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Experimental Investigation on Influence of Binder Constituents on Workability, Strength and Microstructure of SCGC

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Abstract: The present study investigates the influence of bacteria on varying binder constituents to enhance the workability, strength, and microstructure properties of self-consolidating geopolymer concrete (SCGC). Geopolymer concrete is a sustainable alternative to conventional cement-based concrete, as it utilizes industrial by-products and reduces carbon emissions. The bacterial strains, known for their ability to promote mineral precipitation and improve concrete properties, are introduced in varying proportions to the geopolymer binder constituents. The goal of this experimental investigation is to better understand how Bacillus Cohnii bacteria affect the workability and strength of alkali-activated Self-consolidating Concrete (SCC) mix compositions. Three mix formulations with variable binder contents in the range of 400 kg/m3 and 450 kg/m3 were the subject of experimental research. This research work aims on investigating various binder constituents on Strength, Workability and Microstructure. Three different SCGC mixes were prepared by varying the percentage fly ash and Alcofine in range of 0%, 10%, 30% and 0%, 5%, 5% to the quantity of GGBFS respectively. Alcofine increases final setting time. For all mixes, ambient curing was done. As per EFNARC recommendations, the fresh qualities of SCGC were determined using the Slump test, T50 slump test, L-Box test, V- funnel test, and J-ring test. By conducting compression tests, split tensile tests, and flexure tests after 7, 14 and 28 days, the strength characteristics of SCGC were identified. The SCGC's microstructure and chemical composition were both determined by SEM and EDS analyses, respectively. According to test results, an alkaline solution sample with a 13M concentration and 450 kg/m3 of binder produced the highest compressive, flexural, and split tensile strengths after 28 days producing values of 58.32 MPa, 3.5 MPa, and 4.27 MPa, respectively.
Keywords: Fly ash, GGBFS, Alccofine, Geopolymer concrete, Self-compacting, Bacillus Cohnii.

I. INTRODUCTION

Concrete is one of the most widely used construction materials, but its production involves a significant carbon footprint due to the cement binder's high energy consumption and CO2 emissions. In recent years, there has been growing interest in developing sustainable alternatives to traditional cement-based concrete. Geopolymer concrete has emerged as a promising eco-friendly alternative, utilizing industrial by-products or natural materials to create a binder that is environmentally friendly and exhibits favorable mechanical properties. The goal of this experimental investigation is to better understand how Bacillus Cohnii bacteria affect the workability and strength of alkali-activated Self-consolidating Concrete (SCC) mix compositions. The idea of enhancing concrete's strength using a microbiologically produced specific growth or filler is examined in this research. The bacteria Bacillus Cohnii was used in this experiment (5). One of the essential factors in concrete is its workability, which refers to its ability to flow easily and self-compact without the need for external energy. Self-consolidating concrete (SCC) addresses this concern, ensuring excellent workability and reducing the need for vibration during casting. Integrating bacteria in concrete production has gained attention for its potential to enhance various properties of concrete through a process called bacterial concrete mineralization. The objective of this research is to experimentally investigate the influence of bacteria on varying binder constituents in self-consolidating geopolymer concrete. The study aims to analyze the effects of bacteria on workability, strength characteristics and microstructure of the concrete, with the ultimate goal of developing a more sustainable and high-performance construction material.
Utilising SCGC lowers maintenance costs and raises building quality overall [8]. A limited number of SCGC-related studies are currently being done. Superplasticizer addition improves SCGC's workability and strength [9]. SCGC mixes are created in accordance with EFNARC standards [10]. In this experiment, 6 distinct SCGC mixtures were created to examine the effects of differing binder ingredients (400 kg/m3 and 450 kg/m3) and the molarity of NaOH liquid (13M) on the workability and strength characteristics of SCGC.

