

STUDIES ON THE BEHAVIOUR OF LOW CALCIUM FLYASH AND SLAG BASED GEOPOLYMER CONCRETE UNDER SEA WATER

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ABSTRACT

Durability is a major concern for concrete, therefore initiatives are needed to improve the durability of concrete. Inorganic cements have many advantages over Portland cement including energy efficiency, reduced greenhouse gas emissions, rapid strength gain, and improved temperature resistance. Alkali activated cements made from waste materials such as fly ash and GGBS are particularly advantageous because of their environmental sustainability. The main objective of this paper is to study the behaviour of low calcium flyash and slag based geopolymer concrete under sea water of M30 and M50 which are designated as G30 and G50 grades respectively. The alkaline solution used for the present study is combination of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH), the ratio of Na_2SiO_3 to NaOH is 2.5 and SiO_2 to Na_2O is 2, since the strength is maximum at these ratios. The test specimens were cast and after one day rest period, half of the specimens were cured in an oven at 60°C for 24 hours and the remaining period cured in sun light until the testing is done and remaining half of the specimens were ambient cured. After 28 days the specimens were immersed in sea water for 30, 60 and 90 days then tested on 30th, 60th and 90th day according to codal procedures and the results are compared with the controlled concrete. From the test results it is observed that the geopolymer concrete has high resistance to sea water than controlled concrete.

Keywords: Fly Ash, Geopolymer Concrete, GGBS, Oven Curing, Ambient Curing and Sea Water

I. INTRODUCTION

Concrete may endure many different types of attacks like fully immersed in seawater or under wetting-drying cycles for an extended time. Seawater normally has 3.5% dissolved salts comprising of sodium chloride, magnesium chloride, calcium chloride, potassium chloride and sodium sulphate. Sulphate ions cause a common attack on cement paste by promoting chemical reactions that result in expansion, cracking and spalling. Although the exact mechanism remains unclear, a reaction between the sodium sulphate (Na_2SO_4) with portlandite (CH), monosulphate and unreacted C3A, forms gypsum (CSH) and ettringite ($\text{C}_6\text{AS}_3\text{H}_{32}$) (Bassouni and Nehdi, 2009). It was found that softening, erosion and loss of concrete constituents in continuous immersion is more dominant than expansion due to the ettringite formation. This unfavorable condition could lead to concrete deterioration such as erosion of concrete cover, salt crystallization and expansion in the concrete pores (Liu, 1991). Surface degradation in the

presence of salts and a temperature difference in continuous immersion and wetting-drying exposure of seawater environments increases the concrete porosity and affect the overall durability. Geo-polymer materials represent an innovative technology that is generating huge amount of interest in the construction industry considering sustainable material. The geo-polymer concrete is a new technology, the name “Geo-polymer” was coined by Prof. J. Davidovits in 1978 and he found that the polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in 3D polymeric chain and ring structure consisting of Si-O-Al-O bonds. The main concept behind this geopolymer is the polymerization of the Si-O-Al-O bond which develops when Al-Si source materials like Fly ash, GGBS or rice husk is mixed with alkaline activating solution (NaOH or KOH solution with Na₂SiO₃ or K₂SiO₃). The geopolymer can be in the form of -Si-O-Al-O- or -Si-O-Al-O-Si-O- or -Si-O-Al-O-Si-O-Si-O-. The geopolymer concrete could resist synthetic seawater without strength degradation and significant weight loss (Fernandez-Jimenez et al. 2007). The purpose of this paper is to study the behaviour of low calcium flyash and slag based geopolymer concrete under sea water of M30 and M50 which are designated as G30 and G50 grades respectively. The change in compressive strength and weight for specimens undergoing continuous immersion in sea water of controlled and geopolymer concrete are evaluated. Acid Durability Factors (ADFs) and Acid Attack Factors (AAFs) of controlled and geopolymer concrete under sea water are also evaluated to determine their resistance to sea water.

II. MATERIALS

2.1 Ordinary Portland Cement

In the experimental investigations, 53-grade of ordinary Portland cement of Ultra-tech Brand is used. The cement thus procured was tested for physical properties in accordance with the IS: 4031-1968 and found to be conforming various specifications of IS 12629-1987.

