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Performance Evaluation of Smart Dynamic Aliminosilicious Composite in Resisting Reinforcement Corrosion Subjected to Aggressive Environment

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Abstract
Reinforcement corrosion is a critical durability issue in concrete structures under aggressive environments. This study examines a Smart Dynamic Aluminosilicious Composite (SDAC) as a protective system for steel reinforcement. SDAC integrates aluminosilicate binders with smart constituents to enhance stability and resist chloride/sulfate ingress. Concrete specimens with SDAC were tested under high-salinity and acidic accelerated corrosion conditions. Results show delayed corrosion initiation, reduced propagation, and improved durability due to its dense, ion-binding matrix. SDAC demonstrates strong potential as a sustainable material for extending reinforced concrete service life in harsh environments.

Keywords: *SDAC Smart Dynamic Aluminosilicious Composite, Ground Granulated Blast Furnace Slag (GGBS), Slump flow test and T50 test, J-ring test, V-funnel test, L-box test, Microstructure test*

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I. INTRODUCTION

Concrete is one of the most widely used construction materials globally, with Ordinary Portland Cement (OPC) serving as its primary binding component. The demand for OPC has been rising steadily, with estimates suggesting an increase from **1.45 billion tons in 2010 to 2.5 billion tons by 2030**. This growing reliance on OPC poses significant environmental challenges.

One of the most pressing concerns is **global warming**, driven largely by the emission of greenhouse gases. Among these gases, **carbon dioxide (CO_2) contributes approximately 60–65% to global warming effects**. The cement industry is a major source of CO_2 emissions, accounting for nearly **10–15% of global CO_2 release** due to the burning of fossil fuels, coal, and other natural resources during production.

While OPC remains indispensable in construction, its environmental footprint has prompted extensive research into sustainable alternatives. Researchers have explored **partial replacement of cement with mineral admixtures** derived from industrial by-products such as:

- **Fly ash**
- **Ground Granulated Blast Furnace Slag (GGBS)**
- **Rice husk ash**

A groundbreaking innovation in this field is **geopolymer concrete**, first introduced by **J. Davidovits**. Unlike conventional concrete, geopolymer concrete is **cement-free** and relies on **aluminosilicate materials** (industrial by-products) activated with alkaline solutions. This approach not only reduces CO_2 emissions but also promotes the recycling of industrial waste, making it a promising sustainable alternative for the construction industry.

In the construction industry, reducing the environmental impacts of Ordinary Portland Cement (OPC) has become a critical priority. One promising solution is the use of **aluminosilicate composites**, commonly referred to as **geopolymer concrete**. This cement-free material belongs to the inorganic polymer family and forms molecular chain structures through **covalent bonding**, achieved by combining mineral admixtures with alkaline activators.

The chemistry of geopolymer concrete is analogous to **zeolite formation**, though it exhibits an **amorphous structure** rather than a crystalline one. A key mineral admixture is **Ground Granulated Blast Furnace Slag (GGBS)**, an industrial by-product rich in silica and alumina. When GGBS reacts with alkaline solutions such as **sodium hydroxide (NaOH)** and **sodium silicate (Na_2SiO_3)**, it develops the binding properties necessary for concrete production.

Key Components

- **Alkaline solutions**: Typically a mixture of NaOH and Na_2SiO_3.
- **Mineral admixtures**:
- GGBS
- Fly ash
- Rice husk ash
- Metakaolin
- Microsilica and nanosilica
- Bagasse ash

1.2 Smart dynamic concrete

During the 1960s, the construction industry in Japan faced significant challenges in concreting structural members. The use of a **high water-to-cement (W/C) ratio** to excessively improve the fresh properties of concrete, combined with **improper compaction practices**, led to poor-quality structures. Rapid construction schedules further aggravated the issue, resulting in inadequate compaction and compromised durability.

Recognizing these problems, **H. Okamura** emphasized the need for a concrete mix with superior fresh properties that could eliminate the requirement for compaction. This led to the development of **Self-Compacting Concrete (SCC)**, and later, its advanced form known as **Smart Dynamic Concrete (SDC)**.

Characteristics of Smart Dynamic Concrete

SDC offers enhanced workability and hardened properties with minimal vibration during placement. Its key features include:

1. **High fluidity**: The flow of fresh SDC is measured between **650–750 mm**.
2. **No vibration required**: Placement does not necessitate external vibration.
3. **Ease of placement**: Fresh SDC can be placed quickly and efficiently.
4. **Elimination of defects**: Issues such as bleeding and segregation are avoided.
5. **Worker safety**: Reduced vibration ensures safer working conditions.

Economic and Practical Benefits

- **Labor cost reduction**: Up to **55% lower labor costs** compared to conventional concreting.
- **Faster placement**: Placement rates can increase by **85%**, improving project efficiency.

Material Innovation

SDC is achieved by using **polycarboxylate-based superplasticizers**, which provide superior dispersion and workability compared to traditional **naphthalene-based polymers**. This advancement ensures better flowability and durability, making SDC a reliable choice for modern construction.

This version organizes your points into **history, characteristics, benefits, and material innovation**, making it clear and professional.

Would you like me to also prepare a **comparative table (Conventional Concrete vs. SCC vs. SDC)** so that the evolution and advantages are visually clear for reports or presentations?

1.3 Chemistry and terminology of geopolymers

During the reaction between GGBS, NaOH and Na2SiO3 poly(sialate) is formed. And this chains with the Si4+ and Al3+ to form the emi-crystalline structures. As this reaction is continuous this leads in formation of 3 polysialates such as:

I. First type - Poly(sialate) type (-Si-O-Al-O),
II. Second type - Poly(sialate-siloxo) type (-Si-O-Al-O-Si-O)
III. third type - Poly(sialate-disiloxo) type (-Si-O-Al-O-Si-O).

II. Objectives

The objectives are as follows:

1. To mix proportion the SDC mix with various Activator ratio (AR) and molarity.
2. To examine the fresh properties and compressive strength of SDC.
3. To study the water absorption of SDC at 24 hours.