II. MATERIALS AND METHODOLOGY

A. *Materials Used*

Fly ash (FA), ground granulated blast furnace slag (GGBFS) and alccofine were used in the production of SCGC. Class F fly ash, GGBFS, and alccofine were purchased from Ultratech RMC plant Peenya in Bangalore, Karnataka, India. The chemical and physical characteristics of the components that make up a binder are shown in Tables 1 and 2, respectively. Alkaline activator liquids were purchased and utilised to prepare samples by Panacea Agrochemicals. Na2SiO3 solution with 54% water content and NaOH flakes with a 95% purity. Na2SiO3 solution's characteristics are shown in Table 3. M-sand was used as the fine aggregate, and Ultratech RMC facility Peenya also provided the coarse aggregate, which was divided into pieces of 20 mm while 12.5 mm in a ratio of 60:40. The bacterial agent, typically Bacillus Cohnii will be selected for its ability to induce calcium carbonate precipitation. According to IS 383:2016 [12], tests on coarse aggregate and M-sand were conducted. The results are listed in Table 4. SCGC was prepared using BASF Masterglenium 8233, a polycarboxylic ether-based superplasticizer that complies with IS 9103 [13]. Superplasticizer's properties are shown in Table 5.

Table1. Bacillus Cohnii Bacterium properties (Data source: NCMR, Pune)

NCMR Accession Number	MCC 2819
Taxonomic Designation	Bacillus cohnii
Strain Designation	LAP217
Source of Isolation	Lonar Lake water sample
Medium Name and Number	34C (Alkaline Nutrient Agar)
pH of Medium	10
Temperature of Growth in 0C	28-30
Incubation Period	2 Days
Risk Group	Do not Know
Oxygen Requirement	Aerobic

Table 2: Physical Properties of Binder Constituents (Fly ash, GGBFS and Alccofine)

Properties		Fly ash	GGBFS	Alccofine
Specific Gravity		2.23	2.91	2.45
Fineness m^2/Kg		370	379	2890
Slag Activity Index	7 days	--	71.22	88.7
	28 days	--	98.7	112.5
Lime Reactivity N/mm^2		6.0	--	--
Soundness (%)		0.027	--	--
Residue on 45 micron sieve (%)		16.9	--	--

Table 3: Properties of Na_2SiO_3 solution

Properties	Specifications
Total solids to liquid ratio by mass	49:51
Colour	Colourless
Density	2.5 g/cc

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Table 4: Properties of Fine Aggregate and Coarse Aggregate

Property	Fine Aggregate	Coarse Aggregate	
		20 mm	12.5 mm
Fineness Modulus of Aggregates	2.83	6.28	3.68
Specific Gravity of Material	2.64	2.75	2.68
Water Absorption Capability	1.5%	0.4%	0.4%

Table 5: Properties of Superplasticiser

Performance Test Data	Superplasticicser
Aspect	Dark Brown Liquid
Relative Density	1.12 to 0.01 at 25 ^{0} C
Content of Chloride ions	<0.2 %
pH	>6 at 25 ^{0} C

Table 6: Chemical Properties of Fly ash

Chemical Requirements		SiO2	Na_2O	MgO	SO3	SiO2+Al2 O3 + Fe2O3	Total Chlorides	Loss of Ignition
Content in %		52.72	0.80	1.94	0.23	87.56	0.004	3.2
Requirements as per IS 3812:2013								
Part 1	Siliceous Pulverized Fuel Ash in %	35.0	1.5	5.0	3.0	70.0	0.05	5.0
	Calcareous Pulverized Fuel Ash in %	25.0	1.5	5.0	3.0	50.0	0.05	5.0
Part 2	Siliceous Pulverized Fuel Ash in %	35.0	1.5	5.0	5.0	70.0	0.05	7.0
	Calcareous Pulverized Fuel Ash in %	25.0	1.5	5.0	5.0	50.0	0.05	7.0

Table 7: Chemical Properties of GGBFS and Alccofine

Sl No	Chemical Requirements	Requirements as per IS 16715:2018	Alccofine	GGBFS
1.	Al2O3	--	18.13	17.68
2.	MgO	(Max) 17.0%	7.1	8.3
3.	CaO	--	36.59	38
4.	MnO	(Max) 5.5%	0.42	0.3
5.	SiO2	--	32.44	32.65
6.	SO3	(Max) 3.0%	0.4	0.1

