Effect Of Delayed Oven Dried Curing On Compressive Strength Of Geopolymer Concrete

S. V. Joshi
Associate Professor ,Civil Engg,
Shri Ramdeobaba College Of Engineering and Management Nagpur, Maharashtra (India)

Dr. M. S. Kadu
Professor & Head, Civil Engg.
Shri Ramdeobaba College Of Engineering and Management Nagpur, Maharashtra (India)

ABSTRACT
Conventional cement concrete usage around the world is second to water. Ordinary Portland cement (OPC) is conventionally used as primary binder to produce conventional OPC concrete. The amount of carbon dioxide released during the manufacture of OPC and the extent of energy required to produce OPC are the matters of environmental concern and poor availability of power. The efforts are being made on various fronts to address these issues. Fly-ash, abundantly available byproduct of coal fired thermal power stations, having no binding properties of its own, is now being widely used as an additive binding material in manufacture of concrete .Fly-ash with alkali activators can produce effective binding material, geo-polymer, through polymerization process which can be used to develop geo-polymer concrete (GPC). The characteristics of alkali activator, decides the quality of geo-polymer and therefore affects the important properties of plastic and hardened concrete. In the present work a mixture of sodium hydroxide solution and sodium silicate solution is used as alkali activator. The present paper deals with studying the effect of delayed oven dried curing on compressive strength of Geo-polymer concrete. The laboratory investigations provides that under hot air oven curing conditions, the compressive strength of geo-polymer concrete depend on the day of curing from the date of casting. It is optimum on fourth day of oven dried curing and oven dried curing substantially enhance the compressive strength of geo polymer concrete even in the last week of testing of sample as compared to ambient curing condition.

Keywords
Geo-polymer concrete, fly-ash, alkaline activator, delayed curing, compressive strength

1. INTRODUCTION
Ordinary Portland cement (OPC) is conventionally used as primary binder to produce concrete. Worldwide the production of cement is increasing about 7% annually. The environmental issues associated with the production of OPC are well known. The extent of energy required to produce OPC is only next to steel and aluminum. The production of one ton of cement liberates about one ton of CO_2 to the atmosphere, as the result of de-carbonation of limestone in the kiln during manufacturing of cement and the combustion of fossil fuels (Roy 1999). The contribution of Portland cement production worldwide to the greenhouse gas emission is estimated to be about 1.35 billion tons annually or about 7% of the total greenhouse gas emissions to the earth's atmosphere (Malhotra2002). The global warming is being seriously considered at national and international level. The greenhouse effect created by the industrial emissions is increasing the global temperature that is resulting in climate changes. Therefore, any action or attempt made to reduce the effect should be encouraged and given more attention. In order to produce environmental-friendly concrete, Mehta (2002) suggested the use of fewer natural resources, less energy, and minimize carbon dioxide emissions. McCaffrey (2002) suggested that the amount of carbon dioxide (CO_2) emissions by the cement industries can be reduced by decreasing the amount of calcinated material in cement, by decreasing the amount of cement in concrete, and by decreasing the number of building elements using cement. In Eastern part of Vidharbha region of the state of Maharashtra (India), there are four major thermal power plants established in the vicinity of Nagpur City and ill-effects of disposal and storage of fly-ash are well known. The relevance of the study lies in exploring the possibility of using abundantly available fly-ash in the manufacture of concrete as an alternative to cement in an attempt to reduce the emission of greenhouse gases, reduction in energy requirement and disposing off the byproducts in an environment-friendly way.

The present work is aimed at evaluating the possibility of using locally available flyash, and to study the effect of delayed oven dried curing on fresh casted sample as well as on the samples which are first ambient cured at room temperature and oven dried cured in the last week of compressive strength testing. And compare the test results with ambient condition cured samples.

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1.1 Geopolymers
Geo-polymers are members of the family of inorganic polymers. The chemical composition of the geo-polymer material is similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline (Palomo et al. 1999; Xu and van Deventer 2000). Unlike ordinary Portland / pozzolonic cements, geo-polymers do not form calcium silicate-hydrates (C-S-H) for matrix formation, but utilize the poly-condensation of silica and alumina and a high alkali content to attain structural strength. Therefore, geo-polymers are sometimes referred to as alkali activated alumino silicate binders. Geo-polymerization involves the chemical reaction of alumino-silicate oxides (Si_2O_5, Al_2O_2) with alkali polysilicates yielding polymeric Si-O-Al bonds. (J. Davidovits- 1985).

