. Table 3.1 shows the chemical composition of binders in mass percentage of GGBS, Flyash and OPC .

GGBS is a latent hydraulic material which can react directly with water, but requires an alkali activator. In concrete, this is the Ca(OH)2 released from the hydration of Portland cement.

Fly ash is a pozzolanic material which reactswith Ca(OH)2 from Portland cement hydration forming calcium silicate hydrate (C-S-H) as the hydration product.

Fig: 3.1: Ground granulated blastfurnace(GGBS)

Fig: 3.2: Class-F Flyash

Fig:3.3: Ordinary Portland Cement(OPC 53Grade)

Table:3.1: Chemical Composition Of Binder(Mass%)

Component	**GGBS**	**FA**	**OPC**
SiO_2	33.45	49.45	19.9
Al_2O_3	13.46	29.61	4.62
Fe_2O_3	0.31	10.72	3.97
CaO	41.74	3.47	64.27
MgO	5.99	1.3	1.73
K_2O	0.29	0.54	0.57
Na_2O	0.16	0.31	0.15
TiO_2	0.84	1.76	0.23
P_2O_5	0.12	0.53	NA
Mn_2O_3	0.40	0.17	0.06
SO_3	2.74	0.27	2.56
LOI	NA	1.45	NA

As shown in **Table 3.2**, the fly ash used in this research is classified as class F flyashaccording to the requirement of IS standards. The fineness of the fly-ash was 86.82% passing 45µ sieve. The percentage of carbon in Gladstone FA was low as indicated by the low loss on ignition (LOI) therefore it has a higher pozzolanic activity and lower water demand. The SO_3 is less than 1% which will ensure high volume stability which is good for durability.

Table:3.2:Gladstone FA as Class F Fly Ash

Component	**SiO_2+ Al_2O_3+Fe_2O_3(%)**	**SO_3(%)**	**Na_2O(%)**	**LOI(%)**
ASTM C618	≥70.0	≤5.0	≤1.5	≤6.0
Class F Flyash	89.78	0.27	0.31	1.45

3.1.2 Alkaline Activators

The alkaline activator used in this study was a sodium silicate based solution which means that the alkaline activator contained sodium silicate and sodium hydroxide. The properties of the Grade D sodium silicate (Na_2SiO_3) supplied by Pentagon Chemicals, Ayapakam, Chennai. The sodium hydroxide solution (NaOH) was prepared by dissolving sodium hydroxide flakes in deionised water at least 1 day prior to mixing.

The alkaline liquid used was a combination of sodium silicate solution and sodium hydroxide solution in the ratio of 2.5. The sodium silicate solution (Na_2O=13.7%, SiO_2=29.4%,and water=55.9% by mass) was purchased from Pentagon chemicals, Chennai,in bulk amount. The sodium hydroxide (NaOH) in flakes of 99% purity was also purchased from Pentagon chemicals.

3.1.3 Aggregates

Local aggregates, comprising 20mm and 12.5mm coarse aggregates and fine aggregates(Natural River Sand), in saturated surface dry condition,were used. The coarse aggregates were crushed granite type aggregates and then fine aggregateswas fine sand. The fineness modulus of combined aggregates was 5.0. The grading of the aggregates is as presented in Table 3.3.

The moisture condition of the aggregate was asaturated surface dry (SSD) condition. The fine aggregate was river sand from local dealers. The coarse aggregates were obtained incrushed form, comprising basalt aggregate.

3.1.3.1 Coarse Aggregate

Coarse aggregates are particles greater than 4.75mm, but generally range between 9.5mm to 37.5mm in diameter. They can either be from Primary, Secondary or Recycled sources. Primary, aggregates are either Land- or Marine-Won. Gravel is a coarse marine-won aggregate; land-won coarse aggregates include gravel and crushed rock. Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder. Secondary aggregates are materials which are the by-products of extractive operations and are derived from a very wide range of materials.

The commercial stone is quarried, crushed, and graded. Much of the crushed stone used is granite, limestone,and trap rock. The last is a term used to designate basalt, gabbro, diorite, and other dark-colored, fine-grained igneous rocks. Graded crushed stone usually consists of only one kind of rock and is broken with sharp edges. Coarse aggregates are usually those particles which are retained on I.S. 4.75mm sieve.The aggregates should be absolutely clean, free from organic matter and other impurities. The aggregate should be capable to resist weather

Coarse aggregate used in this study is of size 12.5mm .

3.1.3.2 Fine Aggregate

Fine aggregate are basically sands from the land or the marine environment. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 9.5mm sieve. As with coarse aggregates these can be from Primary, Secondary or Recycled sources. The sand was first sieved through BIS 4.75 mm sieve to remove any particles greater than 4.75 mm and then was washed to remove the dust. Fine aggregate was tested as per IS 2386-1963. Fine aggregate is an accumulation of grains of mineral matter derived from thedisintegration of rocks. It is distinguished from gravel only by the size of the grains orparticles, but is distinct from clays which contain organic materials. Sands that have beensorted out and separated from the organic material by the action of currents of water or bywinds across arid lands are generally quite uniform in size of grains. Usually commercialsand is obtained from river beds or from sand dunes originally formed by the action ofwinds. Much of the earth's surface is sandy, and these sands are usually quartz and othersiliceous materials. The most useful commercially are silica sands, often above 98% pure.Beach sands usually have smooth, spherical to ovaloid particles from the abrasive action ofwaves and tides and are free of organic matter.

Sand is used for making mortar and concrete and for polishing and sandblasting.Sands containing a little clay are used for making molds in foundries. Clear sands areemployed for filtering water. Sand is sold by the cubic yard (0.76 m3) or ton (0.91 metricton) but is always shipped by weight.The weight varies from 1,538 to 1,842 kg/m3,depending on the composition and size of grain. Construction sand is not shipped greatdistances, and the quality of sands used for this purpose varies according to local supply.Standard sand is a silica sand used in making concrete and cement tests. The fine aggregate obtained from river bed of Koel, clear from all sorts of organic impurities was used in this experimental program.

3.1.4 Super Plasticizer

Sometimes a fifth ingredient is used in addition to four basic ingredients (i.e. Cement, Sand (Fine Aggregate), Coarse Aggregate and Water) to improve upon certain characteristics of concrete. This addition ingredient is called Admixture. The admixtures are added to concrete mix immediately before or during mixing operation to modify certain characteristics of concrete.

The purpose for which admixtures are commonly used in concrete are given below:

- To improve workability
- To accelerate setting and hardening
- To reduce the heat evolution
- To improve durability of concrete
- To impart water proofing properties of concrete
- To reduce shrinkage during setting
- To impart colour to concrete

The super plasticizer used for this experimental investigation is of BASF company , 1125 grade , which is supplied by construction chemicals, vadapalani, chennai.

3.2 PHYSICAL PROPERTIES OF MATERIALS

3.2.1 Sieve Analysis

Sieve analysisis a practice or procedure used to assess the particle size distribution of a granular material. The size distribution is often of critical importance to the way the material performs in use. A sieve analysis can be performed on any type of non-organic or organic granular materials including sands, crushed rock, clays, granite, feldspars, coal, soil, a wide range of manufactured powders, grain and seeds, down to a minimum size depending on the exact method. Being such a simple technique of particle sizing, it is probably the most common.

A gradation test is performed on a sample of aggregate in a laboratory. A typical sieve analysis involves a nested column of sieves with wire mesh cloth.

A representative weighed sample is poured into the top sieve which has the largest screen openings. Each lower sieve in the column has smaller openings than the one above. At the base is a round pan, called the receiver.

The column is typically placed in a mechanical shaker. The shaker shakes the column, usually for some fixed amount of time. After the shaking is complete the material on each sieve is weighed. The weight of the sample of each sieve is then divided by the total weight to give a percentage retained on each sieve.

The size of the average particle on each sieve is then analysed to get a cut-off point or specific size range, which is then captured on a screen.

The results of this test are used to describe the properties of the aggregate and to see if it is appropriate for various civil engineering purposes such as selecting the appropriate aggregate for concrete mixes and asphalt mixes as well as sizing of water production well screens.

The results of this test are provided in graphical form to identify the type of gradation of the aggregate. The complete procedure for this test is outlined in the American Society for Testing and Materials .