Table-1: Chemical Composition of Cement (Source: www.cement.org)

S.NO.	Constituent	Percentage
1	Cao	63.70
2	SiO ₂	22.00
3	Al ₂ O ₃	4.25
4	Fe ₂ O ₃	3.40
5	MgO	1.50
6	SO ₃	1.95

Table 2: Physical Properties of Ordinary Portland Cement of 53 Grade

S.No	Characteristics /Properties	Test Results	Requirements as per IS 12269-1987
1	Normal consistency	33%	----
2	Specific gravity	3.01	3.0 to 3.2
3	Setting time		
	Initial setting time	35 min	Not less than 30 minutes
	Final setting time	550 min	Not more than 600 minutes.
4	Soundness-Lechatlier method	1.55	Not more than 10 mm
5	Fineness of cement by sieving through sieve No.9(90 microns) for a period of 15 minutes	4%	<10%
6	Compressive strength at 28 days	55	----

2.2 Fine Aggregate

In the present investigation, fine aggregate used is obtained from local sources. The sand is made free from clay matter, silt, and organic impurities and sieved on 4.75mm IS sieve. The physical properties of fine aggregate like specific gravity, bulk density, gradation and fineness modulus are tested in accordance with IS: 2386 and the results are shown in table 3, 4 and 5. Grain size distribution of sand shows it is close to Zone II of IS 383-1970.

Table 3: Physical Properties of Fine Aggregate

S.No	Properties	Test Results
1	Specific Gravity	2.63
2	Bulk Density	Loose
		1597 Kg/m ³
		Compacted
		1725 Kg/m ³

Table 4: Sieve Analysis of Fine Aggregate

Quantity of fine aggregate for sieve analysis = 1000gms

S.No	IS Sieve No	Weight Retained (gm)	Percentage Weight Retained	Cumulative Percentage Weight retained	Percentage Weight passed
1	40mm	0	0	0	100
2	20mm	0	0	0	100
3	10mm	0	0	0	100
4	4.75mm	3.5	0.35	0.35	99.65
5	2.36mm	15	1.5	1.85	98.15
6	1.18mm	96	9.6	11.45	88.55
7	600μ	430	43	54.45	45.55
8	300μ	420.5	42.05	96.5	3.5
9	150μ	35	3.5	100	0
Total				264.6	

Fineness modulus of fine aggregate = Cumulative percentage retained/100

$$= 264.6/100 = 2.65$$

Table 5: IS Grading Requirements for Fine Aggregate

Sieve	Percentage by weight passing sieves IS:383-1970			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10mm	100	100	100	100
4.75mm	90-100	90-100	90-100	95-100
2.36mm	60-95	75-90	85-100	95-100
1.18mm	30-70	55-90	75-100	90-100
600μ	15-34	35-59	60-79	80-100
300μ	5-20	8-30	12-40	15-50
150μ	0-10*	0-10*	0-10*	0-10*

* For crushed stone sand the permissible limit is increased to 20%

2.3 Coarse Aggregate

The crushed angular aggregate of 20mm maximum size obtained from the local crushing plants is used as coarse aggregate in the present study. The physical properties of coarse aggregate such as specific gravity, bulk density, flakiness and elongation index are tested in accordance with IS: 2386-1963. The results of coarse aggregate are shown in the table 6. The presence of elongated and flaky particles is 20% and 16.47% of the weight of the coarse aggregate. This shows that the coarse aggregate used in the concrete mixes is considered desirable as the indices are within 10-25%.

Table 6: Physical Properties of Coarse Aggregate

S.No	Properties	Test Results
1	Specific Gravity	2.71
2	Bulk Density Kg/m ³	Loose 1597 Kg/m ³
		Compacted 1725 Kg/m ³
3	Elongation Index (%)	20
4	Flakiness Index (%)	16.47

2.4 Fly Ash

In the present study of work, the Class F-fly ash is used, which is obtained from Vijayawada thermal power station in Andhra Pradesh. The specific surface area of fly ash is found to be 4750 cm²/gm by Blain's Permeability Apparatus. The typical composition of fly ash and chemical requirements are shown in table 7 and 8 respectively.

Table 7: Typical Oxide Composition of Fly Ash

S.NO.	Constituent	Percentage
1	CaO(Lime)	0.7-3.6
2	SiO ₂ (Silica)	49-67
3	Al ₂ O ₃ (Alumina)	16-28
4	Fe ₂ O ₃ (iron oxide)	4-10
5	MgO(magnesia)	0.3-2.6
6	SO ₃ (Sulphur trioxide)	0.1-1.9
7	Surface area m ² /kg	230-600

Table 8: Chemical Requirement of Fly Ash (IS: 3812-part 1 2003)

S.NO.	Characteristics (Percent by mass)	Minimum Requirement in %	Composition of VTPS fly ash in %
1	$\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$	70	86.75
2	SiO_2	35	54
3	Reactive Silica	20	25
4	MgO	5	7
5	SO_3 (Sulphur trioxide)	3	6
6	Available alkali as sodium oxide (Na_2O)	1.5	2.16
7	Loss of ignition	5	7.23

2.5 Ground Granulated Blast Furnace Slag

Ground Granulated Blast Furnace Slag (GGBS) shown in fig 2 is a by product of the steel industry. Blast furnace slag is defined as “the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace”. About 15% by mass of binders was replaced with GGBS.

