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Experimental Study on Corrosion Resistivity of Low Calcium Fly Ash Based Geo Polymer Concrete

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ABSTRACT

The production of Portland cement, a main component of making concrete, contributes significant amount of greenhouse gas, because the production of one ton of Portland cement also releases about one ton of carbon dioxide gas into the atmosphere. Therefore, the introduction of a novel binder called 'geopolymer' by Davidovits promises a good prospect for application in the concrete industry as an alternative binder to Portland cement.

In terms of reducing global warming, the geopolymer technology could reduce the C02 emission to the atmosphere caused by cement and aggregates industries by 80%.Fly ash-based geopolymer concrete is manufactured using fly ash as its source material and does not use Portland cement at all. Beside fly ash, alkaline solution is also utilized to make geopolymer paste which binds the aggregates to form geopolymer concrete. The geopolymer concrete has proven to be having excellent mechanical characteristics and better durability characteristics like permeability, resistance against sulphate and acids.

The corrosion of reinforcement is the single most common source of damage and it is usually clear that inadequate concrete, inadequate cover to the reinforcement or the presence of impurities (and sometimes all three) is the prime cause. In the present work, Open Circuit Potential(OCP) method was used to determine the corrosion activity in the reinforced beams.The effect of corrosion on the tensile behavior of reinforcement under different rates of corrosion was compared. The test results reveals that the Geopolymer concrete performs superior to OPC concrete.

INTRODUCTION

GENERAL DESCRIPTION:

Over the last few decades, there has been considerable research in the field of geopolymer composites in various parts of the world. Interest on geopolymer composites is growing because of the fact, unlike Portland cements, consume no energy and is not detrimental to the environment. Tremendous surge in research in this area has been observed since there is the immense utilization of waste products like fly ash, blast furnace slag etc. for manufacture of geo polymers

The ordinary Portland cement still continues to be the most frequently used binder in the construction industry. The production of this Portland cement contributes a substantial amount of greenhouse gas, because the production of one ton of Portland cement releases one ton of carbon dioxide gas into the atmosphere. Consequently, the novel binder called 'geo-polymer' by Davidovits promises a good prospect for application in the concrete industry as an eco-friendly alternative to the Portland cement. There could be about 80% reduction in CO2 emissions to the atmosphere cause by cement and aggregate industry by the utilization of the geopolymer technology. Thereby resulting in a significant reducing of global warming.

GEOPOLYMER CONCRETE:

The term 'Geopolymer' was coined by Davidovits in 1978 to describe a family of mineral binders with chemical composition similar to zeolites but with an amorphous microstructure. Unlike ordinary Portland/pozzolanic cements, geopolymers do not form calcium-silicate-hydrates (CSHs) for matrix formation and strength, but utilize the polycondensation of silica and alumina precursors to attain structural strength. Two main constituents of geopolymers are: source materials and alkaline liquids. The source material should be rich in silicon (Si) and aluminium (AI). In this case, the source material used is fly ash. The chemical reaction which takes place in this case is a polymerization process; hence the term 'Geopolymer' was initiated to represent the binders.

Geopolymers are members of the inorganic polymer family. The polymerization process involves a significantly fast chemical reaction under alkaline condition on Si-Al minerals, those results in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. The Literature reveals that water is released during the chemical reaction that occurs in the formation of geopolymers. This water expelled from the geopolymer matrix during the curing and further drying periods, leaves behind discontinuous Nano-pores in the matrix, which provide benefits to the performance of geopolymers. The water in a geopolymer mixture, therefore, plays no role in the chemical reaction that takes place; it simply provides the workability to the mixture during handling. This is in distinction the chemical reaction of water in a Portland cement concrete mixture during the hydration process.

FLY ASH-BASED GEOPOLYMER CONCRETE:

Geopolymer concrete in manufacture using source materials rich in silica and alumina. While the cement-based concrete utilizes the formation of calcium-silica hydrates (CSHs) for matrix formation and strength, geopolymers involve the chemical reaction of alumina-silicate oxides with alkali poly silicates yielding polymeric Si-O-Al bonds. In this experimental work, fly ash is used as the source material to make the geopolymer paste as the binder, to produce concrete. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. As in the Portland cement concrete, in fly ash-bash geopolymer concrete, the aggregates occupy the largest volume, i.e. about 75-80% by mass.