1.1.1 Constituents of Geo-polymer
Source Materials

Any material that contains mostly Silicon (Si) and Aluminum (Al) in amorphous form is a possible source material for the manufacture of geo-polymer. Several mineral and industrial by-product materials have been investigated in the past. The calcinated source materials such as fly ash, slag, calcinated kaolin, demonstrated a higher final compressive strength when compared to those made using non-calcinated materials. Among the by-product materials, only fly ash and slag have been proved to be the potential source materials for making geo-polymers. Fly ash is considered to be advantageous due to its high reactivity that comes from its finer particle size than slag. Moreover, low-calcium fly ash is more desirable than slag for geo-polymer feedstock material.

Fly Ash

Fly ash, an abundantly available byproduct of thermal power stations, particles are typically spherical and finer than Portland cement and lime. The diameter ranges from 1 micron to 150micron. Fly ash does not have any cementing properties by itself. In general, the reactivity of fly ash depends upon

Chemical composition, fineness and percentage of amorphous or reactive silica present. It also depends on quality of coal used as fuel. The types and relative amount of incombustible matter in the coal determine the chemical composition of fly ash. Fly ash that results from burning sub-bituminous coals is referred as ASTM Class C fly ash or high-calcium fly ash. It is typically contains more than 20 percent of CaO .On the other hand, fly ash from the bituminous and anthracite coals is referred as ASTM Class F fly ash or low-calcium fly ash. It consists of mainly an aluminosilicate glass and has less than 10 percent of CaO. The color of fly ash can be tan to dark grey depending upon the chemical and mineral constituents (Malhotra and Ramezanianpour 1994). The loss on ignition (LOI) is a measure of unburt carbon remaining in the ash. Fineness of fly ash mostly depends on the operating conditions of coal crushers and the grinding process of the coal itself. Finer gradation generally results in a more reactive ash and contains less carbon.

Low-calcium (ASTM Class F) fly ash is preferred as a source material than high-calcium (ASTM Class C) fly ash. The presence of calcium in high amount may interfere with the polymerization process and alter the microstructure (Gourley 2003). The spherical shape of fly ash often helps to improve the workability of the fresh concrete. Its small size particle acts as filler of voids in the concrete to produce dense and durable concrete.

Devodovits et.al.(2005)claimed that to produce optimal binding properties, the low-calcium fly ash should have the percentage of unburned material (LOI) less than 5%, Fe_2O_3 content should not exceed 10%, and, reactive silica should be between 40 – 50%, and 80 – 90% of particles should be smaller than 45 μm.

Alkaline activators

Alkaline liquid plays an important role in the polymerization process (Palomo et al.1999). Reactions occur at a high rate when the alkaline liquid contains soluble silicate, either sodium or potassium silicate, compared to the use of only sodium hydroxides (Xu and Van Deventer, 2000). Addition of sodium silicate solution to the sodium hydroxide solution to prepare the alkaline liquid enhanced the reaction between the source material and the solution. In general the NaOH solution caused a higher extent of dissolution of minerals than the KOH solution (Palomo et al. 1999) .The compressive strength and the workability of geo-polymer concrete are influenced by the proportions and properties of the constituent materials that make the geo-polymer paste.

Water to Geo-polymer solid ratio by mass also plays important role in development of concrete. It is the ratio of the total mass of water to the total mass of geo polymer solids. The total mass of water is the sum of mass of water contained in the sodium silicate liquid, the mass of water in the sodium hydroxide liquid and the mass of extra water, if any added to the mixture. The total mass of geo-polymer solid is the sum of mass of solids in the sodium silicate solution (i.e. the mass of Na2O and SiO2), the mass of sodium hydroxide solids and the mass of fly ash.

2. METHODOLOGY

The laboratory investigation was focused at studying the effect of delayed oven dried curing on compressive strength of concrete. The methodology adopted for the present study is summarized in the following steps.

2.1 Design of Reference Concrete Mix

As of now, no standard mix design procedure is available for geo-polymer concrete, geo-polymer concrete reference mix is designed by assuming the basic parameters of geo polymer concrete such as the percentage of mass of combined aggregate , density of concrete the mass ratios of fly ash and alkaline activator, and sodium silicate to sodium hydroxide mass ratio. Accordingly the ingredients of concrete are calculated as explained in sample calculations.

