Effect of Curing Temperature on the Strength Properties of M30 Grade GPC made with M-Sand

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Abstract – *The cement industry is one of the main producers of greenhouse gases. Therefore, efforts are needed to make the concrete more environmentally friendly by using fly ash, which helps to overcome global warming and the problems arises in the disposal of fly ash. This article deals with the development of intermittent connection materials in the construction industry. Fly ash based Geopolymer Concrete is a reliable choice, but requires thermal hardening for the polymerization process. In this work we try to investigate the influence of temperature and type of curing on the strength properties of fly ash based geopolymer concrete, with the fine aggregate being replaced by M-sand. Geopolymer concrete grade M30 was prepared with chemically activated treated fly ash using alkaline solutions such as sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH). In this study, a concentrated solution of 16 M sodium hydroxide is used. All samples were cured at different temperatures in an oven at 60°C, 80°C, 100°C, 120°C and 140°C for 16 hours and tested for 7 days. It was concluded that GPC blends cured at 100°C give better results than specimens treated at other curing temperatures.*

Key Words: Geopolymer Concrete, Oven Curing, M-Sand, Alkaline Solution

1. INTRODUCTION

Concrete is the most commonly used building material, consisting of a mixture of cement, sand, coarse aggregates and water. Ordinary portland cement (OPC) is conventionally used as a primary binder for concrete production. Producing one ton of cement requires about 2 tons of raw materials, shale and limestone, and releases a large amount of carbon dioxide (CO_2) into the atmosphere, which contributes significantly to the greenhouse effect. The amount of CO_2 released during the manufacturing process of OPC is of one ton per ton of OPC produced. Worldwide, OPC production accounts for about 7% of global CO_2. That brings about 1.6 billion tons of CO_2 into the atmosphere.

Therefore, it is necessary to find another type of binder to make a greener concrete. The use of industrial by-products in this sector could become an important way for the large-scale and safe disposal of industrial waste and the reduction of construction costs.

1.1 Geopolymer Concrete

Davidovitts completed a very important study in 1978 by discovering geopolymer concrete, which was concrete without cement. This has attracted many attentions, where fly ash has completely replaced the cement. He had his own qualities and left extraordinary impressions in research studies.

The geopolymer is an inorganic alumina-silicate compound made from materials of geological origin or derived materials such as fly ash, rice husk, etc., which are rich in silicon and aluminum. Geopolymers technology could reduce the atmospheric CO_2 emissions of the cement and aggregates industry by about 80%. Direct alkaline activation of industrial waste, such as fly ash, can produce a geopolymer that can be used to construct new concrete for construction. This can be considered as a sustainable approach to construction, as the internal energy content of these new concretes is much lower than that of ordinary Portland cement concrete (OPCC), making Portland cement, one of the largest contributors to the greenhouse, completely eliminate gas emissions.

1.2 Fly Ash Based Geopolymer Concrete

Fly ash is one of the most abundant materials on earth. Due to its role in geopolymerization, it is also a crucial component in the production of geopolymer concrete. Fly ash is a pozzolan powder. A pozzolan is a material that has cementing properties in combination with calcium hydroxide. Fly ash is the major by-product of coal combustion in coal power plants.

Geopolymer concrete generally requires the use of class F fly ash. In this project, a low-calcium fly ash-based geopolymer (ASTM grade F) is used as the binder. Fly ash geopolymer paste binds coarse aggregates, fine aggregates and other unreacted materials to geopolymer concrete with or without excipient.

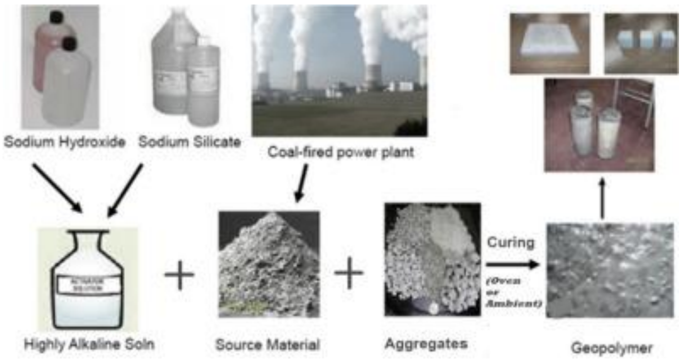

Fig -1: Geopolymer Concrete

1.3 Manufactured Sand

In emerging countries, the need for natural sand is crucial. In India, natural sand deposits are degraded and pose a major threat to the environment. In order to sustainably grow the infrastructure, replacement material is required that meets the technical requirements for fine aggregates and must be available in abundance. Treated sand provides a viable option to replace natural river sand. It is a fine design granulates made of crushing stones and stones.

