Development of Green Concrete and Assessment of its Strength Parameters

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***Abstract*— Cement based concrete is by far the mainly utilized material for civil engineering construction works. Vast production of concrete has brought with it great environmental crisis owing to mining and processing of tons of natural materials, energy consumption in utilisation, disposal of the generated wastes, release of large quantities of CO_2 and other pollutant gases etc.. This paper summarizes the efforts underway to develop the eco friendly and environmentally safe concrete in line to produce a "Green Building" material. The "green" concrete used in this study composed of fly ash, aggregate (both fine and course), Calcium chloride and alkaline liquids. First set of the tests conducted on green concrete were for workability to ascertain its applicability in respect of conventional concrete. Then after Compressive strength test, Flexural strength test and Abrasion test were conducted on the samples. It is found that the strengths of green concrete are comparable to the conventional concrete with relatively lesser cost. Because of light weight, economical costing, ease in handling etc. the green concrete is recommended for light weight civil engineering structures. Further experimental works are suggested to search the new substances for improving the engineering properties of green concrete so that it can easily replace conventional concrete for load bearing structural components too.**

***Index Terms*— Concrete, Compressive, Optimum Moisture Content, Additive, Fly Ash etc**

I. Introduction

Concrete is the most widely used construction material in the world. It contains four basic ingredients: water, cement, fine aggregate (sand) and coarse aggregate. The production of Portland cement is energy-intensive. The production of raw materials used in concrete such as Portland cement requires a significant amount of energy input and causes various environmental problems (e.g., emission of greenhouse gases CO_2). The manufacturing of traditional concrete using Portland cement (PC) releases a large amount of greenhouse gases such as CO_2, during conversion of Lime stone ($CaCo_3$) to lime (CaO). The manufacture of cement releases about 700kg of this carbon dioxide into the atmosphere for every tonne of cement that is produced. CO_2 is also emitted during cement production by combustion of fossil fuel. It is estimated that the production of cement will increase from about from 3.0 billion tons/ year in 2013 to 4.0 billion tons/ year in 2050 (Dr Martin, 2011). India is the second largest producer of cement after China. In India, cumulative growth of cement production was 6.7% during April- November 2012-2013 compared to its 4.8% growth during the same period of 2011-2012.

The "green" concrete in is defined as the concrete produced by utilizing alternative and/or recycled waste materials (such as fly ash and recycled concrete aggregates) to reduce energy consumption, environmental impact, and natural resource use. Generally green concrete contains a mixer of fly ash, chemical binder, sand, aggregate and water. The use of *supplementary cementitious materials* (SCMs), Alternative aggregates (AAs) and other industrial wastes could reduce the environmental impacts of concrete production. Aggregates from recycled waste streams or other non-conventional aggregate materials (e.g., lightweight aggregate) are defined as *alternative aggregate* (AA). The SCMs and AAs are called *"green" raw materials.* According to Mannan and Ganapathy (2004), using agricultural and industrial wastes as replacement materials in the concrete industry has advantages of cost reduction, waste disposal and curtails the rising emissions of green house gases. Thus the conversion of these wastes into useful materials benefits both the environment and the conservation of natural resources. Furthermore, the new technologies will slow down the depletion of raw material (mainly limestone) and fossil fuel (Coal) used for cement production.

II. Literature Survey

The term 'geopolymer' was first introduced by Davidovits in 1978 to describe a family of mineral binders having chemical composition similar to zeolites but with an amorphous microstructure. He also suggested the use of the term 'poly(sialate)' for the chemical designation of geopolymers based on silico-aluminate (Davidovits,1988a, 1988b, 1991; van Jaarsveld et. Al., 2002a); Sialate is an abbreviation for silicon-oxo-aluminate. Poly(sialates) are chain and ring polymers with Si^{4+} and AL^{3+} in IV-fold coordination with oxygen and range from amorphous to semi-crystalline with the empirical formula:

$$\mathbf{Mn\ (-(SiO_2)\ z–AlO_2)n\ .\ wH_2O\ (2\text{-}1)}$$

Where "z" is 1, 2 or 3 or higher up to 32; M is a monovalent cation such as Potassium or sodium, and "n" is a degree of polycondensation (Davidovits, 1984, 1988b, 1994b, 1999). Davidovits (1988b; 1991; 1994b; 1999) has also distinguished 3 types of polysialates, namely the Poly(sialate) type (-Si-O-Al-O), the Poly(sialate-siloxo) type (-Si-O-Al-O-Si-O) and the Poly(sialate-disiloxo) type (-Si-O-Al-O-Si-O).