4. To examine the weight loss of steel reinforcement by accelerated corrosion test.
5. To study the microstructure of SDC by and Scanning Electron Microscopy
(SEM) Energy-dispersive X-ray spectroscopy (EDS).

III. Material Testing And Methodology

3.1 Introduction

The various experimental tests conducted on SDC is clearly discussed in this chapter. This chapter mainly consists of the different materials, mixing casting and curing of SDC with mix proportioning. SDC is mainly manufactured and tested as per BIS. Different tests such as was conducted on workability, compressive strength, 24 hours water absorption and accelerated corrosion test was performed on SDC by varying

1. Activator ratio – 2 and 4.
2. Fly ash: GGBS – 70: 30 and 80: 20.
3. Molarity – 5M and 10M.

3.2 Materials required for SDC.

The materials used for SDC asre as follows:

1. Ground Granulated Blast Furnace Slag (GGBS).
2. Fly-ash.
3. Sodium hydroxide flakes (NaOH).
4. Sodium silicate solution (Na2SiO3).
5. Fine aggregates.
6. Coarse aggregates.
7. Water.

IV. Experimental Work

4.1 Mix Design of SDC

The SDC was proportionated by considering the density of concrete as there is no standard mix proportion for SDC. The different proportions of different materials are as follows

Table.4.1. Total amount of materials required for 1m3.

	Mix no.	Flyash (kg/m^3)	GGBS (kg/m^3)	Sodium hydroxide (kg/m^3)	Water for NaOH (kg/m^3)	Sodium silicate (kg/m^3)	Fine aggregates (kg/m^3)	Coarse aggregates (kg/m^3)	Extra Water (kg/m^3)	Superplastizer (kg/m^3)
SDC_1 mix	S1	331.03	82.76	11.17	50.90	124.14	900	900	23.62	24.83
	S2	331.03	82.76	19.15	42.92	124.14	900	900	34.00	24.83
SDC_2 mix	S3	331.03	82.76	6.70	30.54	148.97	900	900	32.05	24.83
	S4	331.03	82.76	11.49	25.75	148.97	900	900	38.27	24.83
SDC_3 mix	S5	289.66	124.14	11.17	50.90	124.14	900	900	23.62	24.83
	S6	289.66	124.14	19.15	42.92	124.14	900	900	34.00	24.83
SDC_4 mix	S7	289.66	124.14	6.70	30.54	148.97	900	900	32.05	24.83
	S8	289.66	124.14	11.49	25.75	148.97	900	900	38.27	24.83

4.2 Manufacturing of test specimens

The mixing of SDC is carried out in 2 steps. In 1st step the NaOH is mixed with water as per the required molarity and then it is mixed with Na2SiO3. This mix is kept for 24hours to cool. In 2nd step coarse aggregate, fine aggregate, fly ash and GGBS are mixed and to this mix the liquid from 1st step is added and mixed with water for 5 minutes to achieve a proper mix. After mixing the fresh property of SDC is studied and then the mix is transported to cube moulds and cylindrical moulds with steel reinforcement. These moulds will be demoulded after 24 hours and then the concrete cubes and cylinders were kept for ambient curing.


Fig4.1 Mixing of SDC


Fig4.2 Casting of fresh SDC mix


Fig4.3 Curing of SDC

4.3 Tests on SDC
Fresh property tests
4.3.1 Slump flow test and T50 test
4.3.2 J-ring test
4.3.3 V-funnel test
4.3.4 L-box test
4.3.5 Compressive strength test
4.3.6 24-hour water absorption test
4.3.7 Accelerated corrosion test
4.3.8 Microstructure test

Table 4.2. Range values for flow test and T50 test.

Sl.no	Test	Range values	
		Minimum	Maximum
1	Slump flow test	650mm	800mm
2	T-50 slump flow test	2sec	5sec

Table 4.3. Range values for J-ring test.

Sl.no	Test	Typical ranges of values.	
		Minimum	Maximum
1	J-ring test	0mm	10mm

Table 4.4. Range values for V-funnel test.

Sl.no	Test	Typical ranges of values.	
		Minimum	Maximum
1	V-funnel test	8sec	12sec

Table 4.5. Range values for L-box test.

Sl.no	Test	Typical ranges of values.	
		Minimum	Maximum
1	L-box test	0.8	1.0

Feed Components and composition

V. Results And Discussion

5.1 Fresh Property Test Results.
SDC 1 mix:
In SDC1 mix 20% of GGBS and 80% of low calcium fly ash is used. The molarity of NaOH in this mix are 5 M and 10 M with constant activator ratio of 2.

Table. 5.1.1 Workability test results of SDC1 mix

	MIX NO.	AAR	MOLARITY	FLOW (mm)	T50 (secs)	J Ring (mm)	V FUNNEL (secs)	L BOX
SDC1 MIX	S1	2	5	689	3	6	10	0.8
	S2		10	678	4	6	11	0.8

SDC 2 mix :
In SDC2 mix 20% of GGBS and 80% of low calcium fly ash is used. The molarity of NaOH in this mix are 5 M and 10 M with constant activator ratio of 4.

Table. 5.1.2 Workability test results of SDC2 mix

	MIX NO.	AAR	MOLARITY	FLOW (mm)	T50 (secs)	J Ring (mm)	V FUNNEL (secs)	L BOX
SDC2 MIX	S3	4	5	750	3	5	9	0.85
	S4		10	705	3	6	9	0.85

SDC 3 mix :
In SDC3 mix 30% of GGBS and 70% of low calcium fly ash is used. The molarity of NaOH in this mix are 5 M and 10 M with constant activator ratio of 2.