7.	Loss of Ignition	(Max) 3.0%	0.3	0.2
8.	S (Sulphide Sulphur)	(Max) 2.0%	0.5	0.56
9.	Insoluble Residue	(Max) 3.0%		0.2
10.	Glass Content	(Min) 85%	88	98
11.	Moisture Content	(Max) 1.0%	0.2	0.2
12.	(CaO+MgO+Al2O3)/SiO2	(Min) 1.0%	1.93	1.9
13.	Cl (Chloride)	(Max) 0.1%	0.02	0.007

Table 8: Physical Properties of Fly ash

Physical Requirements	Soundness	Lime Reactivity (N/mm2)	Fineness (m2/kg)	Specific Gravity	Residue on 45 Micron Sieve in %
Results	0.032	6.1	371	2.4	17.1
Requirements as per IS 3812:2013					
Part 1	0.8 (Min)	4.5 (Min)	320 (Min)	--	34 9 (Max)
Part 2	0.8 (Max)	--	200 (Min)	--	50 Max)

B. Methodology

1) To assess the physical and chemical properties of M-sand and coarse aggregate as binder ingredients.
2) To determine the amount of ingredients needed by absolute volume technique to prepare SCGC.
3) To create samples of three different mix designs with various binder contents of 400 and 450 kg/m3.
4) To assess the SCGC's new properties using the V-funnel test, L-box test, slump test, and T50 slump test.
5) To determine the results of Strength characteristics by conducting Compression, Split-tensile and Flexural tests for 7, 14 and 28 days.
6) To assess the Micro-structure, Scanning electron microscopy (SEM) and EDS (Energy-Dispersive X-ray Spectroscopy) will be used to examine the microstructure and are advanced techniques commonly used for the analysis of concrete and other materials.

Table 9: SCGC mix identification

Mix Description	Mix ID		
	M1	M2	M3
GGBFS (%)	100	85	65
Fly Ash (%)	0	10	30
Alccofine (%)	0	0	5
Type of Bacteria	Bacillus Cohnii	Bacillus Cohnii	Bacillus Cohnii
Bacteria Cell Concentration (%)	3	3	3

Mix Design

Since there are no set standards for creating mix designs, the self-consolidating geopolymer concrete (SCGC) mixes used in this investigation were developed with reference to prior studies. Superplasticizer and free water were added to SCGC mixtures to make them more workable. By performing the slump flow test and marsh cone test, respectively, it was possible to calculate the amount of free water and superplasticizer that needed to be added to all SCGC mixtures in order to achieve a greater workability. Slump flow test results are shown in Table 10, while marsh cone test results are shown in Figure 1.

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Compression strength tests on 7-day-hardened SCGC cubes were used to estimate the proportion of binder components and molarity of NaOH solution to be used in this investigation. Referring to the preliminary test findings, the mix design used in this study was informed by Nishanth and Dr. Nayana N Patil's research (2022). Details of each SCGC mix's mix design are shown in Table 11.

Table 10: Slump Flow Test Results

Mix ID	S0	S1	S2	S3	S4	S5	S6	S7
% of Free Water	0	2	4	6	8	10	12	14
Slump Flow (mm)	39	156	262	393	480	551	675	811