Geopolymerization involves the chemical reaction of alumino-silicate oxides (Si_2O_5,Al_2O_2) with alkali polysilicates yielding polymeric Si – O – Al bonds. Polysilicates are generally sodium or potassium silicate supplied by chemical industry or manufactured fine silica powder as a by-product of

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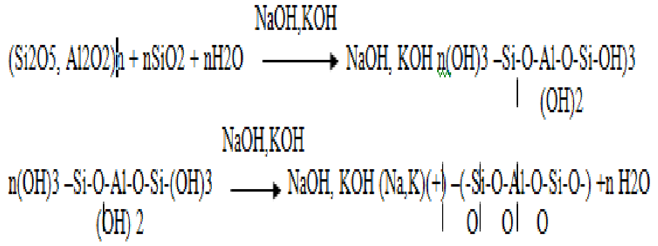
ferro-silicon metallurgy. Following equation shows example of polycondensation by alkalies into poly (silicate –siloxo)



Unlike ordinary Portland/pozzolanic cements, geopolymers do not form calciumsilicate-hydrates (C-S-H) for matrix formation and strength, but utilize the polycondensation of silica and alumina precursors and a high alkali content to attain structural strength. Therefore, geopolymers are sometimes referred to as alkaliactivated alumino silicate binders (Davidovits, 1994a; Palomo et. Al., 1999; Roy,1999; van Jaarsveld et. Al., 2002a). However, Davidovits (1999; 2005) stated that using the term 'alkali-activated' could create significant confusion and generate false granted ideas about geopolymer concrete. For example, the use of the term 'alkali-activated cement' or 'alkali-activated fly ash' can be confused with the term 'Alkali-aggregate reaction (AAR)' , a harmful property well known in concrete. The last term of above equation indicates that water is released during the chemical reaction that occurs in the formation of geopolymers. This water is expelled from the mixture during the curing process.

Since 1972, Davidovits (1988c; 1988d) worked with kaolinite source material with alkalis (NaOH, KOH) to produce geopolymers. The technology for making the geopolmers has been disclosed in various patents issued on the applications of the so called" SILIFACE-Process" . Later, Davidovits (1999) also introduced a pure calcined kaolinite called KANDOXI (**Ka**olinite, **N**acrite, **D**ickite **OXI**de) which is calcined for 6 hours at 750oC. This calcined kaolinite like other calcined materials performed better in making geopolymers compared to the natural ones.

Xu and Van Deventer (1999; 2000) have also studied a wide range of aluminosilicate minerals to make geopolymers. Their study involved sixteen natural Si-Al minerals which covered the ring, chain, sheet, and framework crystal structure groups, as well as the garnet, mica, clay, feldspar, sodalite and zeolite mineral groups. It was found that a wide range of natural alumino-silicate minerals provided potential sources for synthesis of geopolymers. For alkaline solutions, they used sodium or potassium hydroxide. The test results have shown that potassium hydroxide (KOH) gave better results in terms of the compressive strength and the extent of dissolution.

Table1: Applications of Geopolymers Based on Si:Al Atomic Ratio

Si:Al ratio	Applications
1	- Bricks; - Ceramics; - Fire protection
2	-Low CO_2 cements and concretes -Radioactive and toxic waste encapsulation
3	- Fire protection fibre glass composite; - Foundry equipments -Heat resistant composites, 200 - 1000°C -Tooling for aeronautics titanium process
>3	-Sealants for industry, 200 - 600°C; Tooling for aeronautics aluminium
20 – 35	-Fire resistant and heat resistant fibre composites

III. Methodology

This work focuses on the strength increase resulting from the addition of calcium chloride and class F fly ash to fine-grained concrete mix. Fly ash contents are limited to 10% and 20% or as per the requirement of mix design according to IS code 10262. The reason for investigating 10% and 20% class F fly ash contents is that the fly ash (from Sarni Power plant, Betul, M.P.) could have a different chemical content at different place depending upon the quality of coal and process of burning. Samples containing seven different concentrations of calcium chloride (0%, 1%, 2%, 3%, 4%, 5% and 6%) and two Class F fly ash contents (10% and 20%) will be tested for strength at 3, 7, 28 and more cure days. Mixes to be investigated in this study include:

