EXPERIMENTAL INVESTIGATION OF FLY ASH, GGBS, & SILICA FUME BASED GEOPOLYMER CONCRETE

PHASE II REPORT

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ABSTRACT

In this thesis the need to reduce the global anthropogenic carbon dioxide has encouraged more to using a sustainable building material. Cement is the second most consumed product in the world, contributes nearly 7% of the global co_2 emission. Geo polymer concrete (GPC) is manufactured using industrial waste like fly ash, GGBS and silica fumes which is considered as a more ecofriendly alternative to ordinary Portland cement (OPC) based concrete. It improves the quality & durability of concrete and its production is virtually low level of co_2. Concrete made with GGBS will have a high solar resistance and it will not be affected by greenhouse effect of earth. Silica fume improves the characteristics of both fresh & hard concrete. Silica fume enhances the cement paste bond to the aggregates.

The propose of research is to study the STRENGTH OF CONCRETE with varying proportions of Silica Fume, GGBS and Fly Ash as Fine aggregate, to replace some portion in different percentage of coarse aggregates. The proportions of Silica Fume, GGBS and Fly Ash replaced as Fine aggregate 10% to 50 % by weight.

The mix design of concrete is to be calculated with reference to IS 456-2000 and IS 10262-2009 codes provision. The results of COMPRESSIVE STRENGTH TEST, SPLIT TENSILE TEST, FLEXURAL STRENGTH TEST of concrete at 7 days & 28 days is determine and compared to the strength of conventional concrete.

On completion of this project recommendation can be given for effective mix proportion. To utilize project is to replace cement in Geo polymer Concrete with varying proportions of Silica Fume, GGBS and Fly Ash to identify what is the optimum level to use silica fume in the place of Fly ash and GGBS.

ஆய்வுச்சுருக்கம்

இந்த ஆய்வறிக்கையில், உலகளாவிய மானுடவியல் கார்பன் டை ஆக்சைடை குறைக்க வேண்டிய அவசியம் ஒரு நிலையான கட்டுமானப் பொருட்களைப் பயன்படுத்துவதற்கு அதிக ஊக்கத்தை அளித்துள்ளது. சிமெண்ட் உலகில் இரண்டாவது மிக அதிகமாக நுகரப்படும் தயாரிப்பு ஆகும், இது உலகளாவிய கோ 2 உமிழ்வில் கிட்டத்தட்ட 7% பங்களிக்கிறது. ஜியோ பாலிமர் கான்கிரீட் (ஜிபிசி) என்பது தொழில்துறை கழிவுகளை ஈ சாம்பல், ஜிஜிபிஎஸ் மற்றும் சிலிக்கா புகைகளைப் பயன்படுத்தி தயாரிக்கப்படுகிறது, இது சாதாரண போர்ட்லேண்ட் சிமெண்ட் (ஓபிசி) அடிப்படையிலான கான்கிரீட்டிற்கு மிகவும் சூழல் நட்பு மாற்றாக கருதப்படுகிறது. இது கான்கிரீட்டின் தரம் மற்றும் ஆயுள் ஆகியவற்றை மேம்படுத்துகிறது மற்றும் அதன் உற்பத்தி கிட்டத்தட்ட குறைந்த அளவிலான கோ 2 ஆகும். ஜிஜிபிஎஸ் மூலம் தயாரிக்கப்பட்ட கான்கிரீட் அதிக சூரிய எதிர்ப்பைக் கொண்டிருக்கும், மேலும் இது பூமியின் கிரீன்ஹவுஸ் விளைவால் பாதிக்கப்படாது. சிலிக்கா புகை புதிய மற்றும் கடினமான கான்கிரீட் இரண்டின் பண்புகளையும் மேம்படுத்துகிறது. சிலிக்கா பியூம் சிமெண்ட் பேஸ்ட் பிணைப்பை மொத்தமாக மேம்படுத்துகிறது.

சிலிக்கா ஃபியூம், ஜிஜிபிஎஸ் மற்றும் ஃப்ளை ஆஷ் ஆகியவற்றின் மாறுபட்ட விகிதாச்சாரத்துடன் கன்ரேட்டின் வலிமையைப் படிப்பதே ஆராய்ச்சியின் முன்மொழிவாகும், வெவ்வேறு சதவீத கரடுமுரடான திரட்டிகளில் சில பகுதியை மாற்றுவதற்கு. சிலிக்கா ஃபியூம், ஜிஜிபிஎஸ் மற்றும் ஃப்ளை ஆஷ் ஆகியவற்றின் விகிதாச்சாரம் எடையால் 10% முதல் 50% வரை நன்றாக மாற்றப்பட்டது.

கான்கிரீட்டின் கலவை வடிவமைப்பு ஐஎஸ் 456-2000 மற்றும் ஐஎஸ் 10262-2009 குறியீடுகள் வழங்கல் ஆகியவற்றைக் கொண்டு கணக்கிடப்பட வேண்டும். 7 நாட்கள் மற்றும் 28 நாட்களில் கான்கிரீட்டின் COMPRESSIVE STRENGTH TEST, SPLIT TENSILE TEST, FLEXURAL STRENGTH TEST இன் முடிவுகள் தீர்மானிக்கப்பட்டு வழக்கமான கான்கிரீட்டின் வலிமையுடன் ஒப்பிடப்படுகின்றன.

இந்த திட்டம் முடிந்ததும் பயனுள்ள கலவை விகிதத்திற்கு பரிந்துரை வழங்கப்படலாம். ஜியோ பாலிமர் கான்கிரீட்டில் சிமெண்ட்டை சிலிக்கா ஃபியூம், ஜிஜிபிஎஸ் மற்றும் ஃப்ளை ஆஷ் ஆகியவற்றின் மாறுபட்ட விகிதாச்சாரத்துடன் மாற்றுவதே திட்டத்தைப் பயன்படுத்துவதே ஆகும்.

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LIST OF ABBREVIATIONS

GPC	-	Geopolymer Concrete
OPC	-	Ordinary Portland cement
GGBS	-	Ground Granulated Blast Furnace Slag
CO_2	-	Carbon-di-Oxide
AAS	-	Alkali Activator Solution
W/C	-	Water to Cement ratio
SiO_2	-	Silicon dioxide
Al_2O_3	-	Aluminum oxide
CaO	-	Calcium oxide
MgO	-	Magnesium oxide
SO_3	-	Sulphur Trioxide
Fe_2O_3	-	Ferric oxide
MnO_2	-	Manganese dioxide
Vf	-	Volume Fraction
C - S – H	-	Calcium - Silicate - Hydrates
RHA	-	Rice Husk Ash
SS/SH	-	Sodium silicate / Sodium Hydroxide
MPa	-	Mega Pascal
M	-	Molar
RCB	-	Reinforced Concrete Beams
RGPC	-	Reinforced Geopolymer Concrete
RPCC	-	Reinforced Plain Cement Concrete
KN	-	Kilo Newton

μ	-	micron
mm	-	millimeter
FEM	-	Finite Element Method
ASTM	-	American Society for Testing of Materials
XRF	-	X – Ray Fluorescence
Ca	-	Calcium
Na_2SiO_3	-	Sodium Silicate
NaOH	-	Sodium Hydroxide
Na_2O	-	Sodium Oxide
EDS	-	Explosive Detection Systems
Si/Al	-	Silica/Alumina
GBFS	-	Geopolymer Blast Furnace Slag
K_2O	-	Potassium dioxide
TiO_2	-	Titanium dioxide
P_2O_5	-	Potassium Penta Oxide
$CaCO_3$	-	Calcium Carbonate
Cr	-	Chromium
Mn	-	Manganese
Fe	-	Iron

CHAPTER 1
INTRODUCTION

1.1 General

Concrete, is an essential building material is widely used in the construction of infrastructures such as buildings, bridges, highways, dams, and many other facilities. One of the ingredients usually used as a binder in the manufacture of concrete is the Ordinary Portland Cement (OPC) to enhance the strength properties and serviceability requirements by using supplementary materials in concrete. Such supplementary materials are blast furnace slag, fly ash, silica fume, rice husk, crushed stone dust etc. Every 1 ton of concrete leads to CO_2 emissions which vary between 0.05 to 0.13 tons. About 95% of all CO_2 emissions from a cubic yard of concrete are from cement manufacturing.

It is important to reduce CO_2 emissions through the greater use of substitute to ordinary Portland cement (OPC) such as fly ash, clay and others geo-based material. Geopolymer concretes (GPC) are a type of Inorganic polymer composites, to form substantial element of an environmentally sustainable construction and building products industry by replacing supplementing the conventional concretes. The source materials may be industry waste products such as fly ash, slag, red mud, rice-husk ash and silica fume may be used as feed stock for the synthesis of geopolymer. The alkaline liquids are concentrated aqueous alkali hydroxide or silicate solution, with soluble alkali metals, usually Sodium- (Na) or Potassium- (K) based.

High alkaline liquids are used to induce the silicon and aluminium atoms in the source materials to dissolve and form the geopolymeric binder. There are many different views as to which are the main parameters that affect the compressive strength and other mechanical properties of geopolymer concrete. The significant factors affecting the compressive strength are the type of alkaline activator. The curing temperature and the curing time. The important parameters for satisfactory polymerization are the relative amounts of Si, Al, K, Na, and molar ratio of Si to Al present in solution, the type of alkaline activator, the water content, and the curing temperature. This study also examines the mechanical properties of rice husk ash-based geopolymer concrete using coarse aggregate materials by performing compressive strength tests and splitting tensile strength tests and analyzing their uncovered relationships.

1.2 Geopolymer Concrete

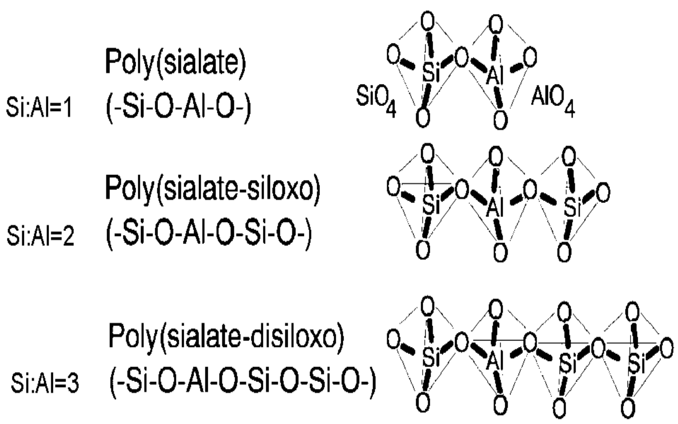
The term 'Geopolymer' was first coined by a Chemistry Professor, Davidovits in 1978 to describe a family of mineral binders with chemical composition similar to Zeolites but with an amorphous microstructure. After that in Civil Engineering profile Professor B.V.Rangan applied, the knowledge of geopolymers and he founded the "Geopolymer Concrete". Polymers are either organic material (i.e. Carbon based) or inorganic polymer. The inorganic polymer comprises the classes of natural polymers, synthetic organic polymers and natural bio polymers. Raw materials used in the synthesis of silicon based polymers are mainly rock forming minerals of geological origin, hence the name becomes geopolymer.