2. REVIEW OF LITERATURES

A literature review or narrative review is a type of review article. A literature review is a scholarly paper, which includes the current knowledge including substantive findings, as well as theoretical and methodological contributions to a particular topic.

Pradeepkumar et al. (2017) submitted an article on the development of GPC strength by employing M-sand instead of river sand. The results showed that M-Sand replacement reduced hydration as well as an increase of 4.08% and 9.51% in compressive strength for 5M and 10M were noted. An increase of 9% and 2% of the tensile strength for 5M and 10M respectively were noted.

Sreenivasulu et al. (2016) replaced sand with granite sludge by 0%, 20%, 40% and 60%. The GPC cubes were cast from 8M using fly ash and 50:50 GGBS. The test results show that the optimal replacement percentage of the granite slurry is 40%.

Kalaivani (2015) studied the flexural strength of fly ash based geopolymer concrete and compare it with conventional concrete. Geopolymer concrete is manufactured by cement fully replacing fly ash which is chemically activated by alkaline solutions like sodium silicate and sodium hydroxide. The concentration of sodium hydroxide was 8M, 10M & 12M. The specimens were cast for each molarity and tested at 7, 14 & 28 days. It was observed that the compressive, split tensile and flexural strength increases with increase in molarity and curing days. It was also observed that flexural strength of geopolymer concrete is lower than the conventional concrete.

Ghosh et al. (2015) studied the effects of synthetic parameters on setting time and ease of workability fly ash based geopolymer paste. It has been witnessed that the development of setting time and workability capacity as well as the microstructure depend mainly on the alkali content, the silica content and the water to binder ratio. To dissolve fly ash during the geopolymerization process, strong alkaline solutions are required. Water plays a vital role in the hardening of geopolymer, dissolution and polycondensation. The water content should be adjusted to a minimum by taking into account of the desired workability of the geopolymer mixture.

George et al. (2011) highlighted the mechanical properties of activated fly ash concrete and compare the results with fly ash concrete. Calcium oxide and sodium silicate in the ratio 1:8 was used for the activation of fly ash. Concrete mixture was prepared by replacing the cement with fly ash at 10%, 20%, 30%, 40%, 50% & 60% with water binder ratio 0.45. Specimens were cast for both activated fly ash concrete and fly ash concrete. It was observed that activated fly ash concrete has better mechanical properties.

Adam A. A et al. (2010) made a study on the influence of the molarity of alkali activator on the strength, sorption capacity and carbonation of GPC based on activated alkaline slag (AAS) and fly ash (FA). Replacing with 30%, 50% and 70% OPC is replaced by GGBS and control concrete. Their report showed that the alkaline modulus had high impact on the sorption capacity of AAS and geopolymer. The phenolphthalein indicator did not give a clear indication between non-carbonate and carbonated areas in the GPC samples, and the sorption capacity of the mixed concrete decreased, but carbonation increased with the level of replacement.

Davidovits (2004) suggested that the binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminum in source materials of geological origin or by-product materials such as fly ash and rice husk ash it is termed as geopolymer.

Naik et al., (2003) investigated that long-term performance test for compressive strength, and density was performed using base samples. It is perceived that the Class F Fly Ash (FA) strength has a more enormous pozzolanic contribution than Class C FA. In general, Class F FA concrete mixtures have a greater resistance to fly ash than Class C FA.

