EXPERIMENTAL INVESTIGATIONS ON CORROSION RESISTIVITY OF LOW CALCIUM FLY ASH-BASED GEOPOLYMER CONCRETE

BOMMANA BOYINA NAVEEN[1], K.RAMA KRISHNA[2]

[1]P.G. Scholar in Structural Engineering, Civil Engineering Department
[2]Asst.Professor, Civil Engineering Department
[1,2]Usha Rama College of Engineering & Technology Andhra Pradesh, India

---

Abstract:- Concrete usage around the world is second only to water. Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete. But the amount of carbon dioxide released during the manufacture of OPC due to the calcinations of lime stone and combustion of fossil fuel is in the order of 900 kg for every ton of OPC produced. Due to growing environmental concerns of the cement industry, alternative cement technologies have become an area of increasing interest. It is now believed that new binders are indispensable for enhanced environmental and durability performance.

In this regard, the geo-polymer concrete (GC) is one of the revolutionary developments related to novel materials resulting in low-cost and environmentally friendly material and is produced by totally replacing the OPC. In geo-polymer Concrete, fly ash and aggregates are mixed with alkaline liquids such as a combination of Sodium Silicate and Sodium Hydroxide. It was seen that geo-polymer concrete made of fully Fly-ash or partial replacement by GGBS results with 80% reduction in CO2 emission compared to OPC.

This paper documents the study of the durability and economic characteristics of low-calcium fly ash based geo-polymer concrete. Geo-polymer mixtures with variations of water/binder ratio, aggregate/binder ratio, aggregate grading, and alkaline/fly ash ratio were investigated. Strength was measured by compressive strength and the test results are included here. This paper also reports the effect of extra water, curing time and curing temperature on the compressive strength of geo-polymer concrete. The results show that the strength of fly ash based geo-polymer concrete was increased by reducing the water/binder and aggregate/binder ratios. Also, longer curing time and curing the concrete specimens at higher temperatures will result in higher compressive strength.

Finally, a raw material cost comparison was carried out for the production of 1 m3 of geo-polymer concrete and cement concrete of same grade. The result shows the overall price of geo-polymer concrete is almost 10% to 20% less than the same quantity of cement concrete.

Keywords: Geo-polymer concrete, Fly ash, Compressive strength, Cost.

1. INTRODUCTION:

Fly ash based geo-polymer concrete has emerged as a new technology in construction materials. The addition of Fly Ash (FA)/Ground Granulated Blast-furnace Slag (GGBS) adds value to the cement, and also reduces the OPC contribution to CO2 emissions during concrete production. The production of only 1 ton of OPC cement is estimated to release

0.9 ton of CO2 gas emission. It was calculated that combining OPC cement with slag could produce 248 kg/m3 of CO2, while the geo-polymer only produces 78 kg/m3. The geo-polymer can be manufactured from a reaction of the alkaline solution with the sodium and alumina in the fly ash to produce a compact cementing material. This material possesses good mechanical properties and durability in aggressive environments.

As in the OPC concrete, the aggregates occupy the largest volume, i.e. about 75-80 % by mass, in geo-polymer concrete. The silicon and the aluminium in the fly ash are activated by a combination of sodium hydroxide and sodium silicate solutions to form the geo- polymer paste that binds the aggregates and other un-reacted materials. The preparation of geo-polymer concrete is carried out using the usual concrete technology methods.

Geopolymer Concrete:

