Engineering Properties of GGBS & Fly ash Synthesized Geopolymer Concrete at Different Environmental Conditions by Comparing with Conventional Concrete

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ABSTRACT--- One of the alternative User friendly materials in place of conventional concrete is geopolymer concrete with same effect. Utilization of raw materials is less in geopolymer binders as well as decreases the emission of carbon dioxide. With these reasons most of the researchers are doing work on these types of resins to create eco-friendly accommodation. This paper presents the historic expansion of alkali-activated resin, the process of geopolymerization and its importance. In this paper integrated the engineering behaviour of flyash and GGBS synthesized binder at different mix proportions as well as at dissimilar curing environments and these properties are compared with conventional concrete. Positive results are appeared at higher percentage of GGBS (70%) compared to all other proportions. It was found that geopolymer concrete is gaining almost 25-30 MPa strength in 24 hours of sunlight curing, but to achieve same strength more than 28 days curing required in Conventional concrete.

Keywords: Durability; Fly ash; Geopolymer Binder; GGBS; Properties.

I. INTRODUCTION

Conventional concrete is recognized most significant material in civil Engineering, every year 3 tons of concrete is devoured by each individual person on the ground. Cement production releases environment harm gases into atmosphere, which is all around 8% in the total contribution of CO_2 emissions in the world (Robbie, 2017). Another problem in the production of cement is the utilization of more raw materials like Lime stone (Robbie, 2017; Schneider et al., 2011). Joseph Davidovits was introduced geopolymer binders in the year 1972 to give significant alternative material to ordinary Portland binders to conquer the problems of CO_2 emissions as well as to decrease the raw material usage (Schneider et al., 2011). Byproducts like GGBS, flyash and silica fume with soluble solutions (Sodium or Potassium) are used to produce alkali-activated binder (Nakshatra, 2018). Recent researches indicate the evidence, that geopolymer concrete marked their importance in the construction industry all over the world (Farina et al., 2018). Manufacture of geopolymer concrete is quite different compared to conventional concrete, because of its utilization of industrial byproducts and consumption of fewer raw materials (Yellaiah et al., 2014). Alkaline solutions prepared 24 hours before preparing the geopolymer binder by synthesizing inorganic waste materials like metakaolin, silica fume, flyash and GGBS. Flyash synthesized geopolymer concrete requires oven curing, but fly ash and GGBS synthesized concrete is not required any oven curing, sunlight curing is sufficient to achieve full strength in 28 days.

With this paper presented the properties of inorganic materials (Flyash and GGBS) used in geopolymer mix. The preliminary parameters like compression, tension and flexural strengths of geopolymer concrete at dissimilar curing conditions are presented and compared with conventional concrete. The best results are obtained at sunlight curing of 28 days for M5 mix.

1.1 Utilization of industrial wastes/Historic Development

Alkali-activate binders' development is taken place from 1930 itself; these are utilized in various fields of structural development (Pan et.al.,2016). The inorganic geopolymer binder/concrete was introduced by Davidovits in the year 1972 (Bellum et al., 2018). The development of inorganic materials from 1939-2018 along with the reference are presented (Table:1).

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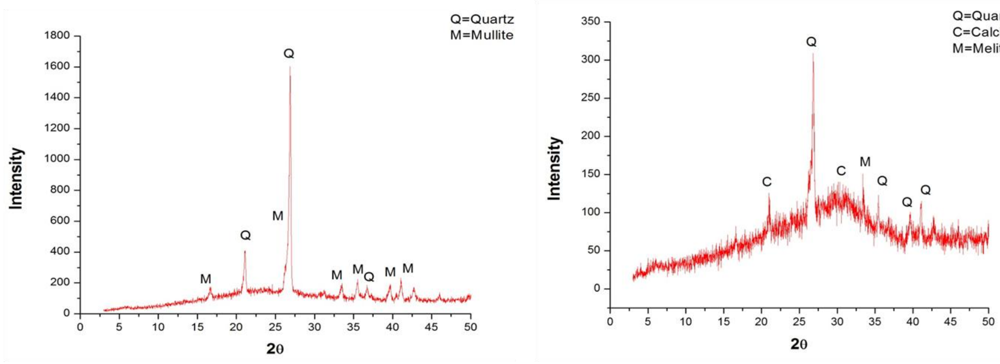
Table No: 1 Bibliography of alkali-activated industrial materials

