Effect of Curing Temperature on Development of Foundry Sand Based Geopolymer Concrete

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Abstract— **The fly ash consist primarily of silica, alumina and iron. Fly ash is a waste by-product material that must be disposed off or recycled. The foundry sand is also a waste by product of metal foundries. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed as "Foundry Waste Sand". Foundry sand is high-quality uniform silica sand that is used to make moulds and cores for ferrous and non-ferrous metal castings. The metal casting industry annually uses an estimated 100 million tons of foundry sand for production [26]. Over time, foundry sand physically degrades until they are no longer suitable for moulds. Consequently, 9 to 10 million tons of sand are discarded each year. So the fly ash and foundry sand is available abundantly, they are the waste materials that are not easily disposed and require more land to dispose. Hence it is essential to make the efforts to utilize these by product in concrete manufacturing in order to make the concrete more environmental friendly.**

I. INTRODUCTION

Concrete is normally used as structural material for all construction. To enhance the strengthening properties and serviceability required, supplementary materials may be added to it. Such supplementary materials are those which conatin, cilicon, aluminium such as blast furnace slag, fly ash, silica fume, steel fibers, glass fibers, rice husk, crushed stone dust etc. Concrete is the 2nd most widely used material in the world. Concrete is a mixture of water, cement, fine aggregate, coarse aggregate with or without adding admixture. Cement is the main ingredient in concrete that glues the component together and produced concrete. The environmental issues created with the production of OPC are well known. The CO_2 produced is to the tune of one tonne for every tonne of OPC produced due to the calcination of limestone and combustion of fossil fuel and has led to the innovation of geopolymer concrete in which the cement is totally replaced with pozzolanic material which is activated by the alkaline solution to act as a binde[4] and [7]. In addition, it consumes natural resources like limestone, shale, sandstone and requires more energy during production. After the production of steel and aluminium OPC is next most energy intensive material [14].

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1.1 *GEOPOLYMER CONCRETE*

In 1978, Davidovits proposed that an alkaline solution could be used to react with fly ash and rice husk ash that contain silicon and aluminium to produce binders. These binder are formed by polymerisation process. The alkaline solution are sodium silicate, sodium hydroxide or potassium hydroxide and potassium silicate may be used. Davidots later in 1994 [22], [23] coined the term 'Geopolymer' to represent these binders. Geopolymer concrete is cement-less concrete gaining popularity globally towards the sustainable development. From the last years the OPC is being replaced with fly-ash.

1.2 *FLY ASH BASED GEOPOLYMER CONCRETE*

The fly ash is used instead of cement along with alkaline liquid to produce geopolymer concrete (figure 1). Fly ash and alkaline solution is used to make binder which binds the coarse & fine aggregate. It's a new technology that reduces carbon dioxide emission to the atmosphere [25]. Inspired by this new technology an attempt has been made to develop an alternative concrete binder or a substitute for cement by using the geopolymer technology and utilizing the fly ash as main ingredient to produce geopolymer concrete. Geopolymer concrete is designed same as cement, concrete design methods.

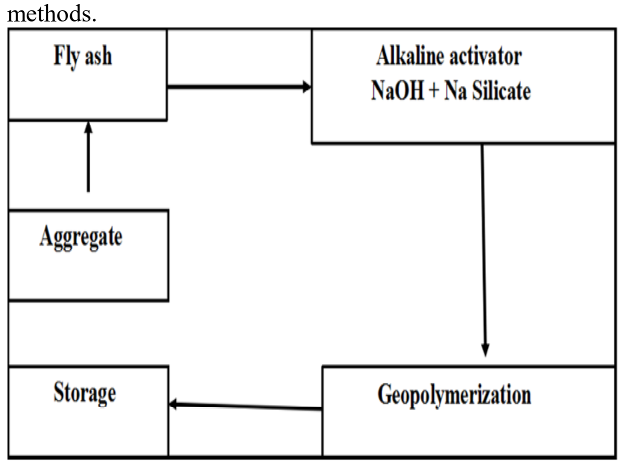

Figure 1 process of making geopolymer concrete

Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline. The polymerisation process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds, as follows: -

$M\ n\ [-(SiO_2)\ z\ -AlO_2]\ n.\ wH_2O$ ……(2-1)

Where: M = the alkaline element or caption such as potassium, sodium or calcium; the symbol indicates the presence of a bond, n is the degree of polycondensation or polymerisation; z is 1, 2, 3, or higher, up to 32.