The cement industry does not fit the contemporary picture of a sustainable industry because it uses raw materials and energy that are non-renewable; extracts its raw materials by mining and manufactures a product that cannot be recycled. On the other hand, the abundant availability of fly ash worldwide creates opportunity to utilize (by – product of burning coal, regarded as a waste material) as substitute for OPC to manufacture concrete. Binders could be produced by polymeric reaction of alkali liquids with the silicon and the aluminum in the source materials such as fly ash and rice husk ash and these binders are termed as Geo-polymer. In Geo-polymer Concrete, fly ash and aggregates are mixed with alkaline liquids such as a combination of Sodium Silicate and Sodium Hydroxide. Pumping of CO2 into the atmosphere is the main culprit for the climate change. Large volume of fly ash is being produced by thermal power stations and part of the fly ash produced is used in concrete industry, low laying area fill, roads and embankment, brick manufacturing etc. The balance amount of fly ash is being stored in fly ash ponds. Hence it is imperative on the part of Scientists and Engineers to devise suitable methodologies for the disposal of fly ash. Disposal of fly ash has the objective of saving vast amount of land meant for ash pond to store fly ash. Further, use of fly ash as a value added material as in the case of geo-polymer concrete, reduces the consumption of cement. Reduction of cement usage will reduce the production of cement which in turn cut the CO2 emissions. Many researchers have worked on the development of geo-polymer cement and concrete for the past few years. The time has come for the review of progress made in the field of development of geo-polymer concrete.

Objectives:-

The aims of the research are:

- To develop a mixture proportioning process of making fly ash based geo-polymer concrete.
- To identify and study the effect of salient parameters that affects the properties of fly ash based geo-polymer concrete.
- To study the short-term engineering properties of fresh and hardened fly ash based geo-polymer concrete.
- To study the economic benefits of fly ash based geo-polymer concrete.

Experimental Programme

This present study mainly focuses on the strength characteristics of low calcium fly ash based geopolymer concrete. Since the available literatures are not sufficient to identify the mix proportion, trial mixtures are selected to identify the mechanical properties. The materials used in the study are listed below.

Materials:

Fly ash:

In this study locally available low calcium fly ash obtained from Kadaieswari Ready Mix Plant, Coimbatore was used. The chemical composition of fly ash used and Ordinary Portaland Cement were compared and tabulated below in Table 1. It can be observed in the table 1 that the fly ash contains low calcium oxide, the molar ratio of Si to Al is 2 and Iron oxide content was higher than Cement. The specific gravity of the fly ash was 2.30 and fineness modulus was 1.38.

Table 2.1 – Chemical properties of Fly ash

Composition (%)	Class C	Class F
SiO	39.90	54.90
Al2O3	16.70	25.80
Fe2O3	5.80	6.90
CaO	24.30	8.70
MgO	4.60	1.80
SO3	3.30	0.60
Na2O & K2O	1.30	0.60

Table 2.2 – Chemical properties of GGBS

Calcium Oxide (CaO)	40%
Silica (SiO2)	35%
Alumina (Al2O3)	13%
Magnesia (MgO)	8%

Table 2.4 – Applications of Geo-polymer material

Si/Al	Application
1	Bricks, Ceramics, Fire protection
2	Low CO2 cements, concrete, radioactive & toxic waste encapsulation
3	Heat resistance composites, foundry equipments, fibre glass composites
>3	Selants for industry
20<Si/Al<35	Fire resistance and heat resistance fibre composites

Mechanism of Corrosion

Steel is used in concrete principally as reinforcement. Concrete ordinarily provide an almost ideal environment for protecting steel from corrosion. Its high alkalinity causes the formation of a thin invisible protective passive fdm of Ferric Oxide (Fe203) on the steel.lt is expected that when the embedded steel is protected from air by an adequate thick cover of low permeability concrete, the corrosion of steel would not arise. This expectation is not fully met in practice, as is evident from the unusually high frequency with which the RCC & PSC structures suffer damage due to steel corrosion. The magnitude of damage is especially large in structures exposed to marine environments. The damage to concrete, resulting from corrosion of embedded steel, manifests in the form of expansion, cracking and eventually spalling of the cover concrete.