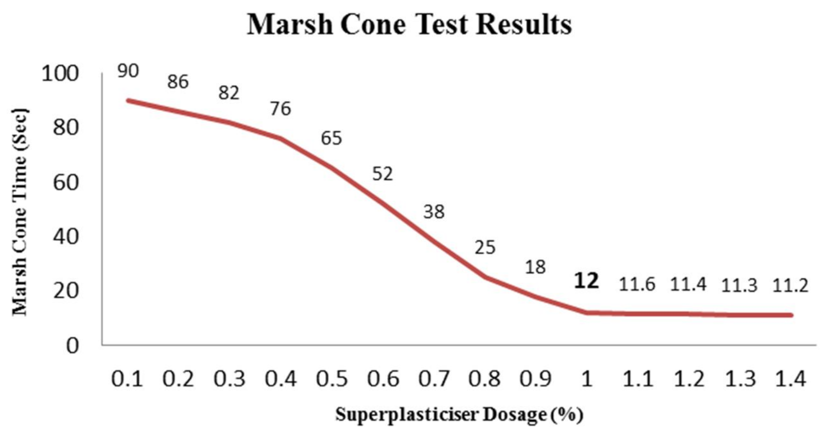

Figure 1: Marsh Cone Test Results

Table 11: Mix Design Details

Mix ID	Molarity	NaoH solids (kg/m^3)	Sodium silicate (kg/m^3)	GGBFS (kg/m^3)	Fly ash (kg/m^3)	Alccofine (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	SP (%)	Extra Water (kg/m^3)
M1	13M	135	135	450	0	292.5	925	925	1	54
M2	13M	135	135	382.5	22.5	135	925	925	1	54
M3	13M	135	135	292.5	22.5	22.5	925	925	1	54

III. TEST RESULTS AND DISCUSSION

A. *Test Results of fresh Concrete*

Self-compacting properties of self-consolidating geopolymer concrete (SCGC) are determined by filling ability, segregation resistance, and passage ability, in accordance with EFNARC recommendations. SCGC should be more workable without sacrificing strong properties. Results of the workability test are shown in Table 12. According to the test findings, SCGC mix without bacteria showed the least amount of slump flow due to increased polymeric reaction brought on by high molar NaOH solution and decreased water content, which hastened concrete hardening. On the other hand, bacteria-containing SCGC mixtures showed improved passing and filling capabilities.

This could be because adding Luria Bertani (LB) broth medium with bacteria caused the water content to rise. The addition of LB broth medium caused the molarity of the NaOH solution to be decreased, delaying the polymeric reaction and lengthening the time it took for the concrete to set.

Compared to previous SCGC mixes, SCGC mix M2, which contained Bacillus Cohnii bacteria, showed outstanding workability features. It should be noted that all SCGC mixes met the requirements of the EFNARC.

Table 11 : Workability Test Results of Fresh SCGC Mixes

Test Parameters	M1	M2	M3	Acceptable Values as per EFNARC Min	Max
Slump Flow (In mm)	692	708	738	650	800
T500mm Slump Flow (In Seconds)	4.9	3.6	2.4	0	5
J-Ring In (mm)	8.2	6.4	4.8	0	10
V-Funnel (In Seconds)	9.74	7.82	5.63	6	12
L-Box Ratio	0.83	0.87	0.96	0.80	1.0

B. Hardened Concrete Test Results

Compression test, Split-tensile test and flexural test were conducted after 7,14 and 28 days as per IS 516-1959 to determine strength characteristics of hardened SCGC mixes. Table 13 represent test results. Figure 2,3 and 4 represent test results graphically. SCGC mix M2 containing Bacillus Cohnii bacteria in cell concentration of 3% of total binder content of gained maximum compressive strength of 58.32 MPa, Split-tensile strength of 4.27 MPa and flexural strength of 3.5 MPa after 28 days of ambient curing. The high strength gain in SCGC mix is due to the development of tetrahedral alumina-silicate structure .This structure is developed due to the formation of geopolymeric gels namely C-S-H, C-A-S-H and N-A-S-H gels. These gels are formed due to exothermic reaction resulting from high CaO content in alccofine and GGBFS. SCGC mix M3 which did not contain bacteria gained least compressive strength of 49.66 MPa, Split-tensile strength of 3.06 MPa and flexural strength of 3.42 MPa after 28 days of ambient curing.

Table 12: 7, 14 and 28 days strength tests results

MIX ID	COMPRESSIVE STRENGTH (MPa)			SPLIT TENSILE STRENGTH (MPa)			FLEXURAL STRENGTH (MPa)		
	7 DAYS	14 DAYS	28 DAYS	7 DAYS	14 DAYS	28 DAYS	7 DAYS	14 DAYS	28 DAYS
M1	46.18	50.93	53.84	3.58	3.69	4.05	3.16	3.27	3.42
M2	49.24	54.19	58.32	3.88	4.03	4.27	3.24	3.34	3.5
M3	41.76	45.84	49.66	2.6	2.79	3.06	3.17	3.31	3.43