Reference	Year	Implication	Reference	Year	Implication
Feret	1939	Slags use to compose cement	Kaushal et al.	1989	Nuclear Wastes Forms from Alkaline Mixtures
Purdon	1940	Alkali-Slag combination	Wu et al.	1990	Slag Cement Activation
Glukhovsky	1959	Hypothetical Basis Growth of Alkaline Base Cements	Roy et.al.,	1991	Cement produced from Alkali-Activation (Rapidly Setting)
Glukhovsky	1965	Earliest called ‘‘alkaline cements’’	Roy & Silsbee	1992	Alkali Activated cements -an overview
Davidovits	1979	‘‘Geopolymer’’ term introduced	Palomo and Glasser	1992	CBC with Metakaolin
Malinowski	1979	Ancient aqueducts characterized	Roy and Malek	1993	Slag Cements
Langton and Roy	1984	Characterized earliest construction materials	Krivenko	1994	Alkaline Cements
Krivenko	1986	DSc Thesis, R_2O-RO-SiO_2-H_2O	Davidovits	2010	MK-750 Based geopolymer concrete.
Malolepsy and Petri	1986	Creation of Synthetic Melilite Slags	Davidovits	2012	Structural composites for high temperatures about 1000^oC
Malek et al.	1986	Slag cement-low level radioactive Form of waste	Davidovits	2013	Foundry Resins (Nano-poly (Silaxilanol))
Davidovits	1987	Compared olden and recent Concepts	Davidovits	2014	Geopolymer bricks (LTGS) low temperature (70^oC)
Roy and Langton	1989	Earliest concepts of analogs	Liew et al.	2016	Geopolymeric material made from coal ash
Majundar et al.	1989	Slag Activation- C12A7	Naskar and Chakraborty	2016	fly ash has vary a low cost compared to potential ecological benefit
Talling and Brandstetr	1989	Alkali-activated slag	Marina Dudnikova et al.	2018	Construction, 3D printing using geopolymers
Deja and Melolepsy	1989	Resistance to chemical environment	Dr. Tomi Nissien	2018	Foam introduced to geopolymers

II. MATERIAL AND PROPERTIES

Flyash an industrial byproduct is available at thermal power plants (burning of coal) (Paratibha et al., 2015; Bakharev, 2004). In this paper Class - F fly ash have used & procured from NTPC (National Thermal Power Corporation, Vijayawada). GGBS is acquired through extinguish Iron manufacturing plants from a fire furnace in liquid or vapor form to bring a smooth finishing item i.e., then dried out & chipped into a small particles. In the current study GGBS was taken from SVK Ready Mix Plant, Perecharla. And their properties like specific gravity and density are shown in Table:2. The mineralogical compositions of flyash & GGBS, analyzed from XRD (X-Ray Diffraction) method and these are interoperated in origin software (Figure:1).



1(a) 1(b)

Figure No: 1(a) X-Ray Diffraction of flyash inorganic sample, 1(b) X-Ray Diffraction of GGBS

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SEM (Scanning Electron Microscope) analysis was conducted to calculate particle size division of flyash and GGBS (Figure:2). The SEM analysis of flyash and GGBS operated at high vacuum and at high voltage of 5kv. In this analysis we found the particle size ranges between 14 to 23 µm. In the similar manner analyzed for GGBS, for this the particle ranges from 2 to 6 µm. The SEM images of fly ash at 100 µm, fly ash at 50 µm, GGBFS at 50 µm and GGBFS at 20 µm are included in this paper (Figure 2a, 2b, 2c & 2d).