A suitable sieve size for the aggregate should be selected and placed in order of decreasing size, from top to bottom, in a mechanical sieve shaker. A pan should be placed underneath the nest of sieves to collect the aggregate that passes through the smallest. The entire nest is then agitated, and the material whose diameter is smaller than the mesh opening pass through the sieves. After the aggregate reaches the pan, the amount of material retained in each sieve is then weighed.

The sieve analysis set up for coarse aggregate is shown in Figure 3.4. and sieve analysis setup for fine aggregate is shown in Figure 3.5.

The aggregates used in this experimental investigation is coarse aggrgates of size 20mm and 12.5mm. and then is been used as fine aggregate.

The grading of the 20mm coarse aggregate , 12.5mm coarse aggregate ,fine aggregate is shown in Table 3.1, Table 3.2, Table3.3 respectively. From the results of sieve analysis it is clear that the coarse aggregate are of correct sizes as per IS standards, the fine aggregate used in this experimental investigation belongs to ZoneIII .

Fig:3.4: Coarse Aggregate Sieve Setup

Fig:3.5: Fine Aggregate Sieve Setup

Table :3.3: Sieve Analysis Of Coarse Aggregate (20mm)

Sieve size	Weight	Weight Retained %	Cumulative weight retained %	Cumulative passing aggregate %	Remarks
40mm	0	0	0	100	
20mm	720	24	24	87.23	**85-100**
10mm	2270	75.67	99.67	0.33	
4.75mm	10	0.33	100	0	
Pan	0	0	100	0	
total	3000	100 %			

Table:3.4: Sieve Analysis Of Coarse Aggregate (12.5mm)

Sieve size	Weight	Weight Retained %	Cumulative weight retained %	Cumulative passing aggregate %	Remarks
16mm	0	0	0	100	
12.5mm	145	4.83	4.83	**95.17**	**95-100**
10mm	1100	36.67	41.5	58.5	
4.75mm	1670	55.67	97.17	2.83	
Pan	85	2.83	100	0	
Total	3000	100 %			

Table:3.5: Sieve Analysis Of Fine Aggregate

Sieve size	Weight	Weight Retained %	Cumulative weight retained %	Cumulative passing aggregate %	Remarks
4.75mm	30	3	3	97	
2.36mm	70	7	10	90	
1.18mm	260	26	36	64	Zone III
600µ	205	20.5	56.5	43.5	
300 µ	285	28.5	85	15	
150 µ	120	12	97	3	
Pan	30	3	100	0	
Total	1000	100			

3.2.2 Bulk Density

Bulk density of aggregates is the mass of aggregates required to fill the container of a unit volume after aggregates are batched based on volume.It depends on the packing of aggregate i.e. Either **loosely packed aggregates or well densecompactedaggregates.** In case, if the **specific gravity** of material is known, then it depends on the **shape and size of particles**. It is because, if all the particles are of **same size** than packing can be done up to a very limited extent. If the addition of smaller particles is possible within the voids of larger particles than these smaller particlesenhance the bulk density of the **packed material**. Shape of the particles also influence very widely, because closeness particles depends on the **shape of aggregates**.

The test will be carried out by using metal cylinder having prescribed depth and diameter and the bulk density is to be determined depending on the **maximum size of aggregates** and the **degree of compaction**.

Loose bulk density can be determined by **filling the container with dried aggregates until it overflows from the container.** Now level the top surface of container by rolling a rod on it. After that, weight the aggregate mass that is inside the container and divide it by the volume of container. This will give you the bulk density of the loose aggregates.

Compacted bulk density can be determined by filling the container in three layers and tamped each layer with a 16mm diameter rounded nosed rod. After filling in three layers, now **leveled the top surface** and evaluate compacted bulk density by using the **same expression** as for loose bulk density.The bulk density results of combined aggregates are tabulated below in Table:3.6.

Table:3.6:Bulk Density Of Combined Aggregtes

Bulk Density	20mm Aggregate	12.5mm Aggregate	Fine Aggregate
Kg/m³	1646	1554	1716.66

3.2.3Specific Gravity

3.2.3.1 Apparent Specific Gravityand Water Absorption Of Aggregates

A balance or scale having a capacity of 1 kg or more, sensitive to 0.1 g or less and accurate within 0.1 percent of the test load at any point within the range of use for this test. Within any 100 g range of test load, a difference between readings shall be accurate within 0.1 g.A flask or other suitable container into which the fine aggregate test sample can be readily introduced and in which the volume content can be reproduced within ± 0.1 cm^3 . The volume of the container filled to mark shall be at least 50 percent greater than the space required to accommodate the test sample. A volumetric flask of 500 cm^3 capacity or a jar fitted with a pycnometer top is satisfactory for a 500 g test samples of most fine aggregates.

Obtain approximately 1000 g of the fine aggregate from the sample by use of sample splitter or by quartering. Dry it in a suitable pan or vessel to constant weight at a temperature of 100 to 110ºC. Wash the sample thoroughly on a 71 mm sieve.Allow the sample to cool to a comfortable handling temperature, cover with water and permit to stand for 24 ± 4 hours.

Decant excess water with care to avoid loss of fines, spread the sample on a flat surface exposed to a gently moving current of warm air, and stir frequently to secure uniform drying. Continue this operation until the test specimen approaches a free-flowing condition. Then, place a portion of the partially dried fine aggregate loosely into the mold, held firmly on a smooth non-absorbent surface with the large diameter down, lightly tamp the surface 25 times with the tamper and lift the mold vertically. Immediately introduce into the pycnometer 500 g of the fine aggregate and fill with water to approximately 90 percent of capacity.Roll, invert and agitate the pycnometer to eliminate all air bubbles. Adjust its temperature to 23 ± 1.7ºC, if necessary by immersion in circulating water and bring the water level in the pycnometer to its calibrated capacity. Leave pycnometer in circulating water or water bath for 30 ± 5 minutes to ensure constant temperature. Continue to agitate every 10 minutes to ensure all air bubbles are eliminated. Dry off pycnometer and weigh. Record this and all other weights to the nearest 0.1 g. Remove the fine aggregate from the pycnometer, dry to constant weight at a temperature of 100 to 110o C, cool in air at room temperature for 1/2 to 1 1/2 hours and weigh.

Fig:3.6: Soaking Of Aggregates

Fig:3.7Pycnometer + Sample Aggregate + Water

Calculations

Apparent specific gravity

A- Weight of aggregate sample
B- Weight of pynometer + sample + water
C- Weight of pycnometer + water
D- Oven Dried weight of sample

Apparent specific gravity = $D / A-(B-C)$.
Water absorption = $((A-D) / D) x 100$.

The specific gravity and water absorption results of combined aggregate is shown in Table: 3.7

Table:3.7 Specific Gravity and water absorptionof Combined Aggregates

Aggregate Type	Specific gravity	Water absorption (%)
20mm aggregate	**2.7**	**0.5**
12.5 aggregate	**2.65**	**0.67**
Fine aggregate	**2.54**	**1.69**

3.2.3.2 Specific Gravity Of Cementitious Material (Le Chatelier flask)

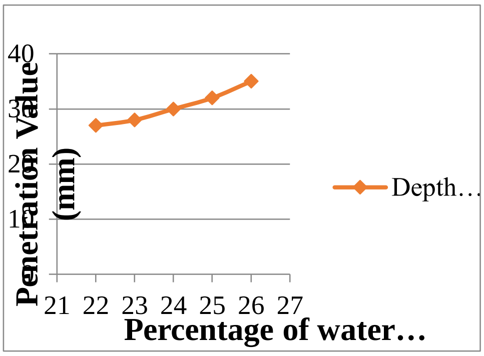
Specific gravity of cementitious materials are been found by le chatelier apparatus. The body of the flask holds approximately 250ml. The oval bulb in the neck holds 17ml. Volume below the bulb is graduated from 0 to 1.0ml in 0.1ml subdivisions, with an additional 0.1 subdivision below the 0 and above the 1.0ml mark. The neck is graduated from 18 to 24ml in 0.1ml subdivisions above the bulb (white graduations).

The flask is filled up with kerosene up to the white marking in the flask , later cementitious material is now added slowly with ahelp of a small scoop in very small amounts. After adding 64 grams of cementitous materials into the kerosene filled flask. Now the reading in the flask is noted until where the kerosene is raised. And the apparatus is kept undisturbed for 24 hrs and then the volum is noted.figure 3.10 shows the setup of Le-chateliers flask.