Table. 5.1.3 Workability test results of SDC3 mix

	MIX NO.	AAR	MOLARITY	FLOW (mm)	T50 (secs)	J Ring (mm)	V FUNNEL (secs)	L BOX
SDC3 MIX	S5	2	5	670	4	9	12	0.95
	S6		10	660	5	10	12	0.95

SDC 4 mix :
In this mix the percentages of fly is 70% and GGBS is 30%, the molarity is 5M and 10M and the alkaline activator ratio is set constant i.e. 4

Table. 5.1.4 Workability test results of SDC4 mix

	MIX NO.	AAR	MOLARITY	FLOW (mm)	T50 (secs)	J Ring (mm)	V FUNNEL (secs)	L BOX
SDC4 MIX	S7	4	5	725	4	8	11	0.9
	S8		10	695	4	9	11	0.9

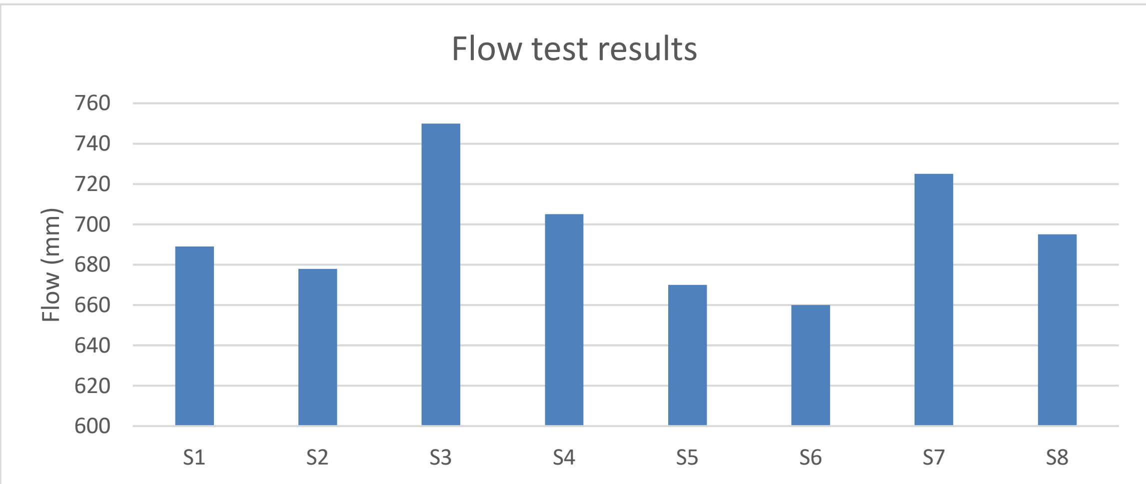

Figure 5.1 Flow test results of SDC mix.