Naik et al. (2003) investigated that the long-term performance tests for compressive strength, resistance to chloride ion penetration, and density using core specimens. It was observed that greater pozzolanic strength contribution of Class F fly ash relative to Class C fly ash. Generally, the concrete mixtures containing Class F fly ash exhibited higher resistance to chloride-ion penetration relative to mixtures containing Class C fly ash. It was further observed that the highest long-term compressive strength was achieved for the high-volume fly ash mixture incorporating 67% Class F fly ash at the age of 7 years and visual observations revealed that the pavement sections containing high volumes of Class F fly ash (35 to 67% FA) concrete performed well in the field with only minor surface scaling. All other pavement sections have experienced very little surface damage due to the scaling.

Malhotra et al., (2002) predicted that the global impact of OPC production on greenhouse gas emissions would be around 1.35 billion tonnes per year. Greenhouse lies in the environment of the Earth. Cement is the most energy exhaustive building material after aluminium and steel.

Sahu et al (2003) have examined the significant increase in compressive strength, modulus of rapture and split tensile strength for both the concrete mixes when sand is partially replaced by stone dust.

3. MATERIAL PROPERTIES & MIX DESIGN

3.1 Fly Ash

Fly ash is the alumino silicate source material used for the synthesis of geopolymeric binder. Class F fly ash obtained from the Mettur Thermal power plant of Tamil Nadu was used for this study.

Table -1: Physical Properties of Fly Ash

Physical parameters	Class F fly ash	Guidelines as per IS 3812:1981
Colour	Light grey	-
Residue retained on 45μ sieve (%)	29.3	34 (Maximum)
Specific surface area (Blaine's Air permeability test) (m^2/kg)	341	320
Specific gravity	2.32	-
Moisture content (%)	0.52	2 (Maximum)
Autoclave expansion (%)	0.048	0.8

Table -2: Chemical Composition of Fly Ash

Chemical Composition	Class F fly ash	Guidelines as per IS 3812:1981
SiO_2	55.1	35 (Minimum)
Al_2O_3	27.8	-
Fe_2O_3	7.85	-
$SiO_2 + Al_2O_3 + Fe_2O_3$	90.75	70 (Minimum)
MgO	1.42	5 (Maximum)
SO_3	1.22	2.75 (Minimum)
Na_2O	0.89	1.5 (Minimum)
CaO	0.09	5 (Maximum)
LOI	2.33	12 (Maximum)

3.2 Manufactured Sand

Manufactured sand is made by crushing rock depositions to create fine aggregate of angular in shape and has rougher surface texture than river sand particles. The shape and texture of crushed sand particles could lead to improvements in the strength of concrete due to greater interlocking between particles. Fine aggregate properties were evaluated as per the IS 383-1970 methods.

Table -3: Properties of Manufactured Sand

Property	Value
Type	Crushed
Shape	Spherical
Maximum Size	4.75mm
Fineness modulus	2.92
Bulk Density (kg/m^3)	1814
Water absorption	1.6
Specific Gravity	2.85

3.3 Coarse Aggregate

Coarse aggregates comprising of max size 20mm. Aggregates were in saturated surface dry condition. The obtained properties on the coarse aggregate used in this investigation are illustrated in table 4.

Table -4: Properties of Coarse Aggregate

Property	Value
Type	Crushed
Shape	Angular
Maximum Size	20mm
Fineness modulus	6.4
Bulk Density (kg/m^3)	1654
Water absorption	0.85
Specific Gravity	2.72

3.4 Alkaline solution

A combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions were used for the activation of fly ash.

Table -5: Properties of sodium hydroxide pellets

Flakes size	Specific gravity	Purity
3 mm	2.13	98%

Table -6: Properties of sodium silicate

Composition	% by mass
Na_2O	7.5 - 8.5
SiO_2	25– 28
Water	65.3– 37.5
Specific gravity	1.53
pH	Neutral

3.5 Super plasticizer

In this project super plasticizer CONPLAST – SP 430 in the form of sulphonated Napthalene polymers complies with IS 9103-1999 is used to improve the workability of concrete. It is formulated to produce high quality concrete of reduced permeability. The table 4.6 shows the properties of CONPLAST – SP 430.

Table -7: Properties of conplast-SP430

Physical tests	Analysis
Appearance	Brown liquid
Specific gravity	1.224
Chloride content	NIL
Air entrainment	1%

3.6 Preparation of GPC

Sodium Hydroxide pellets are taken and dissolved in water at the rate of 10 molar concentrations. It is strongly recommended that the sodium hydroxide solution and sodium silicate gel must be mixed and prepared 24 hours prior to use and also if it exceeds 36 hours it terminate to semi solid liquid state. So the prepared solution should be used within this time.