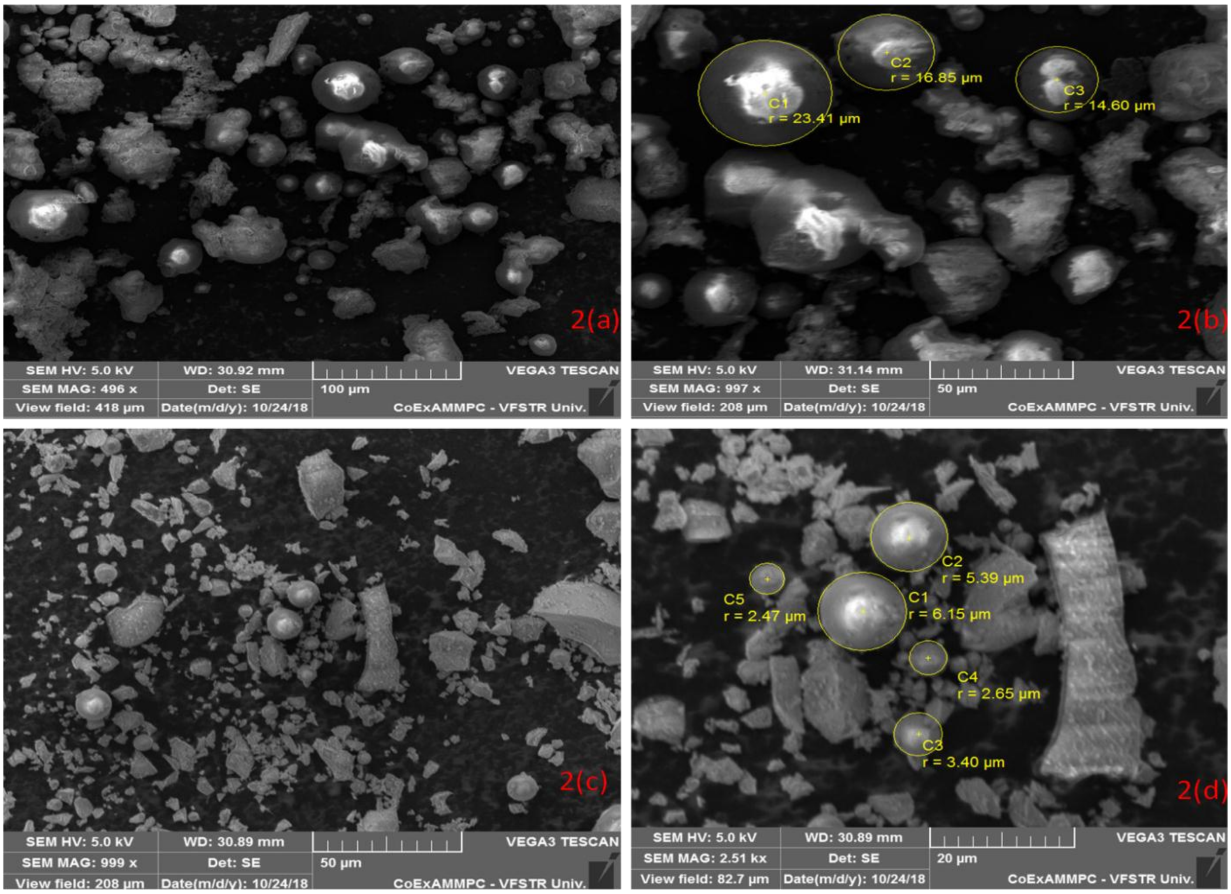

Figure No: 2(a) SEM of flyash at 100 µm, 2(b) SEM of flyash at 50 µm, 2(c) SEM image of GGBFS at 50 µm, 2(d) SEM image of GGBFS at 20 µm

III. ALKALI-ACTIVATED BINDER

Geopolymer/ alkali-activated binders are usually formed by the synthesis of inorganic materials by alkaline solutions (Gorhan and Kurklu, 2014). Alkali-activation of alumino-silicate materials like GGBS, silica fume, fly ash and metakaolin has a complex process, in the present paper fly ash and GGBS was synthesized by alkaline solutions (NaOH and Na_2SiO_3). The alkaline liquids was geared up by mixing of NaOH pellets with water (depending on molarities) for 8 to 10 minutes and then mixed with sodium silicate solution and synthesized by flyash and GGBS. NaOH to Na_2SiO_3 ratio was maintained constant as 2.5.

Locally available Krishna river sand was taken and the properties like G=2.40, %FM = 2.20 and meeting the requirements & grading to Zone-III according to IS:383-1970. Coarse aggregates are precise molded pounded rock with greatest size 20 mm and its FM and G are 6.97 & 2.89. GGBS of FM = 0.25 assumed in this work. Consumable water with pH = 7.11 was utilized for the GPC preparation. In the mix of geopolymer concrete, super plasticizers are used to improve the workability of concrete by addition different percentages; in this paper 4% of CONPLAST super plasticizer was used.