2.2 Computation of Ingredients of Geo-polymer Concrete:

Aggregate

Geologically, major portion of the Vidharbha region of Maharashtra is covered with black basalt. Therefore, coarse aggregates (CA) derived from basalt are used. Experimental trials suggested that CA of the size of 14 mm and less can produce a cohesive mix. A combination of 14 mm (20 %), 10 mm (40 %) and 7 mm (40 %) is proposed in the present work. The fineness modulus of CA is **5.20.** Locally available good quality sand having fineness modulus 2.46 is used as fine aggregate (FA). The mass of combined aggregates (CA + FA) is taken as 77% of mass of concrete in the proportion of 65:35

Alkaline Liquid

Further for the laboratory investigations alkaline liquid is prepared using commercially available sodium silicate liquid and12 molar concentration sodium hydroxide liquid. .Sodium silicate liquid content Na_2O = 14.61 %, SiO_2 = 25.18% and water = 59.99 %. In alkaline liquid, ratio by mass of sodium silicate to sodium hydroxide is maintained as 2.5, ratio of alkaline liquid to fly-ash by mass is maintained as 0.35 and water to geo solid ratio by mass is 0.2559.

Fly ash

Flyash is procured from Khaperkheda Thermal Power Station (KTPS) -- Nagpur in Vidharbha region (Maharashtra/India). The Table 1 provides the comparison of chemical composition of the fly ash used in the present study and researchers used fly ash

Table 1: Comparison of Chemical composition of Fly Ash

Composition	*Rangan et al* (2005) Batch I	flyash for present work
SiO_2	53.36	60.02
Al_20_3	26.49	34.25
Fe_20_3	10.86	1.19
CaO	1.34	1.05
MgO	0.77	1.30
SO_3	1.70	0.36
Na_2O	0.37	0.26
K_2O	0.80	0.82
TiO_2	1.47	1.62
P_2O_5	1.43	0.48
LOI	1.39	2.17

While preparing workable mix in laboratory, it was observed that water to geo solids ratio required to develop workable geo-polymer concrete is almost in the range of 0.24 to 0.28**.** It was maintained as 0.2559 throughout laboratory investigation.

2.3 Sample calculation

Geo polymer concrete (1cum) using fly-ash and alkaline liquid, materials are calculated considering mass density of geo-polymer concrete as 2400 kg/cum, mass ratio of alkaline liquid to fly ash as 0.35, and mass ratio of sodium silicate to sodium hydroxide as 2.5 as follows,

- Mass of combined aggregate (CA+FA) =0.77 x 2400 = 1848 Kg,
- Mass of alkaline liquid and fly-ash = 2400 – 1848 = 552 kg,
- Mass of fly-ash = 552 / 1.35 = 408.89 kg,
- Mass of alkaline liquid = 552 – 409 = 143 kg,.
- Mass of sodium hydroxide liquid = 143 / (1 +2.5) = 40.85 kg
- Mass of sodium silicate liquid = 143 – 40.85 = 102.15 kg,
- Mass of coarse aggregate = 0.65 x 1848 = 1201.20 Kg,
- Mass of fine aggregate = 0.35 x 1848 = 646.80 Kg,
- Therefore CA: FA as 65 : 35.

Table 2: Determination of quantities of ingredients of geo-polymer concrete for 1 cum

Ratio of alkaline liquid to fly ash	Mass of Alkaline liquid in Kg	Mass of NaOH Liquid In Kg	Mass of Sodium silicate liquid in Kg.	Mass of Flyash in Kg.	Fine aggregate in Kg.	Coarse Aggregate in Kg.	Super plasticizer in Kg.
0.35	143	40.85	102.15	409	646.80	1201.20	nil

2.4 Casting and testing of cubes.

In order to study the effect of delayed oven dry curing on fresh samples and ambient cured samples at room temperature, on compressive strength of geo-polymer concrete. Samples are casted as cubes (size 100x100 mm) and cylinders (size 100 x200 mm) for particular combination of mix. The specimens are cured in ambient condition at room temperature and hot air oven condition at 75^o C temperature for 24 hrs duration. Fresh specimens are tested for 28 days characteristic strength and first ambient cured and oven dried in last week samples are tested after certain weeks. Fresh samples as cube and cylinder are casted, cured and tested simultaneously under the same environment. A test samples of three specimens is considered to calculate average compressive strength of geo-polymer concrete

3. TEST RESULTS:

In line with the objectives of the present work, concrete samples are casted and tested as per requirement and the test results are presented as follows.