Table: 9 Chemical Compositions of GGBS

S.No	Constituent	Percentage
1	Silicon dioxide (SiO ₂)	33.2
2	Alumina tri-oxide (Al ₂ O ₃)	18.3
3	Ferric oxide (Fe ₂ O ₃)	0.6
4	Calcium oxide (CaO)	32.9
5	Magnesium Oxide (MgO)	11.6
6	Sulphur tri-oxide (SO ₃)	1.0
7	Potassium oxide (K ₂ O)	0.91
8	Sodium oxide (Na ₂ O)	0.21
9	Chlorides (Cl)	0.006

Table: 10 Physical Properties of GGBS

S No	Characteristics	Result
1.	Colour	Dull white
2.	Fineness(Blaine's) m ² /kg	450
3.	Specific Gravity	2.91
4.	Glass content percent	93
5.	Bulk Density kg/m ³	1100

2.6 Water

Water free from chemicals, oils and other forms of impurities is to be used for mixing of concrete as per IS: 456:2000.

2.7 Geopolymers

Geopolymers are member of the family of inorganic polymers, and are a chain structures formed on a backbone of Al and Si ions. The chemical composition of this geopolymer material is similar to natural zeolitic materials, but they have amorphous microstructure instead of crystalline (Palomo, Grutzeck et al. 1999; Xu and van Deventer 2000).

2.7.1 Constituents of Geopolymer

2.7.1.1 Source Materials

Any material that contains mostly Silicon (Si) and Aluminium (Al) in amorphous form is a possible source material for the manufacture of geopolymer. Several minerals and industrial by-product materials have been investigated in the past. Low calcium fly ash (ASTM Class F) 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 polymerisation process and alter the microstructure (Gourley 2003). On the nature of the source material, it was stated that the calcined source materials, such as fly ash, slag, calcined kaolin, demonstrated a higher final compressive strength when compared to those made using non-calcined materials, for instance kaolin clay, mine tailings, and naturally occurring minerals (Barbosa, MacKenzie et al. 2000). However, Xu and van Deventer (Xu and van Deventer 2002) found that using a combination of calcined (e.g. fly ash) and non-calcined material (e.g. kaolinite or kaolin clay and albite) resulted in significant improvement in compressive strength and reduction in reaction time. Natural Al-Si minerals have shown the potential to be the source materials for geopolymerisation, although quantitative prediction on the suitability of the specific mineral as the source material is still not available, due to the complexity of the reaction mechanisms involved (Xu and van Deventer 2000). Among the by-product materials, only fly ash and slag have been proved to be the potential source materials for making geopolymers. The other characteristics that influenced the suitability of fly ash to be a source material for geopolymers are the particle size, amorphous content, as well as morphology and the origin of fly ash.

2.7.1.2 Alkaline Activators

The most common alkaline activator used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3) or potassium silicate (Davidovits 1999; Palomo, Grutzeck et al. 1999; Barbosa, MacKenzie et al. 2000; Xu and van Deventer 2000; Swanepoel and Strydom 2002; Xu and van Deventer 2002). The use of a single alkaline activator has been reported (Palomo, Grutzeck et al. 1999; Teixeira-Pinto, Fernandes et al. 2002), Palomo et al (1999) concluded that the type of activator plays an important role in the polymerisation process. Reactions occur at a high rate when the alkaline activator contains soluble silicate, either sodium or potassium silicate, compared to the use of only alkaline hydroxides.

Xu and van Deventer (2000) confirmed that the addition of sodium silicate solution to the sodium hydroxide solution as the alkaline activator enhanced the reaction between the source material and the solution. Furthermore, after a study of the geopolymerisation of sixteen natural Al-Si minerals, they found that generally the NaOH solution caused a higher extent of dissolution of minerals than the KOH solution.

2.7.1.3 Superplasticiser

High range water reducing (Master Glenium B233) super plasticizer was used in the mixtures at the rate of 1.5% of fly ash to improve the workability of the fresh geopolymer concrete.

III. EXPERIMENTAL INVESTIGATION

3.1 General

This paper presents experimental data on the behavior of fly ash and slag based geopolymer concrete under sea water of M30 and M50 which are designated as G30 and G50 grades respectively. The alkaline solution used for the present study is combination of sodium silicate (Na₂SiO₃) and sodium hydroxide. The ratio of Na₂SiO₃ to NaOH is 2.5 and SiO₂ to Na₂O is 2.09 has been used since the compressive strength is maximum at these ratios. The cubes of size 100mm×100mm×100mm were cast and after one day rest period, half of the specimens were cured in an oven at 60°C for 24 hours (OC) and the remaining period cured in sun light until the specimens immersed in sea water and remaining half of the specimens were ambient cured (AC). After 28 days the specimens were immersed under sea water for 30, 60 and 90 days then the loss of compressive strengths and weights of both grades of controlled and geopolymer concrete are evaluated on 30th, 60th and 90th day according to codal procedures and the results are compared with the controlled concrete. Acid Durability Factors (ADFs) and Acid Attack Factors (AAFs) of controlled and geopolymer concrete when immersed under sea water are also evaluated to determine their resistance to sea water attack and the obtained results have been studied and compared.