Materials	Course aggregate	Fine Aggregate	Cement	Fly ash	GGBS	Density of Sodium Silicate	Sodium Hydroxide	Water	Super Plasticizers
Specific Gravity	2.71	2.48	3.15	2.1	2.22	1.53	1	1	2.12

Table No: 2 Specific gravity and density of different materials

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Geopolymer binder is prepared in the similar manner to conventional cement mortar in place of cement by flyash & GGBS & liquid with activator solution at different proportions (Yellaiah et al., 2014). "Geopolymer" literature shows group of minerals that have a polymeric silicon-oxygen-aluminum structure, like that found in zeolite, (Ganapati et al., 2012). To enhance early strength of geopolymer concrete along with class-F flyash, GGBS was also added in different mix ratios (Nath et al., 2012).

3.1 Geopolymerization

The preponderance recognized antacid fluid utilized in Geopolymerization is a blend of NaOH / KOH & Na_2SiO_3. At the point when any of the source materials for instance flyash in strong frame are blended by means of antacid arrangements of suitable fixation and Na_2SiO_3, geopolymers are shaped that amid the polymerization response of fly ash (Nakshatra, 2018; Gawwada et al., 2016). The Geopolymerization process includes a considerably quick concoction reaction in the form on Si-Al in a 3-D polymeric network chain/ring structure in the form of Si-O-Al-O bonds. Geopolymers are regularly combined by blending industrial byproducts containing Al-Si & the essential arrangements. Preliminary we use are kaolinite, clay , zeolite , flyash , silica fume , slag , POFA , rice husk powder , redmud or some other materials (Benjamin et al., 2011).

The execution, including the quality of geopolymer concrete on a basic level affected by blend of material, composite of a fastener, binder, water-substance & diminishing condition. The obsession & estimations of solvent base activator which impacts the geopolymerization rate & choosing last nature of hardened binder. Additionally, the activator Molarity course of action would impact content of water added to it . Hydroxyl particles (water) in activator course of action add to opportunity of Si and Al from the geopolymer cover. All things considered, geopolymerization increase with reestablishing time and diminishing temperature up to 90^{o}C (Bakharev, 2004). The superior Young's modulus is accomplished utilizing warm restoring because of a higher level of geopolymerization (Aughenbaugh et al., 2015). The kind of alkaline solutions used in the preparation of GPC plays an important position in the process of geopolymerization (Mustafa et al., 2012; Palomo et al., 1999). The grater molarities of NaOH solution was more influential in dissolving fly ash particles and can result in better-quality geopolymerization (Gorhan and Kurklu, 2014).

3.2 Applications of geopolymers

Geopolymer possess early high strength, low shrinkage, freeze-thaw confrontation, sulphate confrontation, corrosion confrontation, acid confrontation, fire confrontation, and no dangerous alkali-aggregate reaction (Bhavin et al., 2013). Depending on Si:Al ratios the applications of geopolymers are greatly influenced in Civil Engineering applications. Based on experimental tests, geopolymer concrete can become firm rapidly at sunlight temperature and gain the compressive strength in the range of 20 MPa after only 4 hours of curing and about 40-50 MPa in 28 days.

IV. MIX DESIGN OF GEOPOLYMER CONCRETE

4.1 Standards

Davidovits explained the material proportion ranges in geopolymer concrete mix are either alkaline liquid to cementitious materials, NaOH to Na_2SiO_3, Water to GGBS/Flyash are presented in his webinar lectures. The range of super plasticizer is taken in between 0.5-6% of mass of cementitious materials like fly ash and GGBS. If requires the extra/additional water content, then it is ranges between 0.02 to 0.06 % to the mass of cementitious materials (Table:3).

Materials	Range
Alkaline liquids/CM	0.3 to 0.45
NaOH/Na_2SiO_3	2 to 2.5
Water / Inorganic materials	0.16 to 0.24
Total Fine & Coarse aggregate	66 % to 85%
Total fine Aggregates	29-30%
Addition of excess water	0.02 to 0.06 % to the mass of cementitious material
super plasticizers	0.5-6 % to the mass of cementitious material