Fig:3.8:LeChatelier'sFlask

By this experimental method of finding the specific gravity of cementitious materials the specific gravity results of GGBS and FLYASH is been tabulated below in Table :3.8.

Table:3.8 Specific Gravity (Le Chatelier)



3.2.4 Standard Consistency of cement

For finding out initial setting time, final setting time and soundness of cement, and strength a parameter known as standard consistency has to be used. It is pertinent at this stage to describe the procedure of conducting standard consistency test. The standard consistency of a cement paste is defined as that consistency which will permit a vicat plunger having 10 mm diameter and 50 mm length to penetrate to a depth of 33-35 mm from the top of the mould. The apparatus is called Vicat Apparatus.

This apparatus is used to find out the percentage of water required to produce a cement paste of standard consistency. The standard consistency of the cement paste is some time called normal consistency. The following procedure is adopted to find out standard consistency.Take about 60 gm of cement and prepare a paste with a weighed quantity of water (say 25 per cent by weight of cement for first trial). The paste must be prepared in a standard manner and filled into Vicatmould within 3-5 minutes. After completely filling the mould, shake the mould to expel air. A standard plunger of 10 mm diameter, 50 mm long is attached and brought down to touch the surface of the test block and quickly released allowing it to sink into the paste by its own weight.

Take the reading by noting the depth of penetration of the plunger. Conduct 2nd trial (say with 30 per cent of water) and find out the depth of penetration of plunger. Similarly, conduct trials with higher and higher water/cement ratios till such time the plunger penetrates for a depth of 33-35 mm from the top. That particular percentage of water which allows the plunger to penetrate only to a depth of 33-35 mm from the top is known as the percentage of water required to produce a cement paste of standard consistency. This percentage is usually denoted as ‘P’. The test is required to be conducted in a constant temperature (27°±2°C).

Table: 3.9 Standard Consistency Test for Cement

PERCENTAGE OF WATER ADDED (%)	**PENETRATION VALUE(mm)**
22	27
23	28
24	30
25	32
26	35

Fig:3.9: Depth Of Penetration Of Cement(OPC)

Cementitious material	**Specific gravity**
GGBS	**2.80**
FLY ASH	**2.02**
OPC 53 Grade	**3.52**

3.2.5 Setting Time of Cement

Attach the initial setting time needle in the Vicat’s apparatus.

- Keep a corner of the non-porous plate on the base of the equipment and allow the needle to rest on the plate as. Record the initial reading from the Vicat’s scale in mm.
- Bring the test block under the needle. Lower the needle gently (abutting the top use of the rod against dash pot) until it comes in contact with the surfaceof the test block and quickly release allowing it to penetrate into the test block. Record the final reading from the Vicat’s scale in mm.
- Repeat this procedure until the difference between the initial and final reading becomes 5 ± 0.5 mm. the elapsing time between when the water is added to the cement and the time at which the above mentioned condition is obtained shall be reported as the initial setting time.

Table 3.10: Initial Setting Time for Cement

TIME (min)	**PENETRATION VALUE (mm)**
0	35
5	35
10	34
15	34
20	32
25	31
30	31
35	30
40	30

Thus the Initial Settling Time is found to be 40 minutes. (Needle failed to pierce the block 5 mm from the bottom)

Final Setting Time of Cement

- Replace the needle of the Vicat’s apparatus by the needle with an annular attachment.
- The cement shall be considered the finally set, when upon applying the needle gently to the surface of the test block. The needle makes an impression there on which the annular

attachment fails to make an impression on the test block.

- The elapsing time between when water is added to the cement and the time at which the needle makes an impression on the surface of the test block, while the annular attachment fails to do so shall be reported as the final setting time.

Fig.3.10: Vicat's Apparatus

Table 3.11: Final Setting Time for Cement

TIME (hours)	INFERENCE
0	-
4	-
8	Needle only makes an impression on the test block

Thus the Final setting time is found to be 8 hours.

3.2.6 Standard Consistency of GGBS

For finding out initial setting time, final setting time and soundness of GGBS, and strength a parameter known as standard consistency has to be used. It is pertinent at this stage to describe the procedure of conducting standard consistency test.

The standard consistency of a GGBS paste is defined as that consistency which will permit a vicat plunger having 10 mm diameter and 50 mm length to penetrate to a depth of 33-35 mm from the top of the mould. The apparatus is called Vicat Apparatus.

This apparatus is used to find out the percentage of water required to produce a GGBS paste of standard consistency.

The standard consistency of the GGBS paste is some time called normal consistency. The following procedure is adopted to find out standard consistency.

Take about 64 gm of GGBS and prepare a paste with a weighed quantity of water (say 25 per cent by weight of cement for first trial). The paste must be prepared in a standard manner and filled into Vicatmould within 3-5 minutes.

After completely filling the mould, shake the mould to expel air. A standard plunger of 10 mm diameter, 50 mm long is attached and brought down to touch the surface of the test block and quickly released allowing it to sink into the paste by its own weight.

Take the reading by noting the depth of penetration of the plunger. Conduct 2nd trial (say with 30 per cent of water) and find out the depth of penetration of plunger. Similarly, conduct trials with higher and higher water/GGBS ratios till such time the plunger penetrates for a depth of 33-35 mm from the top.

That particular percentage of water which allows the plunger to penetrate only to a depth of 33-35 mm from the top is known as the percentage of water required to produce a GGBS paste of standard consistency.

This percentage is usually denoted as 'P'. The test is required to be conducted in a constant temperature (27°±2°C).

Table 3.12: Standard Consistency Test for GGBS

PERCENTAGE OF WATER ADDED	PENETRATION VALUE (mm)
25	16
26	20
27	26
28	31
29	35
30	40

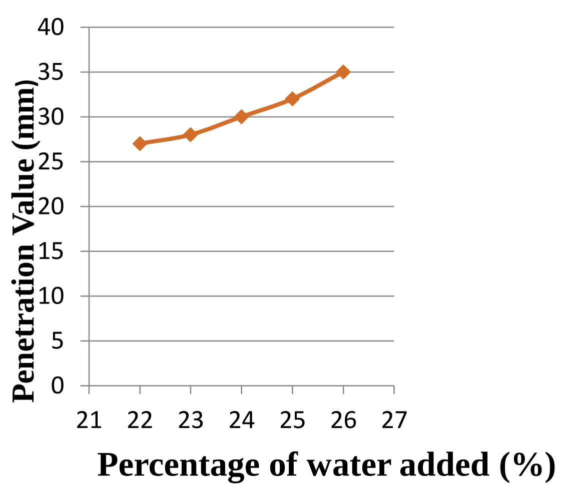


Fig:3.11: Standard Consistency for GGBS

3.2.7 Setting Time Of GGBS

Initial Settling Time of GGBS

Attach the initial setting time needle in the Vicat's apparatus.

- Keep a corner of the non-porous plate on the base of the equipment and allow the needle to rest on the plate as. Record the initial reading from the Vicat's scale in mm.
- Bring the test block under the needle. Lower the needle gently (abutting the top use of the rod

against dash pot) until it comes in contact with the surface of the test block and quickly release allowing it to penetrate into the test block. Record the final reading from the Vicat's scale in mm.

- Repeat this procedure until the difference between the initial and final reading becomes 5±0.5 mm. the elapsing time between when the water is added to the GGBS and the time at which the above mentioned condition is obtained shall be reported as the initial setting time.

Table 3.13: Initial Setting Time Test for GGBS

TIME (min)	PENETRATION VALUE (mm)
0	35
5	35
10	34
15	34
20	33
25	33
30	33
35	31
40	31
45	31
50	30
55	30

Thus the Initial Settling time of GGBS is found to be55 minutes.

Final Setting Time for GGBS

- Replace the needle of the Vicat's apparatus by the needle with an annular attachment.
- The cement shall be considered the finally set, when upon applying the needle gently to the surface of the test block. The needle makes an impression there on which the annular attachment fails to make an impression on the test block.
- The elapsing time between when water is added to the GGBS and the time at which the needle makes an impression on the surface of the test block, while the annular attachment fails to do so shall be reported as the final setting time.

Table 3.14: Final setting time test for GGBS

TIME (hours)	INFERENCE
0	-
4	-
8	-
10	Needle only makes an impression on the test block

Thus the Final setting time of GGBS is found to be 10 hours.