3.7 MIX PROPORTIONING

Mix design for M30 grade geopolymer concrete is done based on the guidelines mentioned in IS 10262:2009. The various parameters considered for the mix design is shown below

- Type of fly ash : Class F fly ash
- Characteristic compressive strength of Geopolymer Concrete (f_{ck}) = 30MPa
- Type of alkaline activators used: NaOH & Na_2SiO_3
- Concentration of Sodium hydroxide (Molarity): 10M
- Solution-to-fly ash ratio by mass: 0.35
- Sodium silicate-to-sodium hydroxide ratio by mass: 2.5
- Type of Curing: Oven Curing

Table -8: Mix Proportioning

Material description	Quantity (kg/m^3)		Proportion	Total Weight of GPC (kg/m^3)
Fly ash	404		1	2528
NaOH	101	2.5	0.35	
Na_2SiO_3	40.4			
Fine aggregate	658.39		1.63	
Coarse aggregate	1257.99		3.11	
Water	66.22		0.16	

4. EXPERIMENTAL INVESTIGATION

The effect of curing temperature on the strength properties of geopolymer concrete made with fly ash was assessed under varying curing methods such as oven and steam curing and curing temperature such as 60°C, 80°C, 100°C, 120^{0}C and 140°C.

Table -9: Effect of Curing Temperature on GPC by Oven Curing

Specimen ID	Temperature (^{0}C)	Curing Time (Hrs)	Testing Age (Days)	Average Compressive Strength (MPa)
OC60	60	16	7	13.18
OC80	80			29.41
OC100	100			48.15
OC120	120			44.37
OC140	140			24.72

Table -10: Effect of Curing Temperature on GPC by Steam Curing

Specimen ID	Temperature (^{0}C)	Curing Time (Hrs)	Testing Age (Days)	Average Compressive Strength (MPa)
SC60	60	16	7	17.39
SC80	80			32.53
SC100	100			42.57
SC120	120			41.8
SC140	140			21.64

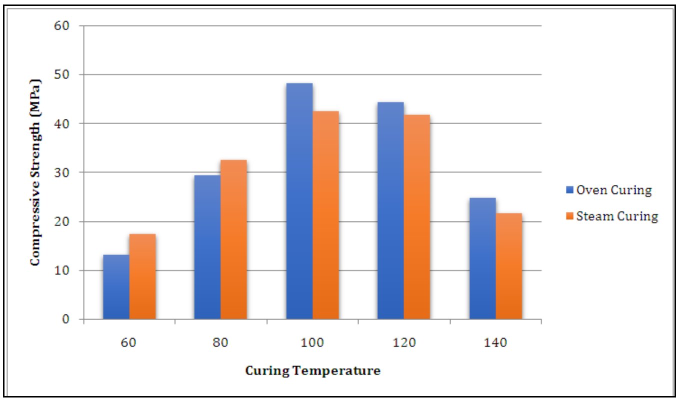

Chart -1: Effect of Curing Temperature on Compressive Strength of GPC

Based on the preliminary investigation, the curing temperature that can be adopted in curing for GPC is 100^{0}C which could provide optimum results than the lower temperatures and oven curing will provide the effective and economical results than the steam curing. Then the M-Sand was replaced in the GPC mixes at an interval of 20% from 0 to 100.

Table -10: Compressive Strength Test Results

Specimen ID	Average Compressive Strength (N/mm^2)		
	3 days	14 days	28 days
GPC0MS	15.46	33.65	38.56

GPC20MS	16.53	36.02	40.99
GPC40MS	17.59	37.96	43.16
GPC60MS	18.47	38.31	44.6
GPC80MS	19.66	39.77	45.15
GPC100MS	20.38	40.14	45.93