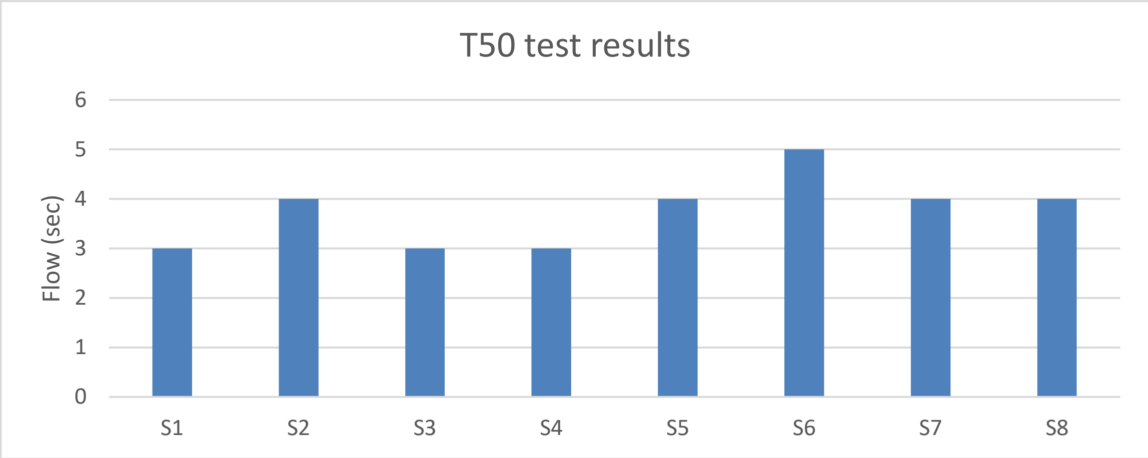

Figure 5.2 T50 test results of SDC mix

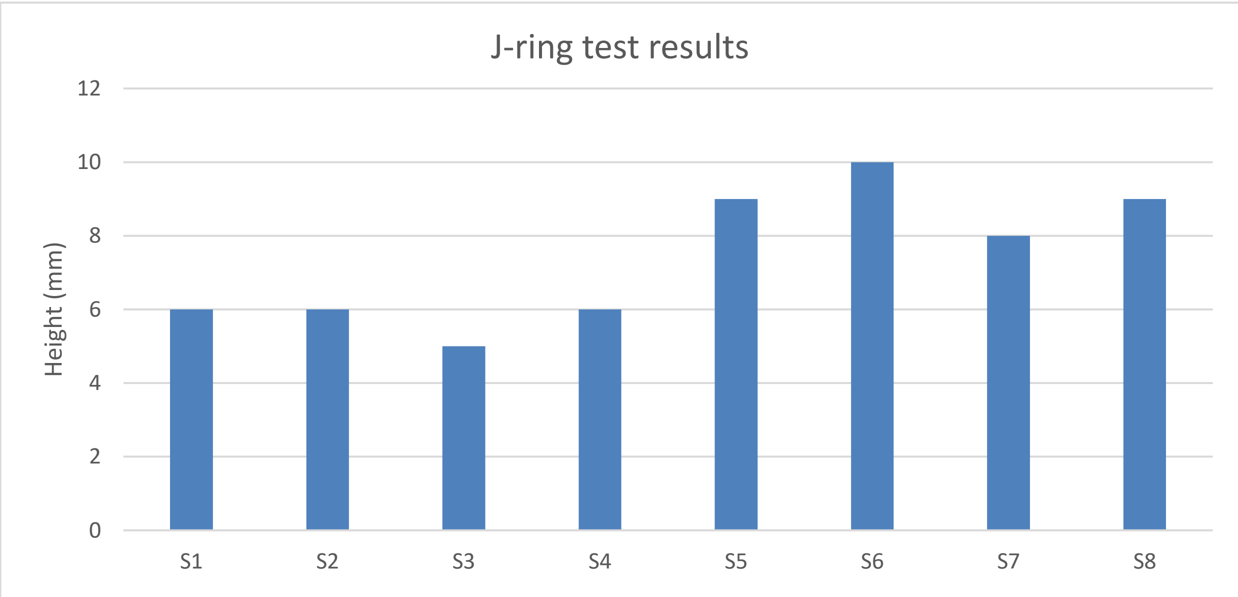

Figure 5.3 J-ring test results of SDC mix

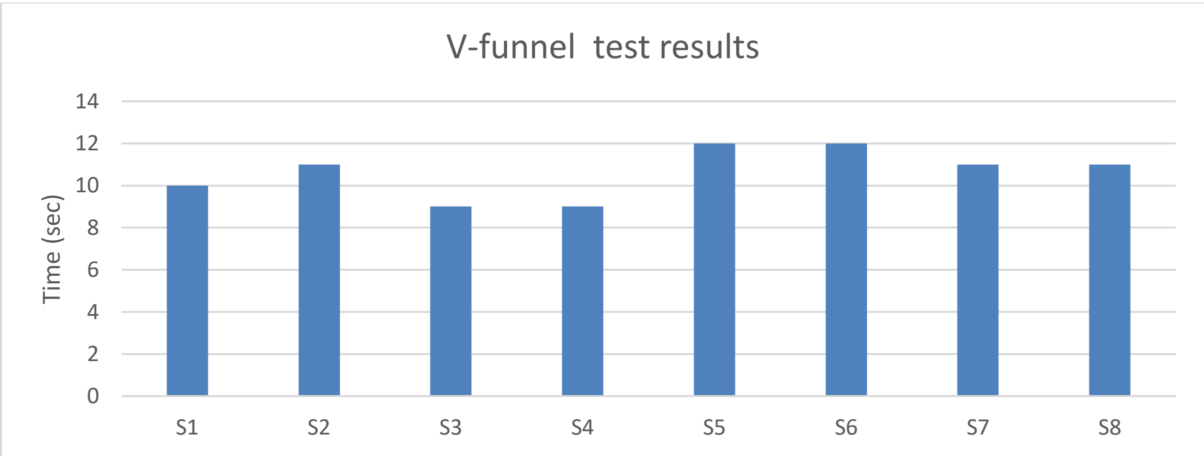

Figure 5.4 V-funnel test results of SDC mix

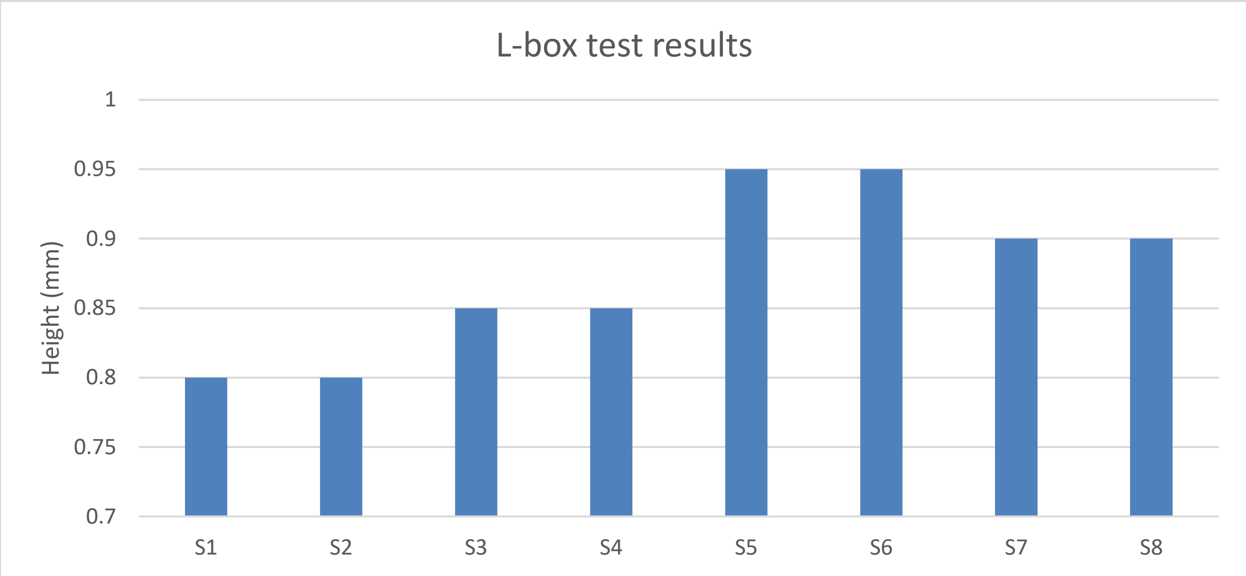

Figure 6.5 L-box test results of SDC

5.2 Compressive Strength Test Results.

SDC 1 mix :
In SDC1 mix 20% of GGBS and 80% of low calcium fly ash is used. The molarity of NaOH in this mix are 5 M and 10 M with constant activator ratio of 2.

Table. 5.2.1 Compressive Strength of SDC1 mix

	Mix no.	AAR	MOLARITY	COMPRESSIVE STRENGTH(MPa)	
GPC 1				7 days	28 days
	G1	2	5	30.00	33.00
	G2		10	36.00	38.00