The schematic formation of Geopolymer material can be shown as described by Equations (1) and (2) by [22]

$n(Si_2O_5,Al_2O2)+2nSiO_2+4nH_2O+NaOH$ or KOH → Na+,K+ + $n(OH)_3$-Si-O-Al- -O-Si-$(OH)_3$ ....(1)

(Si-Al materials) |

(OH) (Geopolymer precursor)

$n(OH)_3$-Si-O-Al--O-Si-$(OH)_3$ + NaOH or KOH → (Na+,K+)-(-Si-O-Al--O-Si-O-) + $4nH_2O$ .... (2)

| |

| |

$(OH)_2$ O

O O (geopolymer backbone)

The chemical reaction may comprise the following steps [23]

• Dissolution of Si and Al atoms from the source material through the action of Hydroxide ions.

• Transportation or orientation or condensation of precursor ions into monomers.

• Setting or polycondensation/polymerisation of monomers into polymeric structures.

However, these three steps can overlap with each other and occur almost simultaneously, thus making it difficult to isolate and examine each of them separately.

A geopolymer can take one of the three basic forms [23]:

• 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-Si-O-Si-O-] as the repeating unit.

The main contents in fly ash those would be activated are silicon and aluminium. The fly ash mixed with an alkaline solution (the alkaline solution prepared by mixing sodium silicate and sodium hydroxide) and the binder are produced by polymerization. The aggregates are one of the important constituents which are responsible for strength development. The gap between the coarse aggregate are filled with fine aggregates and gap of fine aggregate are filled with the binder material. Fine aggregates are those particles which pass through 4.75mm sieve eg: crushed stone and natural sand. From the crusher, stone dust and natural sand the river sand is most commonly used as aggregate in concrete, which is becoming scarce and expensive due to the cost of transportation from their resources. The environmental issue created due to depletion of these sources. So the foundry sand can be used and it is free of cost available and having an alternate to river sand. Foundry sand is a by product of Metal foundries. Foundry sand is a waste material not easily disposed, it requires more land to dispose it. So we reuse foundry sand to make environmentally friendly concrete. It also reduces the demand of natural river sand and stone dust. This research was carried out to see the effect on properties of geopolymer concrete with partial replacement of foundry sand at different temperature.

Fly ash based geopolymer concrete has many advantages over OPC : -

Geopolymer concrete (GPC) using fly ash has greater corrosion resistance, and substantially higher fire resistance (up to 2400° F). The compressive and tensile strengths of geopolymer concrete are high and rapid strength gain and lower shrinkage. Durability aspects of geopolymer products include good sustainability to weathering effects. Several experimental studies showed that geopolymer concrete specimens immersed in sulphuric acid and caloric acid were found to be resistant to acid attack. While the Portland based cement showed deleterious reaction and resulted in surface deterioration followed by weight loss [22]. Extensive studies have also demonstrated that heat-cured fly ash based geopolymer concrete has an excellent resistance to sulphate attack due to the formation of stronger polymer chain due to poly condensation reaction.

The effects of acid attack also cause reduction in compressive strength of heat-cured geopolymer concrete; the amount of degradation depends on the concentration of the acid solution and exposure time period. However, the sulfuric acid resistance of heat cured geopolymer concrete is considerably better than that of OPC concrete as preveous studies. Several studies have shown that fibre addition is an effective method to improve the mechanical characteristics of brittle material such as concrete by providing crack arresting mechanism.

1.2.1 *FLY ASH*

In India the first ever study on use of fly ash in concrete was carried out in 1955 by CBRI, Roorkee (1), in the form of a review of American and Australian research work on Fly ash. Later, Fly ash was used in small proportions in mass concreting for dams and other hydraulic. Fly ash closely resembles volcanic ashes. It was used in production of the earliest known hydraulic cement about 2,300 years ago. Instead of volcanoes, today's fly ash comes primarily from coal-fired electricity generating power plants. These power plants grind coal to powder fineness before it is burned. Fly ash – the mineral residue produced by burning coal - is captured from the power plant's exhaust gases and collected for use. Fly ash is a fine, glass powder recovered from the gases of burning coal during the production of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. Fly ash is one of the residues created during the combustion of coal in coal-fired power plants. Fine particles rise with flue gasses and are collected with filter bags or electrostatic precipitators. Fly ash is a waste by-product material that must be disposed off or recycled 131 million tons of fly ash is produced annual by 460 coal-fired power plants in the U.S. alone.