3.3 MIX DESIGN

Currently no standardized methods of mix design for geo-polymer concrete mixes are available. So mixesare essentially designed by trials as of now. Four trial mixes, whose performance had been found satisfactory in theform of both workability and strength points of view, were considered as candidate mixes herein.

3.3.1 Mix Proportions

Table:3.15: mix proportion of conventional concrete M40 grade

Cement	Fine aggregate	Coarse aggregate Kg/mm^2	
		20 mm	12 mm
420	716.51	566.61	552.02

Table:3.16: mix proportion og AAS-FA based geopolymer concrete(2.5)

20mm Aggregate	370 kg/m^3.
12.5mm Aggregate	924 kg/m^3.
Fine Aggregate	554 kg/m^3.
Ground Granulated Blast Furnace	394.29 kg/m^3.
Fly Ash	394.29 kg/m^3.
Super Plasticizer	6 kg/m^3.
Sodium Silicate Solution	112.65 kg/m^3.
Sodium Hydroxide Solution	45.06 kg/m^3.

3.4MANUFACTURE OF TEST SPECIMENS

3.4.1 Preparation Of Alkaline Activator Solution

The sodium hydroxide (NaOH) solids of 99% purity were dissolved in De-ionized water (Distilled Water) to make the solution.

The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance ,NaOH solution with a concentration of 12M consisted of 12 x 40 = 480gms of NaOH solids(in flake form) per litre of solution, where 40 is the molecular weight of NaOH. The sodium silicate solution and the sodium hydroxide solution were mixed together at least one day prior to use tp prepare the alkaline liquid. On the day of casting of the specimens, the alkaline liquid was mixed together with the super plasticizer to prepare the liquid componenet of the mixture.

3.4.2 Manufacture Of Fresh AAS-FA Based Geopolymer Concrete

The mixing procedure of AAS-FA based GPC is done as per IS standards in pan mixer.

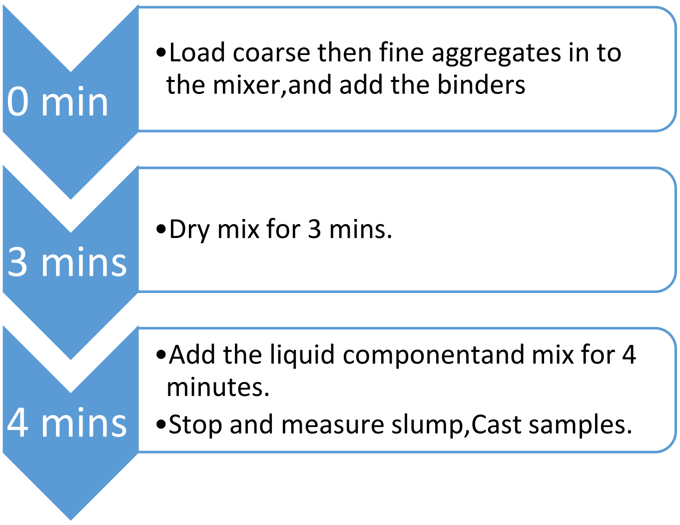


Fig:3.12: Mixing procedure and casting AAS and FA-based geopolymer concrete

The GGBS and FLY ASH and the aggregates were first dry mixed together in a 40litre capacity laboratory concrete pan mixer for about 3 minutes. The liquid component of the mixture was then added to the dry materials and the mixing is continued for further about 4 minutes to manufacture the fresh concrete.

The fresh AAS-FA based GPC was casted into moulds immediately after mixing, in three layers for cylindrical, cubical, and prism beam specimens. For compaction of specimens, each layer was given 60 to 80 manual strokes using rodding bar and vibrated for 12 to 15 seconds on a vibrating table.

Before the fresh concrete was cast into the moulds, the slump value of the fresh concrete was measured.Totally twenty four cubes of size 100mx 100m x100m was casted per mix to find the compressive strength at 14D,28D,56D,and 90D in which twelve for each two different curing regimes., time period. And also six cylinders of size 75mm x 150mm was casted to find the split tensile strength on 56D and 90D.Also six prism beams of size 100mx100mmx500mm was casted to chck the flexural properties on 56D and 90D. At last four cylinders are also casted to check the durability properties at 56D and 90D, in which two is for sorpitivity and another teo is for RCPT.

Fig:3.13:NaOH Flakes (99% Purity)

Fig:3.14:Preparation Of Alkali solution

Fig:3.15:Aggregates And Mixture Of Geopolymers

Fig:3.16: Casting Moulds

Fig:3.17: 40 Litre Capacity Concrete Pan Mixer

Fig:3.18: Slump Cone Test

Fig:3.19: Casted Specimens

3.5CURING OF SPECIMENS

After casting, the test specimens are ready to let for curing.two types of curing regims were used in this study namely open air curing , dry curing. For dry curing, the test specimens were cured in the Hot Air Oven and for open air curing the pecimens are arranged in open air in ambient temperature until the day of testing.
Dry curing is done oly for cube specimens, 12 set of specimens per mix is separately casted for dry curing pupose , specimens which are yet to dry cured are been placed into hot air oven immediately after casting along wuth the mould at 100˚c for 24 hours . after which the specimens are demoulded and placed in normal ambient temperature until the day of testing.

For open air curing, the 12 set of specimens , cylindrical and beam specimens are also to be open air cured , after casting the specimens are left undisturbed for minimum of 3 days , after that the specimens are demoulded and placed in ambient temperature until the day of testing.

Fig:3.20: Specimens Cured In Hot Air Oven (Dry Curing)

Fig:3.21: Specimens Left At Ambient Temperature (Open Air Curing)

CHAPTER 4
RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter discuss the experimental results which are presented. Each of the testing result data plotted in tables and bar charts corresponds to the mean value of test results of concrete specimens in a series.

4.2 TESTING

Testing of hardened concrete plays an important role in controlling and confirming the quality of cement concrete works. Systematic testing of raw materials, fresh concrete and hardened concrete are inseparable part of any quality control programme for concrete, which helps to achieve higher efficiency of material used and greater assurance of the performance of the concrete with regard to both strength and durability. The test methods should be simple, direct, and convenient to apply.

- Compression test
- Flexural test
- Split tensile test
- RCPT
- Sorptivity

4.2.1 Compressive Strength

Compressive Strength is the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine. Some materials fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load. Compressive strength is a key value for design of structures.

Measurements of compressive strength are affected by the specific test method and conditions of measurement. Compressive strengths are usually reported in relationship to a specific technical standard.

Compressive strength measurements were performed on an CTM machine with a loading capacity of 3000 kN under a load control regime with a loading rate of 2.3kN/S for cubes specimens of size 100mmx100mmx100mm as per IS standards.

A minimumof three cubes were tested for each data point. The specimens were tested at 14, 28,56 and 90 days after casting.Fig:4.1 shows the set up of CTM (compressive testing machine).

Fig:4.1: compressive testing machine(CTM)

Fig:4.2:Specimens Under Testing

Fig:4.3: ComputerisedValue Showing The Load In kN And Rate Of Load In kN/S

Fig:4.4:Testing Of 16M Specimen

The testing results of compressive strength of dry cured and open air cured specimens are been tabulated in Table:4.1 and Table 4.2. also the results are shown in terms of bar chart in Figure 4.5 and Figure4.6.