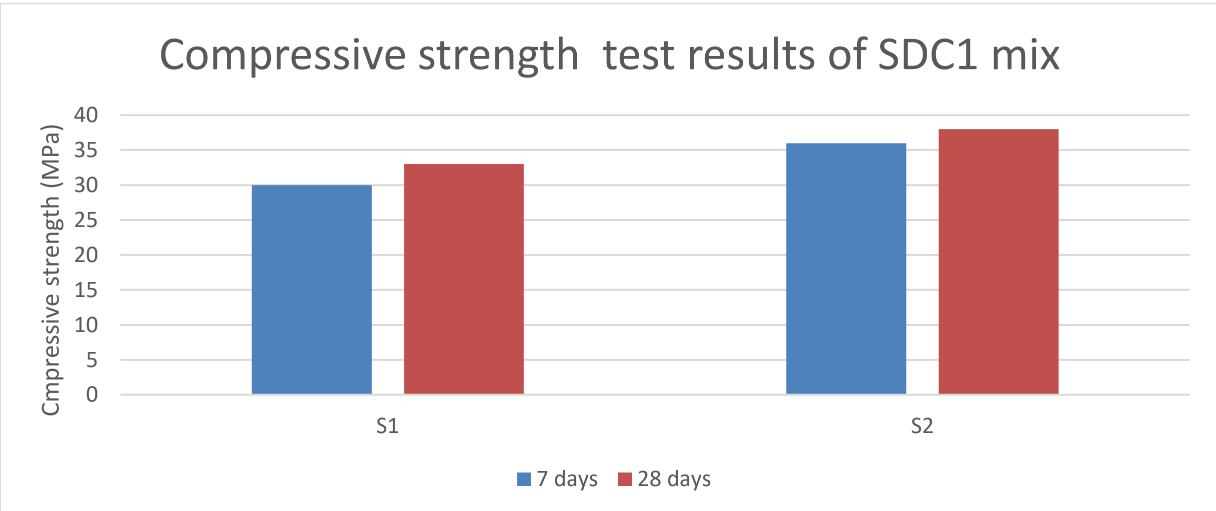

Figure 5.6 Compressive strength test results of SDC1 mix.

SDC 2 mix :
In SDC2 mix 20% of GGBS and 80% of low calcium fly ash is used. The molarity of NaOH in this mix are 5 M and 10 M with constant activator ratio of 4.

Table. 5.2.2 Compressive Strength of SDC2 mix

	MIX NO.	AAR	MOLARITY	COMPRESSIVE STRENGTH(Mpa)	
GPC 2				7 days	28 days
	G3	4	5	34.00	37.00
	G4		10	41.00	46.00

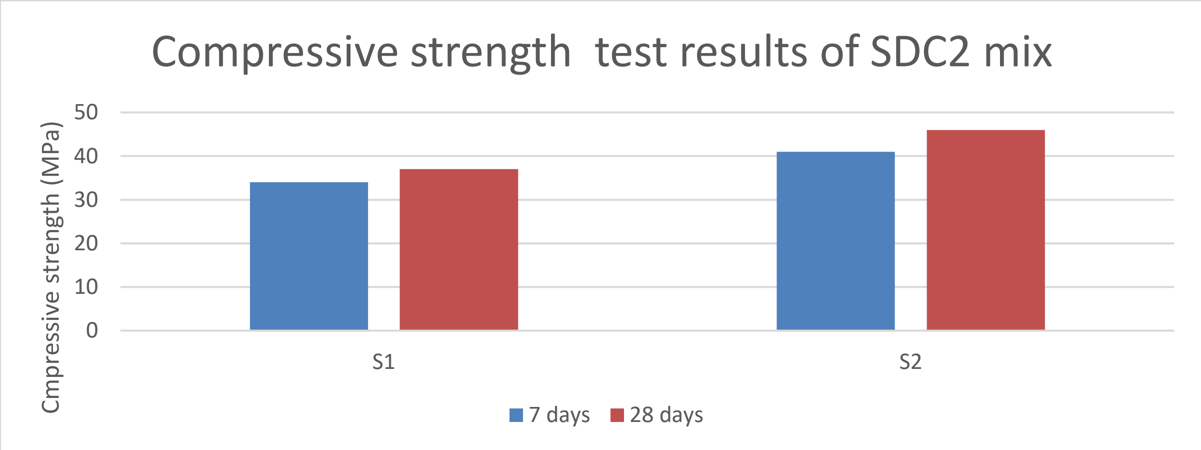

Figure 5.7 Compressive strength test results of SDC2 mix.

SDC 3 mix :

In SDC3 mix 30% of GGBS and 70% of low calcium fly ash is used. The molarity of NaOH in this mix are 5 M and 10 M with constant activator ratio of 2.

Table. 5.2.3 Compressive Strength of SDC3 mix

	MIX NO.	AAR	MOLARITY	COMPRESSIVE STRENGTH	
GPC 3				7 days	28 days
	G5	2	5	38.00	41.00
	G6		10	43.00	48.00

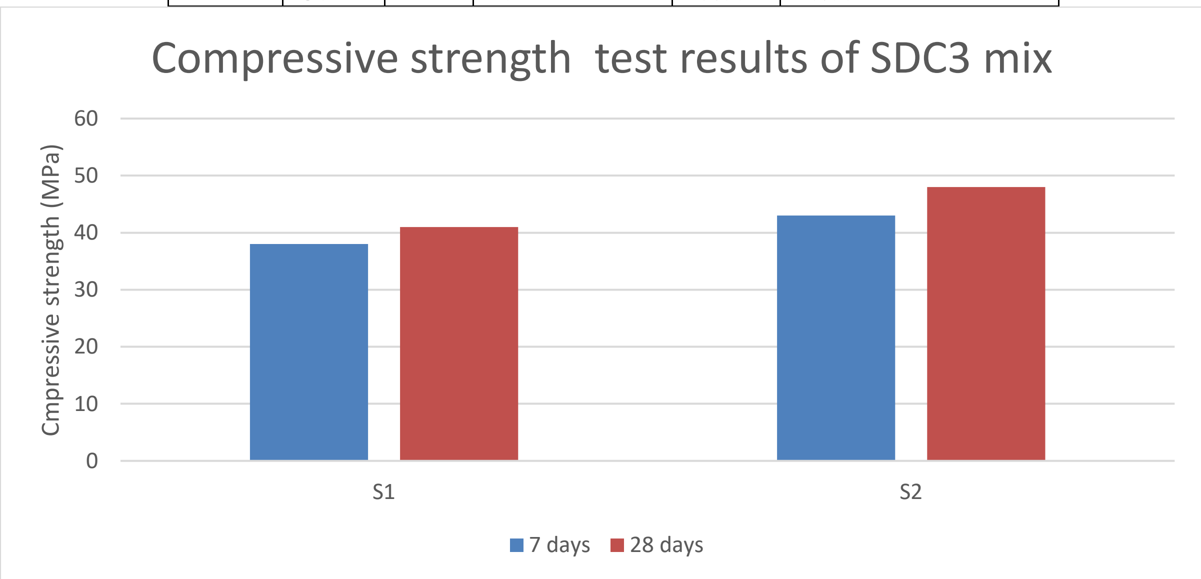

Figure 5.8 Compressive strength test results of SDC3 mix.

