Effect of Temperature on Strength Properties of Geopolymer Concrete

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Abstract— Generally ordinary Portland cement is using in concrete for construction. It results in the increase of cement demand. Production cement results in the emission of carbon dioxide (CO_2) in equal amount from the industries. About 7% of world emission CO_2 was produced from cement industries. Which shows serious effect on environment results in global warming and greenhouse effect etc. To overcome this issues replacing concrete with geopolymers which are rich in silica and alumina. Fly ash and GGBS based geopolymer concrete of different molarities (6M, 8M & 10M) was casted. Sample cubes (150mmx150mmx150mm) of GPC were placed in oven immediately after demoulding for curing up to 20hrs duration. Cubes were cured at different temperatures (50ºC, 60ºC, 70ºC, 80ºC & 90ºC) for a constant period. After curing in oven cubes moved room for normal curing period. Workability test, NDT, compressive strength test were performed. Workability decreases with increase in molarity of alkaline solution. Different molarity GPC has different optimum strength and optimum temperatures. No extra water other than alkaline solution was used. Strength increases in curing period for ambient cured GPC. Strength increases up to optimum temperature for oven cured GPC.

Key words: Fly Ash, GGBS, Molarity, Oven Curing, Curing Period, Curing Temperature, Compressive Strength

I. INTRODUCTION

In 1978, Davidovits Joseph [1] introduced geopolymers which are rich silica and alumina. Geopolymers are non-disposal waste materials from thermal and steel plant industries. Materials like fly ash, ground granulated blast furnace slag, silica fume, rice husk ash etc.., are used in the manufacturing of GPC. Geopolymers used in place of cement in concrete, that concrete known as geopolymer concrete. Generally geopolymer concrete attains more strength than normal concrete. GPC doesn't require any water curing. Curing of GPC can be done under ambient condition. Strength of GPC increases with increase in curing period.[2]

Geopolymer concrete exhibits unique nature under temperature effect. Generally ordinary Portland concrete is cured by water treatment method. Geopolymer concrete is cured in room temperature. After casting geopolymer concrete, it doesn't require any water curing. Generally geopolymer concrete attains good strength under room temperature condition. In geopolymer concrete, the alkaline solution act as accelerator when exposure in room temperature. The polymerization is the main reaction, which results in good strength. The strength of geopolymer concrete increases when cured at high temperature conditions. Geoplymer concrete can attain strength >70N/mm^2 under high temperature conditions [2&3]. Geopolymer concrete can attain higher strength in 24hrs under high temperature curing conditions. Strength, durability, heat resistance increases when geopolymer concrete cured at high temperature conditions.

The present work is aimed to study about effect of temperature on strength properties of geopolymer concrete. The study carried on low calcium fly ash and GGBS based geopolymer concrete. Alkaline solution is a combination of sodium silicate and sodium hydroxide solution. Fly ash, GGBS, alkaline solution, coarse aggregates, fine aggregate & super plasticizer were used in manufacturing of GPC. GPC of different molarities was casted. Curing of GPC carried in oven at different temperature (50ºC, 60ºC, 70ºC, 80ºC & 90ºC) condition for constant period of 20hrs duration. Samples cubes of different molarity GPC were moulded. 3 sample cubes were casted for each molarity for every temperature condition. Samples were placed in oven immediately after demoulding. Samples were cured in oven [4] for a period of 20hrs at each temperature condition. After completion of oven curing period samples were in room for period 7days and 28days period. Workability test performed at fresh stage of concrete. Compressive strength test, non-destructive test performed after completion of curing period of 7days & 28days.

II. EXPERIMENTAL STUDY

A. Materials

In this project, fly ash & GGBS were used as binders whose chemical and physical properties are tabulated in Table1 & Table2. According to ASTM C 618 (2003)[6] class F fly ash produced from Rayalaseema thermal plant, Andhra pradesh and GGBS imported from AASTRA chemicals, Chennai, Tamilnadu were used in the manufacturing of GPC.

