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An Investigational Work on Mechanical Properties of Low Calcium Fly Ash Based Geopolymer Concrete with GGBS

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ABSTRACT:
The use of Portland cement in concrete construction is under critical review due to high amount of carbon dioxide gas free to the atmosphere during of making cement. In recent years, challenges to increase the utilization of fly ash to partially replace the use of Portland cement in concrete are gathering momentum. The by-product material were dumped in landfills areas, creating a threat to the environment. Geopolymer concrete is a 'new' material that does not need the presence of Portland cement as a binder. Instead, the source of materials such as fly ash, GGBS etc; that are rich in Silicon (Si) and Aluminium (Al), are activated by alkaline liquids to produce the binder. This experimental work has given, the details of development of the process of making fly ash and slag based geopolymer concrete. Due to the lack of proper knowledge about the mix design procedures to make fly ash and slag based geopolymer concrete and about their performance, as concluded from literature study. The technology that is currently in use to manufacture and testing of geopolymer concrete is same that of controlled concrete. Low calcium fly ash and slag was chosen as the binder material to be activated by the geo-polymerisation process to obtain the concrete binder, to totally replace the use of Portland cement. The main parameters affecting the compressive strength of hardened fly ash and slag based geopolymer concrete are alkaline liquid to fly ash ratio, Na2SiO3 to NaOH ratio, SiO2 to Na2O, molarity of NaOH, different curing methods and temperature etc. Split tensile strength and flexural strengths are also increased over controlled concrete of standard grades (M30 & M50). This improvement in strengths is due to making the concrete dense by modifying the pore structure

KEYWORDS: Flyash, GGBS, Geopolymer concrete, compressive strength, Split tensile strength, Flexural strength.

I. INTRODUCTION

In this paper Concrete is one of the most widely used construction materials in the world, and is actually the second most consumable product after water. The environmental issues associated with the production of OPC are well known. Global reducing is associated with the reduction of the amount of sunlight reach to the earth due to pollution particles in the air blocking the sunlight. Cement is also among the most energy -intensive construction materials, after aluminium and steel. In order to produce environmentally friendly concrete, Mehta (2002) suggested the use of fewer natural resources, less energy, and minimise carbon dioxide emissions. He categorised these short-term efforts as 'industrial ecology'. The long-term goal of reducing the impact of unwanted by -products of industry can be attained by lowering the rate of material consumption. However, concrete technology remains a growing field, and research is still needed to enhance the durability and sustainability of this material. Geopolymer concrete (GPC) has been described as one of the most revolutionary development in concrete construction. The novelty of this thesis is that an attempt has been made to investigate the mechanical properties studies of fly ash and slag based geopolymer concrete of G30 and G50 grades which are equivalent to M30 and M50 grades of controlled concrete, which will have large potential applications in prestressed, cast-in-situ and precast industries.

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Problem Identification:
1. It was an eminent fact that production of one tonne of cement generates an equal amount of carbon di -oxide polluting the atmosphere which becomes a major threat to the environment.
2. In addition, large quantity of energy is also required for the production of cement and reducing the performance of the structure in terms of strength and durability aspects.
3. The thermal power plants using coal produces fly ash and steel plants produces GGBS, which has to be dumped requiring large areas and it is a big problem if the waste is not being reused. To defeat this disadvantage, it requires developing an alternative binder with usage of industrial wastes. G PC addresses the above issues in making concrete as a sustainable material because it doesn't require any cement, thereby avoiding pollution of the environment.

Objectives:
1. To improve a mix proportioning for making fly ash (Class-F) and slag based geopolymer concrete.
2. To study the parameters affects the properties of slag based geopolymer concrete and fly ash.
3. To investigate, the mechanical properties of fly ash and slag based geopolymer concrete.

II. MATERIALS AND MIX PROPORTIONS

Cement:
Ordinary Portland cement of 53 Grade of Ultra -tech Brand conforming to IS: 12269-1987 was used in this investigation. The cement used has been tested for various properties as per IS: 4031 -1988 and are reported in table 2.1 and 2.2.