SDC 4 mix :

In this mix the percentages of fly is 70% and GGBS is 30%, the molarity is 5M and 10M and the alkaline activator ratio is set constant i.e. 4

Table. 5.2.4 Compressive Strength of SDC3 mix

	MIX NO.	AAR	MOLARITY	COMPRESSIVE STRENGTH(MPa)	
GPC 4				7 days	28 days
	G7	4	5	46.00	51.00
	G8		10	57.00	60.00

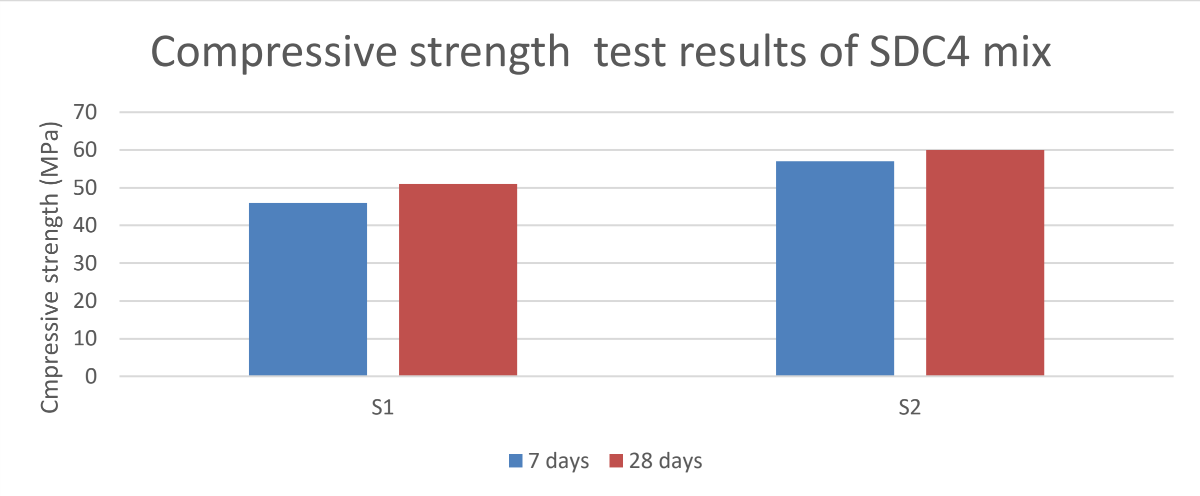

Figure 5.9 Compressive strength test results of SDC4 mix.

5.3 24 hours Water Absorption Test Results

The 24 hours Water Absorption Test Results of hardened SDC mix is shown in Table 5.3.1.

Table.5.3.1 Test results of SDC subjected to 24 hours water absorption.

	Mix no.	Alkaline activator ratio	Molarity	24 HOUR Water (H_20) Absorption			
				Dry weight of specimen (kg)	Density (kg/m^3)	wet weight of specimen (kg)	water absorption percentage (%)
SDC1	S1	2	5	7.909	2343.41	7.855	0.68
	S2	2	10	7.981	2364.74	7.947	0.43
SDC2	S3	4	5	8.022	2376.89	7.991	0.39
	S4	4	10	8.059	2387.85	8.03	0.36
SDC3	S5	2	5	8.084	2395.26	80.56	0.35
	S6	2	10	7.750	2296.30	7.724	0.34
SDC4	S7	4	5	8.101	2400.30	8.079	0.27
	S8	4	10	8.147	2413.93	8.129	0.22