A geopolymer is essentially a mineral chemical compound or mixture of compound consisting of repeating units , silico – oxide (-SI-O-SI-O-), silico-aluminate (-SI-O-AL-O-), ferro-silico-aluminate (-AL-O-SI-O-AL-O-), created through a process of geopolymerization.

Poly(sialates) are chain and ring polymers with Si_4+ and AL_3+ in IV-fold coordination with oxygen and range from amorphous to semi-crystalline with the empirical formula

$$Mn\ (-(SiO_2)\ z\text{–}AlO_2)n.\ wH_2O$$

where "z" is 1, 2 or 3 or higher up to 32; M is a monovalent cation such as potassium or sodium, and "n" is a degree of polycondensation (Davidovits, 1984, B.V.Rangan 2006) three types of polysilates are present namely Poly (sialate) type (-Si-O-Al-O), the Poly(sialate-siloxo) type (-Si-O-Al-O-Si-O) and the Poly(sialate-disiloxo) type (-Si-O-Al-O-Si-O).



Through the polycondensation process geopolymer matrices are formed for example.

$$n(Si_2O_5,Al_2O_2)+2nSiO_2+4nH_2O+NaOH \text{ or } KOH \rightarrow Na^+,K^+ + n(OH)_3\text{-}Si\text{-}O\text{-}\underset{\underset{(OH)_2}{|}}{Al^-}\text{-}O\text{-}Si\text{-}(OH)_3 \qquad (2\text{-}2)$$

(Si-Al materials) (Geopolymer precursor)

$$n(OH)_3\text{-}Si\text{-}O\text{-}\underset{\underset{(OH)_2}{|}}{Al^-}\text{-}O\text{-}Si\text{-}(OH)_3 + NaOH \text{ or } KOH \rightarrow (Na+,K+)\text{-}(\text{-}\underset{\underset{|}{\underset{O}{|}}}{\overset{|}{Si}}\text{-}O\text{-}\underset{\underset{|}{\underset{O}{|}}}{\overset{|}{Al^-}}\text{-}O\text{-}\underset{\underset{|}{\underset{O}{|}}}{\overset{|}{Si}}\text{-}O\text{-}) + 4nH_2O \qquad (2\text{-}3)$$

(Geopolymer backbone)

It utilizes the polycondensation of silica and alumina precursors and a high alkali content to attain structural strength. The geopolymer concrete mainly consists of source materials and alkaline liquids. The source materials should be rich in Silicon (Si) and Aluminium (Al). The materials rich in silicon and Aluminium can be used as a source by product materials like fly ash, Metakaoline, GGBS (Ground Granulated Blast Furnace Slag), Rich Husk Ash, Red mud etc., or the natural binders like kaolinite, clays, micas, spinel, etc. Alkaline liquids are usually sodium based or potassium based.

1.2.1 MATERIALS USED IN GEOPOLYMER CONCRETE

The general description about the materials used for this concrete and Geopolymer Concrete is explained.

Fly ash

Fly ash, also known as flue-ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue. Ash that does not rise is called bottom ash. In an industrial context, Fly ash usually refers to ash produced during combustion of coal.

Fly ash is generally captured by electrostatic precipitators or other particle filteration equipment before the flue gases reach the chimneys of coal fired power plants, and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash. Fly ash is the most widely used material worldwide. This is particularly an important issue for India, which currently produces over 100 million ton of Fly ash annually.

Classification of Fly ash

A. Class F Fly ash

The burning of harder, older anthracite and bituminous coal typically produces Class F Fly ash. This Fly ash is pozzolanic in nature, and contains less than 20% Lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of class F Fly ash requires a cementing agent, such as Portland Cement, Quicklime, or Hydrated lime - mixed with water to react cementitious compounds. Alternatively, adding a chemical Sodium silicate (water glass) to a Class F Ash can form as Fly ash is shown in Fig 1.1

Fig 1.1 Class F Fly ash

B. Class C Fly ash

Fly ash produced from the burning of younger lignite or sub-bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C Fly ash hardens and gets stronger over time. Class C Fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C Fly ash does not require an activator. Alkali and sulfate contents are generally higher in Class C Fly ashes. Class C fly ash is shown in Fig 1.2. The Properties of Fly ash are represented in table 1.1.

Fig1.2 Class C Fly ash

Table 1.1 Properties of Fly Ash

Oxides	**Mettur Fly ash**	**Requirements as per IS 3812-2003**
SiO_2	55.99%	SiO_2 >35% Total - >70%
Al_2O_3	15.23%	
Fe_2O_3	21.78%	
CaO	0.17%	-
MgO	2.45%	<5%
LOI	0.62%	<12%

GGBS (Ground Granulated Blast Furnace Slag)

Ground Granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron. These operate at a temperature of about 1,500 degrees centigrade and are fed with a carefully controlled mixture of iron-ore, coke and limestone. The iron ore is reduced to iron and the remaining materials form a slag that floats a top of the iron. Although normally designated as “GGBS” in the UK, it can also be referred to as “GGBFS” or “slag cement”. The main components of blast furnace slag are CaO (30-50%), SiO_2 (28-38%), Al_2O_3(8-24%), and MgO (1-18%). In general, increasing the CaO content of the slag results in raised slag basicity and an increase in compressive strength. The MgO and Al_2O_3 content show the same trend upto respectively 10-12% and 14% beyond. The GGBS can be used to increase properties in geopolymer concrete. Granulated blast slag is shown in fig.1.3. The properties of GGBS are shown in Table 1.2.

Fig.1.3 GGBS

Table 1.2 Properties of Ground Granulated Blast Furnace Slag

S.No	Oxides	Percentage
1	SiO_2	41.24
2	Al_2O_3	20.64
3	Fe_2O_3	7.28
4	CaO	2.455
5	MgO	2.93
6	LOI	Nil

Silica Fume

Silica fume, also known as micro silica, Silica fume particles viewed in a transmission electron microscope (CAS number 69012-64-2, EINECS number 273-761-1) is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete.

Silica fume is an ultrafine material with Properties spherical particles less than 1µm in diameter, the average being about 0.15µm. This makes it approximately 100 times smaller than the average cement particle. The bulk density of silica fume depends on the degree of densification in the silo and varies from 130 (undensified) to 600 kg/m^3. The specific gravity of silica fume is generally in the range of 2.2 to 2.3. The specific surface area of silica fume can be measured with the BET method or nitrogen adsorption method. It typically ranges from 15,000 to 30,000 m^2/kg. Silica Fume is shown in fig.1.4. The properties of Silica Fume are shown in Table 1.3.

Fig1.4 Silica fume

Table 1.3 Properties of Silica fume

Oxides	**Percentage**
SiO_2	94.3
Al_2O_3	0.09
Fe_2O_3	0.10
CaO	0.30
MgO	0.43
SO_3	-
K_2O	0.83
Na_2O	0.27

Alkali Activator solution

In conventional concrete ordinary potable water is added in concrete for binding and curing purpose. In Geopolymer concrete water is replaced with alkaline liquids and it activates the alumina and silica in the source material. Water is added to cement for hydration process. In geopolymer concrete generally sodium or potassium-based activators are used.

Fig 1.5 Alkaline Solution

According to the properties, availability, cost and applications two combinations of alkaline liquids are used.

They are

1. Sodium hydroxide and sodium silicate
2. Potassium hydroxide and potassium silicate

The reaction takes place while adding the alkaline liquids to source materials is termed as polycondensation process. We use Sodium hydroxide and sodium silicate in our Project, the chemical composition is given in the Table 3.9 & 3.10. The process takes place in geopolymer concrete and ordinary cement concrete is explained in Fig 1.12.

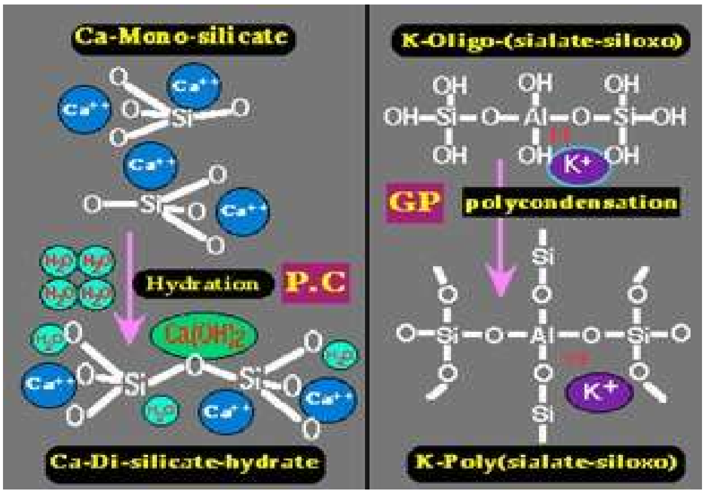


Fig 1.6 Polycondensation Process

Table 1.4 Properties of Sodium Silicate

COMPOSITION	PERCENTAGE
SiO_2	34.52
Na_2O	25.88
WATER	39.6

Table 1.5 Properties of Sodium Hydroxide

COMPOSITION	PERCENTAGE
Carbonate (Na_2Co_3)	2
Chloride (Cl)	0.01
Sulphate (So_2)	0.05
Lead(pb)	0.001
Iron (Fe)	0.001
Potassium(K)	0.01
Zinc (Zn)	0.02

Super Plasticizer

Super plasticizers, also known as high range water reducers, are chemical admixtures used where well-dispersed particle suspension is required. These polymers are used as dispersants to avoid particle segregation (gravel, coarse and fine sands), and to improve the flow characteristics (rheology) of suspensions such as in concrete applications. Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enables the production of self-consolidating concrete and high performance concrete. This effect drastically improves the performance of the hardening fresh paste.

The strength of concrete increases when water to cement ratio decreases. However, their working mechanisms lack a full understanding, revealing in certain cases cement super plasticizer incompatibilities. The addition of super plasticizer in the truck during transit is a fairly new development within the industry. Admixtures added in transit through automated slump management systems allows concrete producers to maintain slump until discharge without reducing concrete quality.

Super plasticizers can be classified into four types such as

1. Sulfonated Melamine Formaldehyde condensates (SMF)
2. Sulfonated Naphthalene Formaldehyde condensates (SNF)
3. Modified LignoSulfonates (MLS)
4. PolyCarboxylate Derivatives (PC)

The selection of concrete super plasticizer is based on the type of concrete used, namely ready mix, precast, high strength, high performance, self-compacting, shotcrete, etc. In this project, we use SP-430 as a super plasticizer to increase the workability.

1.2.2 Application of Geopolymer Concrete

1. Fire- and heat-resistant coatings.
2. Adhesives & medicinal applications.
3. High-temperature ceramics.
4. New binders for fire-resistant fiber composites.
5. Toxic and radioactive waste encapsulation.
6. New cements for concrete.

1.3 Objectives of the study

1. To study the Fresh and hardened properties of geopolymer concrete.
2. To study the mechanical properties such as Compressive Strength, Split Tensile Strength, Flexural Strength for the fly ash, GGBS and silica fume based geopolymer concrete.
3. To study the Performance of geopolymer Concrete.
4. To obtain the optimum proportion of flyash, GGBS and silica fume.

