



EFFECT OF OVEN CURING ON STRENGTH OF GEOPOLYMER CONCRETE WITH PARTIAL REPLACEMENT OF FLY ASH WITH COMBINED EQUAL MASSES OF SILICA FLUME AND GGBS

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Abstract: Concrete is one of the most vital materials in construction industry. As the demand of concrete increases the Portland cement usage also increases due to the excess usage of cement, pollution also increases. To reduce the use of Portland cement in the concrete and utilization of industrial waste in the field of civil engineering. By introducing a new building material which significantly reduces the usage of Portland cement. On other hand the thermal power plants are consuming millions of tons of coal, in the process of power generation and as a result of that large quantities of fly ash is being produced which is a major problem. To overcome these two major problems i.e., to reducing the usage of OPC and proper utilization of fly ash, the concept proposed by Davidovits, is adopted to study new material called Geopolymer concrete

Index Terms – concrete, GGBS, Fly ash, Silica fumes and Geopolymers.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

For constructing any structure, main material needed is concrete. Concrete is most widely used for construction in the world. More than a ton of concrete is produced every year for each human. Cement production requires high amount of energy. A tonne of ordinary Portland cement (OPC) production releases about a tonne of CO₂, which is a greenhouse gas which finally causes global warming. The main concern in these days are namely, waste disposal & Global warming. In India about 2,169,783 thousands of metric tons of CO₂ is emitted in the year of 2013.

1.2 INTRODUCING GEOPOLYMER CONCRETE

“Geopolymer” is one such a new binder, which was introduced as environmental friendly material, that can be used in place of concrete and which has nearly all such properties of concrete. It was introduced by French scientist Prof.J.Davidovits. He utilised silica (SiO₂) and alumina (Al₂O₃) available in the specially processed clay to get inorganic polymeric system of alumino-silicates. Two main constituents of geopolymers are: (i) Geopolymer source materials and (ii) Alkaline activator liquids. The source materials should be alumino-silicate based and rich in both silica (Si) and aluminium (Al).

1.3 TERMINOLGY AND CHEMISTRY OF GEOPOLYMER

The term geopolymer was first introduced by Davidovits in 1978 to represent a broad range of materials characterized by chains or networks of inorganic molecules. Geopolymers are chains or networks of mineral molecules linked with covalent bonds. Geopolymer is produced by polymeric reaction of alkaline liquid with source material of geological origin or by by-product materials such as Fly ash (FA) Ground Granulated Blast Furnace Slag (GGBS), e.t.c., Because of the chemical reaction that takes place in this case is polymerization process. Davidovits introduced the term Geopolymer to represent these binders.

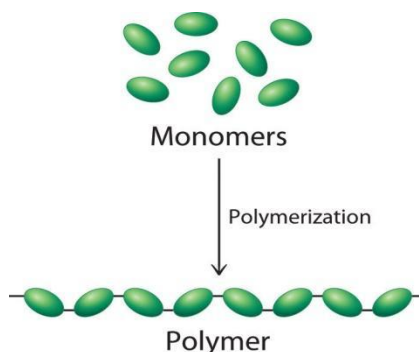


Figure 1.3.1 Polymerization process

Geopolymers have the chemical composition similar to zeolites but they can be formed amorphous structure. He also suggested the use of the term poly for the chemical designation of geopolymers based on silico-aluminate. Poly (sialates) are chain and ring polymers with Si^{4+} and Al^{3+} in four fold coordination with oxygen and amorphous to semi-crystalline with the empirical formula.