- Control (Normal Concrete mix only)
- Aggregate mix+ Class F fly ash
- Aggregate mix + Calcium chloride+ Class F fly ash
- Aggregate mix + Calcium chloride+ Class F fly ash + Alkali Solutions

Table 2: Approximate Chemical Analysis for Class F Fly Ash and Calcium Chloride

Class F Fly Ash		Calcium Chloride	
Chemical Composition	Contents %	Chemical Composition	Contents %
Silicon Dioxide (SiO_2)	48	Calcium Chloride	87
Aluminum Oxide (Al_2O_3)	24	Total Magnesium (as MgCl2)	0.4
Iron Oxide (Fe_2O_3)	2	Iron (Fe) 15 ppm	0.2
Sum of SiO_2, Al_2O_3, Fe_2O_3,	74	Alkali Chlorides (as NaCl)	6
Calcium Oxide (CaO)	17	Other Impurities	3
Magnesium Oxide (MgO)	4		
Sulfur Trioxide (SO_3)	0.74		
Sodium Oxide (Na_2O), %	0.19		
other Organic matters etc.	4.07		

Table 3: Composition of Ingredients of Concrete

Aggregate	Content (%)
Gravel (Course)	**16**
Gravel (Fine)	**42**
Sand (Course)	**27**
Sand (Fine)	**15**

Manufacture of Fresh Concrete and Casting

The fly ash and the aggregates will be first mixed together in the laboratory concrete pan mixer for about 3 minutes. The liquid component of the mixture will be then added to the dry materials and the mixing continued for further about 4 minutes to manufacture the fresh concrete The fresh concrete will be cast into the moulds immediately after mixing, in three layers for cylindrical specimens and two layers for prismatic specimens. For compaction of the specimens, each layer was given 60t-80 manual strokes using a rodding bar, and then table vibrated for 12-15 seconds.

Curing of Test Specimens

After casting, the test specimens will covered with vacuum bagging film to minimise the water evaporation during curing at an elevated temperature. Two types of heat curing is proposed to be used in this study, i.e. dry curing and steam curing. For dry curing, the test specimens will be cured in the oven and for steam curing, they will be cured in the steam curing chamber. The specimens will be heat-cured at 60°C for 24 hours.

COMPACTION PROPERTIES

Moisture density relationships were investigated before preparing specimens for unconfined compressive strength tests. Ingredients of concrete made of composition as stated are mixed and then dried in the oven for two days. Then, calcium chloride was weighed in a bowl and water was added to the bowl. The mixture was stirred until calcium chloride completely dissolved into the water. Finally, the calcium chloride solution was mixed with soil and fly ash in a large pan until the liquid calcium chloride was uniformly distributed in the concrete.

Optimum Moisture Content (OMC)

Samples containing six different concentrations of calcium chloride (0%, 1%, 2%, 3%, 4%, and 5%) and two Class F fly ash contents (10% and 12%) were tested. Dry density for each sample was calculated as follows:

$$\rho = M/V$$

$$\rho_d = \rho / (1+w)$$

where ρ=total density, M=total mass, V=total volume, ρ_d=dry density, w=water content

IV. RESULTS

The relationships between dry density and water content at different calcium chloride and fly ash concentrations were obtained as shown in Table and Figure. Dry density showed increasing tendency and optimum water contents decreased upto 4% $CaCl_2$ content. Also, at 20% fly ash contents there is increase in values of both the parameter similar to 10% fly ash concentrations.