Fine Aggregate
Locally available clean, well -graded, natural river sand having fineness modulus of 2.65 and specific gravity of 2.63 conforming to Zone II of IS 383-1970 was used as fine aggregate. Various properties of fine aggregate are evaluated in accordance with IS: 2386 -1963 Parts I to VIII and tabulated in table 2.3

S.NO.	Constituent	Percentage
1	Cao	63.70
2	SiO 2	22.00
3	Al2O3	4.25
4	Fe2O3	3.40
5	MgO	1.50
6	SO3	1.95

Table2.1Chemical Properties of OPC(53Grade)

S.No	Characteristics /Properties	Test Results	Requirements as per IS 12269-1987
1	Normal consistency	33%	----
2	Specific gravity	3.01	3.0 to 3.2
3	Setting time Initial setting time Final setting time	35 min 550 min	Not less than 30 minutes Not more than 600 minutes.
4	Soundness -Lechatlier method	1.55	Not more than 10 mm
5	Fineness of cement by sieving through sieve No.9(90 microns) for a period of 15 minutes	4%	<10%
6	Compressive strength at 28 days	55	----

Table2 .2Physical Properties of OPC of 53 Grade

Coarse Aggregate
Crushed granite angular aggregate of size 20 mm and 10 mm size from local source with specific gravity of 2.71 was used as coarse aggregate. The physical characteristics of coarse aggregate are tested in accordance with IS: 2386 – 1963 Parts I to VIII and are tabulated in table 2.3.

Property	Fine Aggregate	Coarse Aggregate
Specific gravity	2.63	2.71
Type	natural	crushed
Total water absorption	1.00%	1.60%
Moisture content	0.15%	0.70%
Bulk Density (Loose)	1423 kg/m3	1597 kg/m3
Bulk Density(Compacted)	1612 kg/m3	1725 kg/m3
Fineness Modulus	2.65 (Zone II)	6.45

Table 2.3: Properties of Fine and Coarse Aggregate

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Characteristics	Value
Color	Light brown liquid
Specific gravity at 25°C	1.08
pH	≥6
Chloride ion content	< 0.2%

Table2.4: Properties of Super plasticizer

Parameter	Results	Limits as per IS 456 – 2000
pH	6.6	6.5 – 8.5
Chlorides (mg/l)	49	2000 (PCC)
		500 (RCC)
Alkalinity (ml)	8	< 25
Sulphates (mg/l)	116	400
Fluorides (mg/l)	0.089	1.5
Organic Solids (mg/l)	53	200
Inorganic Solids (mg/l)	129	3000
Suspended matter (mg/l)	40	2000

Table2.5:Properties of Water Sample

S.NO.	Constituent	Percentage
1	CaO(Lime)	0.7-3.6
2	SiO_2(Silica)	49-67
3	Al_2O_3(Alumina)	16-28
4	Fe_2O_3(ironoxide)	4-10
5	MgO(magnesia)	0.3-2.6
6	SO_3(Sulphurtrioxide)	0.1-1.9
7	Surfaceaream^2/kg	230-600

Table 2.6: Typical Oxide Composition of FlyAsh

S.NO.	Characteristics (Percent by mass)	Minimum Requirement	Composition of VTPS fly ash in %
1	SiO2 + Al2O3 +Fe2O3	70	86.75
2	SiO 2	35	54
3	Reactive Silica	20	25
4	MgO	5	7
5	SO3(Sulphur trioxide)	3	6
6	Available alkali as sodium oxide (Na 2O)	1.5	2.16
7	Loss of ignition	5	7.23

Table2.7: Chemical Requirement of FlyAsh

GGBS

Ground Granulated Blast Furnace Slag (GGBS) chemical and physical properties are given in table 3.8 and 3.9 is a byproduct of the steel industry. Blast furnace slag is defined as the non - metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace. About 15% by mass of binders was replaced with GGBS.

S.No	Constituent	Percentage
1	Silicon dioxide (SiO 2)	33.2
2	Alumina tri-oxide (Al2O3)	18.3
3	Ferric oxide (Fe 2O3)	0.6
4	Calcium oxide (Cao)	32.9
5	Magnesium Oxide (MgO)	11.6
6	Sulphur tri -oxide (SO3)	1.0
7	Potassium oxide (K 2O)	0.91
8	Sodium oxide (Na 2O)	0.21
9	Chlorides (Cl)	0.006

Table:2.8 Chemical Compositions of GGBS

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S No	Characteristics	Result
1.	Colour	Dull white
2.	Fineness(Blaine's) m^2/kg	450
3.	Specific Gravity	2.91
4.	Glass content percent	93
5.	Bulk Density kg/m^3	1100