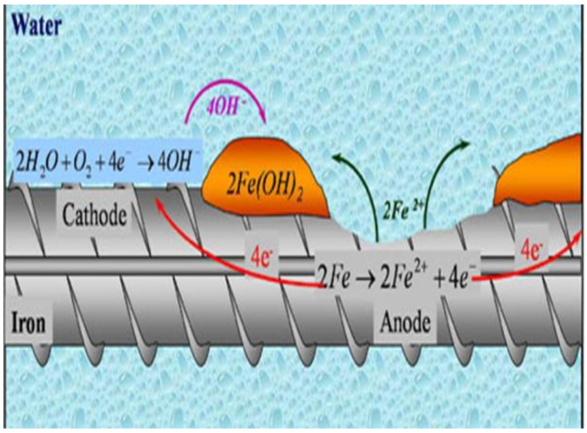

Fig-2.7 Showing the reasons for corrosion

Prevention of Corrosion:

Quality Concrete and Concrete Practices .The first defense against corrosion of steel in concrete is quality concrete and sufficient concrete cover over the reinforcing bars. Quality concrete has a water-to-cementious material ratio (w/c) that is low enough to slow down the penetration of chloride salts and the development of carbonation. The w/c ratio should be less than 0.50 to slow the rate of carbonation and less than 0.40 to minimize chloride penetration. Concretes with low w/c ratios can be produced by (1) increasing the cement content; (2) reducing the water content by using water reducers and super plasticizers; or (3) by using larger amounts of fly ash, slag, or other cementious materials.

How to Limit Corrosion:

- Use good quality concrete air-entrained with a w/c of 0.40 or less.
- Use a minimum concrete cover of 1.5 inches and at least 0.75 inch larger than the nominal maximum size of the coarse aggregate.
- Increase the minimum cover to 2 inches for deicing salt exposure and to 2.5 inches for marine exposure.
- Ensure that the concrete is adequately cured.
- Use fly ash, blast-furnace, slag, or silica fume and/or a proven corrosion inhibitor.

MIXING PROPORTIONS

The following ranges were selected for the constituents of the mixtures used in this study.

- Ratio of sodium silicate solution to sodium hydroxide solution, by mass, of 2.5 was fixed for most of the mixtures because the sodium silicate solution is considerably cheaper than the sodium hydroxide solution.
- Molarity of sodium hydroxide (NaOH) solution in the range of 12M to 16M.
- Ratio of activator solution-to-fly ash, by mass, in the range of 0.30 and 0.40.
- Coarse and fine aggregates as given in Section 3.2.3, of approximately 75% to 80%, of the entire mixture by mass.
- Super plasticiser, as given in Section 3.2.4, in the range of 1% to 2% of fly ash, by mass.
- Extra water, when added, in mass.

Table 3.6: Properties of aggregates

Property	Coarse aggregates	Fine aggregates
Specific gravity	2.612	2.515
Water absorption	0.43%	0.93%
Source	Crushed granite stone	Crusher sand

Table 3.7: Properties of Sodium Silicate solution

Specific gravity	1.39 g/cc
Na2O	9%
SiO2	28%
Weight ratio	3.11

Table 3.8: Properties of Sodium hydroxide solution

Molar mass	40 g/mol
Appearance	White solids
Density	2.13 g/cc
Melting point	318 ^{0}C
Boiling point	1388 ^{0}C

RESULTS:

Figure 4.2: Compressive Strength Testing Machine (2000KN)

Ratio of Activator liquid to Fly ash

It can be observed from the results, that the compressive strength increases with increase in the fly ash content and decrease of water to geo-polymer solids ratio for all ages. Therefore compressive strengths are found to decreases with increase in ratio of activator liquid to fly ash. Because of increased amount of the activator solution and the substantial increase in number of pores as a result of increase in pores due to heat curing.