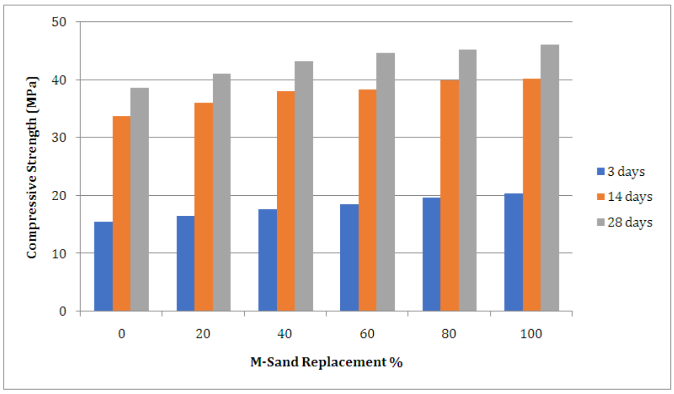

Chart -2: Compressive Strength Test Results

Table -11: Split Tensile Strength Test Results

Specimen ID	Average Split Tensile Strength (N/mm²)		
	3 days	**14 days**	**28 days**
GPC0MS	1.92	3.44	4.35
GPC20MS	1.89	3.48	4.41
GPC40MS	1.94	3.56	4.56
GPC60MS	1.97	3.69	4.81
GPC80MS	2.06	3.78	4.78
GPC100MS	2.12	3.96	4.99

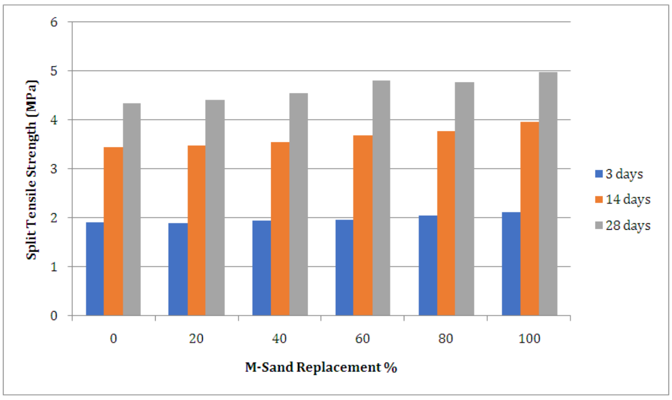

Chart -3: Split Tensile Strength Test Results

Table -12: Flexural Strength Test Results

Specimen ID	Average Flexural Strength (N/mm²)		
	3 days	**14 days**	**28 days**
GPC0MS	3.11	6.56	7.64
GPC20MS	3.22	6.84	7.91
GPC40MS	3.28	7.01	8.16
GPC60MS	3.36	7.18	8.45
GPC80MS	3.51	7.47	8.79
GPC100MS	3.69	7.62	8.95

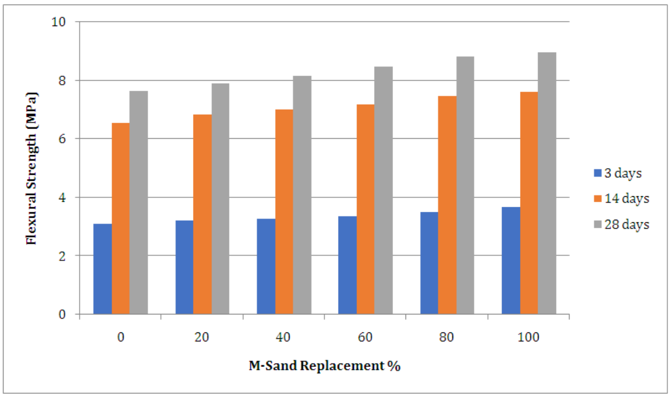

Chart -4: Flexural Strength Test Results

5. CONCLUSIONS

The following are the conclusions are drawn from the experimental investigation done on the M30 grade GPC under varying curing conditions and partial replacement of river sand with M-Sand.

- GPC made with fly ash can be effectively used instead of conventional concrete to minimize the global cement production, consumption.
- Oven curing provides better results than the steam curing when economical and strength parameters are taken into account.
- Curing temperature of 100^{0}C was considered as the optimum curing temperature whereas heating of GPC specimens beyond this limit retards the strength properties abruptly.
- Full replacement of fine aggregate by M-Sand in GPC is feasible with increment in strength properties.
- At 28 days, the strength properties of GPC100MS are 19.11%, 14.71% and 17.15% than GPC0MS.

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