Table:2.9 Physical Properties of GGBS

Specific gravity	1.57
Molar mass	122.06 gm/mol
Na2O (by mass)	14.35%
SiO2 (by mass)	30.00%
Water (by mass)	55.00%
Weight ratio (SiO 2 to Na2O)	2.09
Molarity ratio	0.97

Table2.10:Properties of Na_2SiO_3 Solution

Figure 2.1: Cement Powder

Molar mass	40 gm/mol
Appearance	White solid
Density	2.1 gr/cc
Melting point	318^0C
Boiling point	1390^0C
Amount of heat liberated when dissolved in water	266 cal/gr

Table2.11:Properties of NaOH

Grade of GPC		G30
Flyash(kg/m^3)	307.7 (85%)	362
GGBS(kg/m^3)	54.3 (15%)	
Fine Aggregate(kg/m^3)		682.6
Coarse Aggregate(kg/m^3)		1184.4
NaOH solids out of 46.54kg/m^3 for12 Molarity concentration in kg/m^3		16.80
Na2SiO3(kg/m^3)		116.36
Extra water(kg/m^3)		20
Super plasticizer(GLENIUM B233)@1%(kg/m^3)		3.62
Ratio of mix proportions		1:1.89:3.27
Liquid / binder ratio		0.45
Work ability(mm)		50

Table:2.12 MixProportionsforG30

Grade of Concrete	M30
Cement (kg/m^3)	362
Fine Aggregate (kg/m^3)	682.6
Coarse Aggregate (kg/m^3)	1184.4
Super plasticizer (GLENIUM)@1% (kg/m^3)	3.62
Ratio of mix proportions	1:1.89:3.27
W/C ratio	0.45
Workability (mm)	50

Table:2.13 Mix Proportions for M30

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Grade of Concrete	M50
Cement (kg/m ^{3})	410
Fine Aggregate (kg/m ^{3})	554.4
Coarse Aggregate (kg/m ^{3})	1293.6
Super plasticizer (GLENIUM)@1.5% kg/m ^{3})	6.15
Ratio of mix proportions	1:1.35:3.16
W/C ratio	0.40
Workability (mm)	50

Table:2.14 Mix Proportions for M50

Figure2.2:Coarse Aggregate

Figure2.3: Fine Aggregate

Figure2.4: FlyAsh

III. STUDIES ON MECHANICAL PROPERTIES

This investigation is carried out to develop and optimize the mix proportion of standard grades (G30 & G50) of low calcium fly ash and slag based geopolymer concrete which are equivalent to standard grades (M30 & M50) of controlled concrete at 3, 7 and 28 days.

The development of mix proportion is based on many factors such as alkaline liquid to fly ash ratio, Na 2SiO3 to NaOH ratio, SiO 2 to Na2O, molarity of NaOH, different curing methods and temperature etc. The alkaline solution used for the present study is combination of sodium silicate (Na 2SiO 3) and sodium hydroxide (NaOH), the ratio of Na2SiO 3 to NaOH is 2.5 and SiO 2 to Na2O is 2, since the strength is maximum at these ratios.

Concrete cubes of 150 mm x 150 mm x 150 mm are cast with different percentage of GGBS replaced in fly ash as shown in table 3.1 and after one day rest period, half of the specimens were cured in an oven at 60°C for 24 hours.

The remaining period cured in sun light until the testing is done and remaining half of the specimens were ambient cured and tested to study the compressive strength of geopolymer and controlled concrete under axial compression on completion of 3, 7 and 28 days as per IS: 516 -1999.

The comparative study is done on compressive strength for all the parameters and an optimum compressive strength has been selected for both G30 and G50 which is equivalent to M30 and M50 respectively as shown in table 3.2.