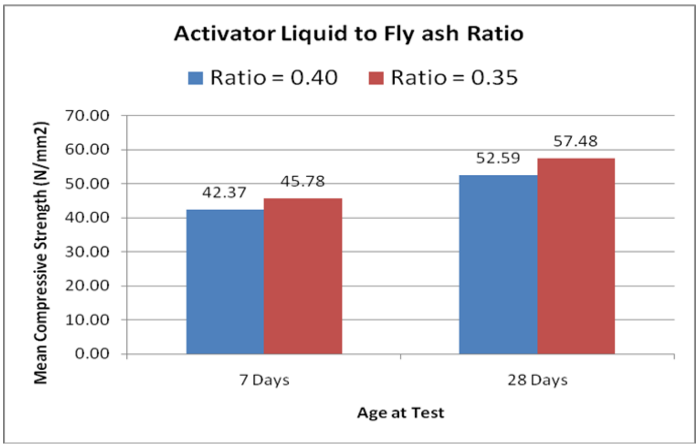

Figure 4.4: Activator Liquid to Fly ash Ratio

Concentration of sodium hydroxide (NaoH) solution in Molar

Molarity of NaoH solution plays a vital role in the strength of geo-polymer concrete. With a higher concentration of NaoH solution a higher compressive strength can be achieved. Satisfactory results were observed at a molarity of 16M.

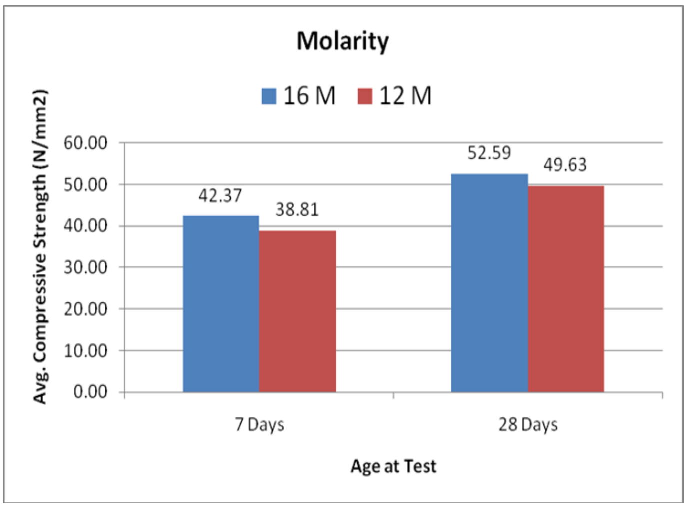

Figure 4.5: Effect of concentration of NaoH solution on Compressive Strength

Curing Temperature

Curing temperature is one of the important factors for the strength point of view of geo- polymer concrete. The main polymerization process or the chemical reaction of geo-polymer concrete takes place with the temperature imposed to it during the curing. It may attain almost its 70% strength with in the first 3 to 4 hours of hot curing. Longer curing time enhanced the polymerization process and results in a higher compressive strength. The rate of increase of strength is rapid in the initial 24 hours of curing beyond that the gain of strength was moderate so the specimens should be cured for 24 hours only which will sufficient enough.

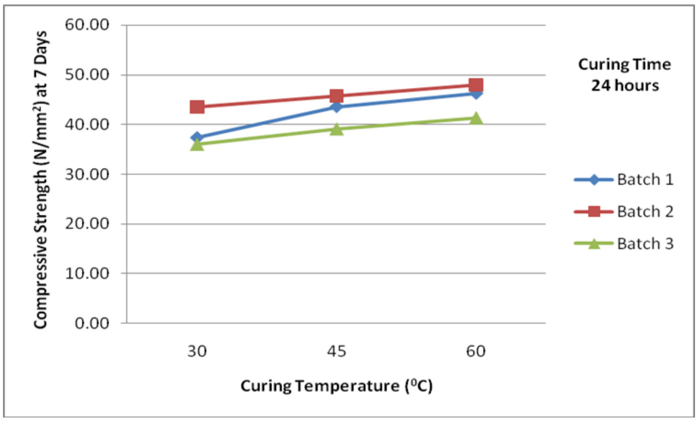

Figure 4.6: Effect of Curing Temparature (1)

Curing Time

The test specimens were cured for various curing periods from 4 to 72 hours at a temperature of 600C. Longer curing period improves the polymerization process resulting in higher compressive strength. The rate of increase in strength was rapid up to 24 hours of curing time.