Where "Z" is 1, 2 or 3..... 32, M is a monovalent cation such as potassium or sodium and n is degree of polycondensation. Davidovits has also distinguished three types of polysialates, namely the 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-Si-O). The structures are shown below:

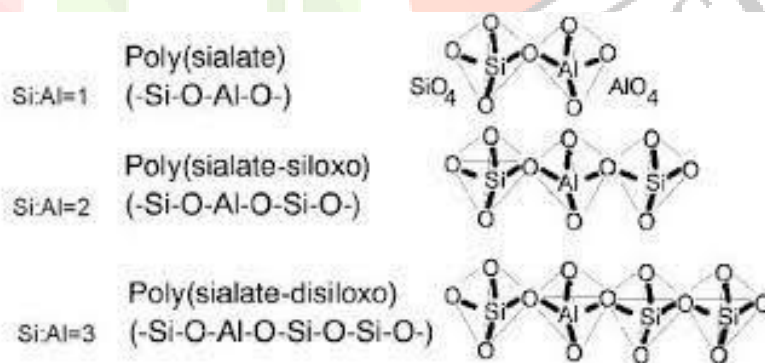


Figure 1.3.2 Chemical Structures of polysialates

Geopolymerization involves the chemical reaction of alumino-silicate oxides with alkali polysilicates yielding polymeric Si-O-Al bonds. The most common alkaline poly silicates used in the geopolymerization are the combination of sodium hydroxide/ potassium hydroxide and sodium silicate/potassium silicate. These combinations increase the rate of reaction.

1.4 FLY ASH

Fly ash was historically known as pulverized fuel ash in the UK, it is a by-product from the burning of pulverized coal in power stations. It has both pozzolanic and physical properties that enhance the performance of mortars. In some parts of Europe natural pozzolanas are available; these are composed of volcanic ashes and their use goes back to Roman times.



Fig. Fly ash

1.4.1 PHYSICAL PROPERTIES OF FLY ASH

1. Fly ash is Spherical in shape
2. Specific Gravity ranges from 1.90 to 2.96
3. The Colour of fly ash ranges from gray to black.
4. Surface area that can range from 100 to 500sq.m/gm

1.4.2 GGBS

Ground Granulated Blast Furnace Slag (GGBS) is a byproduct of the steel industry and is produced by quenching molten blast furnace slag with water. This rapid cooling process results in a glassy, granular material that is then ground into a fine powder.

1.4.3 PHYSICAL PROPERTIES OF GGBS

1. The Color of ggbs is off white.
2. The Bulk Density ranges from 1000 to 1100 kg/m³.
3. Fineness is greater than 350 m/kg.

1.4.4 SILICA FUME

Silica fume, also known as microsilica, is a fine-grain, highly reactive material that is a byproduct of the production of silicon metal and ferrosilicon alloys. It is primarily composed of amorphous silica, with trace amounts of other elements such as aluminum, iron, and calcium.

1.4.5 PHYSICAL PROPERTIES OF SILICA FUME

1. The Color of silica fume is gray to off white.
2. The Bulk Density of Silica fume is 130-430 kg/m³.
3. Specific Gravity is 2.22.

1.5 PROPERTIES OF FLY ASH CONCRETE

Fly ash is the finely divided residue that results from the combustion of pulverized coal and is transported from the combustion chamber by exhaust gases. Fly ash is produced by coal-fired electric and steam generating plants. Typically, coal is pulverized and blown with air the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue.

CHAPTER 2

REVIEW OF LITERATURE

2.1 GENERAL

A wide range of research is undergoing for the usage of Geo-polymer concrete. In this research, some important journal publications have been reviewed to have a broad idea about Geo-polymer concrete and they are listed in references at the end of the report.

2.2 GEO-POLYMERS

Davidovits (1978) proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in by-products materials such as fly ash and GGBS to produce binders. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, which results in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. A geopolymer can take one of the three basic forms:

- Poly (sialate), which has [-Si-O-Al-O-] as the repeating unit.
- Poly (sialate-siloxo) which has [-Si-O-Al-O-Si-O-] as the repeating unit.
- Poly (sialate-disiloxo) which has [-Si-O-Al-O-SiO-] as the repeating unit.