CHAPTER 2

LITERATURE REVIEW

2.1 General

This chapter outlines some of the recent reports published in behavior of geopolymer concrete with flyash, GGBS and silica fume and durability of geopolymer concrete.

2.1.1 Literatures on Geopolymer Concrete

D.Hardjito et al. (2005) reported the Development and properties of Low-calcium fly ash-based Geopolymer concrete**. In** this paper the short-term and long-term properties, structural applications of reinforced low-calcium fly ash-based geopolymer concrete were studied. Ratio of alkaline liquid-to-fly ash by mass, Concentration of sodium hydroxide (NaOH) solution in Molar, Ratio of sodium silicate solution-to-sodium hydroxide solution by mass, curing temperature, Curing time, handling time. Addition of super plasticiser, Rest Period prior to curing, Water content of mixture, Dry curing versus steam curing, mixing time etc makes various changes in geopolymer mix like the higher concentration (molar) of sodium hydroxide solution results in higher compressive strength. Higher the ratio of sodium silicate-to-sodium hydroxide ratio by mass, higher is the compressive strength of fly ash-based geopolymer concrete. The curing temperature in the range of 30^0C to 90^0C increases, the compressive strength. The average density of fly ash-based geopolymer concrete is similar to that of OPC concrete. The Poisson's ratio of fly ash-based geopolymer concrete with compressive strength in the range of 40 to 90 MPa falls between 0.12 and 0.16. These values are similar to those of OPC concrete.

B.V.Rangan et al.(2006) reported the long term properties of low calcium fly ash based geopolymer concrete. The long-term properties included in the study were creep, drying shrinkage, sulphate resistance, and sulfuric acid resistance, and they concluded that the geopolymer concrete with increase in age gives no substantial gain in compressive strength when it is cured under heat conditions. But the fly ash based geopolymer concrete cured in the ambient conditions gains compressive strength with age. Heat cured flyash ash-based GPC undergoes low creep, very little drying shrinkage, excellent resistance to sulfate attack, there is no damage to the surface of test specimens after exposure to sodium sulfate solution up to one year. Also, there is no significant change in mass and compressive strength of specimens after various periods of exposure up to one year but exposure of sulfuric acid solution damages the surface of heat cured geopolymer concrete specimens and causes a mass loss of 3% after one year exposure. The severity of the damage depends on the acid concentration. GPC is significantly better than that of Portland cement concrete.

Wallah.S.E.et al.(2010) investigated the Creep Behavior of Fly Ash-Based geopolymer Concrete he made four different mixes were prepared and it is cured in steam and dry curing conditions then it is taken for specially-built creep testing frame with a hydraulic loading system to find the creep coefficients. From the test results that the fly ash-based geopolymer concrete undergoes low creep which is generally less than that of OPC concrete. After one year of loading, the results for specific creep of fly ash-based geopolymer concrete ranges from 15 to 29 micro strain for concrete compressive strength 67–40 MPa respectively. And the creep coefficient after one year of loading for fly ash based geopolymer concrete with compressive strength of 40, 47, and 57 MPa is around 0.6 to 0.7, while for geopolymer concrete with compressive strength of 67 MPa this value is around 0.4 to 0.5.

Shankar H. Sanni (2012) examined the performance of geopolymer concrete under several environmental conditions. 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 GPC has an excellent resistance to acid and sulphate attack when compared to conventional concrete. Thus, the production of geopolymers have a relative higher strength, excellent volume stability and better durability.

Ganapati Naidu. P et al. (2012) reported the Higher concentrations of G.G.B.S (Slag) result in higher compressive strength of geopolymer concrete. Mixing of G.G.B.S was tested up to 28.57%, beyond that immediate setting was observed. There is no necessity of exposing geopolymer concrete to higher temperature to attain maximum strength if minimum 9% of flyash is replaced by GGBS. Compressive strength of geopolymer concrete increases with increase in percentage of replacement of flyash with GGBS. Flyash was replaced by GGBS up to 28.57%, beyond that fast setting was observed. A maximum of 25% loss in compressive strength was observed when geopolymer concrete exposed to a temperature of 500oC for two hours. 90% of compressive strength was achieved in 14 days. The average density of geopolymer concrete was equal to that of OPC concrete.

Ahmed Mohmed (2013) In this study, an inquiry geopolymer concrete, By Joe product materials (GGBS and SF) and by a reaction between alkaline liquid set was produced with the presence of physical properties of was to determine. GGBS and SF as source material were used to create geopolymer concrete. Sodium silicate solution and sodium hydroxide solution were mixed together as alkaline liquid. Silicon and aluminum in alkaline liquid GGBS and SF loose aggregates and concrete arrived to produce other materials bound geopolymer paste form Reacted with. Aggregates sand and 7 mm, 10 mm and 14 mm granite-type as coarse aggregate. In addition, to improve the workability of the concrete fresh geopolymer superplasticizer was used.

The SF and contained two of geopolymer concrete measurable GGBS cubes 7, 14 and 28 days old, were tested. The behavior of the geopolymer concrete results was aimed to figure out. In addition, geopolymer concrete strength and durability were also tested. Tests results are shown in Chapter 4 that increases strength geopolymer GGBS concrete with age, but SF 7 to 28 days of age were found in the results. The result, the compressive strength geopolymer concrete made of GGBS in 7-14 days and 14-28 days of age at 3 to increase about 12 MPa.

Huajun Zhu et al. (2013) reported that effects of phase changes on the bonding property of geopolymer to hydrated cement. Curing under different conditions was carried out to the geopolymer binder was prepared by activation of heated, bonded with 28 days aged cement paste. The experimental were carried out and cured under the 20 ^{0}C air curing conditions results the bond strength as 1.3 MPa at 7 days and increased to 1.5 MPa at 28 days. While under the 80^0 C steams and water curing conditions, the bond strength can be decreased by 31% and 37% respectively. By the XRD, FTIR and SEM analysis strength loss of the geopolymers and hydrated cement pastes is due to two factors: (1) the increased porosity in cement paste due to the water loss and crystallization of C–S–Hs; and (2) the mineralogical change (crystallization) in geopolymer binder which becomes more ordered structures.

Dr. T.V.S.Vara Lakshmi (2013) investigated incorporation of Silica fume in the geopolymer concrete mixes resulted in finer pore structure thus produce low permeability concrete. The geopolymer concrete produced with different combination of SF and GGBS are able to produce structural concretes of high grades (much more than 45MPa) by self-curing mechanisms only and percentage 40% of SF to 60% GGBS. The GPC mixes were produced easily using equipment similar to those used for production of conventional cement concretes. The influences of SF on strength of geopolymer concrete mixes were studied. It has been observed that the decreasing the quantity of SF increase of Compressive strength of geopolymer. Apart from less energy intensiveness, the GPCs utilize the industrial wastes for producing the binding system in concrete. There are both environmental and economic benefits of using SF, fly ash and GGBS.

Sonal P. Thakkar et al. (2014) studied that strength of geopolymer concrete for oven curing is more than ambient cured geopolymer concrete at 3, 7 and 28 days. The geopolymer concrete using GGBFS as a sole binder achieves more strength than that of normal control concrete when oven curing is done. A higher concentration of GGBFS result in higher compressive strength of geopolymer concrete. At 7 days when combination of 50:50 Fly ash and GGBFS content is used the strength is nearly equal to control concrete of same age with oven curing. Geopolymer concrete using various combinations of fly ash and GGBFS gives optimum dosage at 50:50 proportion of each of GGBFS and fly ash. As the percentage of slag increase, its strength also increases and significant strength can be achieved even at ambient curing. At 28 days for 50:50 Fly Ash and GGBFS combination content the oven cured and ambient cured samples yield strength that is nearly equal to 25 MPa indicating that geopolymer concrete can achieve desired strength at ambient curing.

T.V.Srinivas Murthy et.al (2015) have replaced fully OPC by GGBS and alkaline liquids are used as the binding materials. They have casted cubes, cylinder and prisms to determine the strength properties. The curing is carried out in oven at 65degree C and carried out the tests. The results are compared with conventional concrete. Thus, higher the concentration of NaOH and higher the ratio of sodium hydroxide to sodium silicate higher is the compressive strength of GGBS based GPC. To improve the workability addition of naphthalene, sulphonate based super plasticizer of about 4% of the binding material (GGBS) mass is used. The test results show the use of GGBS based GPC the compressive, split, flexural strength increased by 13.82%,18.23%,30.19% as compared to conventional concrete.

Sherif Yehia, Sharef Farrag, Kareem Helal, (2015) studied the influence of Silica fume, Flyash, GGBS, and combinations of them on the mechanical properties and flowability of SCCHSLWC was examined. All mixes considered in the investigation was compared to mix without any use of SCMs. SF, being highly reactive, helped achieve the highest compressive strength among all mixes, while it noticeably affects flowability. On the other hand, FA and GGBS did not affect flowability as SF did, but they led to lower compressive strength than that of SF, lower strength gain rate, and lower early strength. Nevertheless, GGBS helped increase the flexural strength of the mixes. Equally important, the applicability of the ACI 318 mechanical properties reduction factor of LWC relative to NWC (λ) when different SCMs are utilized was assessed in a comparable range of compressive and flexural strength. In general, the results show that the utilization of various SCMs, individually or in combination, does not lead to an alteration of the λ value. However, the modification factor λ needs to be further investigated especially some of the supplementary materials have a retarder effect leading to slow gain of strength at early ages.

D.Suresh, K. Nagaraju, (2015) studied the movement of moisture of GGBS mixes, probably due to the dense and strong microstructure of the interfacial aggregate/binder transition zone are probably responsible for the high resistance of GGBS mixes to attack in aggressive environments such as silage pits. The mineral composition of GGBS cement paste (with less aluminates and portlandite than Portland cement) probably contributes to this resistance. As we have seen GGBS is a good replacement to cement in some cases and serves effectively but it can’t replace cement completely. But even though it replaces partially it gives very good results and a greener approach in construction and sustainable development which we are engineers are keen about today.

Dr. H.Narendra (2015) studied the sustainable Geo-polymer concrete has been achieved in a sequential procedure starting with the trial mixes designed by the Rangan method of mix design which is regarded as a simple mix design. Rangan method gives the calculation of quantity of materials used in the mix design but the dosage of super plasticizer are finalized using trial and error. About 60% of M-sand and 40% of pond ash as sand replacement is found to be the optimum amount in order to get a favorable strength. Compressive strength of concrete increases with increasing the concentration of sodium hydroxide. Use of GGBS about 20% by mass of fly ash in a geo-polymer concrete, increases the strength of concrete and cured under ambient curing There by making it as sustainable geo-polymer concrete.

P.Vignesh, K.Vivek (2015) Based on the experimental investigation the optimum replacement level of fly ash by GGBS in GPC will be carried out. Water absorption property is lesser than the nominal concrete. Achieving strength in a short time i.e. 70% of the compressive strength in first 4 hours of setting. Determines the different strength properties of geo-polymer concrete with percentage replacement of GGBS.