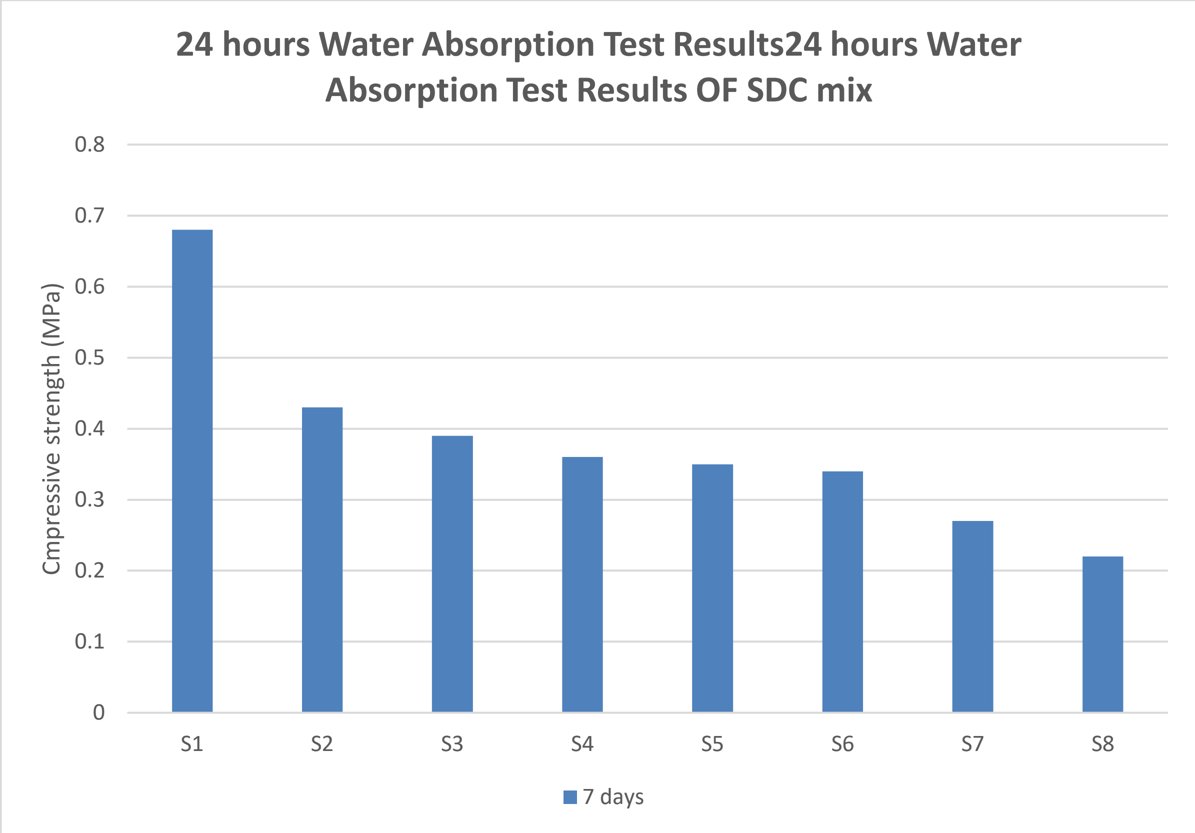

Figure 5.10 24 hours Water Absorption Test Results24 hours Water Absorption Test Results OF SDC mix

5.4 Accelerated Corrosion Test

The SDC test specimens were kept immereded in HCl solution and Na_2SO_4 solution before Accelerated corrosion test was performed on SDC mix and after the test the loss in mass of steel reinforcement were calculate and the results is shown in below table.

Table.5.4.1 Accelerated Corrosion Test Results (Mass loss)

	Mix no.	Alkaline activator ratio	Molarity	Initial weight of reinforcement (kg)	HCl		Na_2SO_4	
					Final weight of reinforcement (kg)	Weight loss (%)	Final weight of reinforcement (kg)	Weight loss (%)
SDC1	S1	2	5	0.245	0.229	6.99	0.238	2.94
	S2	2	10	0.244	0.229	6.55	0.239	2.09
SDC2	S3	4	5	0.243	0.23	5.65	0.239	1.67
	S4	4	10	0.245	2.232	5.6	0.241	1.66
SDC3	S5	2	5	0.244	2.232	5.17	0.242	0.83
	S6	2	10	0.242	0.234	3.42	0.244	0.41
SDC4	S7	4	5	0.245	0.239	2.51	0.244	0.41
	S8	4	10	0.243	0.238	2.1	0.242	0.4

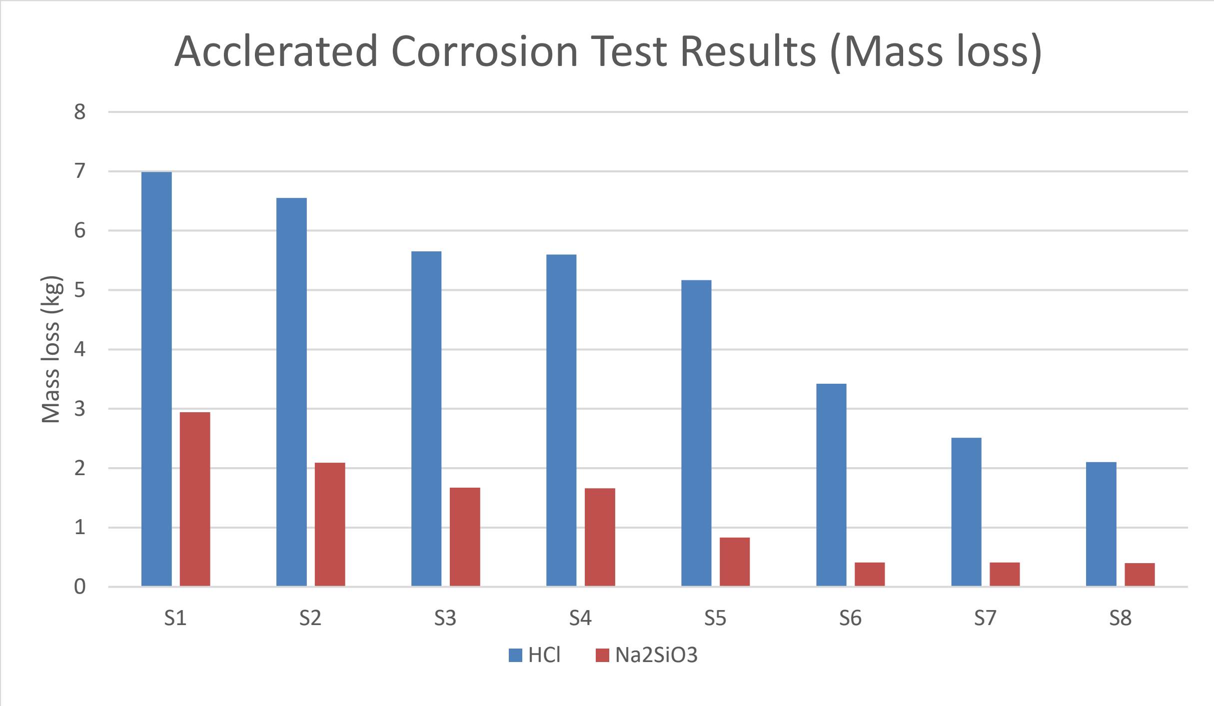

Figure 5.11 Accelerated Corrosion Test Results (Mass loss)

5.5 Microstructure Test Results

From SEM test results is can be seen that SDC mix has:

1. High quantity of fully reacted GGBS and fly ash.
2. Very less partially reacted GGBS.
3. Moderate partially reacted fly ash.
4. No voids.
5. No cracks.
6. No unreacted GGBS and fly ash.

From EDS test results is can be seen that SDC mix has:

1. Sulphur.
2. Potassium.
3. Oxygen.
4. Iron.
5. Sodium.
6. Magnesium.
7. Aluminum.
8. Silicon.
9. Calcium.
10. Manganese.