1) Compressive Strength

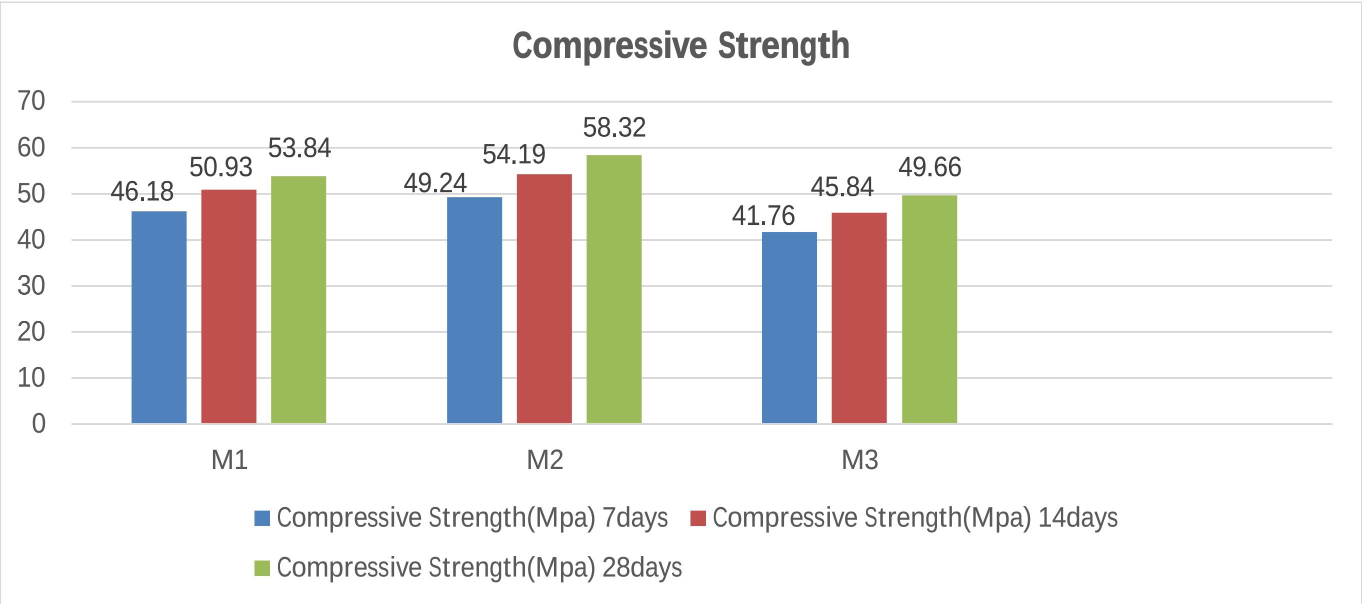

Fig 2 : Compression strength test results

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2) Split Tensile Strength

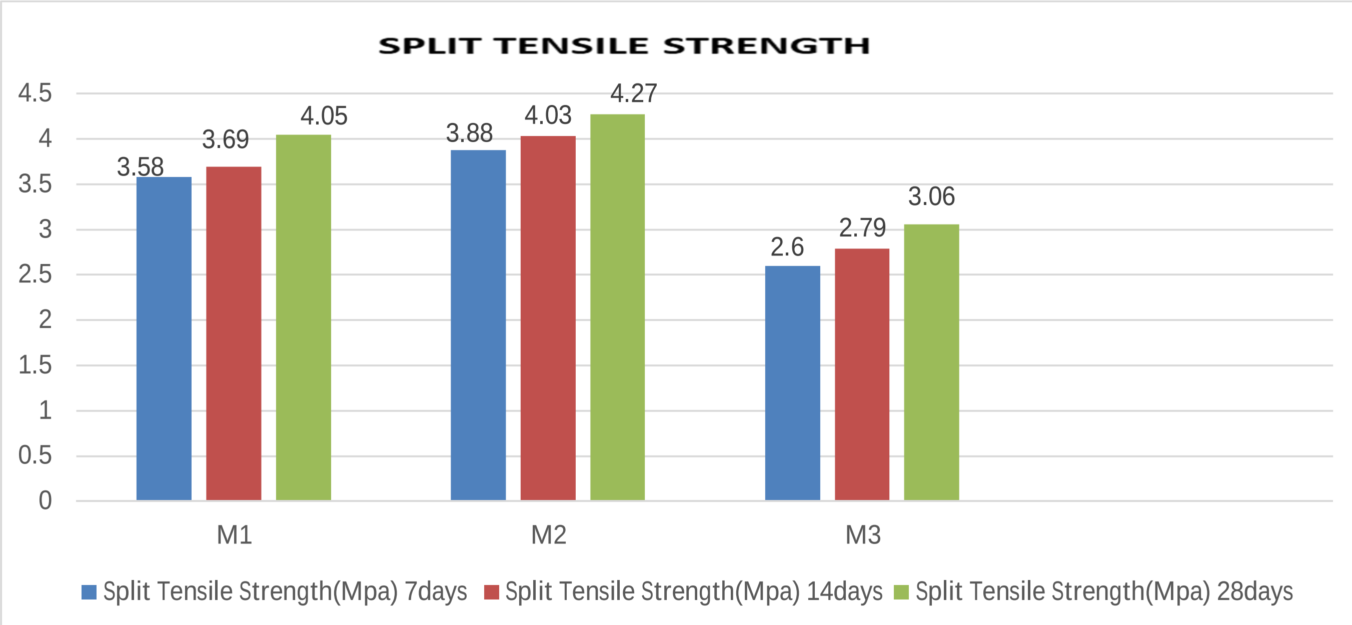

Fig 3: Split-tensile strength test results

3) Flexural Strength

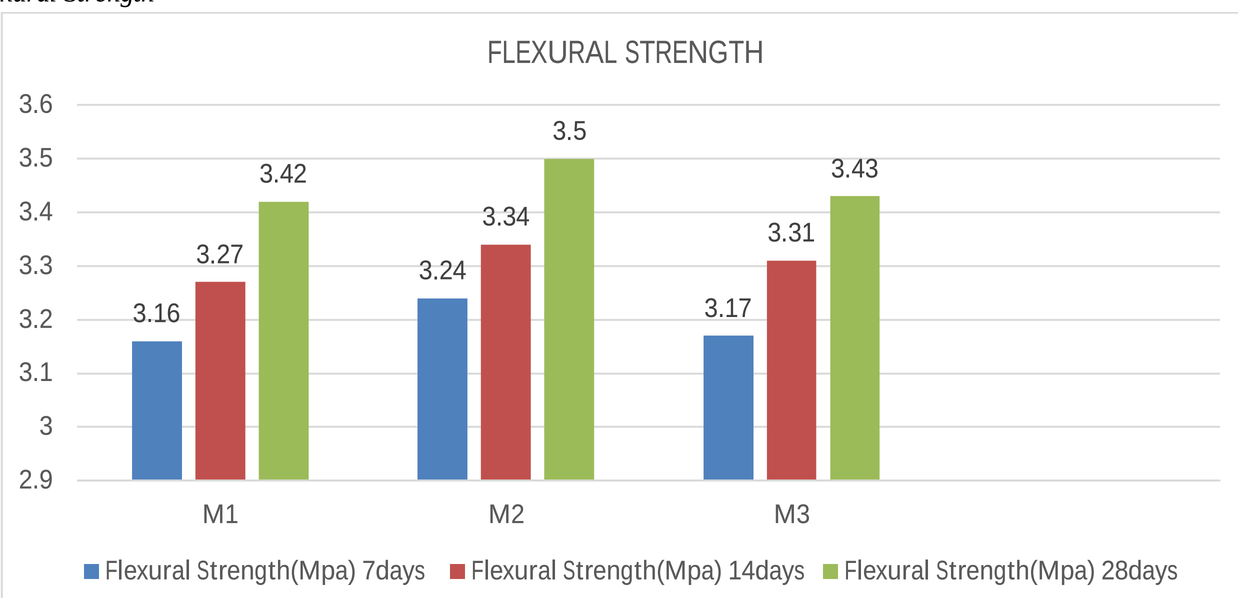

Fig 4: Flexural strength test results

IV. SCANNING ELECTRON MICROSCOPY (SEM)

After 28 days of casting, SEM analysis was performed on the SCGC mixes M1, M2, and M3. Figure depicts a micrograph of SCGC mix M1, which contains 450 kg/m3 of binder, 13 M NaOH solution, and 100% GGBFS. Analysis reveals that the uniform distribution of C-S-H gel led to the production of a dense microstructure with smaller-sized pores and fissures. Aluminosilicate gel forms early as a result of the polymerization reaction being sped up by the high CaO component in GGBFS [10]. In the micrograph of mix M0, some GGBFS particles that have not yet reacted may be seen. Higher binder content and a quicker polymerization process may be to blame for this [15].Figure 4 shows micrograph of SCGC mix of M1,M2and M3.