P.Nath et.al (2015) have aimed to achieve fly ash-based geopolymer concretes suitable for ambient curing condition. Class F fly ash was used as the base material and the binding materials used are sodium hydroxide and sodium silicate solutions. Grounded blast furnace slag was added in different proportions to the mix to enhance the early age properties of concrete. Setting times of geopolymer pastes, workability of fresh concrete and compressive strength after curing at 20-23ºC were investigated. Setting time and compressive strength of geo-polymers varied with the variation of alkaline activator to fly ash ratio and sodium silicate to sodium hydroxide ratio in the alkaline activator solution. With the increase of alkaline activator solution in the mix from 35% to 45% of total binder, the setting time increased and compressive strength decreased. Alkaline activator solution with SS/SH ratio of 2.5 achieved lesser slump and setting time than those with 1.5 and 2.

Neethu Susan Mathew, S. Usha (2015) has studied the slag to fly ash ratio required for geopolymer concrete which can be cured at ambient temperature is found to be 50: 50. Ambient cured fly ash–ground granulated blast slag (GGBS) based geopolymer concrete attains the target compressive strength at 7th day itself and hence can be used for structural application where early furnace strength is required. The average split tensile strength of geopolymer concrete is higher than the control mix by 10.26%. The flexural strength values for geopolymer concrete mixture is higher than OPC control mix by 4.7%. Bond strength values of geopolymer concrete are comparable with OPC based concrete. The Geopolymer concrete can almost 72.9%, thereby improving the durability of concrete.

K.Prasanna (2016) has studied the geopolymer concrete strength within 24 hours at ambient temperature without water curing. The necessity of heat curing of concrete was eliminated by incorporating GGBS and fly ash in a concrete mix. The strength of geo polymer concrete was increased with increase in percentage of GGBS in a mix. Low-calcium fly ash (ASTM Class F) is used as the source material, instead of the Portland cement, to make concrete. Low-calcium fly ash-based geo polymer concrete has excellent compressive strength and is suitable for structural applications. The salient factors that influence the properties of the fresh concrete and the hardened concrete have been identified. Geo polymer concrete structural members are similar to those observed in the case of Portland cement concrete. Therefore, the design provisions contained in the current standards and codes can be used to design reinforced lowcalcium fly ash-based geo polymer concrete structural members. Heat-cured low-calcium fly ash-based geo polymer concrete also shows excellent resistance to sulfate attack, good acid resistance, undergoes low creep, and suffers very little drying shrinkage. The paper has identified several economic benefits of using geo polymer concrete.

G.Gayathri, V.S.Ramya, T.Yasotha (2016) studied the replacement of E-Waste found possible and economical based on previous studies. In this study the cement is fully replaced by industrial byproducts fly ash and GGBS. The following points are arrived from the present study. From the past studies it has been proved that using E-waste doesn't 't affects the properties of geopolymer concrete majorly. The initial setting time with 90 percent fly ash + 10 percent GGBS obtained as 19.9 hours the normal consistency obtained at 28 percentage. Use of E-waste as partial replacement of fine aggregate is economical. Reuse of E-waste reduces environmental hazards. Partial replacement of E-waste as fine aggregate proved as well graded aggregate. Geopolymer concrete represent as a Green concrete and also as a Eco-friendly concrete as it reduces the CO2 emission in the world.

Abhishek C. Ayachit (2016) has proposed the guidelines for the design of fly ash based geopolymer concrete of ordinary and standard grade on the basis of quantity and fineness of fly ash, quantity of water and grading of fine aggregate by maintaining water- to-geopolymer binder ratio of 0.40, solution-to-fly ash ratio of 0.35, and sodium silicate-to-sodium hydroxide ratio of 2 with concentration of sodium hydroxide as 13 M. Heat curing was done at 60 °C for duration of 24 h and tested after 7 days after oven heating. Experimental results of M20, M25, M30, M35 and M40 grades of geopolymer concrete mixes using proposed method of mix design shows promising results of workability and compressive strength. So, these guidelines help in design of fly ash based geopolymer concrete of Ordinary and Standard Grades as mentioned in IS 456: 2000.

K.Mahendra,N.Arunachelam (2017). Geopolymer is an innovative, environmentally friendly construction material for the sustainable development, using the combination of fly ash and alkali as a binding agent in place of Ordinary Portland Cement. It is one of the promising alternative binder technologies to reduce CO2 emissions in the atmosphere. This paper presents the experimental study performed to investigate the effect of low-calcium fly ash based geopolymer mortar incorporating Silica powder. The mixture of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) is used as an alkaline activator in the ratio of 1:2.5 and the concentration of sodium hydroxide are 8M, 10M and 12M. The silica powder was replaced in place of fly ash by varying percentages of 2%, 4%, 6%, 8% and 10% and studied for its compressive strength and compared with the control geopolymer mortar cubes.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

This chapter deals with the methodology adopted for the present investigation. The work sequence represented in flow chart as shown in Fig.3.1

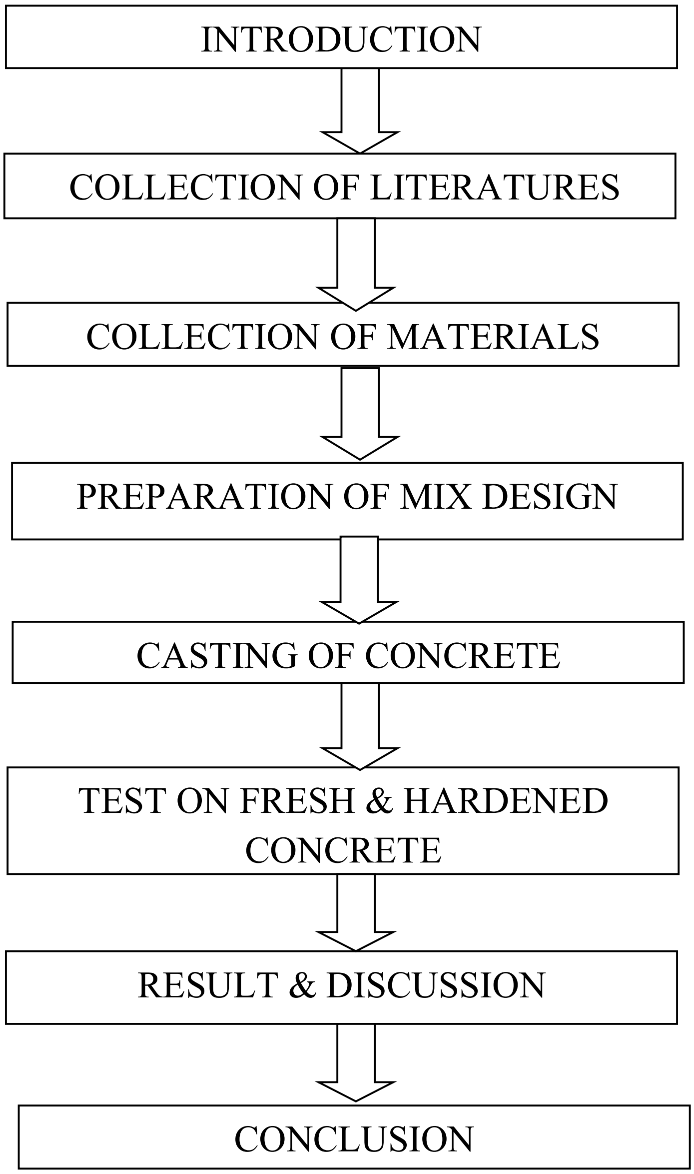


Fig.3.1 Flow Chart representation of Methodology

3.2 METHODOLOGY:

Stage 1: Introduction

Brief introduction has been given about concrete and necessity of Geopolymer concrete. Also, the merits and demerits of Fly ash based geopolymer concrete are given. The objective of present investigation also briefed.

Stage 2: Literature Review

In geopolymer concrete various literatures are collected and studied. The literature review is carried out in Flyash based GPC.

Stage 3: Collection of Materials

In Geopolymer concrete material such as Fly ash, GGBS, Silica fume, Fine aggregate, coarse aggregate & Chemicals like NaOH, Na_2SO_4 are collected as per the mix proportion.

Stage 4: Preparation Mix Design

There is no standard mix design for Fly ash based Geopolymer concrete. From the literature review the various mix ratios are arrived for different combinations.

Stage 5: Casting of Concrete

The specimen is cast according to IS for finding their mechanical properties.

Stage 6: Test on Fresh Concrete

The Compaction Factor test is carried out to find out the workability of the concrete.

Stage 7: Test on Hardened Concrete

The tests for Mechanical properties are carried out at the age of 7, 14, & 28 days in Compression Testing Machine and Universal Testing Machine.

Stage 8: Test results & Discussion

From the test result various comparison are done and reasons are discussed.

Stage 9: Conclusion

In these various conclusions have been given and recommended for various applications.

CHAPTER 4

EXPERIMENTAL INVESTIGATION

4.1 General

This chapter deals with the mechanical properties, chemical composition and merits and demerits of the material used is discussed.

4.2 Materials used

4.2.1 Fly ash

Fly ash, is also known as flue-ash, is one of the residues generate in combustion, and comprises the fine particles that rise with the flue gases and produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants, and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash. The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash and class C fly ash. The class C flyash contains more than 20% lime (CaO). The class C fly ash is pozzolanic in nature, and contains less than 20% lime (CaO).

Table 4.1 gives the chemical properties of the Class F dry fly ash conforming to IS 3812-2003 obtained from Mettur Thermal power station of Tamil Nadu from Southern part of India was made use of in the casting of the specimens. Quality of fly ash across all major thermal plants in India is reasonably uniform and consistent. Indian fly ash is relatively low in reactive silica ranging 25% to 35%. Fly ash can be utilized directly in concrete replacing cement up to 35% as per IS 456: 2000. Fly ash if added beyond 35% in concrete will be considered as part of replacement for cement. Fly ash addition in concrete needs proper storage, dosing and mixing system in the form of mechanized batching plant, otherwise fly ash may not disperse thoroughly in the mix and concrete produced may not be of consistent quality.

Geo-polymer concrete can utilize fly ash up to 90% - 95% as cementitious material by alkali activation and elevated temperature at $50^{O}C$ to $60^{O}C$. It is widely used in pre-cast industries in countries like Australia, New Zealand, etc. With the increasing awareness of precast in India, there is opportunity to use geo-polymer on larger scale and increase fly ash consumption. The merits and demerits of fly ash is discussed below.

Table 4.1 Chemical composition of Fly Ash

<table>
<tr><th>Oxides</th><th>Mettur Fly ash</th><th>Requirements as per IS 3812-2003</th></tr>
<tr><td>SiO_2</td><td>55.99%</td><td rowspan="3">SiO_2 >35%
Total - >70%</td></tr>
<tr><td>Al_2O_3</td><td>15.23%</td></tr>
<tr><td>Fe_2O_3</td><td>21.78%</td></tr>
<tr><td>CaO</td><td>0.17%</td><td>-</td></tr>
<tr><td>MgO</td><td>2.45%</td><td><5%</td></tr>
<tr><td>LOI</td><td>0.62%</td><td><12%</td></tr>
</table>

4.2.2 GGBS (Ground Granulated Blast Furnace Slag)

GGBS is obtained by quenching molten iron slag and it is a byproduct of iron and steel blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. GGBS is used to make durable concrete structures in combination with ordinary Portland cement and other pozzolanic materials. GGBS has been widely used in Europe, and increasingly in the United States and in Asia (particularly in Japan and Singapore) for its superiority in concrete durability, extending the lifespan of buildings from fifty years to a hundred years.