Table : 4.1 : Compressive Strength Results Of 12M Specimens

Specimen number	Curing regim	Molarity	Age In Days	Average compressive strength(Mpa)
DC 10,11,12	Dry curing	12 M	14	54.90
DC 7,8,9	Dry curing	12 M	28	58.9
DC 4,5,6	Dry curing	12 M	56	60.21
DC 1,2,3	Dry curing	12 M	90	62.15
OAC 10,11,12	Openair curing	12 M	14	53.81
OAC 7,8,9	Openair curing	12 M	28	58
OAC 4,5,6	Openair curing	12 M	56	77.34
OAC 1,2,3	Openair curing	12 M	90	85.01

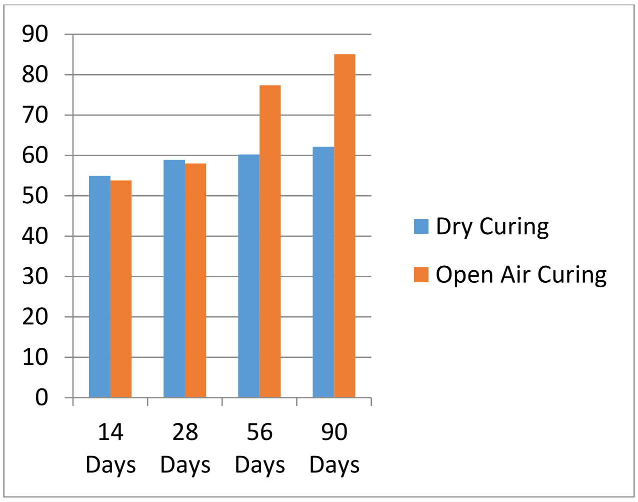


Fig:4.5Compreessive Strength Of 12M Specimens

Table : 4.2: Compressive Strength Results Of 16M Specimens

Specimen number	Curing regime	Molarity	Age In Days	Average compressive strength(Mpa)
DC 10,11,12	Dry curing	16 M	14	51.8
DC 7,8,9	Dry curing	16 M	28	62.3
DC 4,5,6	Dry curing	16 M	56	56.05
DC 1,2,3	Dry curing	16 M	90	71.58
OAC 10,11,12	Openair curing	16 M	14	55.5
OAC 7,8,9	Openair curing	16 M	28	67.2
OAC 4,5,6	Openair curing	16 M	56	64.40
OAC 1,2,3	Openair curing	16 M	90	84.42

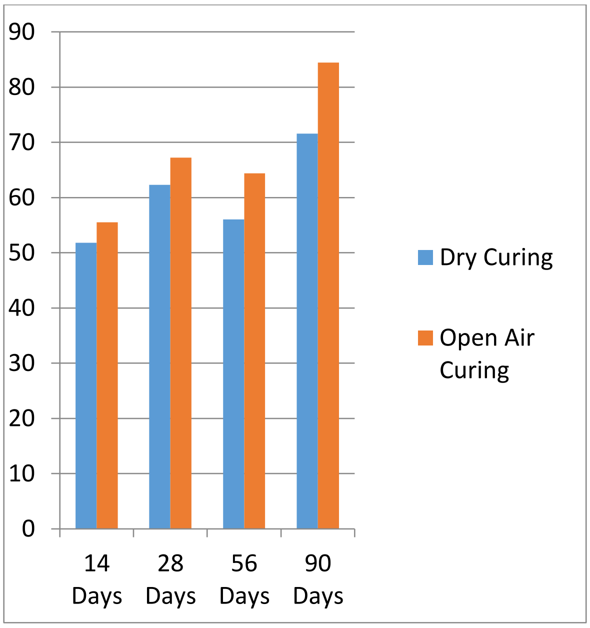


Fig:4.6Compressive Strength Of 16M Specimens

Table:4.3: Compressive Strength Of M40 Grade Control Mix

Specimen Number	Age In Days	Average compressivestrength(Mpa)
CTL 10,11,12	14	50.06
CTL 7,8,9	28	54.34
CTL 4,5,6	56	68.02
CTL 1,2,3	90	77.04

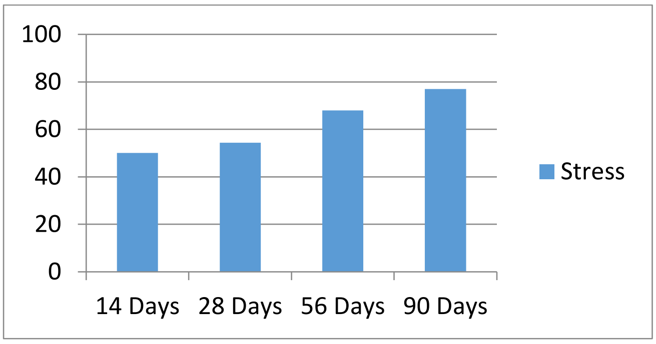


Fig:4.7: Compressive Strength Of Control Mix Specimens

4.2.2 Split Tensile Strength

Tensile strength is one of the basic and important properties of the concrete. Theconcrete is not usually expected to resist the direct tension because of its low tensile strength andbrittle nature. However, the determination of tensile strength of concrete is necessary todetermine the load at which the concrete members may crack. The cracking is a form of tensionfailure.

Split tensile strength measurements were performed on an CTM machine with a
loading capacity of 3000 kN under a load control regime with a loading rate of 1.2kN/S for cylinder specimens of size 75mmx150mm as per IS standards.

A minimumof three cylinders were tested for each data point. The specimens were tested at 56 and 90 days after casting

Fig:4.8:Split Tensile Setup

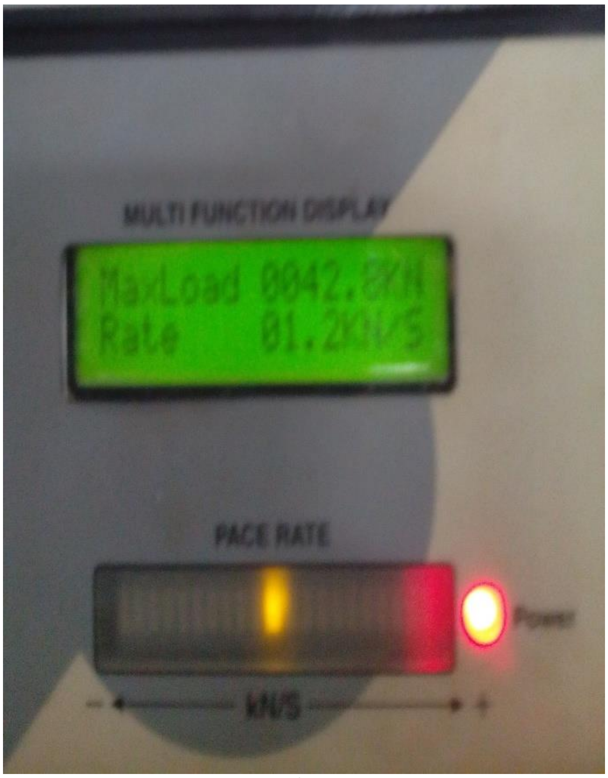


Fig:4.9:Result Of Tested Specimen

The testing results of Split Tensile strength of dry cured and open air cured specimens are been tabulated in Table:4.4. also the results are shown in terms of bar chart in Figure 4.10.

Table:4.4: Split Tensile Strength Of 12M And 16M Specimens

Specimen Number	**Curing regim**	**Molarity**	**Age In Days**	**Average split tensile strength(Mpa)**
OAC-A 4,5,6	Openair curing	12M	56	2.26
OAC-A 1,2,3	Openair curing	12M	90	2.61
OAC-B 4,5,6	Openair curing	16M	56	2.01
OAC-B 1,2,3	Openair curing	16M	90	2.30

Fig:4.10: Split Tensile Strength Of 12 MAnd 16M Specimens

Table:4.5: Split Tensile Strength Results Of Control Mix

Specimen number	**Age in Days**	**Tensile strength (Mpa)**
CTL-S- 4,5,6	56	2.30
CTL-S- 1,2,3	90	2.45

Fig:4.11 :Split Tensile Strength Of Control Mix Specimens

4.2.3 Flexural Strength

Flexural strength testingswer performed on a universal testing machine (UTM) .which is computerized control.

The specimens to be tested for flexure are of size 100mmx100mmx400mm prism beams where the dimensions is nothing but the loading area on the beam.

Fig:4.12: Marked Specimens For Flexural Test

Fig:4.13: UTM Set Up

Fig:4.14: Flexural Testing Of Specimen

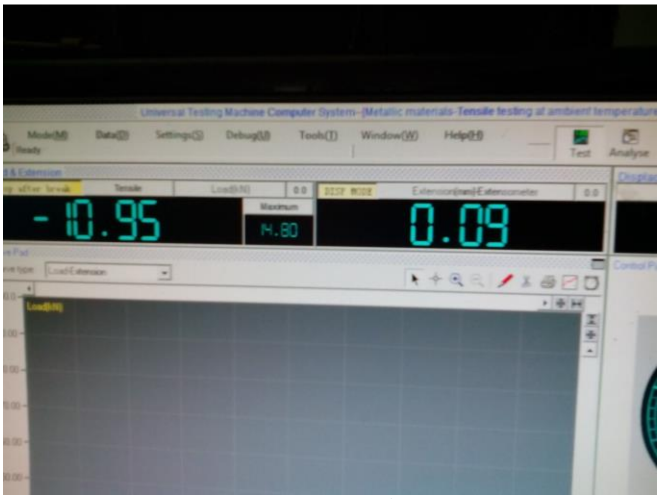


Fig:4.15: Computerized Result Of Tested Specimen

The testing results of flexural strength of dry cured and open air cured specimens are been tabulated in Table:4.4. also the results are shown in terms of bar chart in Figure 4.16.