Chemical composition	
Particulars	% of composition
Silica(Sio2)	65.6
Alumina(Al2O3)	28.0
Iron Oxide(Fe2O3)	3.0
Lime(Cao)	1.0
Magnesium(MgO)	1.0
Titanium Oxide(TiO)	0.5
Sulphur Trioxide(So3)	0.2
Loss on Ignition	0.29
Physical properties	
Specific gravity	2.15
Fineness(m^2/kg)	360

Table 1: chemical and physical properties of fly ash

Chemical composition	
Particulars	% of composition
Chemical moduli $CaO+MgO+SiO_2$ $(CaO+MgO)/SiO_2$ CaO/SiO_2	 76.3 1.30 1.07
Magnesia	7.73
Sulphide Sulphur	0.50
Sulphite	038
Manganese	0.12

Chloride	0.009
Glass	91
Insoluble residue	0.49
Loss on Ignition	0.26
Physical properties	
Specific gravity	2.85
Fineness(m^2/kg)	390

Table 2: chemical and physical properties of GGBS

The alkaline liquid used was a combination of sodium silicate solution (Na_2O = 14.7%, SiO_2 = 29.4% and water = 55.9%) was purchased from Alnoor chemicals, Chennai and sodium hydroxide (NaOH) in pellets form with 97% - 98% purity was purchased from Astra chemicals, Chennai To obtain 1molarity of alkaline solution, we have to add 1*40gms of NaOH pellets in total volume of water. i.e., l liter of alkaline solution contain 40gms of sodium hydroxide pellets for 1molarity of solution. Alkaline solution of 6M, 8M & 10M is prepared for manufacturing of different molarity GPC. The sodium silicate solution and sodium hydroxide solution were mixed together one day before prior to use. Crushed granite stones of size 20mm and 10mm used as coarse aggregate, river sand used as fine aggregate [4&5]. The specific gravity and water absorption of the coarse aggregate 20mm and 10mm were 2.66 and 0.46% respectively. The specific gravity and water absorption of the fine aggregate were 2.62 and 1.09% respectively.

B. Mix design

Based on the past research on GPC, the mix proportions were selected based on B.V.Rangan's [3] method. The parameters that are maintained in these project are detailed below.

1) Fixed parameters

- 100% cement replaced by fly ash and GGBS
- Combined aggregates =77%
- Binder material and liquid solution = 23%
- Coarse aggregates = 70 %
- Fine aggregates = 30%
- Fly ash=75%
- GGBS= 25%
- Ratio of Sodium silicates to sodium hydroxide =2.5
- Ratio of fly alkaline liquid Solution to fly ash = 0.35
- Coarse aggregate = 60% 20mm + 40 % 10 mm
- Oven curing duration = 20hrs
- Super plasticizer = 0.7% of binder material

2) Variable parameters

- Molarity of sodium hydroxide solution = 6,8,10M
- Oven temperature = 50,60,70,80,90^{0}c

The complete mix design of these project according to B.V.Rangan's mix design was mentioned below.

- Taking density of concrete was 2400kg/m^3.
- Mass of combined aggregates was 77% of density.
- Mass of combined aggregates = (77*2400)/100 = 1848 kg/m^3
- Mass of fly ash, GGBS and alkaline liquid =2400-1848 = 552 kg/m^3
- Mass of coarse aggregates = (70*1848)/100 = 1293.6 kg/m^3
- Mass of 20mm C.A = (60*1293.6)/100 = 776.16 kg/m^3
- Mass of 10mm C.A = (40*1293.6)/100 = 517.44 kg/m^3
- Mass of fine aggregates = (30*1848)/100 = 554.4 kg/m^3
- Mass of flyash+GGBS = 552/(1+0.35) = 408.8 kg/m^3
- Mass of alkaline liquid = 552-408.8 = 143.11 kg/m^3
- Mass of fly ash = (75*408.8)/100 = 306.6 kg/m^3
- Mass of GGBS = 408.8-306.6 = 102.2 kg/m^3
- Mass of NaOH = 143.11(1+2.5) = 40.88 kg/m^3
- Mass of Na_2SiO_3 = 143.11-40.88 = 102.22 kg/m^3
- Quantity of Super plasticizer = (0.7*408.8)/100 = 2.862 lit/m^3

No extra water other than the alkaline solution and super plasticizer was used.
Volume of cube is 0.0034m^3.