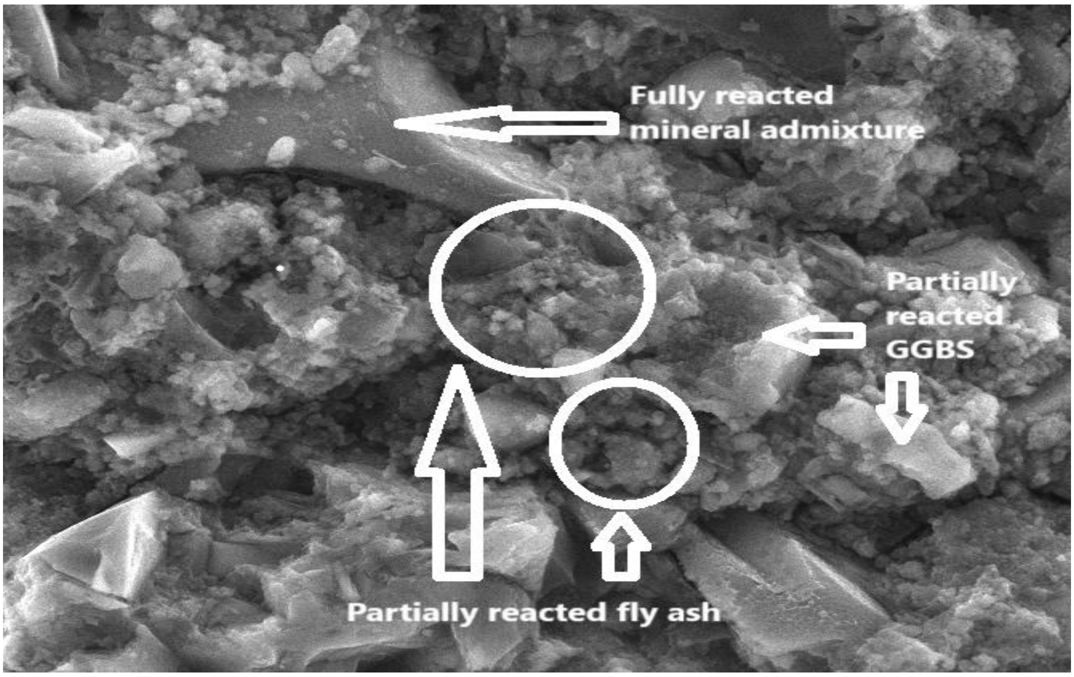

Figure. 5.11 SEM test results of SDC mix.

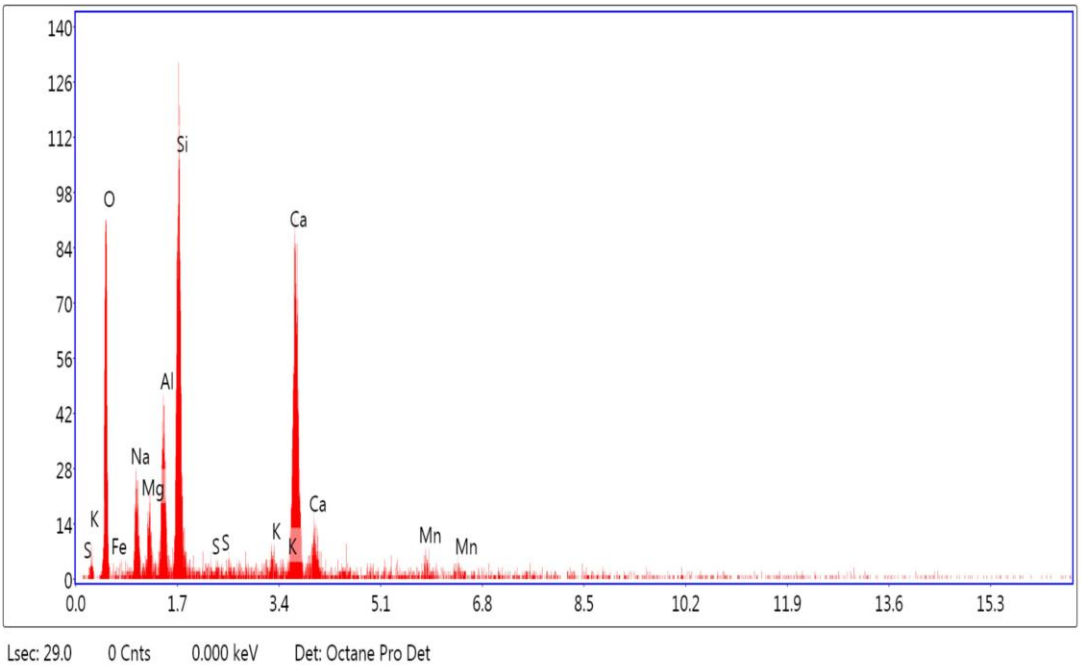

Figure. 5.12 EDS test results of SDC mix.

VI. Conclusions

- SDC mix had density similar to OPC concrete.
- Use of GGBS and Fly ash in SDC proved with better fresh properties and hardened properties.
- The fresh properties of SDC improved with increase in fly ash and decrease in GGBS.
- Increase in activator ratio increased fresh properties.
- Increase in molarity decreased fresh property.
- S3 mix had better workability when compared with respect to other SDC mix.
- Increase in GGBS, molarity and activator ratio increased compressive strength.
- G8 mix had maximum compressive strength of 60 MPa.
- GGBS, molarity and activator ratio with higher dosage not only increase compressive strength but also reduces 24 hours water absorption.

- S8 mix had very less 24 hours water absorption of 0.22%
- The mix with 80% GGBS, 10 M and activator ratio of 4 had very less mass loss due to accelerated corrosion test i.e S8 mix had 0.21% HCl immersion and 0.4% for Na_2SiO_3 immersion.
- SEM test results indicated compact structure with no void and cracks.
- EDS test results indicated all the elements present due to the geopolymerization reaction.
- From test results it can be noted that SDC can be used for construction as a sustainable material of construction instead of OPC concrete.

6.1 Future scope

- Test on other durability properties.
- Test on structural members.
- Test on fiber reinforced SDC.
- Test on other mineral admixture based SDC.
- Test on light weight SDC.

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