Table No: 3 Material Standards used in geopolymer concrete mix

4.2 Mix Design of Geopolymer Concrete per Cubic Meter

The materials are used in the geopolymer concrete mix design are Fly ash, GGBS, sodium hydroxide, sodium silicate, fine aggregates, course aggregates, water and super plasticizer. Based on unit weight of plain cement concrete (2400kg/m^3) & mix proportions of geopolymer concrete was carried. The proportions of fine and coarse aggregates used as 70% and 30% respectively. The ratio of alkaline liquid to cementitious materials was taken as 0.35 and ratio of NaOH to Na_2SiO_3 was 2.5, all these proportions and quantity of materials are taken as per the standards of "Davidovits". Compared to conventional concrete geopolymer concretes exhibits less workability, for that to improve the workability conplast super plasticizer (4%) was used (Table:4). Unexpectedly , the workability of GPC was increasing by preparing alkaline solutions 3-4 days before casting the specimens.

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Aggregates Used	Quantity	Aggregates Used	Quantity
Unit weight of concrete	2400 kg/m^3	SiO_2	33.69%
Percentage of aggregate in total mass of concrete	70%	H_2O	51.01%
Aggregate content in total mass of concrete	1680 kg/m^3	Water content in sodium silicate	69 kg
Total Fine aggregates used	30%	solids content in sodium silicate	65kg
Fine aggregate in total mass of aggregate	504 kg/m^3	**Water required in sodium hydroxide**	
Coarse aggregate in total mass of aggregate	1176 kg/m^3	Molarity ratio	14
Cementitious materials used		Mass of NaOH solids	560 gm
Ratio of alkaline liquid to cementitious material	0.35	NaOH	56%
Mass of Cementitious material and alkaline liquid	720 kg/m^3	H_2O	44%
Mass of Cementitious material	533 kg/m^3	Solid content in sodium hydroxide	30 kg
Mass of alkaline liquid	187 kg/m^3	Water content in sodium hydroxide	23 kg
Fly ash (30%)	159.9 kg/m^3	Total water content	92 kg
GGBFS (70%)	373.1 kg/m^3	Total solid content	628 kg
Alkaline liquids required		Water to cementitious material ratio	0.146
Ratio of $Na_2SiO_3$and NaOH	2.5	**Super plasticizer requirement**	
Mass of NaOH	53 kg/m^3	Super plasticizer	4%
Mass of sodium silicates	134 kg/m^3	Mass of super plasticizers	25.12 kg/m^3
Water required in Sodium silicate		Percentage of extra water content	1%
Na_2O	15.30%	Extra water content	5.33 kg/m^3

Table No: 4 Mix Design of different materials per cubic meter (14M of NaOH)

The quantities/percentages of different materials in the geopolymer concrete were prepared on unit weight basis of different materials for 1000 kg. The quantity of materials was prepared with the help of unit weight of those materials (corrected values are used for fine and course aggregates). The material quantities were prepared for 25 cubes, 12 cylinders and 4 beams in every individual mix. All the mix design values are prepared in the Microsoft office excel worksheet. Microsoft office excels worksheet will helpful to prepare the quantities for different molarities of NaOH, dissimilar percentages of cementitious materials (Fly ash and GGBS ratios). Geopolymer concrete mixes was prepared at dissimilar molarities of NaOH solutions as well as different percentages of cementitious materials (Table:5). The below expression/equation was used to prepare the mix quantities of different materials.

Material quantity=Unit weight x Dimensions of mould x No of moulds

Table No: 5 Mix proportions weight of all materials for 25 cubes, 12 cylinders and 4 prisms (6M, 30% GGBS & 70%FA)

Materials	M1 (6M NaOH, 30% GGBS & 70%FA)	M2 (8M NaOH, 40% GGBS & 60%FA)	M3 (10M NaOH, 50% GGBS & 50%FA)	M4 (12M NaOH, 60% GGBS & 40%FA)	M5 (14M NaOH, 70% GGBS & 30%FA)
Coarse aggregate	132.26	132.26	132.26	132.26	132.26
Fine aggregate	57.01	57.01	57.01	57.01	57.01
Flyash	44.87	38.46	32.05	25.64	19.23
GGBFS	19.23	25.64	32.05	38.46	44.87
Mass of sodium silicate	7.81	7.81	7.81	7.81	7.81
Total water content in sodium silicate	8.29	8.29	8.29	8.29	8.29
Total sodium silicate	16.11	16.11	16.11	16.11	16.11
Mass of sodium hydroxide	1.56	2.04	2.64	3.12	3.6
Total water content in sodium hydroxide	4.81	4.33	3.72	3.24	2.76