Table:4.6: Flexuralstrength Results Of 12M And 16M Specimens

Specimen Number	Curing regim	Molarity	Age in Days	Average Flexural strength(Mpa)
OAC-F 4,5,6	Openair curing	12M	56	4.27
OAC-F 1,2,3	Openair curing	12M	90	5.78
OAC-F 4,5,6	Openair curing	16M	56	4.95
OAC-F 1,2,3	Openair curing	16M	90	5.97

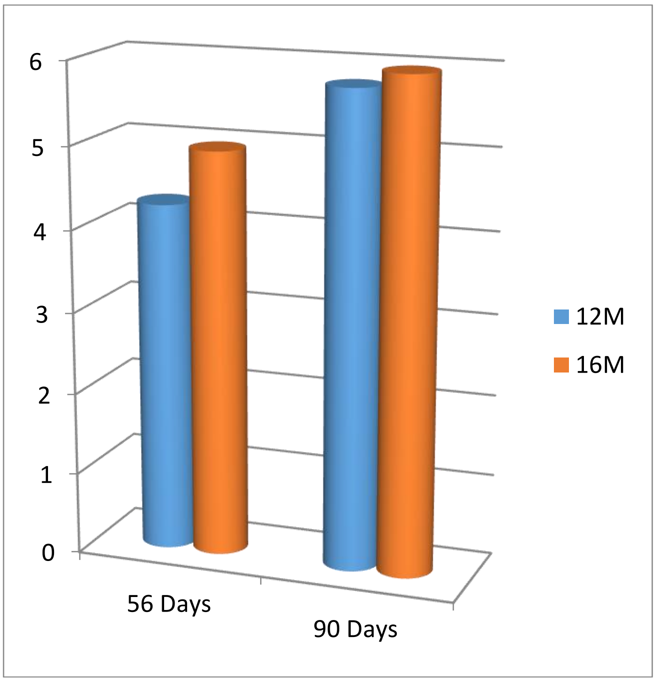


Fig:4.16: Flexuralstrength Results Of 12M And 16M Specimens

Table:4.7: Flexural Strength Results Of Control Mix

Specimen number	Age in days	Flexural strength (Mpa)
CTL-F- 4,5,6	56	4.7
CTL-F- 1,2,3	90	5.4

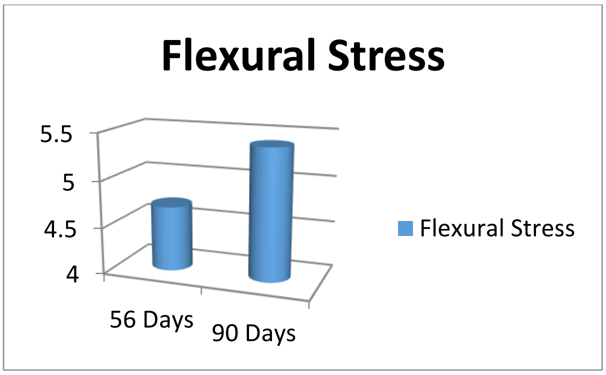


Fig:4.17:Flexural Strength Of Control Mix Specimens

4.2.4 Rapid Chloride Permeability Test(RCPT)

Corrosion of reinforcing steel dueto chloride ingress is one of themost common environmentalattacks that lead to the deterioration ofconcrete structures. Corrosion-relateddamage to bridge deck overlays, parkinggarages, marine structures, and manufacturingplants results in millions ofdollars spent annually on repairs. Thisdurability problem has received widespreadattention in recent years becauseof its frequent occurrence and the associatedhigh cost of repairs.Chlorides penetrate crack-free concreteby a variety of mechanisms: capillaryabsorption, hydrostatic pressure,diffusion, and evaporativetransport. Of these, diffusionis predominant. Diffusionoccurs when the concentrationof chloride on the outsideof the concrete memberis greater than on the inside.This results in chloride ionsmoving through the concreteto the level of the rebar. Whenthis occurs in combinationwith wetting and drying cyclesand in the presence ofoxygen, conditions are rightfor reinforcement corrosion.

For specification and quality-controlpurposes in projects, we prefer atest that is simple to conduct and thatcan be performed in a short time. Therapid chloride permeability test meetsthese goals. First developed by Whitingin 1981, RCPT has had resultsthat correlate well with results from theclassical 90-day salt ponding test.Standardized testing procedures arein AASHTO T 277 or ASTM C 1202.The RCPT is performed by monitoringthe amount of electrical current that passes through a sample 50 mm thickby 100 mm in diameter in 6 hours. This sample is typically cutas a slice of a core or cylinder. A voltageof 60V DC is maintained acrossthe ends of the sample throughout thetest. One lead is immersed in a 3.0%salt (NaCl) solution and the other in a0.3 M sodium hydroxide (NaOH) solution.Based on the charge that passesthrough the sample, a qualitative ratingis made of the concrete’s permeability. Versatile and easy to conduct,the RCPT has beenadopted as a standard andis now widely used.The use of supplementary cementitiousmaterials and rigorous moist curingwill significantly reduce the chloridepermeability, particularly at concreteages past 56 days and 90days, and this longer timeto achieve the desired qualities shouldnot be overlooked. If the limitationsinherent to RCPT are understood, thistest can be used for a wide range ofapplications, testing, and quality controlpurposes.


Fig:4.18: Specimen Cut Using Wet Cutting Blade


Fig:4.19: Specimen Left To Dry After Cutting


Fig:4.20: Specimens Painted With Epoxy


Fig:4.21: Vaccum Pump

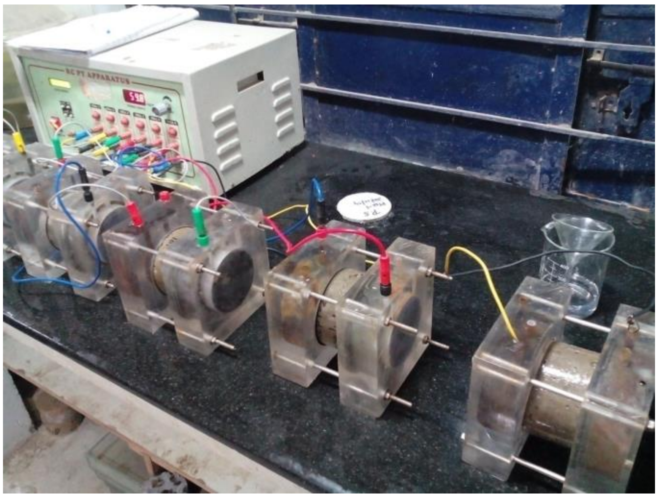


Fig:4.22: RCPT Setup

Advantages

- Is relatively quick can be used for quality control.
- Has simple and convenient setup and procedures.
- Provides results that are easy to interpret.
- Correlates well with 90-day chloride ponding test.

Disadvantages

- May not represent the true permeability (or potential permeability) for concrete that contains supplementary cementitious materials or chemical admixtures.
- May allow measurements before a steady state is achieved
- Can cause physical and chemical changes in the specimen, resulting in unrealistic values
- May not be suitable for concretes that contain conducting materials (such as steel or carbon fibers) and has low inherent repeatability and reproducibility.