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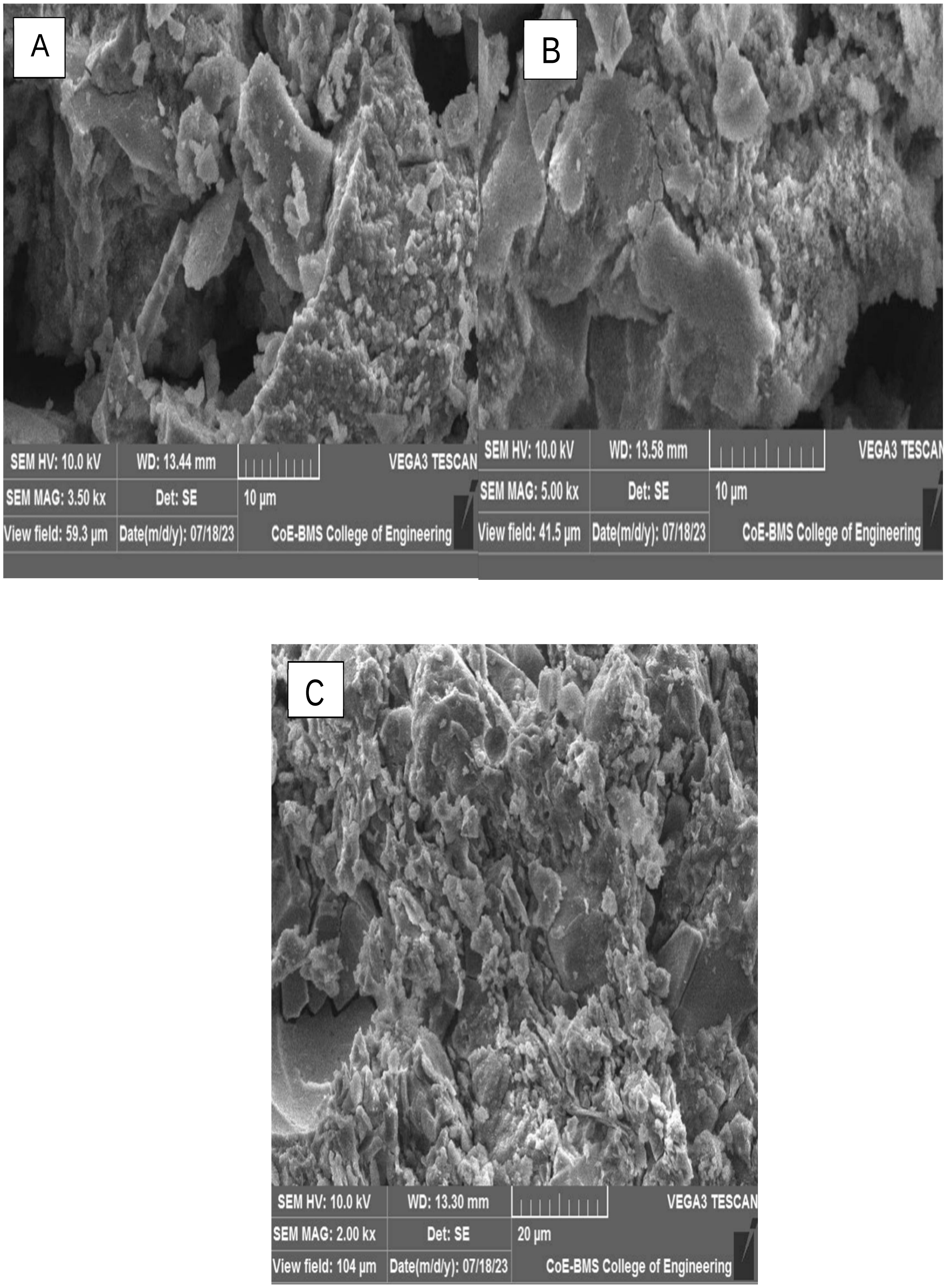
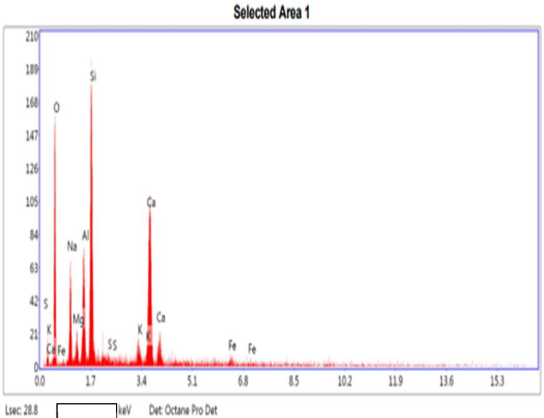