Table 11: Properties of Na₂SiO₃ Solution

Specific gravity	1.57
Molar mass	122.06 gm/mol
Na ₂ O (by mass)	14.35%
SiO ₂ (by mass)	30.00%
Water (by mass)	55.00%
Weight ratio (SiO ₂ to Na ₂ O)	2.09
Molarity ratio	0.97

Table 12: Properties of NaOH

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

Table 13: Composition of artificial sea water as per ASTM D1141

Composition	Concentration, g/lit
Sodium chloride	24.53
Magnesium chloride	5.2
Sodium sulphate	4.09
Calcium chloride	1.16
Potassium chloride	0.695

Table 14: Mix proportions for G30 grade of Geopolymer concrete

Grade of GPC		G30
Fly ash (Kg/m ³)	307.7	362
GGBS (Kg/m ³)	54.3	
Fine Aggregate (Kg/m ³)		682.6
Coarse Aggregate (Kg/m ³)		1184.4

NaOH solids out of 46.54 Kg/m ³ for 12 Molarity concentration in Kg/m ³	16.80
Na ₂ SiO ₃ (Kg/m ³)	116.36
Extra water (Kg/m ³)	20
Super plasticizer (GLENIUM B233)@ 1% (Kg/m ³)	3.62
Ratio of mix proportions	1:1.89:3.27
Liquid/binder ratio	0.45
Workability (mm)	50

Table 15: Mix Proportions of Controlled Concrete Expressed as Equivalent Proportions of GPC

Grade of Concrete	M30
Cement (Kg/m ³)	362
Fine Aggregate (Kg/m ³)	682.6
Coarse Aggregate (Kg/m ³)	1184.4
Super plasticizer (GLENIUM)@1% (Kg/m ³)	3.62
Ratio of mix proportions	1:1.89:3.27
W/C ratio	0.45
Workability (mm)	50

Table 16: Mix Proportions for G50 grade of Geopolymer Concrete

Grade of GPC	G50	
Fly ash (Kg/m ³)	348.5	410

GGBS (Kg/m ³)	61.5	
Fine Aggregate (Kg/m ³)		554.4
Coarse Aggregate (Kg/m ³)		1293.6
NaOH solids out of 46.86 Kg/m ³ For 16 Molarity concentration in Kg/m ³		20.81
Na ₂ SiO ₃ (Kg/m ³)		117.14
Extra water (Kg/m ³)		45
Super plasticizer (GLENIUM)@ 1.5% (Kg/m ³)		6.15
Ratio of mix proportions		1:1.35:3.16
Liquid/binder ratio		0.40
Workability (mm)		50

Table 17: Mix Proportions of OPC Controlled Concrete Expressed as Equivalent Proportions of GPC

Grade of Concrete	M50
Cement (Kg/m ³)	410
Fine Aggregate (Kg/m ³)	554.4
Coarse Aggregate (Kg/m ³)	1293.6
Super plasticizer (GLENIUM)@1.5% Kg/m ³	6.15
Ratio of mix proportions	1:1.35:3.16
W/C ratio	0.40
Workability (mm)	50

3.2 Mixing and Casting of Geopolymer Concrete

Geopolymer concrete can be manufactured by adopting the conventional concrete techniques used in the manufacture of Portland cement concrete. In the laboratory, the fly ash and the aggregates were first mixed together dry in a pan mixer for about three minutes. The alkaline liquid was mixed with the super plasticizer and extra water if any. The liquid component of the mixture was then added to the dry material and the mixing continued usually for another four minutes. The fresh concrete was cast and compacted by the usual methods used in the case of Portland cement concrete. The workability of the fresh concrete was measured by means of the conventional slump test.