The different trials of geopolymer mix with different composition of fly ash and GGBS as shown in table 4.1.The results of the compressive strength at 3, 7 and 28 days for standard grades (G30 & G50) of geopolymer and equivalent grades (M30 & M50) of controlled concrete are tabulated in Table 4.3 to 4.6 and are shown in Fig 3.3 to 3.6 The compressive strength of geopolymer concrete depends on many factors such as alkaline liquid to fl y ash ratio, Na 2SiO 3 to NaOH ratio, SiO 2 to Na2O, molarity of NaOH, different curing methods and temperature etc. The compressive strength of geopolymer concrete depends on ratio of Na2SiO 3 to NaOH; from the literature review it has been found that the strength is maximum at ratio 2.5 . Keeping this ratio as fixed, the other parameters like composition of mix and molarity of NaOH has changed. It has been experimentally found that the compressive strength is increased as the molarity of NaOH is increased for 8M to 16M, then it is decreased from 16M to 18M. The table 4.2 shows the compressive strength for all types of mixes and for different molarity of NaOH. An optimum compressive strength has been selected from mix4 i.e. 85 % fly ash and 15% GGBS at 12M and 16M for G30 and G50 respectively as the compressive strength of concrete is reached to target mean strength on 28 th day. Target mean strength has not reached up to 14M in other mixes for G30 and at the same time it is more than required in case of mix4 of 14M. To keep the mix as economical the mix4 has been optimized as it is reached to required target mean strength at 28 days. Similarly target mean strength has not reached up to 16M in other mixes for G50 and at the same time it is less than required in case of mix4 of 18M. So it is optimized at 16M of mix4 as it is reached to required target mean strength at 28 days.

Type of Mix	Composition of Mix
Mix1	100%flyash
Mix2	95%FA+5%GGBS
Mix3	90%FA+10%GGBS
Mix4	85%FA+15%GGBS

Table3.1: Shows Type and Composition of Mix

Grade of concrete	Type of Mix	3 days strength			
G30	Molarity	8M	10M	12M	14 M
	Mix1	23.88	25.01	28.43	30.52
	Mix2	24.59	25.74	29.27	31.13
	Mix3	25.98	27.22	30.95	32.74
	Mix4	28.38	29.65	**33.45**	35.85
G50	Molarity	12M	14M	16M	18 M
	Mix1	37.32	40.22	45.19	34.53
	Mix2	38.64	41.64	46.79	35.75
	Mix3	40.39	43.53	48.92	37.38
	Mix4	44.11	47.69	**54.19**	41.05

Table3.2: Compressive Strength (MPa) of Geopolymer Concrete for 3days

Grade of concrete	Type of Mix	7 days strength			
G30	Molarity	8M	10M	12M	14 M
	Mix1	25.25	26.61	30.06	32.47
	Mix2	25.99	27.39	30.95	32.93
	Mix3	27.48	28.96	32.72	34.63
	Mix4	30.01	31.36	**35.29**	38.01
G50	Molarity	12 M	14M	16M	18 M
	Mix1	40.09	42.96	47.22	37.37
	Mix2	41.51	44.48	48.89	38.69
	Mix3	43.39	46.5	51.17	40.46
	Mix4	47.08	50.62	**55.63**	44.42

Table3.3: Compressive Strength (MPa) of Geopolymer Concrete for 7 days

Grade of concrete	Type of Mix	28 days strength			
G30	Molarity	8M	10 M	12M	14M
	Mix1	27.45	29.08	32.68	35.29
	Mix2	28.26	29.93	33.64	35.99
	Mix3	29.87	31.65	35.57	37.85
	Mix4	32.62	34.28	**38.95**	41.45
G50	Molarity	12 M	14 M	16M	18M
	Mix1	42.65	45.7	50.78	40.62
	Mix2	44.16	47.32	52.58	42.06
	Mix3	46.17	49.47	54.97	43.98
	Mix4	50.36	53.78	**59.75**	48.29

Table 3.4 :Compressive Strength(MPa) of Geopolymer Concrete for 28 days

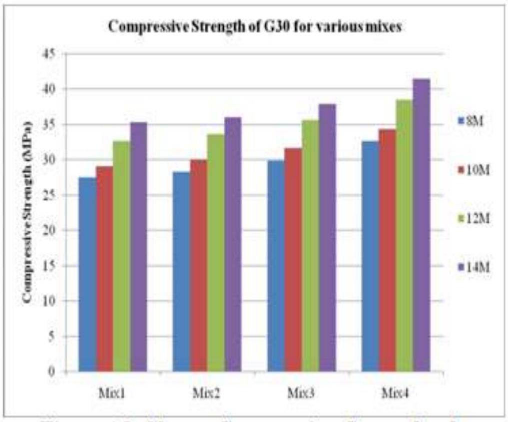

Figure 4.1: Shows Compressive Strength of G30 mixes for various Molarities of NaOH