4.2.4.1 RCPT Test Results

Formula for calculating coulombs:

$$\mathbf{Q} = (900x\,(I_0+2I_{30}+2I_{60}+2I_{90}+2I_{120}+2I_{150}+2I_{180}+2I_{210}-+2I_{240}+2I_{270}+2I_{300}+2I_{330}+I_{360})/1000)$$

Table:4.8: RCPT Results For 12M (56 days)

TIME(mins)	TOP	MIDDLE	BOTTOM
0	256	255	243
30	267	288	274
60	288	320	300
90	296	380	405
120	320	439	434
150	320	503	483
180	354	555	491
210	366	564	492
240	366	564	508
270	369	574	524
300	376	579	534
330	381	587	341
360	388	594	552
Total	7245	10399.5	9690.3
Q		9111.6	

Table:4.9: RCPT Results For 16M (56 days)

TIME(mins)	TOP	MIDDLE	BOTTOM
0	179	231	200
30	215	284	268
60	239	332	319
90	240	363	343
120	267	391	403
150	307	419	427
180	347	547	427
210	459	831	595
240	460	838	595
270	463	843	597
300	471	848	608
330	479	864	617
360	486	871	621
Total	7703.1	12799.8	10097.1
Q		10200	

Table:4.10: RCPT Results For 12M (90days)

TIME(mins)	TOP	MIDDLE	BOTTOM
0	143	171	111
30	147	172	112
60	160	189	131
90	172	195	131
120	195	211	132
150	211	212	156
180	222	214	157
210	226	214	157
240	233	216	158
270	242	218	158
300	247	218	158
330	248	222	159
360	252	223	159
Total	4500.9	4460.4	3139.2
Q		4033.5	

Table:4.11: RCPT Results For 16M (90days)

TIME(mins)	TOP	MIDDLE	BOTTOM
0	159	124	191
30	179	135	210
60	196	143	229
90	227	147	252
120	256	152	264
150	290	180	275
180	312	191	279
210	315	199	286
240	325	208	289
270	326	217	296
300	326	223	297
330	328	225	302
360	330	227	309
Total	5984.1	3951.9	6458
Q		5464.6	

Table:4.12: RCPT Results For Control Mix(56 days)

TIME(mins)	TOP	MIDDLE	BOTTOM
0	71	107	64
30	80	131	65
60	81	133	75
90	84	136	84
120	87	140	87
150	91	143	92
180	91	144	92
210	91	144	92
240	95	146	92
270	95	148	92
300	95	151	95
330	96	151	95
360	96	151	95
Total	1925.1	3052.8	1872.9
Q		2283.6	

Table:4.13: RCPT Results For Control Mix(90days)

TIME(mins)	TOP	MIDDLE	BOTTOM
0	88	121	77
30	91	126	86
60	93	129	112
90	123	138	143
120	142	151	160
150	167	157	185
180	168	168	185
210	170	182	186
240	171	194	187
270	171	194	192
300	171	196	192
330	173	196	193
360	173	210	195
Total	3186.9	3782.7	3522.6
Q		3497.4	

Fig:4.23:RCPT Results

4.2.5 Sorpitivity

The sorptivity tests were undertaken for duplicate specimens with a 100 mmdiameter and 50 mm height in accordance with ASTM C1585-04. The sides of the specimens were coated with epoxy to allow free water movement only through the bottom face (unidirectional flow). The specimens were then placed in a shallow tray layered with over chicken mesh.The water level was adjusted such that only a 3-5 mm section of the specimen was immersed in water. The weights of specimens were measured after 1,5,10,20,30 and at every 30minutes upto 6 hours,the initial weight also having been recorded.

Weighingwas done by removing specimens from the tray, shaking off excess surface moisture, and placing them with their dry surfaces on an electronic pan balance so that the absorbing surface would not be touched, and thenreturning them to their sponges within 15 s. The results were plotted against the square root of the time to obtain a slope of the best fit straight line.
The upper surface of the specimes of each section is been tapped to avoid the water flow through top surface during testing.(Fig:4.21).

Fig:4.24Specimens Been Epoxy Coated And Tapped At Top Surface

Fig:4.25:Specimens Under Testing

The absorption, *I*, is the change in mass divided by theproduct of the cross-sectional area of the test specimen and thedensity of water. For the purpose of this test, the temperaturedependence of the density of water is neglected and a value of 0.01g/mm3 is used. The units of *I* are mm.$I = mt/ (axd)$ *mm.*

Table:4.14: Sorptivity Results Of 12M At Top (56 Days)

Test time (s)	**√time (s½)**	**Mass (g)**	**Δ Mass (g)**	**ΔMass / area x density of water = I (mm)**
0	0	958	0.00	0.0000
60	8	958.6	0.6	0.0764
300	17	959.53	1.53	0.1948
600	24	961.62	3.62	0.4608
1200	35	962.63	4.63	0.5894
1800	42	964.27	6.27	0.7982
3600	60	965.09	7.09	0.9025
7200	85	965.15	7.15	0.9101
10800	104	967.25	9.25	1.1775
14400	120	967.30	9.3	1.1839
18000	134	967.34	9.34	1.1889
21600	147	967.36	9.36	1.1915

Table:4.15: Sorptivity Results Of 12M At Middle (56 Days)

Test time (s)	**√time (s½)**	**Mass (g)**	**Δ Mass (g)**	**ΔMass / area x density of water = I (mm)**
0	0	976.89	0.00	0.0000
60	8	977.883	0.99	0.1260
300	17	978.48	1.58	0.2011
600	24	978.84	1.94	0.2470
1200	35	979.57	2.67	0.3399
1800	42	980.05	3.15	0.4009
3600	60	981.54	4.64	0.5906
7200	85	983.41	6.51	0.8286
10800	104	984.38	7.48	0.9521
14400	120	984.38	7.48	0.9521
18000	134	984.39	7.49	0.9534
21600	147	984.39	7.49	0.9534

Table:4.16: Sorptivity Results Of 12M At Bottom (56 Days)

Test time (s)	√time (s½)	Mass (g)	Δ Mass (g)	ΔMass / area x density of water = I (mm)
0	0	1067.75	0.00	0.0000
60	8	1069.54	1.79	0.2278
300	17	1069.82	2.07	0.2634
600	24	1070.09	2.34	0.2978
1200	35	1070.12	2.37	0.3016
1800	42	1070.15	2.4	0.3054
3600	60	1072.46	4.71	0.5995
7200	85	1074.39	6.64	0.8452
10800	104	1074.97	7.22	0.9190
14400	120	1074.98	7.23	0.9203
18000	134	1074.99	7.24	0.9215
21600	147	1074.99	7.24	0.9215

Fig:4.26: Sorpitivity Results Of 12M Specimen (56 days)

Table:4.17: Sorptivity Results Of 16M At Top (56 Days)

Test time (s)	√time (s½)	Mass (g)	Δ Mass (g)	ΔMass / area x density of water = I (mm)
0	0	981.09	0.00	0.0000
60	8	982.03	0.94	0.1196
300	17	982.53	1.44	0.1832
600	24	982.89	1.8	0.2291
1200	35	983.60	2.51	0.3195
1800	42	984.5	3.41	0.4340
3600	60	985.26	4.17	0.5308
7200	85	986.57	5.48	0.6975
10800	104	987.49	6.4	0.8146
14400	120	987.51	6.43	0.8184
18000	134	987.52	6.43	0.8184
21600	147	987.53	6.44	0.8185

Table:4.18: Sorptivity Results Of 16M At Middle (56 Days)

Test time (s)	√time (s½)	Mass (g)	Δ Mass (g)	ΔMass / area x density of water = I (mm)
0	0	954.14	0.00	0.0000
60	8	955.37	1.23	0.1565
300	17	955.63	1.49	0.1896
600	24	955.72	1.58	0.2011
1200	35	956.33	2.19	0.2787
1800	42	957	2.86	0.3640
3600	60	957.91	3.77	0.4799
7200	85	959.01	4.57	0.5817
10800	104	959.70	5.26	0.6695
14400	120	959.73	5.29	0.6733
18000	134	959.73	5.29	0.6733
21600	147	959.75	5.3	0.6746

Table:4.19: Sorptivity Results Of 16M At Bottom (56 Days)

Test time (s)	√time (s½)	Mass (g)	Δ Mass (g)	ΔMass / area x density of water = I (mm)
0	0	1010.36	0.00	0.0000
60	8	1011.54	1.18	0.1502
300	17	1011.79	1.43	0.1820
600	24	1012.04	1.63	0.2074
1200	35	1012.72	2.31	0.2940
1800	42	1013.5	3.09	0.3933
3600	60	1014.54	4.13	0.5257
7200	85	1015.83	5.42	0.6899
10800	104	1016.74	6.33	0.8057
14400	120	1016.77	6.36	0.8095
18000	134	1016.77	6.36	0.8095
21600	147	1016.77	6.36`	0.8095