C. Test methods

1) Workability Test- slump cone test is performed on fresh concrete to determine workability of the geopolymer concrete. Slump test results determine the consistence of fresh concrete before it sets. Slump cone test carried according to IS-1199:1959[7].
2) Compressive Strength Test- The most common test that is used to determine strength of the concrete is compressive strength test. This is carried by compressive strength testing machine (CTM). The compressive strength testing machine with the capacity of 2000kn. The concrete cubes of size 150mmx150mmx150mm were casted and cured and carried for compressive strength test. The compressive strength of the cubes conducted after completion of curing period. In these project the compressive strength test for cubes conducted at 7days and 28days. For each molarity and for every temperature condition 3 samples were tested and average of 3 samples results were calculated. The compressive strength is carried according to IS-516:1959[8].
3) Non-Destructive Test- Non-destructive test is one modern technology technique used to determine physical properties of a material, component or a system without causing any damage. Different types of non-destructive tests are used in present day technology. In work, two types of non-destructive tests are used. They are, ultrasonic pulse velocity test and rebound hammer test.
4) Ultrasonic Pulse Velocity Test- The ultrasonic pulse velocity test is a non-destructive used to check the quality of concrete. The quality of concrete is checked by measuring the velocity of an ultrasonic pulse passing through a concrete. The ultrasonic pulse velocity is performed according to the guidance of IS-13311(part1):1992[9].
5) Rebound Hammer Test- The most commonly used non-destructive test in present day in the world. Rebound hammer test is also known as Schmidt hammer. It is mainly used to determine elastic properties or strength of

concrete, mainly to determine hardness of surface and penetration resistance. This test also used to determine quality of concrete as per standard specifications. Rebound hammer consists of spring controlled mass that slides on a plunger within a tabular housing. The rebound hammer test carried as per IS-13311(part2):1992[10].

III. Results and Discussion

A. Workability Test (Slump cone test)

The test carried when the concrete is in fresh state or in other words immediately after mixing of concrete. The test conducted for every molarity geopolymer concrete at stage freshness before casting the samples. The test results for 6M, 8M, 10M geopolymer concrete was tabulated below and explained about the results.

Molarity of GPC	Slump Value (mm)
6M	12
8M	10.5
10M	9

Table 3: Results of slump cone test

From the results, the workability of the geopolymer concrete decreases with increase in molarity of alkaline solution. The concentration of solid NaOH increases with increase in molarity of solution. Concrete hardens very fast. Workability of concrete is low due to no additional or extra water is used. Workability of GPC decreases due to increase of viscosity. Workability decreases with increase in molarity due to decrease of water content in alkaline solution.

B. Compressive Strength Test

In present work, the compressive strength test performed at 7days and 28days. The procedure of compressive strength followed in these project according to IS-516:1959. The compressive strength conducted on 3 samples for each temperature condition cured of every molarity geopolymer concrete. The values of every sample cube cured under different temperatures were noted. The average value of 3 samples of each temperature condition of every molarity geopolymer concrete taken as final value of strength.

Molarity of GPC	Compressive strength (N/mm^2)	
	7 days	28 days
6M	37.7	47.83
8M	39.6	50.65
10M	44.55	54.7

Table 4: Compressive strength test results of 6M, 8M, 10M of GPC cured under room condition

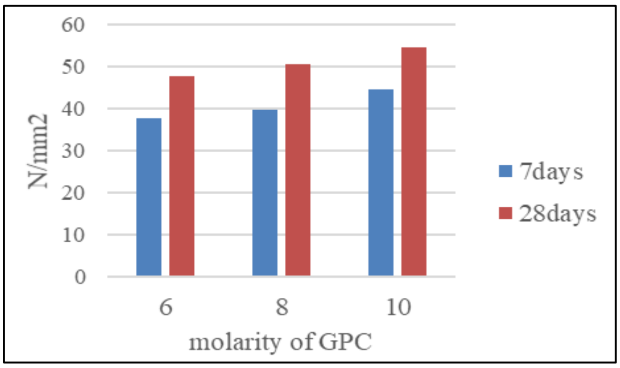

Fig 1: Compressive strength test results of 6M, 8M & 10M GPC

From the results, strength of geopolymer concrete increases with increases in molarity. Strength of GPC increases with increase in curing period. Strength of GPC increases with increase in concentration of solid NaOH in alkaline solution. Higher molarity of alkaline solution gives higher strength. Strength of GPC increases due to polymerization of concrete.