TABLE 2.1 APPLICATIONS OF GEOPOLYMER CONCRETE

Molar ratio of Si/Al	Application
1	Bricks, ceramics, fire protection
2	Low CO ₂ cements, concrete, radioactive and toxic waste conveying structures
3	Heat resistant composites, fibre glass composites.
>3	Sealants fro industry
20<Si/Al<35	Fire resistance and heat resistance

2.3 CONSTITUENTS OF GEO-POLYMER

2.3.1 SOURCE MATERIALS

Any material that is rich in Silicon (Si) and Aluminium (Al) in amorphous form can be used as a source material for the manufacture of geopolymer concrete.

Davidovits (1988) worked with kaolinite source material with alkalies (NaOH/ KOH) to produce geopolymers. The technology involved in producing geopolymers have been disclosed in various patents issued on the applications of the so called "SILIFACE-Process". Later, Davidovits (1999) also introduced a pure calcined kaolinite kandoxi (KAolinite, Nacrite, Dickite OXide) which is calcined for 6 hours at 750°C. This calcined kaolinite like other calcined materials performed better in making geopolymers compared to the natural ones. Among the waste or byproduct materials Fly ash and Slag are the most potential sources of geopolymers. Several studies have been reported related to the use of these source materials.

Van Jaarsveld et al (2003) found that fly ash with higher amount of CaO produced higher compressive strength, due to the formation of Calcium-Aluminate-Hydrate and other calcium compounds especially in the early ages. The other characteristics that influenced the suitability of Fly ash to be a source material for Geopolymers are the particle size, amorphous content, as well as morphology and the origin of Fly ash.

CHAPTER 3 PROPERTIES OF MATERIALS USED FOR THE STUDY

3.1 FINE AGGREGATE:

Locally available sand which is passed through 4.75mm sieve is used. It has the following properties.

Table 3.1 Properties of Fine Aggregate

Test name		Sand
Sieve analysis (zone)		Zone – II
Specific gravity		2.64
Fineness modulus		2.60
Bulk density	1. Dry	01458 kg/m ³
	2. Rodded	1611 kg/m ³

3.2 COARSE AGGREGATE:

Coarse aggregates of size 20mm having following properties taken from local supplier are used.

Table 3.2 Properties of Coarse Aggregate

Test name	20mm
Sieve analysis	Done
Specific gravity	2.8
Fineness modulus	7.14
Bulk density	1700 kg/m ³
Flakiness Index (%)	11.45

3.3 FLY ASH

Fly ash (FA) is used as a ingredient in the binder system. Low-calcium fly ash is preferred as a source material, because high amounts of calcium interferes with the polymerization process. Fly ash is brought from Vijayawada Thermal Power Station (VTPS). When pulverized coal is burned in a dry, bottom boiler, about 80 percent of the unburned material or ash is entrained in the flue gas and is captured and recovered as fly ash. The physical and chemical Properties of fly ash is given in table 3.3.1 and table 3.3.2.

Table 3.3.1 Physical Properties of Fly ash

Physical Properties OF FLY ASH	
Specific gravity	2.05
Density	1.2 kg/m ³
Particle size	90 micrometers
Hardness	3

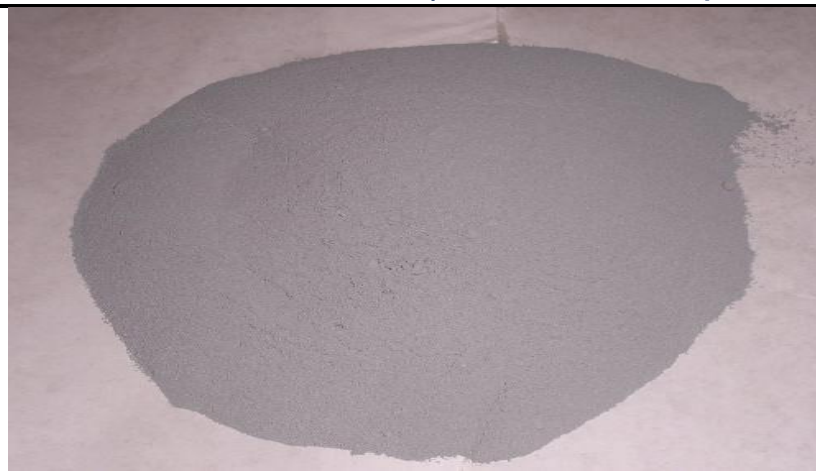


Fig 3.1 Appearance of micro silica fume (Grade 920-D)