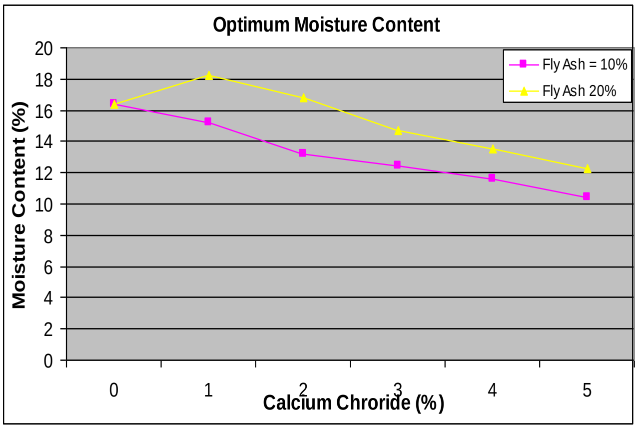


Figure 1: Results of Standard Proctor Test for Optimum Moisture Content

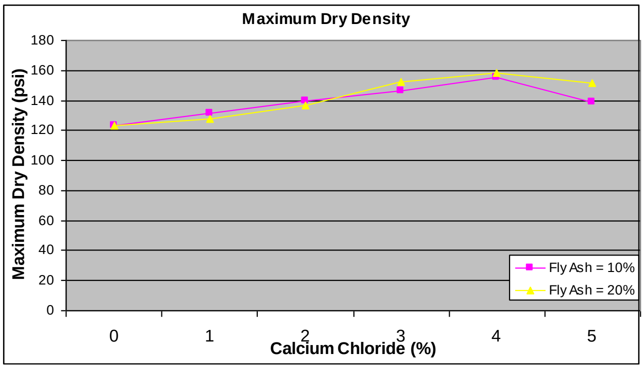


Figure 2: Results of Standard Proctor Test for Maximum Dry Density

It is required to find out optimum calcium chloride content. There are two reasons why calcium chloride content should be limited. One is calcium chloride has a limited solubility. It means calcium chloride can not be used more than optimum water content in each sample to get highest strength because calcium chloride brings strength when it is used in solution. Because they will only be fines in the samples as long as calcium chloride stays in solid form and need more water to be dissolved. Each designed samples have different optimum water contents depending on calcium chloride and fly ash contents as shown Figure 1 and 2.

Table 4: Data of Optimum Moisture Contents and Maximum Dry Density Tests

Mix Design		Standard Proctor Test	
$CaCl_2$	**Fly Ash**	**OMC (%)**	**ρd (pcf)**
0%	0%	16.4	123.3
1%	10%	15.2	131.2
2%	10%	13.2	139.7
3%	10%	12.4	146.4
4%	10%	11.6	155.1
5%	10%	10.4	139.2
1%	20%	18.2	127.4
2%	20%	16.8	136.4
3%	20%	14.7	152.7
4%	20%	13.5	158.5
5%	20%	12.3	151.6

Determination of Compressive Strength (for 3, 7, and 28 days strength) The relationships between unconfined compressive strength and curing time at different calcium chloride and Class F fly ash amount mix design were plotted in Figures 3a and 3b. Samples containing calcium chloride at all concentrations (0, 1, 2, 3, 4 and 5%, based on dry weight) showed a trend of increasing unconfined compressive strength within 24 hours and up to 56 days. However, this strength gain was lost at 90 days in the samples containing

10% fly ash as shown in Figure 5-7. The sample with 4% calcium chloride and 15% Class F fly ash showed a continued trend of increasing strength at 90 days. It should be noted that all samples with long cure times showed brittle failures. This trend was more noticeable either at high calcium chloride concentration or at 28 or longer cure days. The control samples showed over 100% strength gain over 90 days. This trend is most likely due to drying during curing. Further, the soil samples containing calcium chloride may likely have lost moisture at a lower rate, or even gained moisture (Figure 3a and 2b). Since the soil samples were not cured at constant moisture contents, definitive conclusions cannot be mode regarding the effects of cure time.