C. Effect of temperature on compressive strength of GPC

The effect of temperature on geopolymer concrete strength of different molarities is discussed briefly. The GPC of different molarities is cured under different temperature conditions and carried for test after completion of 7days and 28days curing period. The compressive strength test results of each molarity GPC has tabulated and discussed.

Temperature (°C)	Compressive strength (N/mm^2)	
	7 days	28 days
50	54.35	53.97
60	57.02	57.35
70	60.25	61.3
80	55.75	57.35
90	50.35	52.5

Table 5: Compressive strength test results of 6M GPC

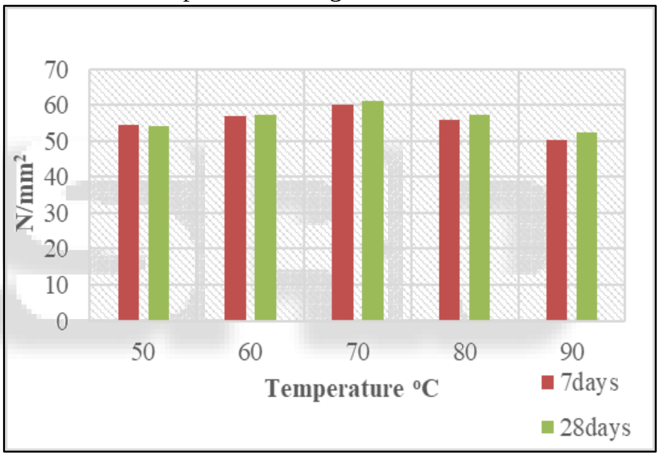

Fig 2: Compressive strength results of 6M GPC

Temperature (°C)	Compressive strength (N/mm^2)	
	7 days	28 days
50	56.9	59.4
60	60.26	61.05
70	61.35	62.05
80	53.82	57.05
90	53.18	56.35

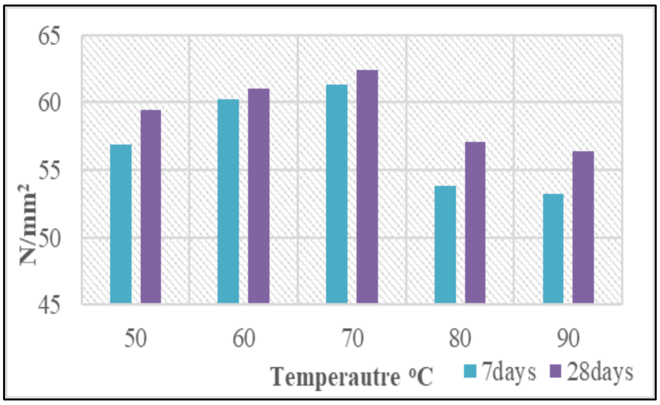

Fig. 3: Compressive strength results of 8M GPC

Temperature (°C)	Compressive strength (N/mm²)	
	7 days	28 days
50	60.35	60.5
60	61.38	62
70	63.86	64.1
80	65.28	67.12
90	54.28	56.33

Table 6: Compressive strength test results of 10M GPC

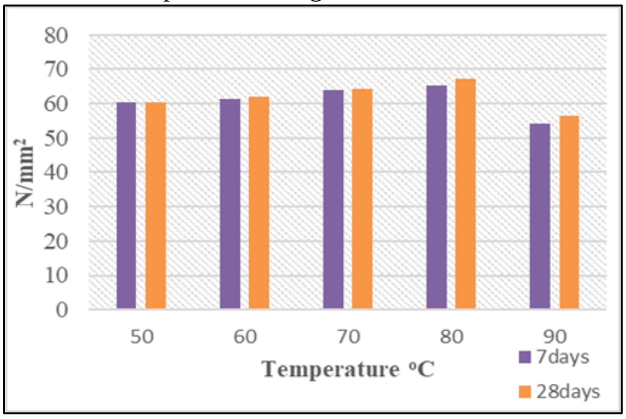

Fig. 4: Compressive strength results of 10M GPC

From the compressive strength results of different molarity GPC cured in oven at different temperature conditions concludes that, the strength of GPC increases with increase in temperature. Strength of GPC increases up to optimum temperature. Beyond, optimum temperature the strength decreases slightly due to rate of polymerization is not beyond optimum temperature due to development of voids in concrete. Different molarity GPC has different optimum temperature condition. It was clear that strength of GPC at 7days and 28 days test doesn't vary much. GPC attains maximum strength in short period when cured in oven under high temperature.