Sodium-based activators were chosen because they were cheaper than Potassium-based activators. The sodium hydroxide was used in flake or pellet form. It is recommended that the alkaline liquid is prepared by mixing both the solutions together at least 24 hours prior to use. The mass of NAOH solids varied depending on the concentration of the solution expressed in terms of molar, M. The concentration of NAOH solution can vary in the range of 8M to 16M. The mass of water is the major component in both the alkaline solutions. In order to improve workability, a Naphthalene Sulphonate Formaldehyde (SNF) based super plasticizer has been added to the mixture.

CORROSION:

Corrosion is the gradual destruction of materials, (usually metals), by chemical reaction with its environment.

In the most common use of the word, this means electrochemical oxidation of metals in reaction with an oxidant such as oxygen. Rusting, the formation of iron oxides is a well-known example of electrochemical corrosion. This type of damage typically produces oxides or salts of the original metal. Corrosion can also occur in materials other than metals, such as ceramics or polymers, although in this context, the term degradation is more common. Corrosion degrades the useful properties of materials and structures including strength, appearance and permeability to liquids and gases.

Many structural alloys corrode merely from exposure to moisture in air, but the process can be strongly affected by exposure to certain substances. Corrosion can be concentrated locally to form a pit or crack, or it can extend across a wide area more or less uniformly corroding the surface. Because corrosion is a diffusion-controlled process, it occurs on exposed surfaces. As a result, methods to reduce the activity of the exposed surface, such as passivation and chromate conversion, can increase a material's corrosion resistance. However, some corrosion mechanisms are less visible and less predictable.

Iron is unstable in nature, and because reinforcing steel used in precast concrete is made largely of iron, it, too, becomes unstable when exposed to corrosive agents such as salt, carbonation, and even air. Iron, as we commonly recognize it, is not generally found in nature because of its instability. It takes a great deal of energy to produce iron from its ore, and even then it is so unstable that it must be coated to keep it from reverting back to its ore forms (hematite, magnetite, and limonite).

The two most common causes of reinforcement corrosion are

- localized breakdown of the passive film on the steel by chloride ions and
- general breakdown of passivity by neutralization of the concrete, predominantly by reaction with atmospheric carbon dioxide.
- Sound concrete is an ideal environment for steel but the increased use of deicing salts and the increased concentration of carbon dioxide in modern environments. Principally due to industrial pollution, has resulted in corrosion of the rebar becoming the primary cause of failure of this material. The scale of this problem has reached alarming proportions in various parts of the world.

CORROSION OF STEEL:

ASTM terminology defines corrosion as “the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties.” For steel embedded in concrete, corrosion results in the formation of rust which has two to four times the volume of the original steel and none of the good mechanical properties. Corrosion also produces pits or holes in the surface of reinforcing steel, reducing strength capacity as a result of the reduced cross-sectional area.

EXPERIMENTAL PROGRAMMEE

GENERAL: The main objective of the present experimental investigation is to obtain specific experimental data, which helps to compare the corrosion activity of ordinary Portland cement beams and geopolymer concrete beams.

MATERIALS

CEMENT:

Ordinary Portland cement of 53 grade, available in local market is used in the investigation. The cement used for all tests is from the same batch. The cement used has been tested for various properties as per IS: 4031-1988

Grade: OPC 53

Brand: Bharati Cement

Date of manufacture:

FINE AGGREGATE:

Locally available RIVER SAND is used as fine aggregate and is tested for various properties required. The sand passing through IS sieve 2.36mm was taken.

COARSE AGGREGATE:

The coarse aggregate used is locally available crushed granite stone of 20mm size. Tests are conducted to determine its physical properties. The aggregates passing through IS 20mm sieve and retaining on 12.6mm sieve were taken for the experimental procedures

Size of aggregate: 20m

WATER:

Water used for mixing and curing is fresh potable water, conforming to IS: 3025 - 1964 part 22, part 23 and IS: 456 - 2000.

FLY ASH:

Fly Ash is from the National Thermal Power Corporation (NTPC), Ramagundam, Telangana

Table l:Typical Oxide Composition of Indian fly ash.

SNo	Characteristics	Percentage
1.	Silica, SiO_2	**49-67**
2.	Alumina Al_2O_3	**16-28**

3	Iron oxide Fe2O3	**4-10**
4.	Lime Ca0	**0.7-3.6**
5.	Magnesia Mg 0	**0.3-2.6**
6.	Sulfur Trioxide SO3	**0.1-2.1**
7.	Loss on Ignition	**0.4-1.9**

Table 2: Chemical requirements of fly ash

S.No.	**Characteristics**	**Requirements (% by weight)**	**Fly Ash used**
1	Silicon dioxide (Si02)plus aluminum oxide	70 (minimum)	94.78
2	Silicon dioxide (Si02)	35 (minimum)	66.81
3	Magnesium Oxide (MgO)	5 (max.)	2.55
4.	Total sulphur as sulphur trioxide	2.75 (max.)	0.87
5.	Loss on ignition	12 (max.)	1.8

SODIUM SILICATE:

The Sodium Silicate liquid used in this study was provided in liquid form by Kiran Global Chems Limited, Chennai.