Table 3.7.1 Physical Properties of Silica Fume

Physical Properties	
Specific gravity	2.1-2.2
Bulk unit weight (kg/m ³)	200-400
Loss of ignition	2-4
Specific surface area (m ² /kg)	15000-20000
Hardness	6

Table 3.7.2 Composition of Silica Fume

CaO(%)	0.6-1.6
SiO ₂ (%)	86-96
Al ₂ O ₃ (%)	0.2-0.6
MgO(%)	0.3-0.35
Fe ₂ O ₃ (%)	0.3-1.0
SO ₃ (%)	0.1-0.4
Na ₂ O(%)	0.8-1.8
K ₂ O(%)	1.5-3.5
C(%)	0.5-2.0
H ₂ O (%)	0.3-1.0

3.5 ALKALINE ACTIVATOR SOLUTIONS

Alkaline activator solutions (AAS) that are used in this experimental study are sodium hydroxide solution (NaOH) and sodium silicate solution (Na₂SiO₃). Some properties of these chemicals used are:

NaOH:

Flakes are used of 95% purity.

Different molarities solutions are prepared.

Molar weight = 40 g/mol

Na₂SiO₃:

It is a thick viscous solution.

Molar weight = 122 g/mol

3.5.1 MOLECULAR FORMULA

$$\text{Molarity} = \frac{\text{Wt (gm)}}{\text{Molecular wt}} \times \frac{1000}{\text{Vol (ml)}}$$

3.6 SUPER PLASTICIZER

Super plasticizer is generally used to improve the workability of fresh concrete. Glenium B233 supplied by BASF has been used in this research.

3.7 TESTS DONE ON MATERIALS

3.7.1 Determination of specific gravity of fine aggregate

Aim: To determine the specific gravity of fine aggregate using Pycnometer method.

Apparatus: Pycnometer, weighing balance, sand and distilled water.

Procedure:

1. Pycnometer is cleaned with distilled water and dried.
2. The weight W_1 of the clean, dry pycnometer with cap is noted.
3. After one third of density bottle filled with sand. The weight W_2 is noted.
4. Additional water is poured into the pycnometer to fill it completely up to the top of the cap. The weight W_3 is noted. The pycnometer outside is dried.

$$G = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)}$$

The procedure is repeated twice, from steps 3-5 with other specimens from the material. The specific gravity is reported as the average of three readings.

Table 3.7.1.1 Observations of specific gravity of FA

S.NO	Weight in grams	Trail 1	Trail 2	Trail 3
1	W_1	637	637	637
2	W_2	1180	1189	1194
3	W_3	1864	1871	1871
4	W_4	1525.5	1525.5	1525.5
5	G	2.65	2.66	2.63

Average specific gravity of sand=2.64

EXPERIMENTAL PROGRAMME

4.1 GENERAL

This chapter experimental programme consists of mix design of geo-polymer concrete, manufacturing procedure, curing and is then followed by description of specimens used and test procedures.

4.2 MIX DESIGN

For Geo-polymer concrete, there is no design method or codal provisions are available. Hence, the method of mix design that is used for conventional concrete is followed by making slight modifications to the assumptions. Hence, proportion is being fixed by using trial and error method.

The mix proportions given by N A Lloyd and B V Rangan are taken as reference and several trails were prepared with GGBS and FA having a constant molarity of NaOH as 3M. The proportion which resulted high workability and considerable compressive strength when tested for 24 hr has been fixed for rest of the trails.

4.3 FLUID - BINDER RATIO

The fluid-binder ratio in GGBS (Ground Granulated Blast Furnace Slag) concrete refers to the ratio of the amount of water used in the mix to the amount of GGBS binder used. The fluid-binder ratio is an important factor that affects the workability, strength, and durability of the concrete.