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V. EFFECT OF CURING TEMPERATURES

Curing is one of the major processes in the strength point of view, in case only fly ash synthesized geopolymer concrete means oven curing is required for at least 24 hours. Here, in this paper geopolymer concrete was synthesized by fly ash and GGBS, so only we went for sunlight and room curing. At this curing conditions determined strength of concrete by means of compression , tensile & flexural strength of GPC and compared it with conventional concrete. Flyash (Class-F) geopolymer mixtures harden quietly at adjacent hotness & shows diminutive strength gained at earlier in contrast to oven cured specimens. Mechanical strengths of GPC cured at Atmospheric conditions shows potential or excellent result compared to water curing [Nurruddin et al., 2018]. In this paper two curing methods are followed one is sunlight and another one is cured at room temperature by maintaining constant (approximately) (Figure:3).

Figure No:3 Geopolymer concrete specimens Curing at different environments

VI. ENGINEERING PROPERTIES OF GEOPOLYMER CONCRETE

The engineering properties were calculated at different curing temperatures and dissimilar molarities of NaOH solution. Material proportions are taken separately on percentage basis of Fly ash and GGBS. All the test specimens are cured at different environmental conditions (sunlight and room). The testing of these specimens can be seen in Figure:4.

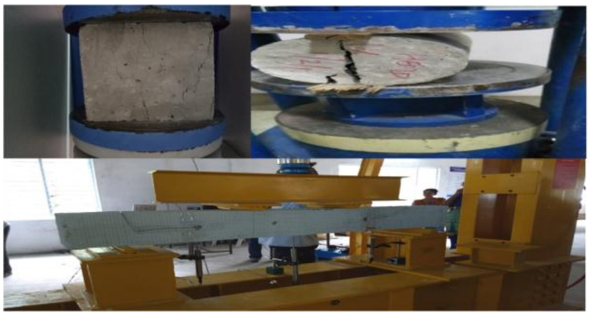

Figure No: 4 Testing of geopolymer concrete specimens

6.1 Compressive strength

The plastic geopolymer concrete is mixed & casted into cubical specimens of required size immediately after mixing & compacted in three layers of fresh concrete & given 60 to 80 strokes manually by using a round steel bar, and then vibrated for 30-60 seconds on a vibrating table. After 24 hours, specimens are taken from moulds and cured at sunlight and room temperatures for 1, 3, 7, 14 and 28 days respectively. Standard cube moulds (150x150x150) are used to calculate the strength of concrete for both OPC & GPC. Testing of all the specimens are carried according to the requirements of IS 516:1959. In experimental study it was clear , that the strength of GPC is slowly increasing along with the time of curing in both room (Figure:5) and sunlight (Figure:6). But, general water curing is only adopted for conventional concrete.

$$\frac{Maximum\ load\ at\ failure}{Surface\ Area\ of\ the\ specimen} = Compressive\ Strength(MPa)$$