Table 3: Properties of Sodium silicate solution

Specific gravity	1.6
Molar mass	122.06 gr/molar
Na2o (by mass)	14.7 %
Sio2 (by mass)	29.4 %
Weight of solids (by mass)	44.5%
Water (by mass)	55.90%
Weight Ratio (sio2 to na2o)	2
Molar ratio	2.06

SODIUM HYDROXIDE:

Sodium Hydroxide was provided by Genesynth Fine Chemicals, Hyderabad. The chemical was given in pellet/flakes form with 98% purity.

Table 4: Properties of Sodium Hydroxide

Molar mass	40 gm/mol
Appearance	White solid
Density	2.1 gr/mol
Melting point	318° c
Boiling point	1390 °c
Amount of heat liberated when	266 cal /gr

SUPER PLASTICIZER:

Naphthalene Sulphonate Formaldehyde (SNF) based super plasticizer was provided by BASF chemical company by the product name - Rheobuild - 920SH.

COMPRESSIVE STRENGTH OF CEMENT:

CODE: IS 4031 Part-VI

DESCRIPTION: Compressive strength is the capacity of a material or structure to withstand axially directed pushing forces. It provides data of force vs. deformation for the conditions of the test method.

APPARATUS: Mould of (7.06*7.06) cm dimensions, CTM

CEMENT MORTAR: 1:3 cement and sand

WATER PERCENTAGE: (P/4 +3) %(weight of sample)

RESULT: Compressive strength of OPC 53 grade for 3 days is 26Mpa

IS LIMIT: As per code compressive strength of cement when tested shall be minimum 53Mpa (for 28 day)

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TABLE 5: PHYSICAL PROPERTIES OF CEMENT

PHYSICAL PROPERTY TESTED	IS SPECIFICATIONS	RESULTS OBTAINNED
Fineness of cement	% Residue <10%	3%
	% Fineness :- >90%	97%
Specific gravity	3.15	3.1
Standard consistency	30-32%	32%
Initial setting time	>30 minutes	55
Final setting time	<600	350
Compressive strength	53 MPa for	26 MPa

TESTS ON FINE AGGREGATE:

SPECIFIC GRAVITY OF FINE AGGREGATE:CODE: IS 2386 Part-Ill

DESCRIPTION: Specific gravity test is used to find the specific gravity of fine aggregate sample by determining the ratio of weight of given volume of aggregate to the weight of equal volume of water. Aggregate specific gravity is needed to determine weight-to-volume relationships.

FINENESS MODULUS OF FINE AGGREGATE:

CODE: IS 2386 Part-1

DESCRIPTION: Fineness modulus (FM) is defined as an empirical figure obtained by adding the total percentage of the sample of an aggregate retained on each of a specified series of sieves, and dividing the sum by 100. In general fineness modulus is defined as size of the aggregate.

TABLE 6: FINENESS MODULUS OF FINE AGGREGATE

SI no.	IS Sieve Size	Weight retained gm.	Cumulative Weight retained gm	Cumulative %Weight Retained	Cumulative % Passing	Grading Limits IS 383-1970 Zone II
1	10 mm	0	0	0	100	100
2	4.75mm	4	4	0.4	99.6	90 -
3	2.36mm	40	44	4.9	94.9	75 -
4	1.18mm	184	228	22.8	75.9	55 -
5	600microns	355	583	58.3	39.9	35 -
6	300 microns	310	909	90.9	8.9	8-30
7	150 microns	75	984	98.4	1.4	0-10
8	<150microns	14		—	-	-
9	Total	1000		275.7		

RESULT: The fineness modulus of fine aggregate is 2.7

IS LIMITS: As per code fineness modulus should range from 2-4

HENCE OK

PHYSICAL PROPERTIES OF FINE AGGREGATE

PHYSICAL PROPERTY TESTED	IS SPECIFICATIONS	RESULTS OBTAINED
Specific gravity	2.5-26	2.55
Fineness modulus	2-4	2.7

TESTS ON COARSE AGGREGATE:

SPECIFIC GRAVITY OF COARSE AGGREGATE:

CODE: IS 2386 Part-Ill

DESCRIPTION: Specific gravity test is used to find the specific gravity of coarse aggregate sample by determining the ratio of weight of given volume of aggregate to the weight of equal volume of water. Aggregate specific gravity is needed to determine weight-to-volume relationships.