Here alkaline activator solutions used are sodium Hydroxide solution and sodium silicate solution in 1:3 parts

$$\frac{f}{b} = 0.4$$

Where f = Amount of alkaline fluid in kg /m³

b = Binder in kg/m³.

The quantity of binder taken is 20% of density of concrete

Assumed density of concrete = 2440 kg/m³

b = 20% of 2440

= 488 kg/m³

Quantity of fluid $f = 0.4 \times 488 = 196$ kg/m³

Quantity of sodium hydroxide solution = $196 / (1+3)$

= 49 kg/m³

Quantity of sodium silicate solution is = 49×3

= 147 kg/m³

Mix design calculation for 0% GGBS

Assume the density of Geo-polymer concrete as 2440 kg/m³

Assuming the volume of combined aggregates occupied 75-80 % (consider 79%) = 2440×0.79

= 1927 kg/m³

Now, mass of combined aggregate

Mass of Fine aggregate (FA) + Mass of Coarse aggregate (CA) = 1927 kg/m³

Coarse Aggregate = 60% of 1927 kg/m³

= 1157 kg/m³

Fine Aggregate = 40% of 1927 kg/m³

= 770 kg/m³

Mass of Alkaline liquid and Fly ash/ GGBS = $2440 - 1927$

= 513 kg/m³

Assume,

Mass of flyash = 20% of 2440

= 488 kg/m³

Mass of super-plasticizer = 1%

= 0.01% x 2440

= 24.4 kg/m³

Mix Ratio : 1: 1.57: 2.37 (Fly ash: Fine aggregate: Coarse aggregate)



Figure 4.4.1 Sodium Hydroxide Pellets

Figure 4.4.2 Sodium Hydroxide Flakes

4.5 MANUFACTURING & CASTING OF GEO-POLYMER CONCRETE

The method used for the manufacture of geopolymer concrete is nothing new but the same method that is followed for conventional concrete. Firstly, the fine aggregate, coarse aggregate and GGBS/FA are mixed in dry condition for 3-5 minutes and then the alkaline liquid is added, which is a combination of sodium hydroxide and sodium silicate mixed one day prior to casting. The sizes of the cubes that are casted for studying compressive strength are 100mmx100mmx100mm. Cylinders and Beams were casted only for FG0, FG5, FG10, FG15, FG20, FS5, FS10, FS15, FS20 mix was casted using fly ash. Beams casted were of size 500mmx100mmx100mm. Cylinders that were casted are of diameter 150mm and length 300mm.



Figure 4.4 Fresh Geo-polymer concrete

4.6 CURING OF GEO-POLYMER CONCRETE

In this research oven curing has been done. For oven curing cubes, a temperature of 70°C is maintained for 3 hours, 12 hours and 24 hours after casting.

4.7 COMPRESSIVE STRENGTH

Compressive strength can be defined as the capacity of a material or structure to withstand the axially direct pushing forces. The dimensions of specimen for cubes casted are of 100mm x 100mm x 100mm. The results are shown in tables of next chapter. Compressive strength is calculated by using the formula:

$$F_{ck} = P_c/A$$

Where, F_{ck} = characteristic compressive strength

P_c = Failure load in N

A = Area of cube in mm^2



Fig 4.7.1 Compressive testing.

4.8 SPLIT TENSILE STRENGTH

Split tensile strength is calculated by conducting split cylindrical test for specimens. A specimen is placed in Compressive testing machine, with its axis horizontal between the compressive plates. Due to compression loading a fairly uniform tensile stress is developed over nearly $\frac{2}{3}$ of the loaded diameter as obtained. After the failure of the specimen the load at the failure is noted. The split tensile strength is then calculated by the formula:

$$F_t = 2P/\pi d$$

Where, F_t = Tensile strength, MPa

P = load at failure, N

L = Length of cylinder, mm

D = diameter of cylinder

A = loaded area of cylinder, mm^2



Fig 4.8.1 Split testing.