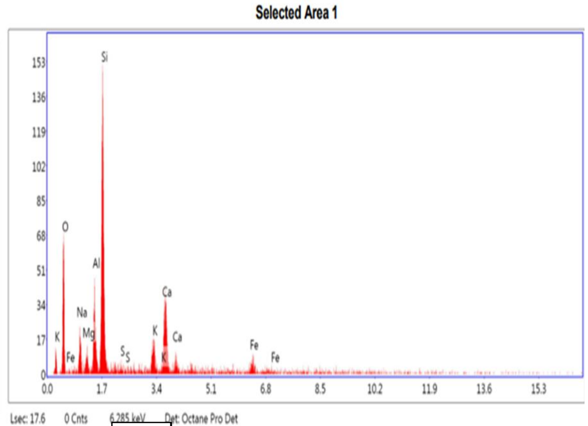
Fig 5 : SEM Analysis of SCGC (A) Mix M1 (B) Mix M2 (C) Mix M3

V. EDS (ENERGY-DISPERSIVE X-RAY SPECTROSCOPY)

Also known as Energy-Dispersive X-ray Analysis (EDXA) or Energy-Dispersive X-ray Microanalysis (EDX), is a technique used to analyze the elemental composition of materials. It is commonly employed in various fields such as materials science, geology, chemistry, and biology to determine the elements present in a sample. Figure 5 shows of SCGC mix of EDS (Energy-Dispersive X-ray Spectroscopy) of M1 and M2.



A



B

eZAF Smart Quant Results with Oxides

Element	Weight %	Atomic %
Na 2O	16.40	16.74
Mg O	3.36	5.28
Al 2O3	15.04	9.33
Si O2	39.41	41.48
S O3	0.87	0.69
K 2O	1.45	0.97
Ca O	22.16	24.99
Fe 2O3	1.31	0.52

eZAF Smart Quant Results with Oxides

Element	Weight %	Atomic %
Na 2O	9.79	10.23
Mg O	3.20	5.15
Al 2O3	12.23	7.77
Si O2	50.96	54.93
S O3	1.11	0.90
K 2O	3.89	2.67
Ca O	14.32	16.54
Fe 2O3	4.50	1.83

Fig 6 : EDS Analysis of SCGC (A) Mix M1 (B) Mix M2

VI. CONCLUSIONS

1) The effect of Bacillus Cohnii bacteria on the workability, strength, and microstructure analysis of self-consolidating geopolymer concrete (SCGC) is examined in this experimental study.
2) The workability, strength, and microstructure of SCGC were improved by the addition of Bacillus Cohnii bacteria at a cell concentration of 3% of the total binder content.
3) This experimental study shows that addition of Bacillus Cohnii bacteria enhanced slump flow by 6.1%, compression strength by 21.7%, split-tensile strength by 64.1% and flexural strength by 6%.
4) Incorporation of Bacillus Cohnii bacteria improved bio-mineralization process which is evident through SEM and EDS analysis.

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