The main components of blast furnace slag are CaO (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%), and MgO (1-18%). In general increasing the CaO content of the slag results in raised slag basicity and an increase in compressive strength. The MgO and Al_2O_3 content show the same trend up to respectively 10-12% and 14%, beyond. The GGBS can be used to increase the properties in geopolymer concrete. The Chemical properties of GGBS is given in the Table 4.2

Table 4.2 Chemical composition of GGBS

Oxides	Percentage
SiO_2	41.24
Al_2O_3	20.64
Fe_2O_3	7.28
CaO	2.455
MgO	2.93
LOI	Nil

4.2.3 Silica Fume

Silica fume, also known as microsilica, Silica fume particles viewed in a transmission electron microscope (CAS number 69012-64-2, EINECS number 273-761-1) is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete.

Silica fume is an ultrafine material with Properties spherical particles less than 1μm in diameter, the average being about 0.15μm. This makes it approximately 100 times smaller than the average cement particle. The bulk density of silica fume depends on the degree of densification in the silo and varies from 130 (undensified) to 600 kg/m^3. The specific gravity of silica fume is generally in the range of 2.2 to 2.3. The specific surface area of silica fume can be measured with the BET method or nitrogen adsorption method. It typically ranges from 15,000 to 30,000 m^2/kg.

It is sometimes confused with fumed silica (also known as pyrogenic silica, CAS number 112945-52-5). However, the production process, particle characteristics and fields of application of fumed silica are all different from those of silica fume. The Chemical properties of Silica Fume is given in the Table 4.3.

Table 4.3 Chemical composition of Silica fume

Oxides	Percentage
SiO_2	94.3
Al_2O_3	0.09
Fe_2O_3	0.10
CaO	0.30
MgO	0.43
SO_3	-
K_2O	0.83
Na_2O	0.27

Properties of Fly ash, GGBS & Silica Fume

Fineness Test

Weigh required quantity of Fly ash or GGBS or Silica Fume to the nearest and place it on the sieve. Agitate the sieve by swirling, planetary and linear movements, until no more fine material passes through it. Weigh the residue and express its mass as a percentage R1, of the quantity first placed on the sieve. Gently brush all the fine material off the base of the sieve. Repeat the whole procedure using a fresh sample to obtain n all to. Then calculate R as the mean of R1 and R2 as a percentage. The mean value gives the fineness percent of fly ash.

Fig. 4.1 90-micron sieve

Specific Gravity

Dry the flask carefully and fill it with kerosene to appoint on the stem between 0 and 1ml. Record the level of the liquid in the flask as initial reading. Put the weighted quantity of fly ash or GGBS or Silica Fume into the flask so that the level of the kerosene rise to required level, care being taken to avoid splashing and to see that materials does not adhere to the sides of the flask above the liquid. After putting all the materials to the flask, roll the flask gently in the inclined position to expel air until no further air bubbles rises to the surface of the liquid. Note down the new liquid level as final reading.

Fig 4.2 Le-Chatelier Flask

Table 4.4 Physical Properties of Fly ash, GGBS & Silica Fume

S.No.	Description	Fineness	Specific gravity
1	*Fly ash*	*300μ*	*2.3*
2	*GGBS*	*30μ*	*2.94*
3	*Silica Fume*	*0.15μ*	*2.2*

4.2.4 FINE AGGREGATE (M-sand)

Sand is used as fine aggregate in mortars and concrete. Rock crushed to the required grain size distribution is termed as manufactured sand (M-sand). In order to arrive at the required grain size distribution, the coarser stone aggregates are crushed in a special rock crusher to obtain M-sand.

The shape of the M-sand particles resembles with that of river sand particles. Flaky and elongated coarse particles are absent in the M-sand.

M-sand is well graded and falls within the limits of grading zone-II sand, grading limits specified in IS 383 code. Code allows 20% fines less than 150 microns is about 18% (IS 383 code limits is 20%).

M-sand contains typical rock forming minerals like quartz, feldspar, mica group of minerals etc. as revealed by X- ray diffraction (XRD) studies. Rock forming minerals like quartz, feldspar, etc. are basically inert in nature. Mica group consists of muscovite, biotite, boromuscovite etc. The mica group of minerals are not interfering in the hydration process and strength development in mortars and concrete. The sand was sieved in 4.75 mm Sieve to remove all pebbles.

Fig 4.3 Fine Aggregate

Properties of fine aggregate

Specific Gravity

Initially the empty dry density bottle was weighed and taken as M_1. Then the bottle is filled with some amount of fine aggregate and it was weighed as M_2. Then the density bottle was filled with water up to the top and it was weighed as M_3. Then the density bottle was dried and then filled up to the top with water and weighed as M_4.

Specific gravity of cement, $G = (M_2 – M_1) / [(M_2 –M_1) – (M_3 –M_4)]$

Where,

M_1 = Mass of empty density bottle

M_2 = Mass of density bottle with fine aggregate

M_3 = Mass of the density bottle with fine aggregate and water.

M_4 = Mass of the density bottle completely filled with water.

Fig 4.4 Pyconometer

Fineness Modulus (By Sieve Analysis)

The sample was brought to an air-dry condition by drying at room temperature. The required quantity of the sample was taken. The sieves are placed in the order of size in a mechanical sieve shaker. Sieving was done for 10 minutes. Then the material retained on each sieve after shaking represents the fraction of the aggregate coarser than the sieve considered and finer than the sieve above. The weight of aggregate retained in each sieve was weighed. Fineness modulus was determined as the ratio of summation of cumulative percentage of weight retained to 100.

Fig 4.5 Sieve Analysis of fine aggregate

Table 4.5 Sieve Analysis result

S.NO	IS Sieve	Size of opening Mm	Weight retained gm	% Wt retained	Cum % Wt retained	% finer
1	4.75mm	4.75	0.008	0.8	0.8	99.2
2	2.36mm	2.36	0.104	10.4	11.2	88.8
3	1.18mm	1.18	0.250	25	36.2	63.8
4	600µ	0.6	0.136	13.6	49.8	50.2
5	425µ	0.425	0.112	11.2	61	39
6	300µ	0.3	0.112	11.2	72.2	27.8
7	150µ	0.15	0.216	21.6	93.8	6.2
8	75µ	0.075	0.052	5.2	99	1
9	Pan	0	0.001	1	100	0

Table 4.6 Physical Properties of Fine Aggregate

S.NO	*DESCRIPTION*	*RESULT*
1	*Specific gravity*	*1.28*
2	*Fineness modulus*	*5.24*

4.2.5 Coarse Aggregate

Hard stones of size less than 12mm were used as coarse aggregate.

Fig 4.6 Coarse Aggregate

Properties of Coarse Aggregate

Specific Gravity

Take 1kg of aggregate. Sieve the sample in 10mm sieve-Remove the fine particles. Place the sieve sample in the glass bowl. Partly fill the vessel with distilled water. Keep the aggregate immersed for 24 hrs. So that they are completely saturated. Remove the air voids, the vessel is then over filled with water and cover the vessel. Dry the vessel in outside. Take the weight that is Water+Aggregate+Vessel. Note the reading as A. The aggregate is now emptied and the aggregate is made to drain out. The aggregate is placed on a dry cloth, till it completely reaches to surface dry condition. Refill the vessel with distilled water. Weight the vessel with water that is Vessel+Water (B). The weight of saturated aggregate is taken out and note the reading as C. Now the aggregate is taken and placed in the oven with a temperature of 100^0 C for 24hrs. After 24 hrs, the aggregate is taken out and cooled in an air tight container. Note down the oven dry aggregate as D.

$$\text{Specific gravity} = \frac{D}{C-(A-B)}$$

Where,

A = Weight of vessel +Sample +Water (gm)

B = Weight of vessel + Water (gm)

C = Weight of Saturated and surface dry Sample (gm)

D = Weight of Oven dry Sample (gm)

Aggregate Crushing Value

Aggregate crushing value is determined with the reference to IS:2386(Part-IV)-1963. The aggregates passing through 12.5mm and retained on 10mm IS sieve are Oven-Dried at a temperature of 100-110^0C for 3-4 hrs. The cylinder of the apparatus is filled in 3 layers, each layer tamped with 25 strokes of a tamping rod. The weight of aggregates is measured (weight-A). The surface of the aggregates is then leveled and the plunger inserted. The apparatus is then placed in the compression testing machine and loaded at a uniform rate so as to achieve required load in 10mins.After this, the load is released. The sample is then sieved through a 2.36mm IS sieve and the fraction passing through the sieve is weighed (weight-B).

Aggregate Crushing Value = $\frac{B}{A} \times 100$

Where,

A = Total weight of aggregate.

B = Weight of Fraction passing through 2.36mm sieve.

Fig 4.7 Aggregate Crushing Test

Impact Test

The test sample consists of aggregates passing 12.5mm sieve and retained on 10mm sieve and dried in an oven for 4hrs at a temperature of 100-110^0 **C.** The aggregates are filled up to about 1/3 full in the cylindrical measure and tamped 25 times with rounded end of the tamping rod. The rest of the cylindrical measure is filled by two layers and each layer being tamped 25 times. The overflow of aggregates in cylindrically measure is cut off by tamping rod using it has a straight edge. Then the entire aggregate sample in a measuring cylinder is weighed nearing to 0. The aggregates from the cylindrical measure are carefully transferred into the cup which is firmly fixed in position on the base plate of machine. Then it is tamped 25 times. The hammer is raised until its lower face is 38cm above the upper surface of aggregate in the cup and allowed to fall freely on the aggregates. The test sample is subjected to a total of 15 such blows each being delivered at an interval of not less than one second. The crushed aggregate is than removed from the cup and the whole of it is sieved on 2.366mm sieve until no significant amount passes. The fraction passing the sieve is weighed accurate to 0.1gm. Repeat the above steps with another fresh sample. Let the original weight of the oven dry sample be W1gm and the weight of fraction passing 2.36mm IS sieve be W_2gm. Then aggregate impact value is expressed as the % of fines formed in terms of the total weight of the sample.

$$\text{Aggregate impact value} = (W_2 / W_1) \text{ X } 100$$

Where,

W_1 - Total weight of sample.

W_2 - Weight of fraction passing through 2.36 mm sieve.

Table 4.7 Aggregate impact values are used to classify the stone aggregates with respect to toughness property as given below.

Aggregate impact value (%)	Toughness Properties
<10	Exceptionally tough / Strong
10 – 20	Very tough / Strong
20 – 30	Good for pavement surface course
>35	Weak for pavement surface course

Fig 4.8 Aggregate Impact Test

Elongation Index

The sample is sieved in accordance with the sieves. Each fraction is gauged individually for length on a metal length gauge. The length gauge used is that specified in the table for the appropriate size of the material. The total weight of the aggregate retained by the length gauge is found. Reference [IS: 2386 (PART-1)-1963(re-affirmed 1997)].