Table:4.20: Sorptivity Results Of 12M At Top (90 Days)

Test time (s)	√time (s½)	Mass (g)	Δ Mass (g)	ΔMass / area x density of water = I (mm)
0	0	1011.20	0.00	0.0000
60	8	1011.76	0.56	0.0712
300	17	1012	0.8	0.1018
600	24	1012.11	0.91	0.1158
1200	35	1012.38	1.18	0.1502
1800	42	1012.61	1.41	0.1794
3600	60	1013.04	1.84	0.2342
7200	85	1013.80	2.6	0.3309
10800	104	1014.28	3.08	0.3920
14400	120	1014.32	3.12	0.3971
18000	134	1014.36	3.16	0.4022
21600	147	1014.39	3.19	0.4060

Table:4.21: Sorptivity Results Of 12M At Middle (90 Days)

Test time (s)	√time (s½)	Mass (g)	Δ Mass (g)	ΔMass / area x density of water = I (mm)
0	0	1005.01	0.00	0.0000
60	8	1005.59	0.58	0.0738
300	17	1005.74	0.73	0.0929
600	24	1005.87	0.86	0.1094
1200	35	1006.12	1.11	0.1412
1800	42	1006.22	1.21	0.1540
3600	60	1006.78	1.77	0.2253
7200	85	1007.38	2.37	0.3016
10800	104	1007.71	2.7	0.3436
14400	120	1007.79	2.78	0.3538
18000	134	1007.83	2.82	0.3589
21600	147	1007.84	2.83	0.3602

Table:4.22: Sorptivity Results Of 12M At Bottom (90 Days)

Test time (s)	√time (s½)	Mass (g)	Δ Mass (g)	ΔMass / area x density of water = I (mm)
0	0	947.19	0.00	0.0000
60	8	947.80	0.41	0.0521
300	17	948.08	0.89	0.1132
600	24	948.25	1.06	0.1349
1200	35	948.58	1.39	0.1769
1800	42	948.79	1.6	0.2036
3600	60	949.37	2.18	0.2774
7200	85	950.25	3.06	0.3895
10800	104	950.57	3.38	0.4302
14400	120	950.69	3.5	0.4455
18000	134	950.73	3.54	0.4506
21600	147	950.74	3.55	0.4518

Table:4.23: Sorptivity Results Of 16M At Top (90 Days)

Test time (s)	√time (s½)	Mass (g)	Δ Mass (g)	ΔMass / area x density of water = I (mm)
0	0	950.1	0.00	0.0000
60	8	951.29	1.19	0.1514
300	17	951.54	1.44	0.1832
600	24	951.79	1.69	0.2151
1200	35	952.12	2.02	0.2571
1800	42	952.34	2.24	0.2851
3600	60	952.86	2.76	0.3513
7200	85	953.67	3.57	0.4544
10800	104	953.99	3.89	0.4951
14400	120	954.12	4.02	0.5117
18000	134	954.16	4.06	0.5168
21600	147	954.17	4.07	0.5180

Table:4.24: Sorptivity Results Of 16M At Middle (90 Days)

Test time (s)	√time (s½)	Mass (g)	Δ Mass (g)	ΔMass / area x density of water = I (mm)
0	0	958.76	0.00	0.0000
60	8	959.08	0.32	0.0407
300	17	959.44	0.36	0.0458
600	24	959.60	0.52	0.0661
1200	35	959.80	0.72	0.0916
1800	42	959.99	0.91	0.1158
3600	60	960.38	1.3	0.1654
7200	85	961.23	2.15	0.2736
10800	104	961.56	2.49	0.3169
14400	120	961.76	2.68	0.3411
18000	134	961.77	2.69	0.3424
21600	147	961.79	2.71	0.3449

Table:4.25: Sorptivity Results Of 16M At Bottom(90 Days)

Test time (s)	√time (s½)	Mass (g)	Δ Mass (g)	ΔMass / area x density of water = I (mm)
0	0	1025.79	0.00	0.0000
60	8	1025.98	0.79	0.1002
300	17	1026.16	0.98	0.1247
600	24	1026.48	1.16	0.1476
1200	35	1026.56	1.48	0.18839
1800	42	1027.04	1.58	0.2011
3600	60	1027.44	2.04	0.2596
7200	85	1027.78	2.78	0.3538
10800	104	1028.21	3.21	0.4086
14400	120	1028.56	3.56	0.4531
18000	134	1028.57	3.57	0.4544
21600	147	1028.58	3.58	0.4557

CHAPTER 5
SUMMARY AND CONCLUSION

5.1 SUMMARY

The research focuses on the strength and durability properties of alkali activatedslag (AAS) and fly ash based geopolymer concrete. Although there are numerousstudies that have assessed the suitability of AAS and fly ash based geopolymeras the binder in concrete, the main focus of these studies has been the strengthproperties and durability in terms of chemical attack. Only limited research hasbeen conducted on the chloride penetration and carbonation of these concretes –the main causes of degradation of concrete structures in practice. This studyprovides new insight into the strength development and the durabilityperformance in terms of chloride and carbonation resistance.The effect of sodium oxide dosage and activator modulus on the compressivestrength of mortar specimens was explored and the results used to designsuitable AAS and geopolymer concrete mixes.Concrete testing has included measurements of workability, compressivestrength, sorptivity, rapid chloride permeability, and chlorideponding. The study of variables affecting the strength demonstrated that both the sodiumoxide dosage and the activator modulus are suitable variables for designing AASand geopolymer concrete mixes.It is concluded that AAS and fly ash based geopolymer concretes can exhibitcomparable strength to OPC. However, withregards to the durability properties such as water sorptivity, chloride resistance; the AAS concrete was found to not perform well as aresult of surface cracking dominating these characteristics. The fly ash basedgeopolymer concrete performed better in water sorptivity and chloride penetrationtests than the OPC concrete, and the AASconcrete. It was found that the fly ash based geopolymer concretes exhibitedhigh charge and high conductivity in the accelerated chloride diffusion tests.However it was concluded that this is a reflection of the concentration andcomposition of the free ions present rather than the ability to resist the diffusion ofchloride ions.

5.2 CONCLUSION

In this project, the aim of the study, methodology and the formulated objectives are described in detail. Initially literature survey has been made and a review of previous research on using GGBS and M-sandin concrete has been studied. The materials to be used in this project are collected and material testing is carried out and a physical property of the materials is also determined. The work has been carried out as per methodology arrived.

As a conclusion the test results shows that there is a increase in the strength parameters namely compressive and flexural strength showed a great difference more than conventional concrete, and also noted that there is an increase in tensile strength with decrease in concentration of Naoh solution. It is well clear that there is a in increase in strength with increase in molarity of the NaOH solution.However, withregards to the Durability properties such as water Sorptivity and Rapid Chloride Penetration Test; the AAS-FA based Geopolymerconcrete was found to not perform well as a result of surface cracking dominating these characteristics.RCPT results shows that the chloride penetration in concrete reduces as days go on.When compared with control mix results with AAS-FA based geopolymer concrete mix it shows a greater improvement of strength parameters in Geopolymer concrete than in conventional concrete.and the cost in present rate seems to be cheaper in case of preparing geopolymer concrete than conventional concrete. Hence AAS and FA based geopolymer concrete has great potential for utilization in construction field as it is Eco-Friendly and also facilitates use of Flyash and GGBS which is a waste product of thermal power plant and coal burning industries.

5.3RECOMMENDATIONS FOR FURTHERRESEARCH

This thesis has dealt with the development of AAS and FA based Geopolymer concrete and an investigation of their durability properties. While much information regarding the performance of the two binders related to durability properties affecting corrosion mechanisms, a number of issues could not be addressed due time constraints. Therefore future work should be undertaken to gain a better understanding of the different AAS and Geopolymer types and their application as durable binders..

Current research has shown that the strength properties of AAS concrete can be controlled by optimizing the Na2O dosage and activator modulus, however the surface cracking seems to be the issue that affects the durability properties of AAS concrete. Further research on reducing the surface cracking will be beneficial. Optimizing the curing methods or using special admixture are some of the possible solutions that could be explored.

It was found in this research that due to the difference in chemical properties,some standards test on durability namely RCPT did not work well for alkali activated binder. A review of the currentstandard tests which were initially developed for normal concrete and its possible modification to be used for