Fig. 1 Shows Cubes after Casting

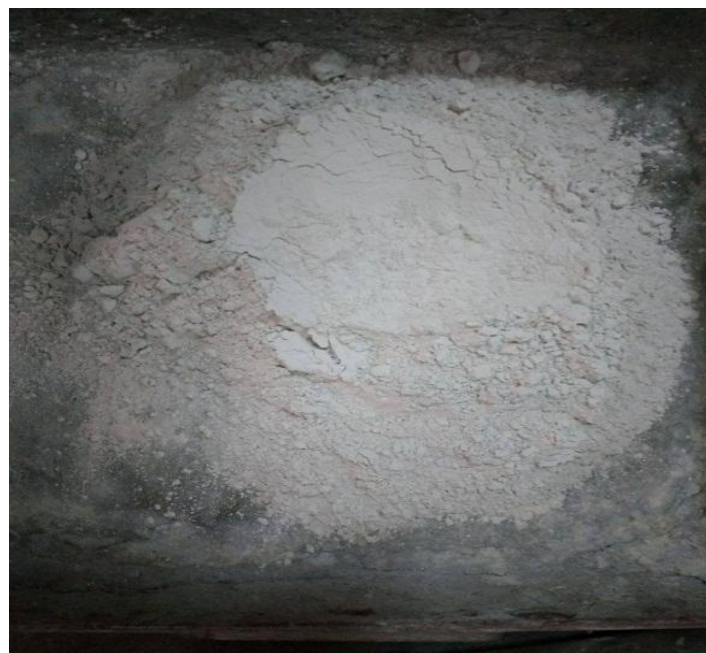


Fig. 2 Shows Ground Granulated Blast Furnace Slag (GGBS)

IV. TEST RESULTS

4.1 Weight Loss and Residual Compressive Strength

The tables 18 & 19 and Figs 3 to 6 shows the weights , percentage loss of weights, compressive strengths and percentage loss of compressive strengths of controlled and geopolymer concrete specimens when immersed under sea water for different curing methods (oven curing (OC), ambient curing (AC) and normal curing (NC)). From the tables and graphs it is observed that as the immersion period increases the percentage loss of compressive strength and weights are increased when immersed under sea water for both the grades.

Table 18: Weight Loss in Percentage of Controlled (M30 & M50) & Geopolymer Concrete (G30 & G50) when immersed in Sea water for different Curing methods

Sl.No.	Type of Concrete		Weights (kg) before Immersion	Immersion Period In Days	Weights (kg) after Immersion in Sea Water	Loss of Weights in Percentage after Immersion in Sea Water
1	M30		2.42	30	2.36	2.49
	G30	Oven Cured	2.22		2.19	1.49
		Ambient Cured	2.23		2.19	1.46
	M50		2.49		2.45	1.41
	G50	Oven Cured	2.29		2.28	0.56
		Ambient Cured	2.30		2.29	0.55
2	M30		2.43	60	2.34	3.55
	G30	Oven Cured	2.23		2.19	1.84
		Ambient Cured	2.24		2.19	1.81
	M50		2.51		2.47	1.72
	G50	Oven Cured	2.30		2.28	1.06
		Ambient Cured	2.29		2.27	1.03

3	M30		2.44	90	2.30	5.57
	G30	Oven Cured	2.22		2.15	3.05
		Ambient Cured	2.23		2.16	3.04
	M50		2.50		2.43	2.87
	G50	Oven Cured	2.31		2.27	1.59
		Ambient Cured	2.29		2.25	1.55

Table 19: Compressive Strength Loss in Percentage of Controlled (M30 & M50) & Geopolymer Concrete (G30 & G50) when immersed in Sea water for different Curing methods

Sl.No.	Type of Concrete	Compressive Strength (MPa) at 28 days before Immersion	Immersion Period In Days	Compressive Strength (MPa) after Immersion in Sea Water	Loss of Compressive Strength in Percentage after Immersion in Sea Water	
1	M30		30	35.35	8.46	
	G30	Oven Cured		38.45	36.15	5.98
		Ambient Cured		37.10	34.89	5.96
	M50			58.42	55.45	5.08
	G50	Oven Cured		59.75	58.04	2.87
		Ambient Cured		58.36	56.71	2.83
2	M30		60	33.85	12.35	
	G30	Oven Cured		38.45	35.23	8.38
		Ambient Cured		37.10	33.99	8.37
	M50			58.42	54.22	7.19

	G50	Oven Cured	59.75		57.76	3.33
		Ambient Cured	58.36		56.43	3.31
3	M30		38.62	90	32.77	15.14
	G30	Oven Cured	38.45		34.51	10.26
		Ambient Cured	37.10		33.32	10.19
	M50		58.42		53.11	9.09
	G50	Oven Cured	59.75		56.31	5.76
		Ambient Cured	58.36		55.02	5.73