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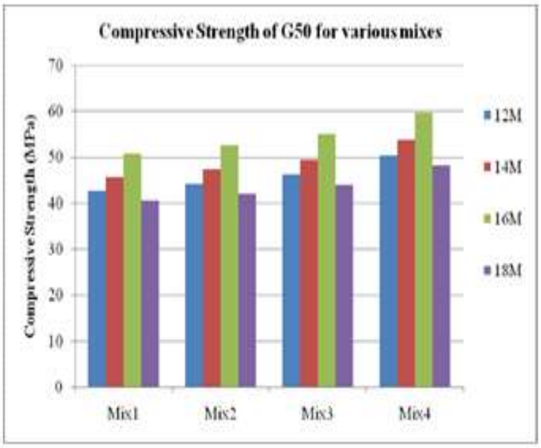

Figure 3.2: Shows Compressive Strength of G50 mixes for various Molarities of NaOH

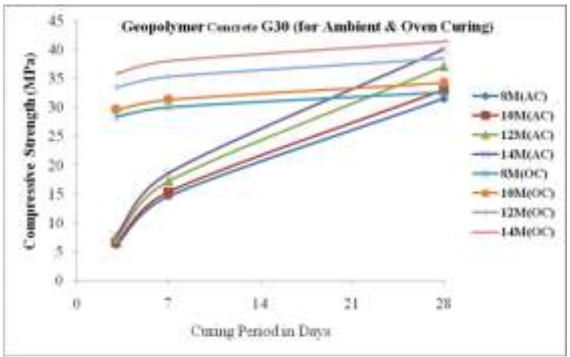

Figure3.3: Shows Compressive Strength of G30Vs Age of Concrete with various Molarity of NaOH for Oven and Ambient Curing

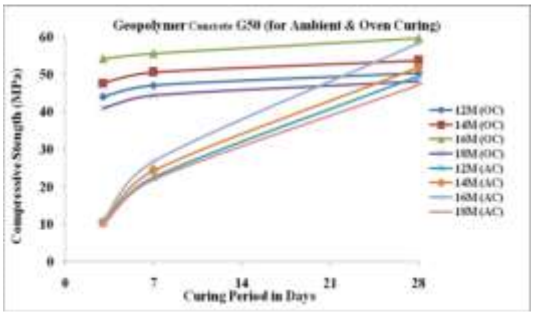

Figure 3.4: Shows Compressive Strength of G50Vs Age of Concrete with various Molarity of NaOH

IV. RESULTS AND DISCUSSION

The results of the compressive strength at 3, 7, 28, 60 and 90 days for standard grades (G30 & G50) of geopolymer and equivalent grades (M30 & M50) of controlled concrete are tabulated in Table 5.1 and the percentage increase in compressive strength of both grades of geopolymer concrete under curing over controlled concrete are shown in Table 4.1 and in Fig 4.1.

Compressive Strength (MPa)					
Age of concrete	**3 days**	**7 days**	**28 days**	**60 days**	**90 days**
M30 Controlled	19.45	27.68	38.62	42.54	43.61
G30 Geopolymer(OC)	33.45	35.29	38.95	42.83	43.85
Increase in %	**71.98**	**27.49**	**0.85**	**0.68**	**0.55**
M50 Controlled	28.92	41.07	58.42	63.39	65.48
G50 Geopolymer(OC)	54.19	55.63	59.75	64.07	65.96
Increase in %	**87.38**	**35.45**	**2.23**	**1.07**	**0.73**

Table 4.1: Increase in Percentage of Compressive Strength of Geopolymer Concrete under Oven Curing over Controlled Concrete

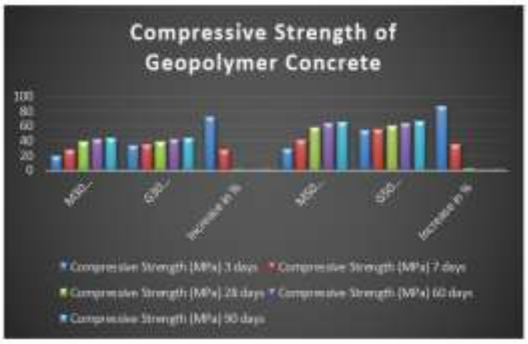

Figure 4.1: Compressive Strength of Geopolymer Concrete

The geopolymer concrete can be cured at ambient and temperature curing. The problem with ambient curing is not getting the early strengths, but 28 days strength is almost equal to oven curing.