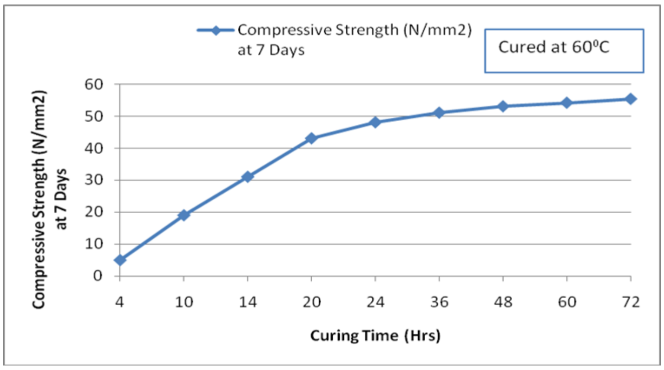

Figure 4.8: Effect of Curing Time on Compressive Strength

Addition of Super Plasticiser

In fresh state, the geo-polymer concrete has a stiff consistency. Although adequate compaction was achievable, an improvement in the workability was considered as desirable. The addition of super plasticiser improved the workability of the fresh concrete but had very little effect on the compressive strength up to about two percent of this admixture to the amount of fly ash by mass. Beyond this value, there was some degradation of the compressive strength.

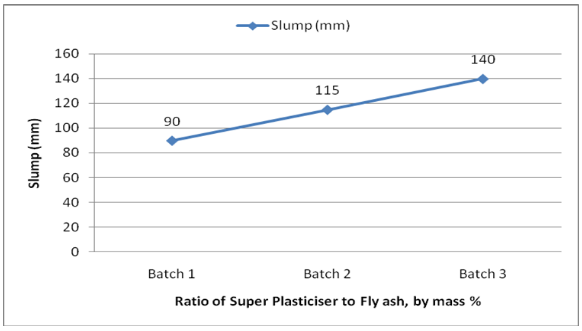

Figure 4.9: Effect of Super Plasticiser content on slump of concrete

STRENGTH COMPARISON

The experimental results obtained were keenly observed and studied well, so as to compare the strength properties of Geo-polymer concrete and conventional cement concrete. On comparing the strength aspects, the GPC was found to be far better than conventional concrete.

Table 4.5: Compressive Strength comparison (Cement Concrete Vs GPC)

S.No	Type of Concrete	28th Day Compressive Strength (N/mm^2)	
A	Conventional Cement Concrete	50.92	51.86
		51.72	
		52.93	
B	Fly ash based Geo-polymer Concrete	56.44	57.48
		57.33	
		58.67	

OPEN CIRCUIT POTENTIAL METHOD:

Open circuit potential (OCP) refers to the difference that exists in electrical potential. It normally occurs between two device terminals when detached from a circuit involving no external load.

It is the potential in a working electrode comparative to the electrode in reference when there is no current or potential existing in the cell. Once a potential relative to the open circuit is made present, the entire system gauges the potential of the open circuit prior to turning on the cell. This is followed by the application of potential relative to the existing measurement. If the primary potential is more than 300 mV, the initial potential should be more than 400 mV.

Table 4.6: Corrosion Condition (ASTM C 876-1991)

(mV vs SCE)	(mV vs	Corrosion Condition
<-426	<-500	Severe corrosion
<-276	<-350	Eligh(<90% risk of corrosion)
-126 to-275	350 to - 200	Intermediate corrosion risk
>- 125	>200	Low(10 % risk of corrosion)

Table 4.7: Corrosion Probability

SET	Cement type	Specimen no.	Average open circuit potential values of 3 specimens	Corrosion condition
1	OPC	M20	-89	Intermediate
	OPC	M40	-122	intermediate
	OPC	M60	-169	High
2	GPC	G20	-84	Intermediate
	GPC	G40	-105	Intermediate
	GPC	G60	-155	Intermediate

The effect of corrosion on the tensile behavior of reinforcement under different rates of corrosion is compared. There is not much noticeable change in the yield strength. Long duration test may be required to analyze the strength of beams.