D. Ultrasonic Pulse Velocity test

The results of UPV test defines quality of concrete. These test conducted on concrete cubes after curing period of 7days and 28days. 6M, 8M, 10M geopolymer concrete cubes cured under room condition and in oven curing for period of 20hrs under different temperature conditions 50°, 60°, 70°, 80° and 90°. For every curing conditions 3samples of each molarity of geopolymer concrete cubes were tested and average are calculated and tabulated. The test results and summary are mentioned below.

Molarity	6M GPC		8M GPC		10M GPC	
Temperature	7days	28days	7days	28days	7days	28days
room	3591	3586	3834	3959	3899	3999
50°C	3958	3985	4011	4047	4060	4072
60°C	4010	4114	4054	4169	4113	4117
70°C	4026	4140	4187	4170	4128	4211
80°C	3821	3952	3995	4019	4330	4220
90°C	3675	3862	3975	3965	3995	4001

Table 7: UPV results of different molarity GPC

From the UPV test results it was clear that the pulse velocity increases with increase in temperature up to optimum temperature. Beyond, optimum temperature the pulse velocity decreases due to development porous nature and voids in concrete cubes. Pulse velocity of all sample of different molarity GPC ranges between 3500m/s to 4500m/s. Hence, it was concluded that the quality of concrete prepared in this work was good.

E. Rebound Hammer Test

The test performed on sample cubes of geopolymer concrete of 6M, 8M, 10M cured under different temperature conditions in oven. Test conducted on samples after curing of 7days and 28days before compressive strength test process. The results of all sample cubes of different molarities of geopolymer concrete are detailed and explained below. For every sample cube 6 times of rebound hammer test is performed and 6 values are obtained and average of six values is taken. For every temperature condition 3samples were tested and average value of 3 samples is taken as final result of rebound. The results of rebound hammer test are tabulated below.

Molarity	6M GPC		8M GPC		10M GPC	
Temperature	7days	28days	7days	28days	7days	28days
room	37	40	34	35	37	41
50°C	36	37	38	39	36	38
60°C	35	41	36	35	31	33
70°C	31	39	34	35	37	37
80°C	35	42	35	34	35	35
90°C	35	36	37	36	35	36

Table 8: Rebound hammer test results of different molarity GPC

From the rebound hammer test results, rebound values of all samples of 6M, 8M, 10M GPC ranges from 30 to 40. From the results the all samples of 6M, 8M, 10M GPC, it was absorbed that quality of geopolymer concrete layer is in good condition.

IV. CONCLUSIONS

1) Workability of GPC decreases with increase in molarity of alkaline solution due to increase of concentration of NaOH Pellets which results in development of viscous nature.
2) Compressive strength of GPC increases with increase in molarity and curing period.
3) Oven cured GPC attains maximum strength with in short period of duration and strength of GPC doesn't vary much for 7days & 28days compressive strength.
4) 6M GPC attains maximum strength of 61.3 N/mm² at 70°C. Hence, 70°C is considered as optimum temperature for 6M GPC.

5) 8M GPC attains maximum strength of 62.45 N/mm^2 at 70ºC. Hence, 70ºC is considered as optimum temperature for 8M GPC.
6) 10M GPC attains maximum strength of 67.12 N/mm^2 at 80ºC. Hence, 80ºC is considered as optimum temperature for 10M GPC.
7) Strength of GPC increases up to optimum temperature, due to rate of polymerization increases up to temperature, beyond optimum polymerization is not significant because development of void and porous in concrete.
8) UPV results of GPC increases with increases up to optimum temperature, beyond optimum temperature pulse velocity decreases due to developing of voids. UPV results of 6M, 8M, 10M GPC ranges from 3500 m/s to 4500 m/s. Hence, GPC samples prepared in this study is in good state.
9) Rebound values of 6M, 8M, 10M GPC ranges from 30 to 40. Hence, Concrete layer of all samples prepared in this study is in good state.

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