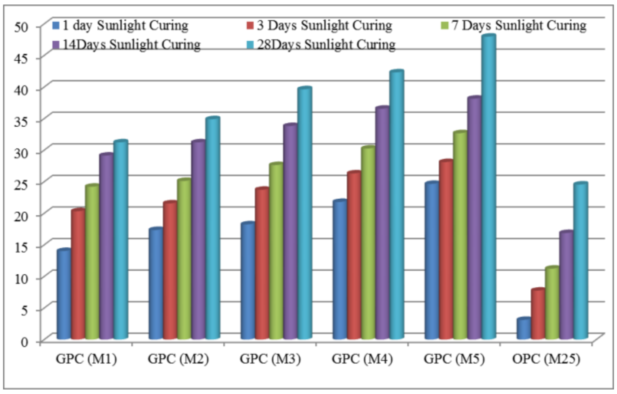

Figure No:5 Compressive strength of OPC and GPC cured at sunlight temperature

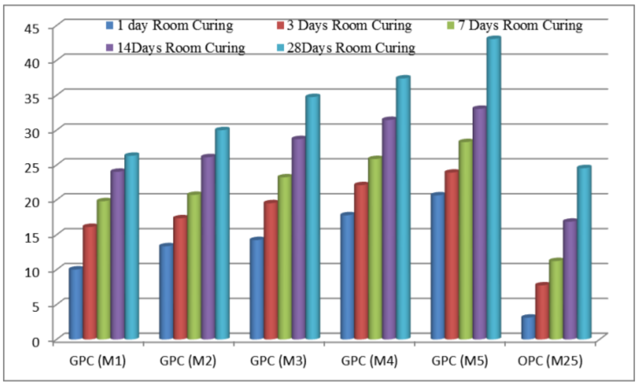

Figure No:6 Compressive strength of OPC and GPC cured at room temperature

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6.2 Split tensile strength

The split tensile strength was conducted to understand the tensile behaviour of fly ash based GPC(geopolymer concrete). Splitting test (indirect tensile test) was done on cylindrical specimens of 150 mm in dia. & 300 mm in height as per standard ASTM-C:496 & cured at the ages of 1, 3, 7, 14 & 28.It depicts the maximum split tensile strength can be calculated based on Eq. (2). In this equation, P is the applied load applied, L = length of the Specimen & D = diameter of the Specimen & F = Tensile strength. The tensile properties of GPC is gradually increased depending on curing age in both sunlight and room (Table:8). But greater strengths are obtained in sunlight curing (Table:7).

Split Tensile Strength MPa (F) = $\frac{2P}{\pi DL}$ ………eq-2

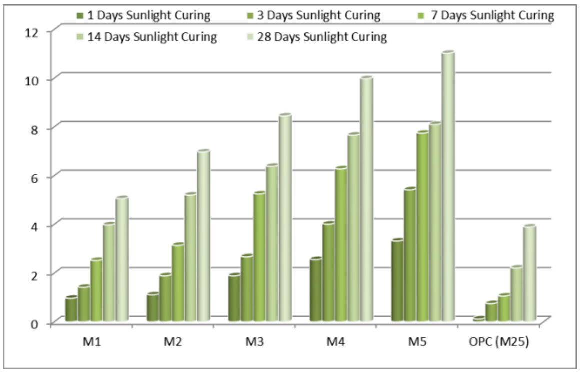

Figure No: 7 Split tensile strength of GPC at sunlight curing

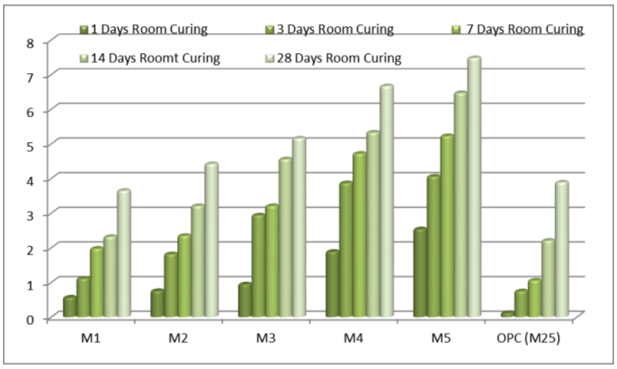

Figure No: 8 Split tensile strength of GPC at room temperature

6.3 Flexural strength

The flexural strength of geopolymer concrete is determined by using a simple beam with two point loading, this procedure is commonly referred as modulus of rupture. The flexural strength of GPC specimens are cured at sunlight and room temperatures for 1, 3, 7, 14 & 28 days respectively. Flexural strength determination was carried according to the requirements of ASTM-C:78-16(Standard method for testing flexural strength).With this experimental investigations, it was clear that flexural strength of GPC is gaining almost 5M-Pa at 28Days of sunlight curing (Table:9), where as in room curing it was 4 MPa (Table:10).