APPARATUS: Pycnometer

RESULT: Specific gravity of coarse aggregate is 2.62

IS LIMIT: As per code specific gravity of coarse aggregate has to range between 2.6-2.7

HENCE

CODE: IS 2386 Part-1

DESCRIPTION: Fineness modulus (FM) is defined as an empirical figure obtained by adding the total percentage of the sample of an aggregate retained on each of a specified series of sieves, and dividing the sum by 100. In general fineness modulus is defined as size of aggregate.

RESULT: The fineness modulus of coarse aggregate is 7.1

IS LIMIT: As per code the fineness modulus of coarse aggregate should range from 5.5-8

HENCE OK

TABLE 8: FINENESS MODULUS OF COARSE AGGREGATE

S I. No	**IS Sieve size**	**Weight retained gm.**	**%weight Retained**	**Cumulative Percentage Weight**
1	40	0	0	0
2	20 mm	35	6	6
3	10 mm	14	3	1
4	4.75	0	0	100
5	2.36	0	0	100
6	1.18	0	0	100
7	600	0	0	100
8	300	0	0	100
9	150	0	0	100
	-			763

Fineness Modulus = 763/100 = 7.63

TABLE 9: PHYSICAL PROPERTIES OF COARSE AGGREGATE

PHYSICAL PROPERTY TESTED	IS SPECIFICATIONS	RESULTS OBTAINED
Specific gravity test	2.6-2.7	2.62
Fineness modulus	5.5-8	7.63

PROCEDURE FOLLOWED

MIXING:

Thorough mixing is essential for the production of uniform, high quality concrete. For this reason equipment and methods should be capable of effectively mixing concrete materials containing the largest specified aggregate to produce uniform mixtures of the lowest slump practical for the work. A concrete mixer is used for this purpose

GEOPOLYMER CONCRETE MIXING:

The primary difference between Geopolymer concrete and Portland cement concrete is the binder. The silicon and aluminum oxides in the low -calcium fly-ash reacts with the alkaline liquid to from the geopolymer paste that binds the loose coarse and fine aggregates and other unreacted materials to form the geopolymer concrete.

The Sodium Hydroxide flakes are to be dissolved in distilled water in correct quantities depending upon the molarity required for each mix design. This NaOH solution is to be mixed and prepared 24hours prior to use. The fly ash, coarse aggregate and fine aggregates are first mixed together in the mixer for three minutes or until the dry materials are thoroughly mixed together. The Sodium Hydroxide and Sodium Silicate solutions are mixed together along with the super plasticizer and water and then added to the dry materials in the mixer. The entire mixture is allowed to mix for four minutes. The fresh concrete is to be tested for slump in a slump cone apparatus which has been properly greased and fitted.

CASTING:

GPC SPECIMENS:

After the sample has been mixed and tested for slump, fill the beam moulds after applying grease to all the faces. The concrete is to be poured in three layers and compacted with manual strokes by applying twenty-five blows to each layer with the help of a tamping rod. While finishing off the surface of the concrete, if the mould is too full the excess concrete should not be removed by scraping off the top surface as this takes off the cement paste that has come on to the top and leaves the concrete short of cement. The correct way is to use a corner of trowel and dig out a fair sample of the concrete as a whole, then finish the surface by trowelling.

OPC SPECIMENS:

After the sample has been mixed and tested for slump, fill the beam moulds after applying grease to all the faces. The concrete is to be poured in three layers and compacted with manual strokes by applying twenty-five blows to each layer with the help of a tamping rod. While finishing off the surface of the concrete, if the mould is too full the excess concrete should not be removed by scraping off the top surface as this takes off the cement paste that has come on to the top and leaves the concrete short of cement. The correct way is to use a corner of trowel and dig out a fair sample of the concrete as a whole, then finish the surface by trowelling.

DEMOULDING:

The Conventional concrete beams should be demoulded between 20-24 hours after they have been made. The Geopolymer concrete beams are to be demoulded after appropriate heat curing has taken place. When removing the cube from the mould, take the mould apart completely. Take care not to damage beam because if any cracking is caused, the compressive strength may be reduced.