Figure4.2: Compressive Strength Testing Machine

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Figure4.3: Split Tensile Test

Figure 4.4: Split Tensile Strength (MPa) of Geopolymer concrete

Figure4.5:Flexure Strength test Specimen

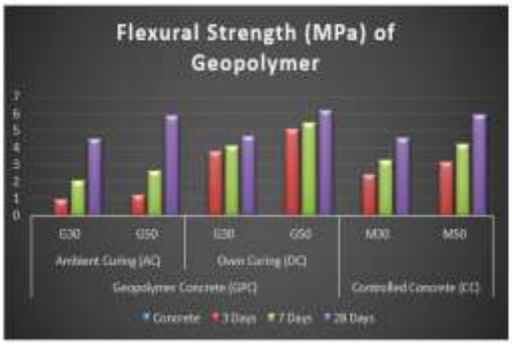

Figure 4.6: Flexural Strength(MPa) of Geopolymer concrete

Age of concrete	**3 days**	**7 days**	**28 days**
M30 Controlled	2.44	3.27	4.57
G30 Geopolymer (OC)	3.77	4.13	4.69
Increase in %	**54.51**	**26.29**	**2.63**
M50 Controlled	3.14	4.21	5.93
G50 Geopolymer (OC)	5.1	5.46	6.22
Increase in %	**62.42**	**29.69**	**4 .89**

Table4.2:Increase in Percentage of Flexural Strength (MPa) of Geopolymer (OC) over Controlled Concrete for differentgrades

V. CONCLUSIONS

1. Conventional mix design method i.e. Indian code (IS Code: 10262-2009) is adopted to obtain the mix proportions for standard grades (G30 & G50) of geopolymer and equivalent grades (M30 & M50) of controlled concrete.

2. Fly ash and GGBS are used to substitute the cement in the mix, which improve the durability and economy of the mix, the reason behind using GGBS in addition to fly ash is to reduce the setting time so that the setting time of GPC is eq ual to as that of controlled concrete, otherwise with fly ash alone the setting time is delayed.

3. The development of mix proportion is based on many factors such as alkaline liquid to fly ash ratio, Na 2SiO 3 to NaOH ratio, SiO 2 to Na2O, molarity of NaOH, dif ferent curing methods and temperature etc.

4. An optimum compressive strength of G30 and G50 grades of geopolymer concrete has been obtained at 85 % fly ash and 15% GGBS with 12M and 16M of NAOH, since the compr essive strength of concrete is reached to target mean strength on 28 th day which are equivalent to M30 and M50 grades of controlled concrete

5. It is observed that in geopolymer concrete (G30),

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the compressive strength showed significant increase by 71.98% and 27.49% over controlled concrete (M30) at 3 days and 7 days respectively, while 28 days, 60 days and 90 days strengths are almost equal to controlled concrete.
6. In G50 grade of geopolymer concrete, it is observ ed that the compressive strength showed significant increase by 87.38% and 35.45% over controlled concrete (M50) at 3 days and 7 days respectively, while 28 days, 60 days and 90 days strengths are almost equal.
7. This rapid increase in compressive strength for 3 days and 7 days may be due to polymerization of alkaline liquid with fly ash and GGBS under oven curing at optimum temperature i.e.60 oC.
8. Low calcium fly ash and slag based geopolymer concrete has attained very early compressive strength under oven c uring, it is about 85.9% & 90.6 % of 28 days strength of G30 and 90.7% & 93.1% of 28 days strength of G50 on 3 rd day and 7 th day respectively. So it can be used wherever early strength is required.
9. It can be suggested that even though early strength is n ot attained under ambient curing, it can be used for structural applications as the 28 days strength is almost equal to strength attained in an oven curing of geopolymer concrete.
10. It is observed that there was a significant increase in split tensile strength at 3 days, relative increase at 7 days and a slight increase at 28 days in geopolymer concrete as compared to controlled concrete of of respective grades. Increase in split tensile strength at the early age is due to polymerization of alkaline liq uid with fly ash and GGBS under oven curing.
11. It is observed that there was a significant increase in flexural strength at 3 days, relative increase at 7 days and a slight increase at 28 days in geopolymer concrete as compared to controlled concrete of of respective grades.

SCOPE FOR FUTURE WORK

1. A more rational mix design method can be attempted alternatively to design a GPC of required strength.
2. The powder content can be altered with other types of mineral admixtures like rice husk ash, silica fume and metakaolin etc. and their durability and economics studies can be done.
3. M sand and pond ash can replace traditional river sand for sustainability.
4. Experiments can be conducted to study the performance of GPC on the behavior of beams subjected to dynamic loads.

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