Elongation index = (P/W) x100

Where,

P = Total weight of aggregate in fraction retained on length gauge

W = Total weight of aggregate fraction passing and retained

Fig 4.9 Length gauge

Table 4.8 Elongation index result

S.NO	Passing through IS sieve(mm)	Retained on IS sieve Mm	Weight of aggregate fraction passing and retained	Length gauge (mm)	Weight of aggregate in fraction retained on length gauge
1	16	12.5	0.055	25.6	0.003
2	12.5	10	0.045	20.2	0.020
3	10	6.3	0.020	14.7	0.005

Flakiness Index

The sample is sieved in accordance with the sieves. Each fraction is gauged in turn for thickness on the thickness gauge. The separate aggregate fractions are passed through the corresponding slots in the thickness gauge. The weight of aggregate passing through each of the slot is determined. Then the total weight of the aggregate passing through the slots of the thickness gauge is determined. REFERENCE: [IS: 2383 (part I) 1963 (re-affirmed 1997)]

Flakiness index = (P/W) X100

Where,

P = Total weight of aggregate in fraction passing thickness gauge

W = Total weight of aggregate fraction passing and retained

Fig 4.10 Thickness gauge

Table 4.9 Flakiness index result

S.NO	Passing through IS sieve (mm)	Retained on IS sieve (mm)	Weight of aggregate fraction passing and retained	Thickness gauge (mm)	Weight of aggregate in fraction passing thickness gauge(gm)
1	16	12.5	0.055	25.6	0.020
2	12.5	10	0.045	20.2	0.003
3	10	6.3	0.020	14.7	0.033

Fineness Modulus (By Sieve Analysis)

The sample was brought to an air-dry condition by drying at room temperature. The required quantity of the sample was taken. The sieves are placed in the order of size in a mechanical sieve shaker. Sieving was done for 10 minutes. Then the material retained on each sieve after shaking represents the fraction of the aggregate coarser than the sieve considered and finer than the sieve above. The weight of aggregate retained in each sieve was weighed. Fineness modulus was determined as the ratio of summation of cumulative percentage of weight retained to 100.

Fig 4.11 Sieve Analysis of Coarse aggregate

Table 4.10 Sieve Analysis result

S.NO	IS Sieve	Weight retained (gm)	% Wt retained	Cum %Wt retained	% finer
1	100mm	0	0	0	-
2	40mm	0	0	0	-
3	20mm	0	0	0	-
4	16mm	0.008	0.8	0.8	99.2
5	12.5mm	0.015	1.5	2.3	97.7
6	10mm	0.376	37.6	39.9	60.1
7	6.3mm	0.573	57.3	97.2	2.8
8	4.75mm	0.028	2.8	100	0
9	2.36mm	0	0	100	0
10	1.18mm	0	0	100	0
11	600µ	0	0	100	0
12	300µ	0	0	100	0
13	150µ	0	0	100	0

Table 4.11 Physical Properties of Coarse Aggregate

S.NO	DESCRIPTION	RESULT
1	Specific gravity	2.91
2	Aggregate Crushing Value	21.92%
3	Impact Value	5.7% (Extremely Strong)
4	Elongation Index	23.33%
5	Flakiness Index	27.5%
6	Fineness Modulus	2.4

4.3 Mix Design

As there are no standard codal provisions for the mix design of geo polymer concrete, the design mix can be arrived by assuming the density of geo polymer concrete as 2400 kg/m^3. The total volume occupied by fine and coarse aggregate is around 77-80%.

- Let us we adopt 77%
- The alkaline liquid to fly ash ratio is kept as 0.4.
- 12 Molarity
- The ratio of sodium silicate to sodium hydroxide is kept as 2.5.
- Extra water 15% of Cementitious material.
- Super Plasticizer 3% of Cementitious material.

Density of concrete = 2400 kg/m^3

Total Aggregate = 77% of density of concrete

= 0.77 * 2400

= **1848 kg/m^3**

Fine aggregate = 30% of total aggregate

= 0.30 * 1848

= **554.40 kg/m^3**

Coarse aggregate = 1848 – 554.4

= **1293.60 kg/m^3**

Binder + Alk. Solution = 23% of 2400

= 0.23 * 2400

= **552 kg/m^3**

Alkaline solution / binder = 0.4

Alkaline solution = 0.4 * fly ash

Binder + 0.4 binder = 552 kg/m^3

1.4 binder = 552

Binder = 552 / 1.4

= **394.28 kg/m^3**

Alkaline solution = 0.4 * 394.286

= **157.714 kg/m^3**

Alkaline solution = NaOH + Na_2SiO_3

NaOH / Na_2SiO_3 = 2.5

NaOH = 2.5 * Na_2SiO_3

Alkaline solution = NaOH + 2.5 NaOH

= 3.5 NaOH

3.5 NaOH = 157.714 kg/m^3

NaOH = **45.06 kg/m^3**

Na_2SiO_3 = 2.5 * 45.06

= **112.65 kg/m^3**

Extra water = 15% of cementitious material

= 0.15 * 394.3 kg/m^3

= **59.14 kg/m^3**

Super plasticizer = 3% of cementitious material

= 0.03 * 394.3

= **11.83 kg/m^3**

The mix proportion for $1m^3$ is show in table 4.12

Table 4.12 Mix Proportions for $1m^3$

BINDER (kg/m^3)	**FA (kg/m^3)**	**CA (kg/m^3)**	**NaOH (kg/m^3)**	**Na_2SiO_2 (kg/m^3)**	**Water (kg/m^3)**	**SP (kg/m^3)**
394.3	554.4	1293.4	45.1	112.6	59.14	11.83

The mix proportion for different combinations were shown in table 4.13

Table 4.13 Mix Proportions for different combinations of 6 Cubes, 3 Cylinders and 3 Prisms

Mix ID	**Fly Ash (kg)**	**Silica fume (kg)**	**GGBS (kg)**	**Fine Aggregate (kg)**	**Coarse Aggregate (kg)**	**NaOH Solution (kg)**	**Na_2SiO_3 Solution (kg)**	**Extra Water (kg)**	**Super plasticizer (kg)**
F50 G50	8.365	0	8.365	23.53	54.87	1.92	4.778	2.509	0.5019
F50 G40 S10	8.365	1.673	6.692	23.53	54.87	1.92	4.778	2.509	0.5019
F50 G30 S20	8.365	3.346	5.019	23.53	54.87	1.92	4.778	2.509	0.5019
F50 G20 S30	8.365	5.019	3.346	23.53	54.87	1.92	4.778	2.509	0.5019
F50 G10 S20	8.365	6.692	1.673	23.53	54.87	1.92	4.778	2.509	0.5019
F50 S50	8.365	8.365	0	23.53	54.87	1.92	4.778	2.509	0.5019

4.4 DIMENSION OF THE SPECIMEN

Cube size : 100mm x 100mm x 100mm

Prism Size : 500mm x 100mm x 100mm

Cylinder Size : Height= 300mm; Diameter= 150mm

4.5 PREPARATION OF ALKALINE SOLUTION

Alkaline solution was prepared one day prior to the mixing. It is prepared by mixing solutions of NaOH and Na_2SiO_3. NaOH solution is of the molarity 12. NaOH solution is prepared by mixing 480 grams of commercial grade NaOH in 1000 ml of distilled water. Care should be taken while mixing the NaOH solution since heat is liberated. Then NaOH solution and $Na_2SiO_3$is mixed in the ratio 1:2.5. Table 4.14 gives the weight of NaOH flakes and Fig 4.12 shows preparation of alkaline solution.

Table 4.14 Weight of NaOH flakes

Required Molarity	Weight in gm. of NaOH flakes
12	480

Fig 4.12 Preparation of Alkaline Solution

4.6 CASTING OF SPECIMEN

4.6.1 Cubes for Compressive Strength

The cubes of size 100 mm X 100 mm X 100 mm were cast to find out the compressive strength of Geopolymer concrete to find out the optimum percentage of binding material in concrete. A total of 36 cubes were casted to find out the compressive strength at the age of 7, 14 and 28 days. A three set of specimens were cast for different combinations. The fresh concrete mix was filled in the steel molds in three equal layers and each layer was well compacted using table vibrator. The Compression Testing Machine of 2000kN capacity was used to find compressive strength of specimens.

4.6.2 Cylinders for Split tensile strength

The cylinders of diameter 150 mm and height 300 mm were cast to find out the Split tensile strength of Geopolymer concrete to find out the optimum percentage of binding material in concrete. A total of 18 cylinders were casted to find the Split Tensile strength of cubes for 28 days. A three set of specimens were cast for different combinations. The fresh concrete mix was filled in the steel molds in three equal layers and each layer was well compacted using table vibrator. The Compression Testing Machine of 2000kN capacity was used to find Split Tensile strength of specimens.

4.6.3 Prisms for Flexural strength

The prisms of size 500 mm X 100 mm X 100 mm were cast to find out the Flexural strength of Geopolymer concrete to find out the optimum percentage of binding material in concrete. A total of 18 prisms have been casted to find the Flexural strength of cubes for 28 days. A three set of specimens were cast for different combinations. The Universal Testing Machine of 400kN capacity was used to find Flexural strength of specimens. Fig 4.13 shows the casting of Geopolymer Concrete.

Fig 4.13 Casting of Specimen

4.7 CURING OF SPECIMEN

The type of curing carried out in the study is Ambient curing. The geopolymer concrete is placed at the room temperature for curing. No external curing is required. The curing process will be carried out by the Moisture content present in the concrete.

4.8 TEST PROCEDURE OF SPECIMENS

4.8.1 Compaction factor

The compacting factor test is considered to be a very good indicator of the workability of concrete and can be used on concrete mixes which have minimal slump. It is more precise and sensitive than slump test and is particularly useful for concrete mixes of very low workability Figure 4.14 shows the experimental setup for compaction factor.

Formula

Compaction factor = $(W_1\text{-}W) / (W_2\text{-}W)$

Where,

W – Empty weight of the cylinder is noted (Kg).

W_1 – weight of partially compacted (Kg).

W_2 – Weight of fully compacted (Kg)

Fig 4.14 Experimental set up for Compaction factor

4.8.2 Compressive Strength

The compressive strength determination was the primary objective. The cube specimens of 100 mm size were tested at the ages of 7, 14 and 28 days. Three identical specimens were tested in all the mixtures. The Fig.3.4 shows the testing specimen under the compression. Testing is done in a CTM and the load is applied until failure of cube takes place.

Then the Compressive strength is found using the formula,

Compressive strength = P/A, N/mm^2

where, P - Breaking load in N,

A - Area in mm^2,

Fig 4.15 Compressive Strength Test

4.8.3 Split Tensile Strength

The Split Tensile strength test was performed after 28 days on standard specimens of diameter 150 and height 300mm cylinder. First the specimen is cast using Geopolymer concrete. After 28 days the specimens were tested. Testing is done in a CTM and the load is applied until failure of cylinder takes place.

Fig 4.16 Split Tensile Strength Test

Then the Split Tensile strength is found using the formula,

Split Tensile strength $=2P/\pi dl$, N/mm^2

where,

P - Breaking load in N,

l - Length of the specimen in mm,

d - Diameter of the specimen in mm.