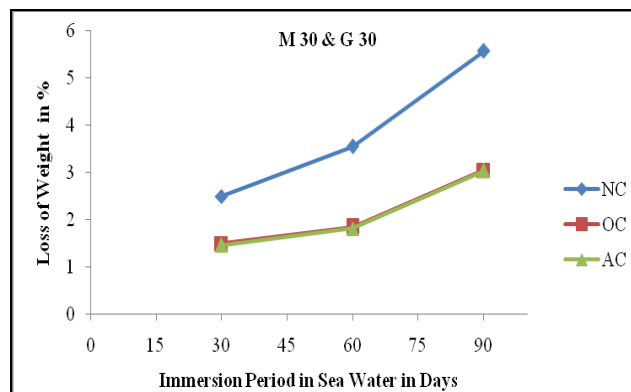


Fig 3: Weight Loss in Percentage of Controlled (M30) & Geopolymer Concrete (G30) when immersed in Sea water for different Curing methods

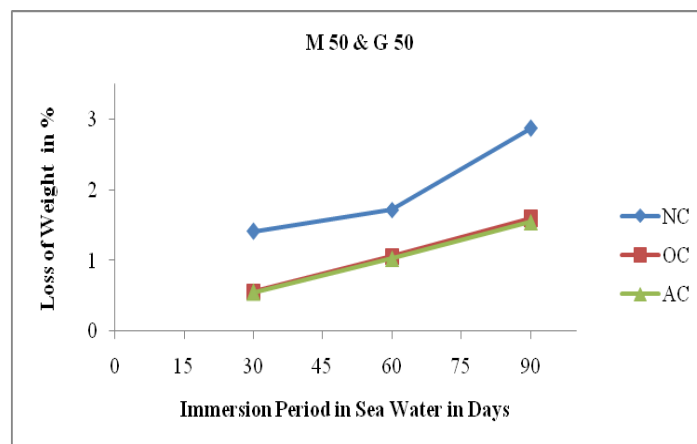


Fig 4: Weight Loss in Percentage of Controlled (M50) & Geopolymer Concrete (G50) when immersed in Sea water for different Curing methods

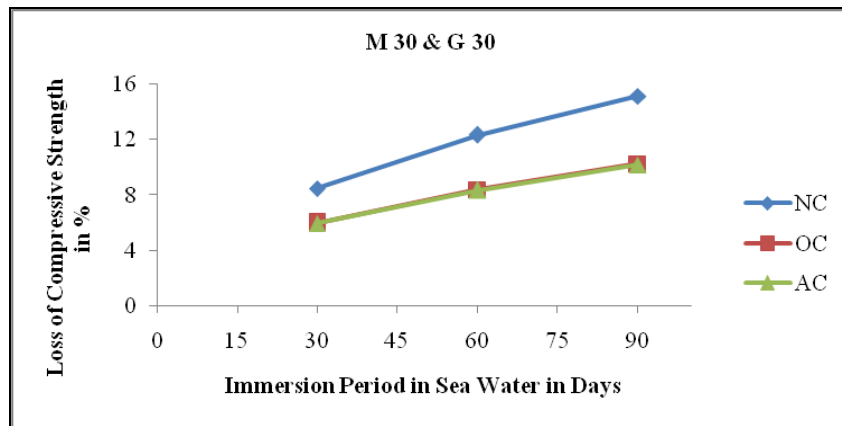


Fig 5: Compressive Strength Loss in Percentage of Controlled (M30) & Geopolymer Concrete (G30) when immersed in Sea water for different Curing methods

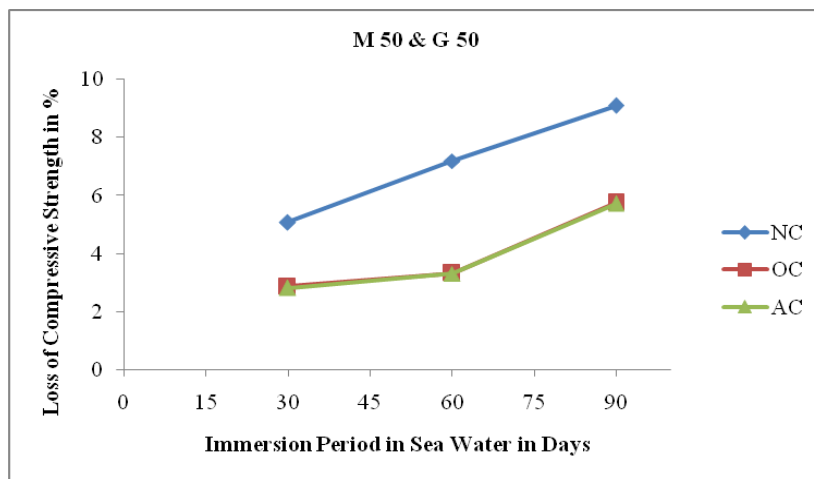


Fig 6: Compressive Strength Loss in Percentage of Controlled (M50) & Geopolymer Concrete (G50) when immersed in Sea water for different Curing methods

4.2 Acid Durability Factors (ADFs) and Acid Attack Factors (AAFs)

4.2.1 Acid Durability Factors

The “Acid Durability Factors” (ADFs) can be designed as follows.

$$ADF = Sr (N/M)$$

where, Sr = relative strength at N days, (%)

N = number of days at which the durability factor is needed.