1.2.1.1 CHEMICAL COMPOSITION

Because fly ash is a by-product material chemical constituents can vary considerably but all fly includes: - SiO_2, CaO also known as Lime, FeO_2, Al_2O_3.

Depending on source coal may include one or more toxic chemicals in trace amounts: Arsenic, Beryllium, Boron, Cadmium, Chromium, Cobalt, Lead, Manganese, Mercury, Molybdenum, Selenium, Strontium, Thallium and Vanadium.

1.2.1.2 CLASSES

(ASTM c-618 – American Society for Testing and Materials, it is an organization that develop standard specification for coal fly ash and raw or calcined natural pozzolana for use in concrete) Defines two classes of fly ash:
Class C
Class F
ASTM C618 requirements:
Loss of Ignition (LOI) is less than 4% in fly ash and 75% of ash must have fineness of 45 µm or less.
Primary difference between Class C and Class F fly ash is the amount of the amount of calcium, silica, alumina, and iron content in the ash.

II. CLASS F

Class F fly ash is Engendered from burning harder, older anthracite and bituminous coal. It contains less than 20% lime content and requires cementing agent like Portland cement, quick lime and hydrated lime. The class F fly ash is utilized in high sulfate exposure conditions and utilized for structural concretes as high performance concretes.

III. CLASS C

The class C fly ash Produced from burning younger lignite and sub bituminous coal. It has higher concentration of alkali & sulphate and contains more than 20% lime. It has Self-cementing properties does not require activator and air entertainer, Not for use in high sulfate conditions. Class C fly ash used primarily residential construction.

1.2.1.3 DIFFERENCE BETWEEN CLASS C & CLASS F FLY ASH CONCRETES

1. Class F fly ash is more effective than Class F fly ash.
2. Class C fly ash generate more heat of hydration than Class F.
3. Class C fly ash will generally not be as resistant to sulfate attack. ASTM C 618 prohibits the use of Class C in high sulfate exposure environments.
4. Class C fly ash will generate more strength at early ages than Class F.
5. Class F fly ash can be used for high fly ash content concretes (up to 40% concrete mass) whereas Class C is not used for high fly ash content.

Low-calcium (ASTM Class F) fly ash is preferred as a source material as compare to high-calcium Class C fly ash. The existence of calcium in higher amount may obstruct with the polymerisation process and change the microstructure. The suitability of various types of fly ash to be Geopolymer source material has been studied by [24]. These authors claimed that to generate optimal binding properties, the low-calcium fly ash should have the percentage of unburned material less than 5%, Fe_2O_3 content should not exceed 10%, and low CaO content, the content of reactive silica should be between 40-50%, and 80-90% of particles should be smaller than 45 µm. On the contrary, found that fly ash with higher amount of CaO produced higher compressive strength, due to the formation of calcium-aluminates-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 Geopolymer are the particle size, amorphous content, as well as morphology and the origin of fly ash.

1.2.1.4 ADVANTAGES OF USING FLY ASH IN CONCRETE

advantages of using flyash in concrete are listed below:-
1. Use the waste material as diverting the material from waste stream.
2. Save the energy that used to produce cement, the cement is main binder content in concrete.
3. The pollution repuced by utilizing the waste ash.
4. Reduces produced during production of cement greenhouse gas emission generated, by using fly ash as substitunal material reduce the greenhouse emission and also reduce the demand Portland cement.
5. Reduces volume of landfill area required for dump the fly ash.
6. Conserves water by reducing water demand in concrete mixes.

Other benefits are: - increased Strength, Increased durability, increased Sulphate Resistance (Class F), reduces water demand and increase workability, reduce segregation & bleeding, lower heat of hydration, decreased Permeability, reduce corrosion, (Mostly Class F) reduces Alkali-Silica Reaction (ASR).

1.2.2 *FOUNDRY SAND*

Metal foundries use huge amount of sand as part of the metal casting process. Foundries successfully recycle and reuse the sand many times in casting process. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed as "Foundry Waste Sand". Foundry sand is high-quality uniform silica sand that is used to make moulds and cores for ferrous and nonferrous metal castings. The metal casting industry annually uses an estimated 100 million tons of foundry sand for production [26]. Over time, foundry sand physically degrades as they are no longer suitable for moulds. Consequently, 9 to 10 million tons of sand is discarded each year.
Foundry sands consisting of green sand typically comprises of high-quality silica sand, 5-10 percent bentonite clay, 2 to 5 percent water and less than 5 percent sea coal. The green sand process constitutes upwards of 90 percent of the moulding materials used. The grain size distribution of most foundry sand is very uniform, with approximately 85 to 95 percent of the material between 0.6 mm and 0.15 mm. Five to twelve percent of foundry sand can be expected to be smaller than 0.075mm. The particle shape is typically sub-angular to round. Foundry sand has low absorption, which can be attributed to the presence of binders and additives. The content of organic impurities (particularly from sea coal binder systems) can vary widely. The specific gravity of foundry sand has been found to vary from 2.39 to 2.70. In