CONCLUSIONS:-

Based on the experimental work reported in this study, the following conclusions are drawn:

- Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of fly ash-based geo-polymer concrete.
- Higher the ratio of sodium silicate-to-sodium hydroxide ratio by mass, higher is the compressive strength of fly ash-based geo-polymer concrete.
- As the curing temperature in the range of 30oC to 60oC increases, the compressive strength of fly ash-based geo-polymer concrete also increases.
- Longer curing time produces higher compressive strength of fly ash based geo- polymer concrete. However, the increase in strength beyond 24 hours is not significant.
- The addition of super plasticiser up to approximately 2% of fly ash by mass, improves the workability of the fresh fly ash based geo-polymer concrete.
- The slump value of the fresh fly-ash-based geo-polymer concrete increases with the increase of extra water added to the mixture.
- As the ratio of water to geo-polymer solids by mass increases, the compressive strength of fly ash based geo-polymer concrete decreases.
- The average density of fly ash based geo-polymer concrete is similar to OPC concrete.
- Geo-polymer concrete with properties such as abundant raw resource, little CO2 emission, less energy consumption, low production cost, high early strength, fast setting, resistant to corrosive environment. These properties make geo-polymer concrete to find great applications in civil engineering.
- The Geo-polymer concrete is about 17% economical than the conventional mix of same Grade.
- Geo polymer concrete behaves similar to OPC concrete.
- Water to geo polymer solids ratio and alkaline liquid to fly-ash ratio are the governing factors for the development of geo polymer concrete.
- The performance of geo polymer reinforced concrete beams exposed to chloride environment is superior to OPC reinforced concrete beams.
- As the grade of concrete increases the corrosion resistance also increases; for both OPC and GP concrete.
- Yield stress and ultimate stress values for OPC and GPC decreases with respect to unexposed reinforced bar.

REFERENCES:-

1. Sourav Kr. Das, Amarendra Kr. Mohapatra and A.K. Rath (2014). “Geo-polymer Concrete – Green Concrete for the Future – A Review”, International Journal of Civil Engineering Research, ISSN 2278-3652, Vol.5, Number 1 (2014), pp 21-28.
2. G. Saravanan, C.A. Jeyasehar and S. Kandasamy (2013). “Fly ash Based Geo-polymer Concrete – A State of the Art Review”, Journal of Engineering Science and Technology Review 6 (1) (2013) 25-32.
3. M. Fareed Ahmed, M. Fadhil Nuruddin, and Nasir Shafiq “Compressive Strength and Workability Characteristics of Low Calcium Fly ash based self Compacting Geo-polymer Concrete”, International Journal of Civil and Environmental Engineering 3:2 2011
4. D. Hardjito (2005), Studies of fly ash based geo-polymer concrete, PhD Thesis, Curtin University of Technology, Perth, Australia.
5. S.S. Jamkar, Y.M. Ghugal and S.V. Patnakar (2013), “Effect of water to geo-polymer binder ratio on the production of fly ash based geo-polymer concrete”, The Indian Concrete Journal.
6. Geo-polymer concrete – Wikipedia, the free encyclopedia
7. A. Palomo, M.W. Grutzeck and M.T. Blanco (1999), “Alkali activated fly ashes a cement for the future Cement Concrete”, 29, 1323-1329.
8. R. Anuradha, V.Sreevidya, R. Venkatasubramani and B.V. Rangan (2012), “Modified Guidelines for Geo-polymer Concrete Mix Design using Indian Standard”, Asian Journal Of Civil Engineering (Building And Housing) Vol 13, No.3, Pages 353 – 364

9. DS Cheema, NA Lloyd and BV Rangan (2009), “Durability of Geo-polymer concrete Box Culverts – A green alternative”.

10. IS: 456-2000. “Plain and reinforced concrete - Code of practice”, Bureau of Indian Standard’s, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110003.

11. IS: 516-1959. “Methods of Tests for Strength of Concrete”, Bureau of Indian Standard’s, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002.