M = number of days at which the exposure is to be terminated.

Acid attack test was terminated at 90 days. So, M is 90 in this case.

4.2.2 Acid Attack Factors

The extent of deterioration at each corner of the struck face and the opposite face is measured in terms of the solid diagonals (in mm) for each of the two cubes and the “Acid Attack Factors” (AAFs) per face is calculated as follows.

$$AAF = (\text{Loss in mm on eight corners of each of 2 cubes}) / 4$$

The table 20 and Figs 7 to 10 shows the Acid Durability Factors (ADFs) and Acid Attack Factors (AAFs) of controlled and geopolymer concrete specimens when immersed in Sea water for different Curing methods. From the tables and graphs it is observed that the Acid Durability Factors (ADFs) increased, whereas the Acid Attack Factors (AAFs) decreased for geopolymer concrete when it is compared with controlled concrete for both the grades when immersed in Sea water for different Curing methods.

Table 20: Acid Durability Factors (ADFs) and Acid Attack Factors (AAFs) of Controlled (M30 & M50) & Geopolymer Concrete (G30 & G50) specimens when immersed in Sea water for different Curing methods

Sl.No.	Type of Concrete		Immersion Period In Days	Acid Durability Factors (ADFs)	Acid Attack Factors (AAFs)
1	M30		30	30.51	0.09
	G30	Oven Cured		31.34	0.00
		Ambient Cured		31.35	0.00
	M50			31.64	0.08
	G50	Oven Cured		32.38	0.00
		Ambient Cured		32.39	0.00
2	M30		60	58.43	0.25
	G30	Oven Cured		61.08	0.09
		Ambient Cured		61.09	0.09
	M50			61.87	0.20

	G50	Oven Cured		64.45	0.05
		Ambient Cured		64.46	0.05
3	M30		90	84.86	0.44
	G30	Oven Cured		89.74	0.14
		Ambient Cured		89.81	0.14
	M50			90.91	0.34
	G50	Oven Cured		94.24	0.11
		Ambient Cured		94.27	0.11

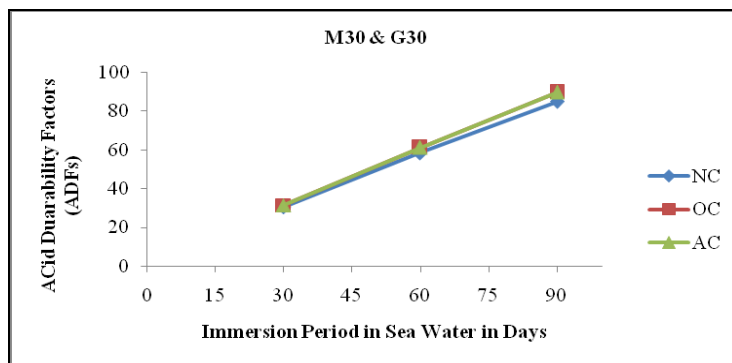


Fig 7: Acid Durability Factors (ADFs) of Controlled (M30) & Geopolymer Concrete (G30) specimens when immersed in Sea water for different Curing methods

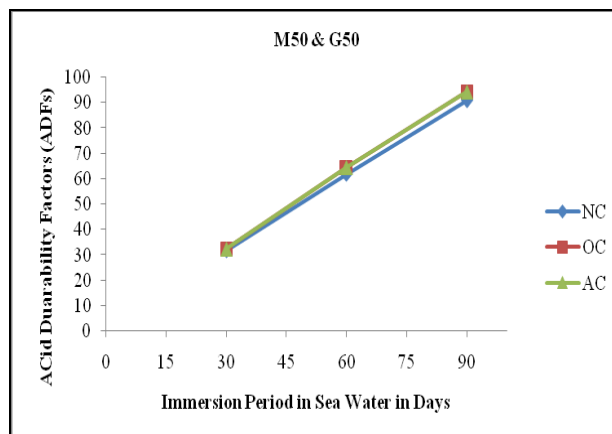


Fig 8: Acid Durability Factors (ADFs) of Controlled (M50) & Geopolymer Concrete (G50) specimens when immersed in Sea water for different Curing methods