After demoulding, each beam should be marked with legible identification on top or bottom using a waterproof crayon or ink. The mould must be thoroughly cleaned after demoulding and ensure that grease or dirt does not collect between the flanges, otherwise the two halves will not fit properly and there will be leakage through the joint and an irregularly shaped beam may result.

CURING:

Care must be taken to properly cure concrete, to achieve best strength and hardness, during this period concrete must be kept under controlled temperature and humid atmosphere. Properly curing concrete leads to increased strength and lower permeability and avoids cracking where the surface dries out prematurely. Improper curing can cause scaling, reduced strength, poor abrasion resistance and cracking

CURING OF GPC SPECIMENS:

After the Geopolymer concrete moulds are casted, the specimens are cured at a temperature of 60°C for 24hours. Two types of curing were applied, Heat curing and Ambient curing. For heat curing, the specimens were covered with a polythene sheet and cured in an oven and for Ambient curing the specimens were left to air for desires period. The heat cured specimens were left to air-dry in the laboratory for another 24hours or until testing.

It is to be noted that the specimens are still in their moulds during the 24hours period of Heat curing. The specimens can be demoulded, after heat curing, and left for Ambient curing.

CURING OF NORMAL CONCRETE SPECIMENS:

The beams must be cured before they are tested. The cubes should be placed immediately after demoulding in the curing tank. The curing temperature of the water in the curing tank should be maintained at 27-30°C. Curing should be continued for 28 days or up to the time of testing. In order to allow satisfactory circulation of water, adequate space should be provided between the beams, and between the beams and the side of the tank.

TESTING

The beam specimens are to be tested for compressive strength in the Compressive Testing Machine (CTM) and then tested for Corrosion in Open Circuit Potential Method

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.

Open circuit potential is also known as open circuit voltage (OCV).

ANALYSIS & DISCUSSION OF RESULTS

Based the Experimental investigations carried out on Ordinary, Standard & High strength geopolymer concrete & Conventional concrete (OPC), the compressive strength results are presented in the following tables

Table 12: Test results of Portland cement concrete mixtures

GRADE OF CONCRETE	M20	M40
compressive strength (7 days curing)n/mm2	18.55	33.77
compressive strength (28 days curing)n/mm2	23.77	43.55
Workability (slump)	Very stiff	High

Table 13: Test results of fly ash-based Geopolymer concrete mixtures

GRADE OF CONCRETE	G20	G40
compressive strength (7 days curing)n/mm2	27.55	40.88
compressive strength (28 days curing)n/mm2	29.25	45.77
Workability (slump)	High	high

OPC TEST RESULTS

ASTM C 876-91 specifies the OPC values and corresponding corrosion conditions are given in the table.

TABLE 14: CORROSION CONDITION (ASTM C 876-1991)

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(mV vs SCE)	(mV vs CSE)	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)

The test results obtained were compared with the values given by ASTM C 876-91 standards and the probability of reinforcement corrosion is predicted.

From the table, it can be observed that GPC behaves in a better manner comparing with OPC for the same chloride solution.

TABLE 15 : CORROSION PROBABILITY

SET	Cement type	Specimen no.	Average open circuit potential	Corrosion condition
1	OPC	M20	-89	Intermediate
	OPC	M40	-122	Intermediate
2	GPC	G20	-84	Intermediate
	GPC	G40	-105	Intermediate

The effect of corrosion on the tensile behaviour 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.

TABLE 16: RESULTS OF TENSION TEST

Set	Cement Type	Specimen no.	Yield stress with corrosion	Ultimate stress with corrosi	Yield stress without corrosi	Ultimate stress without
1	OPC	M20	394.26	471.85	426	492.86
		M40	398.13	479.89	426	492.86
2	GPC	G20	402.96	476.94	426	492.86
		G40	406.29	481.58	426	492.86

The table shows the influence of chloride content on OPC and GPC in the potential values which is the indication of corrosion. At all concentrations, GPC perform superior to OPC.

CONCLUSION:

1. Geopolymer concrete behaves similar to OPC concrete.
2. Water to geopolymer solids ratio and alkaline liquid to fly-ash ratio are the governing factors for the development of geopolymer concrete.
3. The performance of geopolymer reinforced concrete beams exposed to chloride environment is superior to OPC reinforced concrete beams.
4. As the grade of concrete increases the corrosion resistance also increases; for both OPC and GP concrete.
5. Yield stress and ultimate stress values for OPC and GPC decreases with respect to unexposed reinforced bar.
6. The effect of corrosion on the tensile behaviour of reinforcement under different rates of corrosion is compared. There is not much noticeable change in the yield strength.

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