general, foundry sands are dry, with moisture content less than 2 percent. The pH of foundry sand can vary from approximately 4 to 12. Foundry sand used in concrete to improve its strength and durability;can be used as a partial replacement of cement or as a partial replacement of fine aggregates or total replacement of fine aggregate. The physical and chemical characteristics of foundry sand will depend in great part on the type of casting process and the industry sector from which it originates. In modern foundry practice, sand is typically recycled and reused through many production cycles. The automotive industries and its parts are the major generators of foundry sand.

1.2.3 *AGGREGATE*

Aggregate is the granular material, such as gravel, crushed stone, sand, blast-furnace slag, or construction and demolition waste that is used with a cementing medium to produce Concrete. Aggregates classified in to two categories according to size of particals, fine and course. Properties of aggregate like size, shape, strength, surface texture, fineness modulus, bulking of sand, bulk density, unit weight, water absorption, surface moisture, specific gravity, soundness, gradation of aggregate, alkali aggregate reaction and durability are the properties of interest while using it in concrete. Aggregate plays an important role in concrete and its functioning.Effects of aggregate on concrete are: -

1. Aggregate is generally stronger than the cement paste in concrete.
2. In low strength concrete failure may occur through cement paste while high strength concrete failure is likely to occur by failure of bond between paste and aggregate.
3. Bond is influenced by size, shape and surface texture of aggregate.
4. The influence of aggregate size shape texture and grading may be opposite in nature on workability and strength hence these characteristics should be chosen with proper analysis and test.
5. Aggregate characteristics such as specific gravity, bulk density, moisture absorption should be determined for proper design and adjustments of mix proportions of a job site.
6. Determination of soundness, alkali aggregate reactivity etc. helps in quality control for proper durability and strength of concrete.

1.2.4 *ALKALINE LIQUIDS*

Mostly the combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate is used to make alkaline liquid for polymerization by Davidovits J., Palomo A. [23], [24] concluded that the alkaline liquid has a vital role in the polymerisation process. Reactions occur at a high rate when the alkaline liquid contains soluble silicate, either sodium silicate or potassium silicate, compared to the use of only alkaline hydroxides. Addition of sodium silicate solution to the sodium hydroxide solution as the alkaline liquid enhances the reaction between the source material and the solution. The alkaline liquid is prepared by mixing both the solutions together. Sodium hydroxide pellets are dissolved in distilled water. Thereafter some amount of heat is released due to the mixing. After mixing sodium silicate mixed with it.

1.2.4.1 MOLAR CONCENTRATION OF SODIUM HYDROXIDE

The quantity of NaOH solids in alkaline solution, depends on the concentration of the solution. The concentration is expressed in terms of molarity, M. For NaOH solution, for a concentration of 10M consists of 10x40 = 400 grams of sodium hydroxide solids pellet per litre of the solution, where 40 is the molecular weight of NaOH and for 12M the NaOH solution consist 12x40 = 480 grams of sodium hydroxide solids pellet per litre of the solution similar as for other molarity. Increasing molar concentration resulting increase in strength, and the increase in strength is effected up to 16M [27].

1.3 *PROPERTIES OF GEOPOLYMER CONCRETE*

1. Non-toxic, bleeding free.
2. Sets at room temperature.
3. Long working life before stiffening.
4. Impermeable.
5. Higher resistance to heat and resist all inorganic solvents.
6. Higher compressive strength.

1.4 *ADVANTAGES OF GPC*

Fly ash, the main ingredient in GPC, it is a waste material. Hence the price of fly ash is not very high. The compressive strength of geopolymer concrete is 1.5 times higher than that of the compressive strength of ordinary Portland cement concrete [7], for the same mix. The geopolymer Concrete having good workability than ordinary Portland Cement Concrete. Geopolymer concrete has low permeability and has exceptional properties within both salt and acid environment because of its structure as it is made by polymerization reaction [Vikas Reddy Morepally, Peketi Padmakanth]. Almost no corrosion products are found on the surface of the geopolymer. It is fire resistant. It is environmental friendly as it cut offs carbon dioxide from environment. The geopolymer concrete is liable to reduce carbon dioxide emission from 22.5% to 72.5% compared to Portland cement by [10]. It is Eco-friendly since it is made from the waste material.