4.8.4 Flexural Strength

The flexural strength test was performed after 28 days on standard specimens of size 500 x 100 x 100mm. First the specimen is cast using Geopolymer concrete composites with Fly ash, Silica Fume and GGBS. Then the specimen was left for curing for 28 days. After 28 days the specimens were tested. Testing is done in a UTM as per the specifications given in IS 516. All the specimens were subjected to two-point bending test as shown in Figure

Fig 4.17 Flexural Strength Test

Then the flexural strength is found using the formula,

Flexural strength $= Pl/bd^2$, N/mm^2

where,

P - Breaking load in N,

l - Length of the specimen in mm,

b - Breadth of the specimen in mm,

d - Depth of the specimen in mm.

CHAPTER 5

TEST RESULTS AND DISCUSSION

5.1 General

This chapter deals with test results of different Combinations in Geopolymer Concrete.

5.2 TEST RESULTS FOR MECHANICAL PROPERTIES

5.2.1 WORKABILITY TEST RESULTS

The workability of fresh concrete is determined by using compaction factor test. The Compaction factor value for different combinations are given Table 5.1

Table 5.1 Compaction Factor

MIX ID	Empty weight of Cylinder W(Kg)	Weight of Partially Compacted W1(Kg)	Weight of Fully Compacted W2(Kg)	Compaction factor = (W1-W) / (W2-W)
F50G50	7.745	18.895	21.145	0.83
F50G40S10	7.745	19.86	20.52	0.95
F50G30S20	7.745	19.870	20.565	0.94
F50G20S30	7.745	18.955	20.420	0.88
F50G10S40	7.745	19.310	20.585	0.90
F50S50	7.745	19.040	20.930	0.86

5.2.2 COMPRESSION STRENGTH

All cubes of controlled geopolymer concrete were tested in a Compression Testing Machine with the references of IS: 516 – 1959 to determine Compressive Strength of concrete at the age of 7 days.

The Values for Compressive Strength of concrete for all the mixes are listed in Table 5.2

Table 5.2 Compressive Strength Test at the age of 7 days

S.NO	Cube Compressive Strength in N/mm²	
	MIX	**7 DAYS**
1	F50G50	35.25
2	F50G40S10	22.35
3	F50G30S20	25.45
4	F50G20S30	23.8
5	F50G10S40	13.15
6	F50S50	2.25

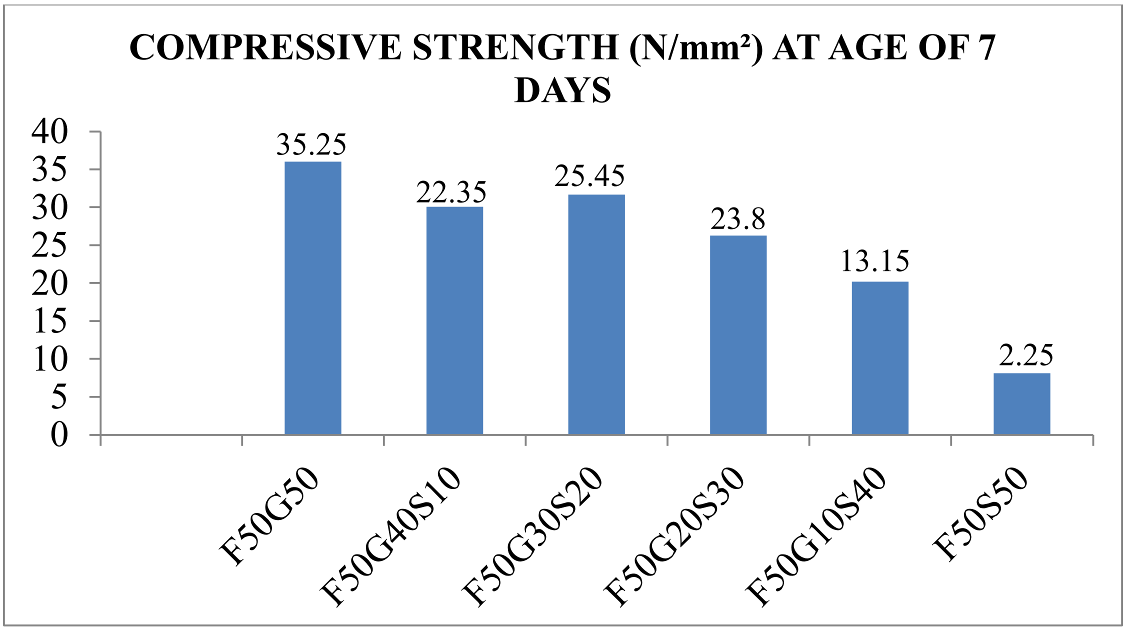


Fig 5.1 Compressive Strength Test at the age of 7 days

All cubes of controlled geopolymer concrete were tested in a Compression Testing Machine with the references of IS: 516 – 1959 to determine Compressive Strength of concrete at the age of 14 days.

The Values for Compressive Strength of concrete for all the mixes are listed in Table 5.3

Table 5.3 Compressive Strength Test at the age of 14 days

S.No	Cube Compressive Strength in N/mm²	
	MIX	14 DAYS
1	F50G50	36
2	F50G40S10	30.05
3	F50G30S20	31.65
4	F50G20S30	26.25
5	F50G10S40	20.2
6	F50S50	8.1

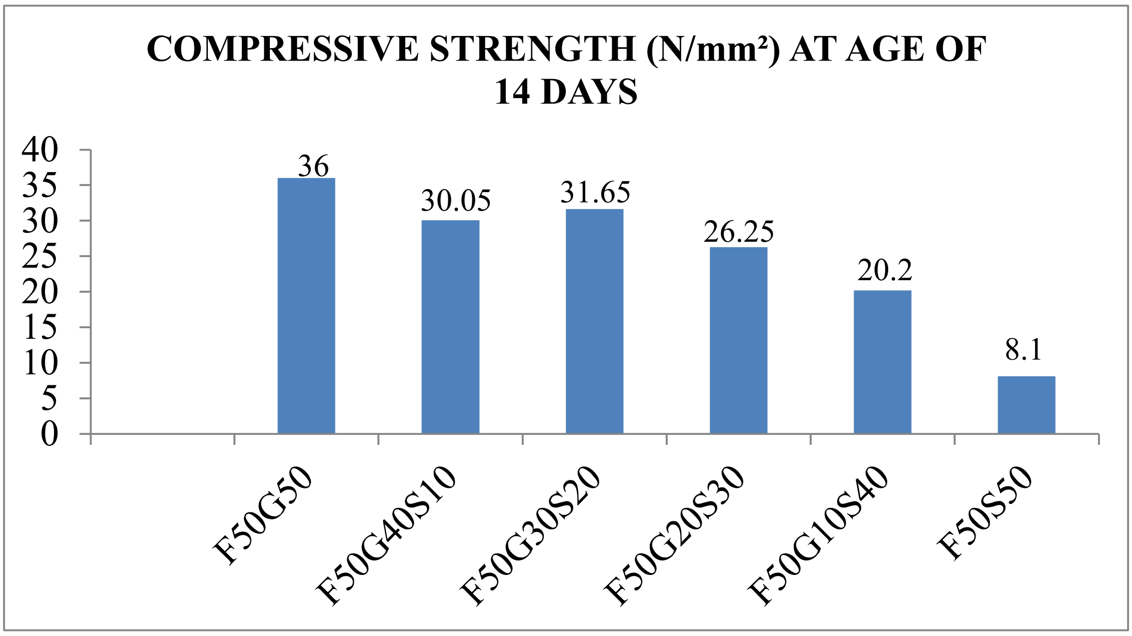


Fig 5.2 Compressive Strength Test at the age of 14 days

All cubes of controlled geopolymer concrete were tested in a Compression Testing Machine with the references of IS: 516 – 1959 to determine Compressive Strength of concrete at the age of 28 days.

The Values for Compressive Strength of concrete for all the mixes are listed in Table 5.4

S.No.	Cube Compressive Strength in N/mm²	
	MIX	28 DAYS
1	F50G50	40.15
2	F50G40S10	33.95

3	F50G30S20	40.8
4	F50G20S30	26.25
5	F50G10S40	20.2
6	F50S50	10.7

Table 5.4 Compressive Strength Test at the age of 28 days

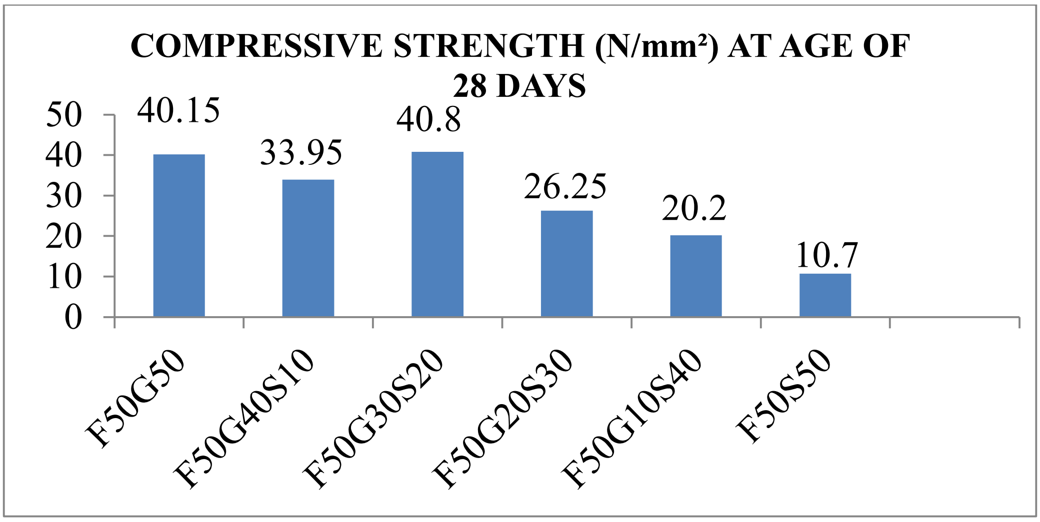


Fig 5.3 Compressive Strength Test at the age of 28 days

The effects of age on compressive strength of different mixes are represented in Fig 5.4. As the age of concrete increases from 7, 14 and 28 days, compressive strength also increases for all the mixes. Fig 5.4 shows the Comparison of Compressive Strength values of the different mixes with the controlled GPC at the age of 7, 14 and 28 days.

Table 5.5 gives the values of Compressive Strength at the age 7, 14 and 28 days.