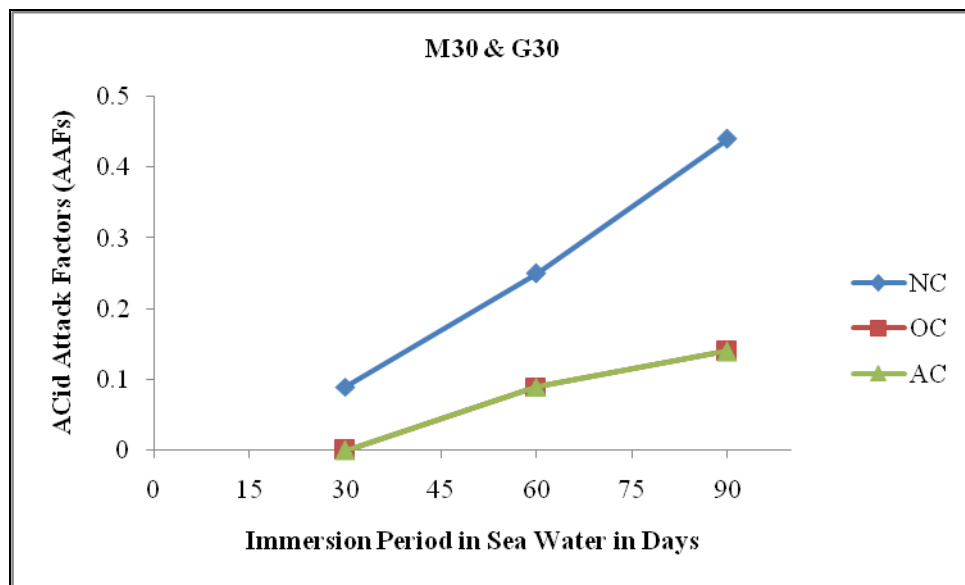


Fig 9: Acid Attack Factors (AAFs) of Controlled (M30) & Geopolymer Concrete (G30) specimens when immersed in Sea water for different Curing methods

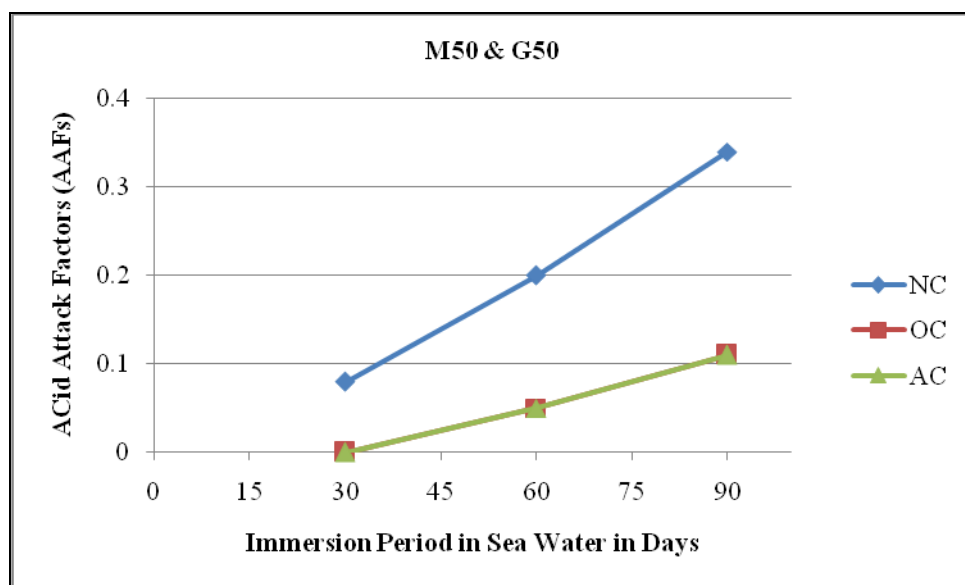


Fig 10: Acid Attack Factors (AAFs) of Controlled (M50) & Geopolymer Concrete (G50) specimens when immersed in Sea water for different Curing methods

V. CONCLUSIONS

The following specific conclusions can be drawn from the present experimental investigation

1. When the specimens are immersed under sea water, the percentage loss of compressive strength and weights are increased as the immersion period increases for both the grades of controlled and geopolymer concrete.

2. The loss of compressive strength of controlled concrete specimens when immersed under sea water is in the range of 5.08 to 15.14%, where as it is about 2.83 to 10.26% in case of geopolymer concrete. Thus, geopolymer concrete is more resistant than controlled concrete.

3. The loss of weight of controlled concrete specimens when immersed under sea water is more than that of geopolymer concrete. Therefore it can be said that geopolymer concrete has more dimension stability than controlled concrete.

4. It can be inferred that geopolymer concrete is more durable in terms of 'Acid Durability Factors' and is less attacked in terms of 'Acid Attack Factors' than controlled concrete at all the ages for both the grades and can perform better in severe aggressive environments due to its high impermeability and alkalinity of concrete mass.

5. It is observed that the loss of compressive strengths and weights are decreased as the grade of concrete is increased in both controlled and geopolymer concrete.

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