1.5 *APPLICATIONS*

Geopolymer finds application in several structure and construction material as use pre-cast concrete products like railway sleepers, electric power poles, parking tiles, marine structures. Its property of resistance to chemical attack makes it useful for marine structures. The geopolymer concrete has better control on site as compared to OPC concrete. However its drawbacks, such as loss of workability, quick setting time and the health and safety implications due to working with strong alkali solutions can easily be adapted in applications such as pre-cast concrete and mass concretes as in dam construction where roller compact geopolymer concrete may be a viable construction method. With respect to the description of the specifications of this type of concrete it can also be used as railway traverse, waste water pipe line, hydraulic structures and pre-tension concrete structures. This type of concrete, especially in countries with greater resources of natural pozzolana or alumina silicate by products, can help decrease energy consumption and environmental impacts.

1.6 *CURING*

On the previous studies geopolymer concrete did not attain strength at room temperature or by water curing. The geopolymer concrete is harden at steam curing or hot curing and the minimum curing period should be 24hours. After casting the specimens, they were kept in rest period in room temperature for 2 days. The term 'Rest Period' was coined to indicate the time taken from the completion of casting of test specimen to the start of curing at an elevated temperature. The geopolymer concrete was demoulded and then placed in an oven for heat curing for 24 hours at a temperature of 60˚C. The cubes were then allowed to cool in room temperature. The heat cured GPC having low drying and shrinkage [5].

1.7 *FLEXURAL STRENGTH*

After casting, the specimens (beam) were tested by universal testing machine at 7 day and 28 days for compressive strength shown in table no.5, 6 and figure no.9, 10.

I.1 Flexural strength of M40 geopolymer concrete at 7 days

Curing Temp.	No replacement		10% replacement		20% replacement		30% replacement	
	Flexural strength	Density Kg/m^3	Flexural strength	Density Kg/m^3	Flexural strength	Density Kg/m^3	Flexural strength	Density Kg/m^3
Ambient	1.69	2300	2.24	2490	2.1	2490	3.3	2310
60°C	4.2	2350	5	2420	3	2230	4.3	2320
90°C	4.74	2320	5.5	2380	3.1	2240	3.4	2310

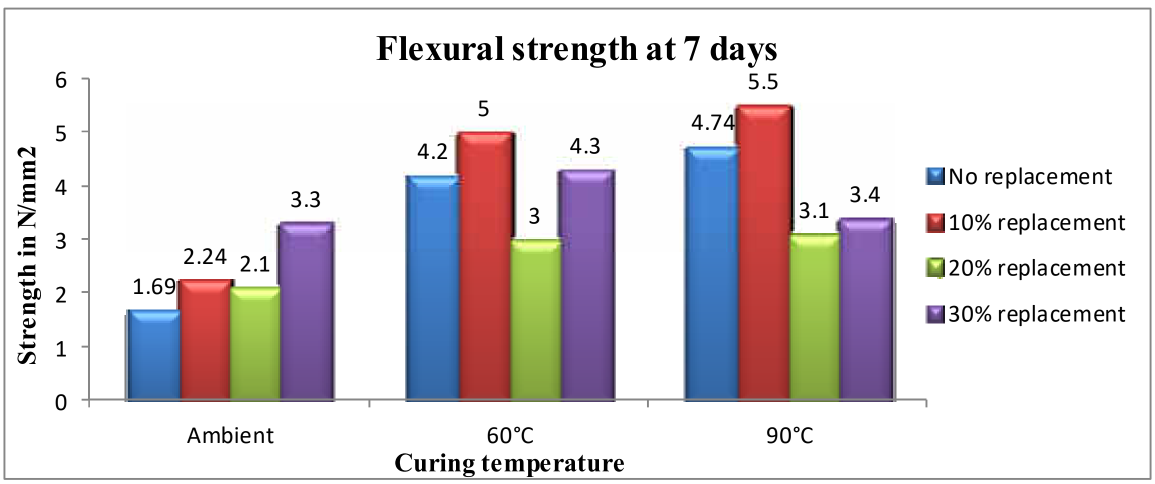

Figure 2 Flexural strength of GPC w.r.t. different curing temperatu and replacement of foundry sand at 7 days