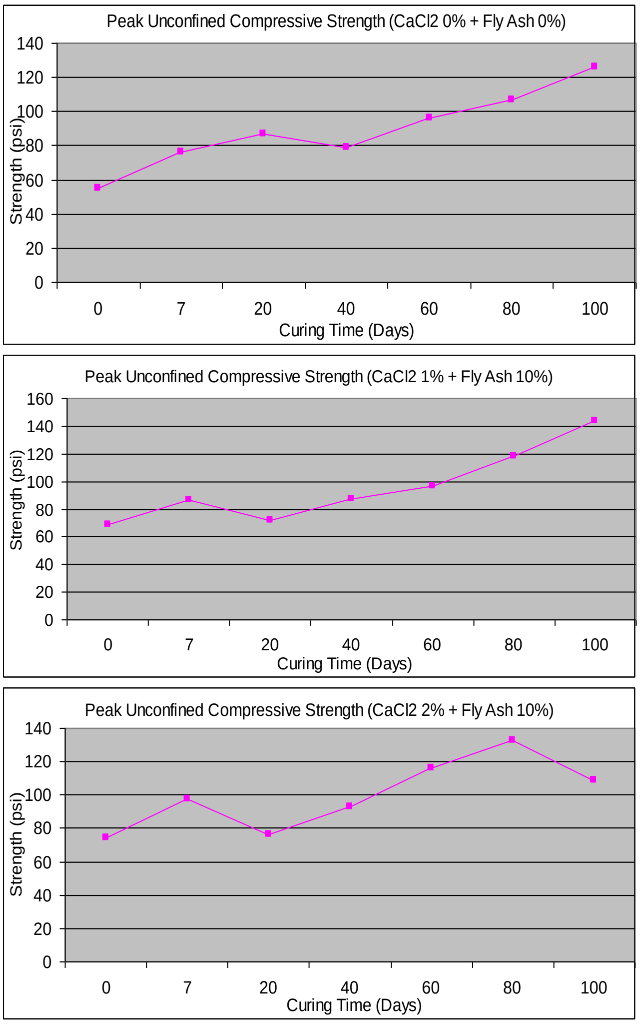
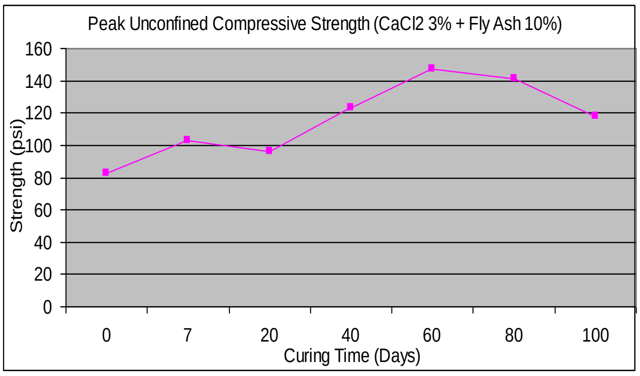


Figure 3: Unconfined Compressive Strength of Green Concrete



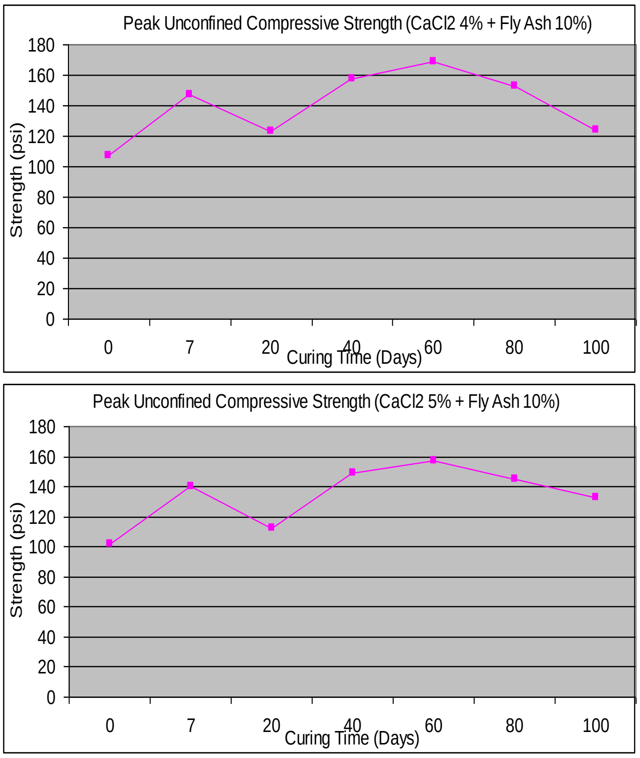


Figure 4: Unconfined Compressive Strength of Green Concrete

Six samples containing four different contents of calcium chloride (0-5%) with class F fly ash (10% and 20%) were tested at 1, 3, 7, 28, 56, and 90 cure days to verify the effectiveness and optimum ratio of calcium chloride and Class F fly ash in soil stabilization. Following determination of Atterberg limits, particle size distribution, optimum moisture content, moisture content variation depending on mix design with cure time and unconfined compression strength were determined according to ASTM method. Based on the lab tests, the following conclusion and recommendations are made.

Significant water content variations appeared to have occurred during the curing period in this test program. Accordingly, any conclusions drawn regarding cure time must be considered tentative. Future investigations should address the issue of moisture changes during curing.

- 4% calcium chloride with 10% Class F fly ash and 4% calcium chloride with 20% Class F fly ash are close to the optimum quantity for early high strength and long-term strength.
- Samples containing calcium chloride and Class F fly ash at any concentrations obtained early high strength. However, all the samples containing calcium chloride obtained around 150 psi unconfined compressive strength at 70-80 days and showed a decreasing tendency after 80 days.
- The addition of fly ash increases peak strength, but also increases sensitivity.

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