CHAPTER 5

RESULTS AND DISCUSSIONS

Compression strength tests, flexural strength tests and split tensile strength tests are performed on fly ash based GPC and GPC in which the fly ash is replaced partially. Separate series of samples with partial replacement by GGBS and silica fume with varying amounts of 0, 5, 10, 15 and 20 % are prepared with 3 Molarity and tested for the strengths mentioned. All the samples for the above tests are cured in heat - curing in an oven.

Heat - curing of the samples is done in an oven maintained at a constant temperature of 70 °C .those maintained for heat - curing are 3 hours, 12 hours and 24 hours. The standard dimensions of samples prepared for all the tests and the procedures for the testing are as per IS 516. The results obtained are presented graphically

Table 5.1 Compressive strength test results for partial replacement of GGBS

Heat curing in hrs	Compressive strength(N/mm ²) of GGBS partial Replacement				
	FG0	FG5	FG10	FG15	FG20
3	30	32.3	34.4	37.2	37.1
12	38	41.6	45.5	48.3	47.5
24	50	55.7	59.9	61.3	60.6

- The increase in GGBS content from 0% to 15% has shown improvement in compressive strength by 24% at 3 hours over curing at 70°C.
- Similarly for 12 hours and 24 hours over curing the increase in compressive strength observed to be 27.1% and 22.6%.
- It is observed that as curing time increased the compressive strength of concrete also increased.

At 12 hours over curing the increase in compressive strength is 26.6% to 29.83%.

At 24 hours over curing the increase in compressive strength is 66.6% to 64.8%.