Table 3: Effect of Delayed Oven Dry curing on Compressive Strength of freshly casted samples

Curing condition	Cube sample of 10 x10 cm in ambient & oven dried at 75-24hr (avg. values) D.C.= 04-11-11, D.T.= 02-12-11 (28 DAY)			Cylinder sample of 10 x20 cm in ambient & oven dried at 75-24hr (avg. values), D.C.= 04-11-11, D.T.=02-12-11, (28 DAY)		
	density	Load in KN	Comp. strength	density	Load in KN	Comp. strength in N/mm2
Ambient	2380	107.70	10.77	2360	52.26	6.65
Oven dry on 3rd day	2296	290.80	**29.08**	2306	199.66	**25.42**
Oven dry on 4th day	**2334**	**385.40**	**38.54**	**2304**	**244.30**	**31.06**
Oven dry on 5th day	2341	280.00	28.0	2297	178.16	22.68
Oven dry on 6th day	2338	260.30	26.03	2282	167.73	21.35
Oven dry on7th day	2317	234.6	23.46	2283	147.46	18.78
Oven dry on 8th day	2341	234.20	23.42	2284	145.98	18.58
Oven dry on 9th day	2307	233.40	23.34	2287	144.86	18.44
Oven dry on11th day	2333	213.50	21.35	2305	143.53	18.27

Table 4:- compressive strength ratio of cylindrical to cubical samples.

Curing condition	Cube sample 28day average compressive strength in N/mm2	Cylinder sample 28day average compressive strength in N/mm2	Ratio of cylinder to cube sample 28day comp. strength
Ambient	10.77	6.65	0.617
Oven dry on 3rd day	29.08	25.42	0.874
Oven dry on 4th day	**38.54**	**31.06**	**0.806**
Oven dry on 5th day	28.0	22.68	0.810
Oven dry on 6th day	26.03	21.35	0.820
Oven dry on7th day	23.46	18.78	0.800
Oven dry on 8th day	23.42	18.57	0.793
Oven dry on 9th day	23.34	18.44	0.790
Oven dry on11th day	21.35	18.27	0.855
		Average	**0.818**

DELAYED OVEN DRIED CURING IN LAST WEEK OF AMBIENT CURED SAMPLES FOR VARIOUS BATCH MIX.

Table 5:-Schedule of casting and testing of samples 10 x 10 cm cube and 10 x 20 cm cylinder

Sample	Batch	Date of casting	Date of Testing	Period in week
cylinder	I	20-04-2011	06-07-2011	11
cylinder	Ii	23-04-2011	09-07-2011	11
cylinder	III	02-05-2011	04-07-2011	09
cylinder	IV	04-05-2011	06-07-2011	09
cube	V	05-06-2011	10-07-2011	05

Table 6:- Comparative study of compressive strength of samples in different curing condition.

Batch	Ambient curing at room temperature, average values		Delayed last week oven dry curing at 75^0-24 hrs, average values		Percentage increase in strength
	Density	Compressive strength in N/mm^2	Density	Compressive strength in N/mm^2	
I	2274	9.52	2273	10.93	14.81
II	2334	15.46	2355	17.42	12.68
III	2325	18.29	2355	20.27	10.83
IV	2302	16.03	2349	19.77	23.33
V	2392	21.64	2466	40.78	88.45

4. CONCLUSIONS

From the laboratory investigations, following conclusions are drawn:

- The density of geo-polymer concrete varies in the range of 2280 - 2350 Kg /cum.
- It can be concluded from the work carried out that the fly ash collected from KTPS, located close to Nagpur, a second capital of Maharashtra, where construction activity is on the hype, can be effectively used as geo-polymer source material.
- Optimum 28 days avg. compressive strength observed at oven dry curing on fourth day from the date of casting.
- As delayed period increases from 5^{th} day onwards then compressive strength of geo polymer concrete go on decreasing.
- 28days average compressive strength of cylindrical sample is less than Cubical sample, and this ratio is almost same as conventional concrete.
- Even the delayed oven dry curing in last week also subtancailly increase the compressive strength as compared to ambient curing.

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