Table 5.5 Comparison on Compressive Strength

S.NO	MIX RATIO	COMPRESSIVE STRENGTH (N/mm²)		
		7 days	14 days	28 days
1	F50G50	35.25	36	40.15
2	F50G40S10	22.35	30.05	33.95
3	F50G30S20	25.45	31.65	40.8
4	F50G20S30	23.8	24.55	26.25
5	F50G10S40	13.15	19.95	20.2
6	F50S50	2.25	8.1	10.7

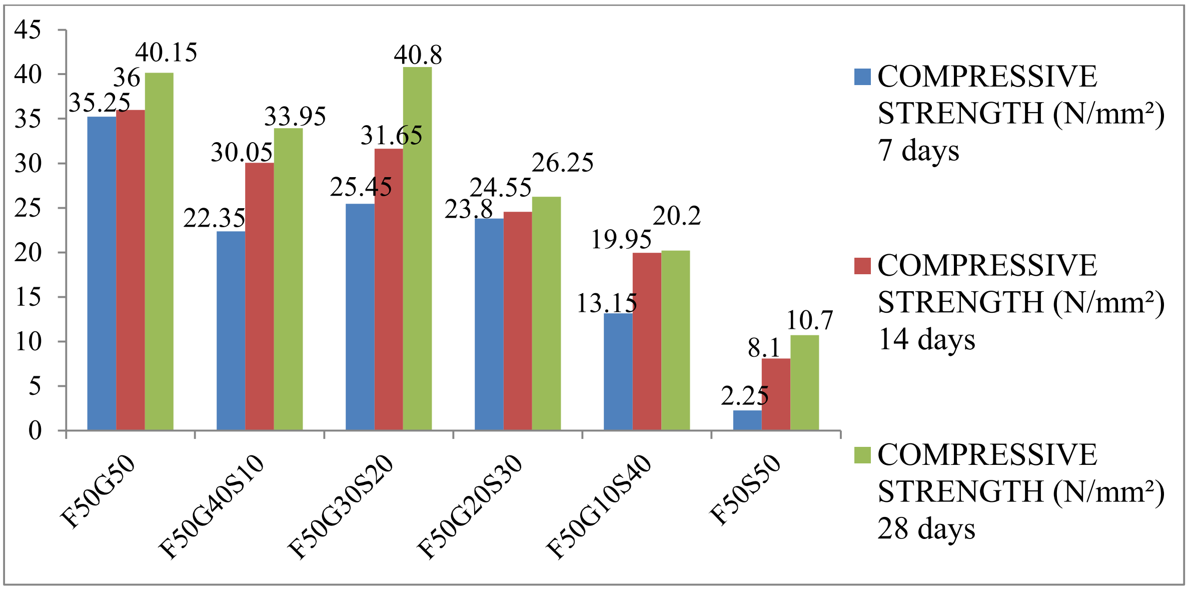


Fig 5.4 Comparison on Compressive Strength

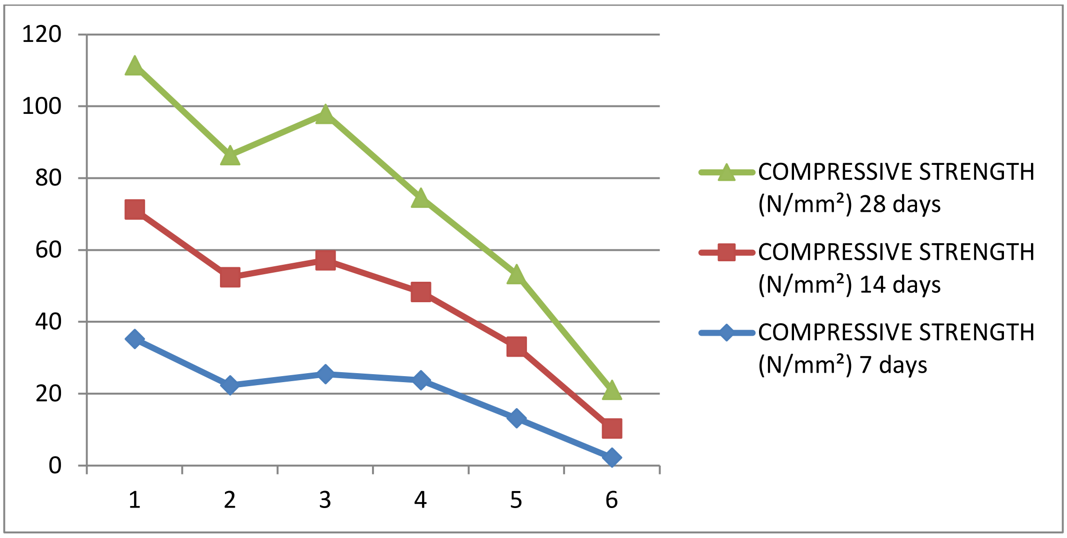


Fig 5.5 Comparison on Compressive Strength

5.2.3 SPLIT TENSILE STRENGTH

The split tensile strength of different mixes at 28 days are represented in Fig. Addition of different proportions of Silica Fume and GGBS effect on split tensile strength.

Table 5.6 Split Tensile Strength at the age of 28 days

S.No	Split Tensile Strength in N/mm²	
	MIX	**28 days**
1	F50G50	2.48
2	F50G40S10	2.4
3	F50G30S20	2.4
4	F50G20S30	2.21
5	F50G10S40	1.96
6	F50S50	0.8

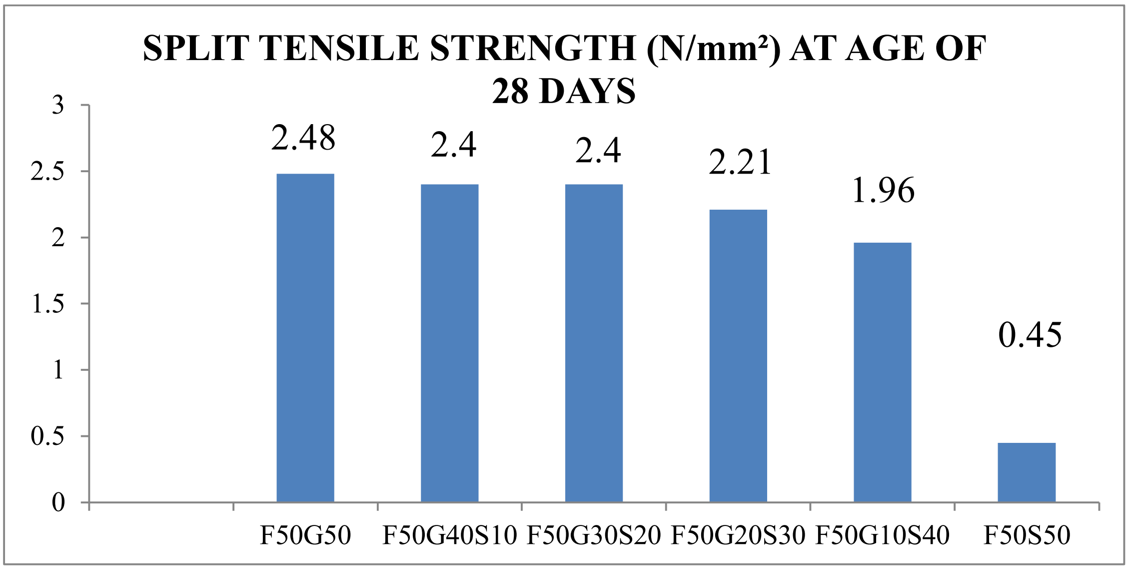


Fig 5.6 Split Tensile Strength at the age of 28 days

5.2.4 FLEXURAL STRENGTH TEST

The Modulus of rupture of different mixes at 28 days are represented in Figure. Addition of different proportions of Silica Fume and GGBS resulted in an improved flexural strength. As the age of concrete increases to 28 days, flexural strength also increases for all the mixes.

Table 5.7 Flexural Strength at the age of 28 days

S.NO	Flexural Strength in N/mm^2	
	MIX	28 days
1	F50G50	1.33
2	F50G40S10	3.6
3	F50G30S20	4.3
4	F50G20S30	3.33
5	F50G10S40	4
6	F50S50	3

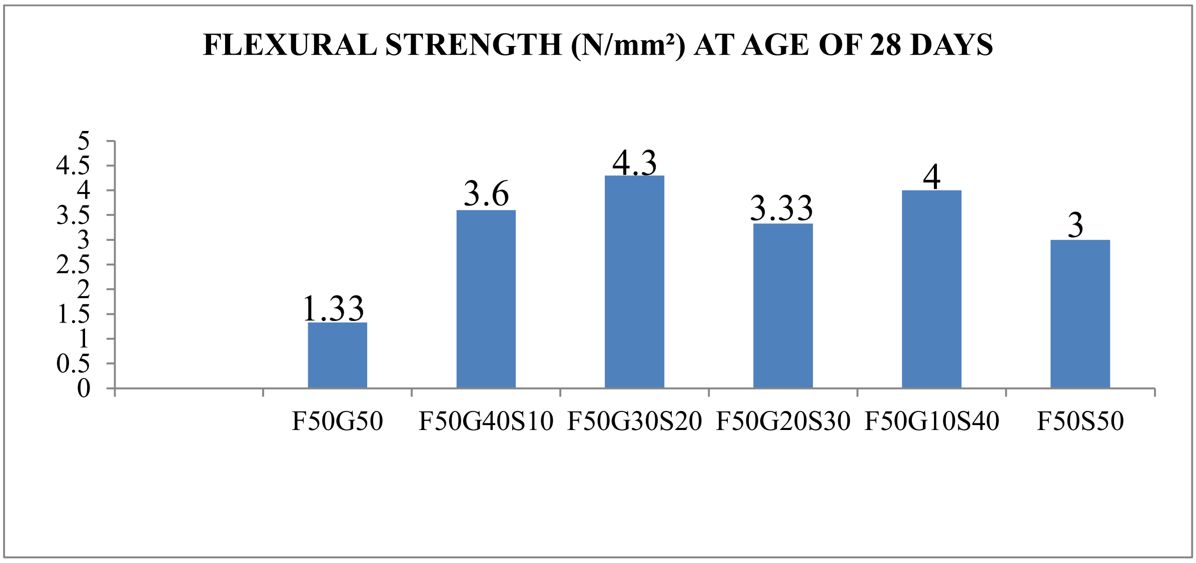


Fig 5.7 Flexural Strength at the age of 28 days

CHAPTER 6

CONCLUSION

Based on the experimental study carried out on specimen the following conclusions are drawn

1. Addition of Silica fume and GGBS in Geopolymer Concrete composites enhanced its mechanical properties.
2. With addition of Silica fume, Various fractions of GPC mix like F50G50, F50G40S10, F50G30S20, F50G20S30, F50G10S40, F50S50 are made.
3. For F50G50, F50G40S10, F50G30S20, F50G20S30, F50G10S40, F50S50 the respective Compressive Strength for 28 days are 40.15, 33.95, 40.8, 26.25, 20.2, 10.7. This shows that the increase in GGBS results in increase in compressive strength.
4. For F50G50, F50G40S10, F50G30S20, F50G20S30, F50G10S40, F50S50 the respective Split Tensile Strength for 28 days are 2.48, 2.4, 2.4, 2.21, 1.96, 0.8.
5. For F50G50, F50G40S10, F50G30S20, F50G20S30, F50G10S40, F50S50 the respective Flexural Strength for 28 days are 1.33, 3.6, 4.3, 3.33, 4, 3. The optimum mix to attain Flexural Strength is F50G30S20.
6. According to the Experimental Investigation the optimum mix of GPC with Fly ash, Silica fume and GGBS is F50G30S20.

CHAPTER 7
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