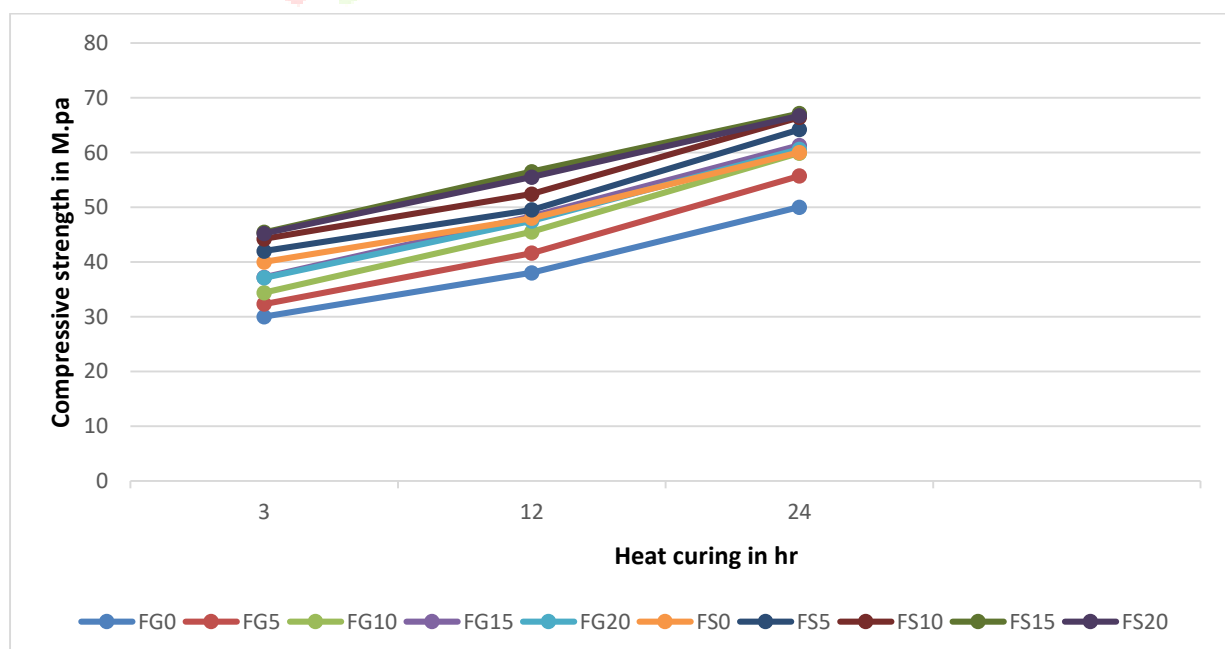
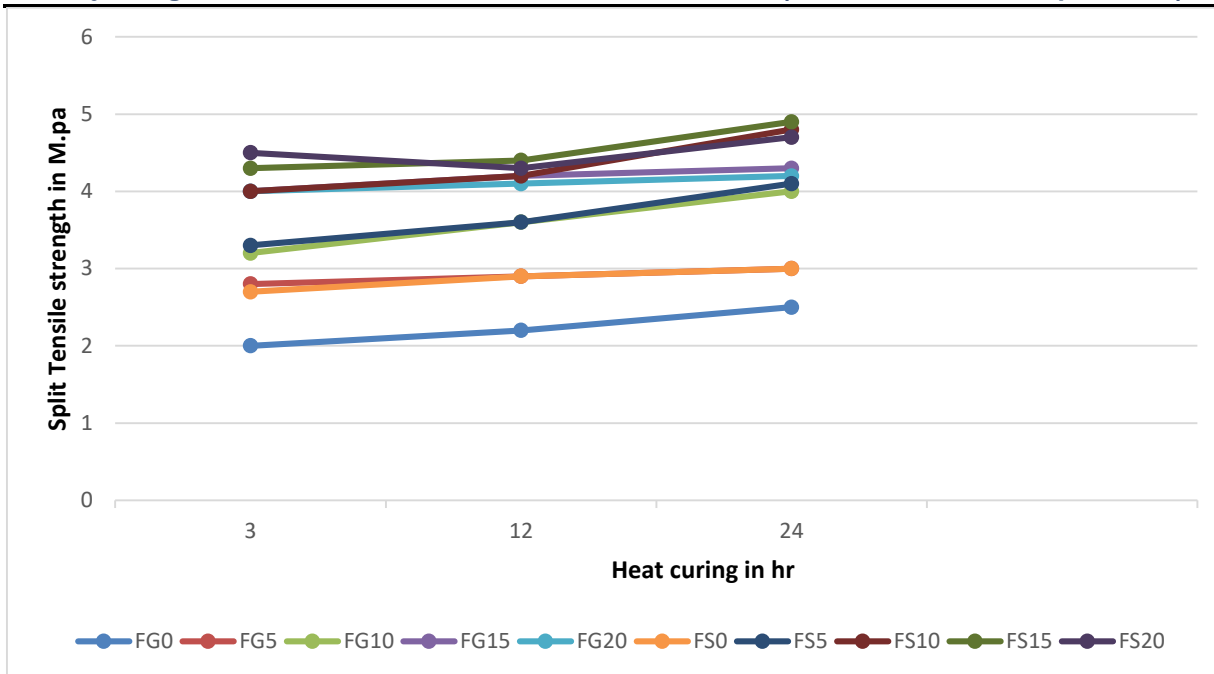


Fig 5.2 Split strength Comparison between G.G.B.S and Silica Fume



CHAPTER 6

CONCLUSION

A thorough experimental investigation was conducted to study compressive strength, split tensile strength and flexural strength of geopolymer concrete specimens prepared by partially replacing cement with fly ash, GGBS, Silica Fume and curing them with heat-curing condition (in Oven at 70°C).

When fly ash was replaced by GGBS and silica fume (SF), all the mechanical properties increased with increasing GGBS content and silica fume content in Oven-curing.

1. The increase in GGBS content upto 15% has shown increase in compressive strength by 27.1% at 12 hours oven curing.
2. The increase in Silica fume content upto 15% has shown increase in compressive strength by 32.7% at 12 hours oven curing.
3. The increase in GGBS content upto 15% has shown increase in Split tensile strength by 50% at 3 hours oven curing.
4. The increase in Silica fume content upto 15% has shown increase in split tensile strength by 63.33% at 24 hours oven curing.
5. The increase in GGBS content upto 15% has shown increase in Flexural strength by 24.32% at 3 hours oven curing.

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