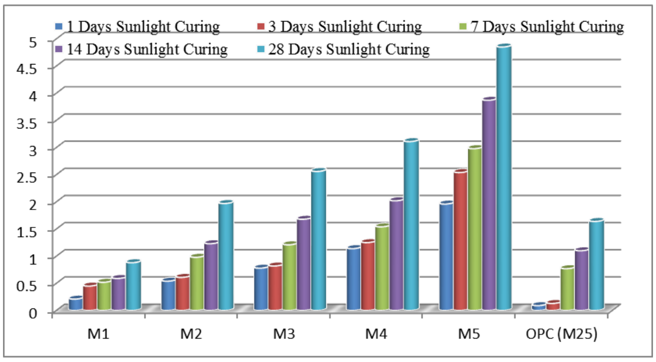

Figure No: 9 Flexural strength of geopolymer concrete at sunlight curing

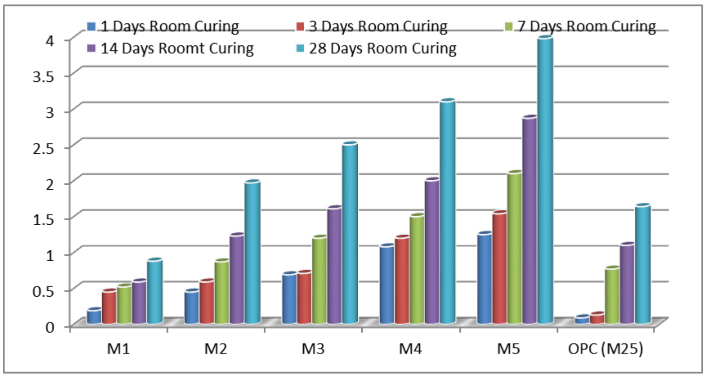

Figure No: 10 Flexural strength of geopolymer concrete at room temperature

VII. RESULTS AND DISCUSSIONS

The compressive strength of geopolymer concrete was calculated at different environmental conditions for maximum of 28 days (Table:6). GPC of dissimilar mixes are cured in both sunlight and room temperatures, OPC of M25 mix is cured in water. For M5 mix of geopolymer concrete achieved greater strength in sunlight curing for 28 days (i.e, 47.89 MPa) compared with room curing. Geopolymer concrete is gaining almost 25 MPa in 24 hours of curing, but in OPC it is taking 28 days to achieve same strength.

Sunlight curing is having more impact on indirect tensile strength of GPC compared to room temperature (Table:6). Strength variance of these two types of curing was almost 2MPa is every condition like 1, 3, 7, 14 and 28 days time period. It was found that strength of OPC for 28 days is less than one day strength of GPC, thus proving that GPC is sustainable strength compared with OPC. There was no much more impact on both sunlight and room curing of GPC, these values is almost same in all ages of curing.

Different molarities of NaOH solution, Proportions of Fly ash and GGBS are showing much more impact on properties of geopolymer concrete. This paper demonstrate that 14 M of NaOH solution, 70% of GGBS and 30% of fly ash mix (M5) was getting higher strength values compared to all other mixes.

Mix	Compressive Strength (MPa)		Split Tensile Strength (MPa)		Flexural Strength (MPa)	
	28 Days Sunlight Curing	28 Days Room Curing	28 Days Sunlight Curing	28 Days Room Curing	28 Days Sunlight Curing	28 Days Room Curing
GPC (M1)	24.31	20	5.06	3.65	0.88	0.88
GPC (M2)	27.74	24.23	6.97	4.42	1.97	1.97
GPC (M3)	32.25	28.75	8.45	5.16	2.56	2.5
GPC (M4)	38.12	33.25	9.98	6.67	3.11	3.1
GPC (M5)	47.89	44.16	11.02	7.48	4.85	3.98
OPC (M25)	24.58	24.58	3.89	3.89	1.64	1.64

Table No:6 Strength variance of GPC and OPC at 28 days of curing

VIII. CONCLUSIONS

In this paper, the consequence of curing temperatures and mix proportions of geopolymer concrete on the mechanical properties was investigated and compared with conventional concrete.

- The synthesis of GGBS and flyash in geopolymer binders has greater impact on engineering properties of geopolymer concrete.
- There is no requirement of exposing geopolymer concrete at higher temperatures to gain maximum strength by addition GGBS. Instead of using only flyash based GPC.
- Higher addition of GGBS fallout in greater compressive strength, but maximum up to 70%. Mixing of GGBS (70%) and fly ash (30%) was resulting 47.89, 11.02 and 4.85 N/mm^2 compressive, tensile and flexural strengths respectively in 28 days of sunlight curing and at 14M of NaOH solution.
- Compressive strength of geopolymer concrete is gaining 25-30 MPa in one day curing where as in conventional concrete it was taking 28 days of curing.
- Compared with different concentrations of NaOH solution, 14 M is giving best properties for GPC.

Sustainable development will takes place as a alternative material to OPC in the future. Most of the researches are going on only in plain geopolymer concrete, better to go with some additives to mix in this concrete to improve tensile and flexural properties.

IX. ACKNOWLEDGEMENT

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