I.2 Flexural strength of M40 geopolymer concrete at 28 days

Curing Temp.	No replacement		10% replacement		20% replacement		30% replacement	
	Flexural strength	Density Kg/m^3	Flexural strength	Density Kg/m^3	Flexural strength	Density Kg/m^3	Flexural strength	Density Kg/m^3
Ambient	2.5	2320	4.94	2270	2.14	2310	3.5	2280
60°C	5	2330	5.1	2410	3	2220	3.4	2320

90°C	6.2	2360	5.7	2370	5.03	2200	3.55	2364

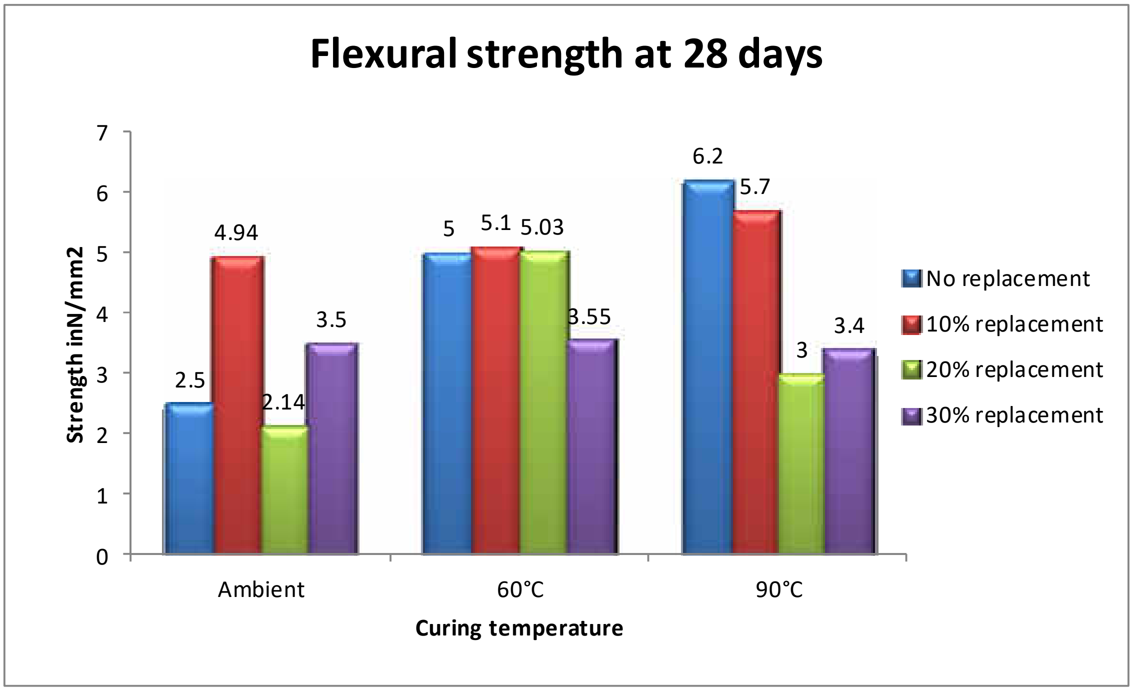

Figure 3 flexural strength of GPC w.r.t. different curing condition and replacement of foundry sand at 28 days

OBSERVATION: -

It has been clearly shown by the above mentioned results that after 7 days of casting geopolymer concrete achieved 80 to 90% and 28 days of casting achieved 100% strength under heat curing. Also it has been observed that during same time period the flexural strength is increased upto 40% by 10 percent replacement of foundry sand at 7 days curing and same as in 28 days curing. Even without replacement of sand the flexural strength gave cus good results. It is clearly indicated by the test results that the behavior of geopolymer concrete is similar for both 7 and 28 days with respect to replacement of foundry sand. It also observed that at ambient curing concrete achieved least strength and the strength increased with increase in temperature upto 90°C.

CONCLUSIONS

Based on the results of the experimental investigation, following conclusions are drawn: -

The heat cured concrete achieved higher compressive strength, split tensile strength and flexural strength in comparison with ambient curing.

The Compressive strength of Geopolymer concrete was found to be increasing with replacement of foundry sand. It is found that replacement of 10% of foundry sand gives highest compressive strength, the strength increased by 35%.

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LIST OF CODES

- Code used in the present studies: -
- Code for fly ash - ASTM C 618
- Code for foundry cand - IS: 1918-1966