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Influence of Initial Unconfined Compressive Strength of Flyash Geopolymer Sand Mix (Artificial Mix) on the Ultimate Strength of Concrete

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Abstract— This study explores the relationship between the unconfined compressive strength of fly ash geopolymer sand and the ultimate strength of concrete. Fly ash, a by-product of coal combustion, is increasingly valued for its ability to enhance concrete as a supplementary cementitious material. The primary objective is to assess how variations in initial compressive strength of concrete mixtures with fly ash impact their ultimate strength. The experimental approach involves preparing concrete mixes with different fly ash proportions as partial cement replacements. Initial compressive strength tests evaluate early-stage strength characteristics, followed by a thorough curing regime to simulate real-world conditions for long-term strength development. The study aims to uncover the relationships between initial and ultimate compressive strengths. Factors such as curing duration, water-cementitious materials ratio, and fly ash content are systematically varied to understand their individual and combined effects on concrete performance. Advanced imaging techniques analyze the concrete's microstructure, providing insights into the mechanisms driving strength development. The findings offer valuable insights for optimizing concrete mix designs with fly ash, aiming to achieve desired ultimate strength levels. Understanding the interplay between initial and ultimate strength is crucial for ensuring the durability and structural integrity of concrete structures, promoting sustainable construction practices through effective fly ash utilization. Ultimately, this research contributes to the advancement of eco-friendly, high-performance concrete formulations, supporting sustainable construction practices.

Index Terms—Concrete, Fly ash, Compression Strength, Sustainable construction, concrete mix design, supplementary cementitious material, microstructural analysis, durability

Introduction

Concrete remains the backbone of modern infrastructure, yet its reliance on Portland cement is a significant source of global CO2 emissions. This environmental challenge has prompted the construction industry to seek sustainable alternatives. Fly ash, a by-product of coal combustion, has emerged as a viable supplementary cementitious material (SCM) due to its potential to enhance concrete properties while mitigating environmental impact. The high silica and alumina content in fly ash allows it to react with calcium hydroxide to form additional cementitious compounds, improving concrete's workability, durability, and strength.

In recent years, geopolymer technology has gained prominence, particularly the use of fly ash geopolymer sand as a binder. This technology activates fly ash with alkaline solutions, resulting in binders with superior mechanical properties, chemical resistance, and thermal stability. Incorporating fly ash geopolymer sand into concrete mix designs holds promise for significantly enhancing concrete's mechanical performance.

This study explores the relationship between the initial unconfined compressive strength of fly ash geopolymer sand and the ultimate strength of concrete. Understanding this correlation is crucial for optimizing concrete mix designs to achieve desired strength levels while promoting sustainability. The research focuses on how varying the proportion of fly ash in the concrete mix influences early-stage compressive strength and ultimate strength. A comprehensive experimental approach involves preparing concrete mixes with different fly ash proportions and conducting initial compressive strength tests.

A key aspect of this study is the implementation of a thorough curing regime that simulates real-world conditions and facilitates long-term strength development. Factors such as curing duration, water-cementitious materials ratio, and fly ash content are systematically varied to understand their individual and combined effects on concrete performance. Additionally, advanced imaging techniques are employed to analyze the microstructure of the concrete, offering insights into the mechanisms influencing strength development.

The findings from this research aim to provide practical insights for the construction industry by optimizing concrete mix designs incorporating fly ash to achieve desired ultimate strength levels. Understanding the interplay between initial and ultimate strength is essential for ensuring the durability and structural integrity of concrete structures. By effectively utilizing fly ash, this study contributes to advancing eco-friendly and high-performance concrete formulations, supporting the shift towards sustainable construction practices. The anticipated results are expected to encourage the broader adoption of fly ash geopolymer technology, paving the way for more sustainable and resilient infrastructure development..

Characterisation Of Flyash And Sand

Fly ash sand, a composite material formed by blending fly ash with sand, has garnered significant attention in recent years due to its potential applications in construction and civil engineering. This innovative material offers promising properties that contribute to sustainability efforts and address challenges in traditional construction practices.

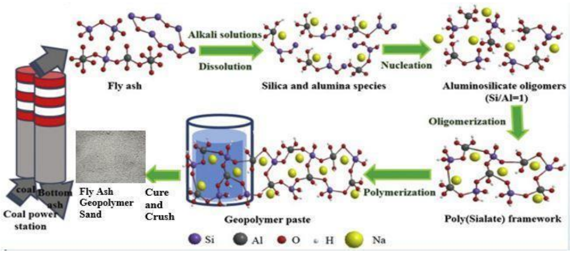


Figure: Process of making Fly Ash – Geopolymerization to Sand

Fly Ash: Fly ash is a byproduct of coal combustion in thermal power plants. It consists of fine particles that are carried away by exhaust gases and collected using electrostatic precipitators or filters. Historically, fly ash has been viewed as a waste product, leading to environmental concerns regarding its disposal. However, its chemical composition and physical properties make it suitable for various applications, including construction materials.

Sand: Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. It serves as a fundamental ingredient in concrete, mortar, and other construction materials due to its abundance, affordability, and workability. However, concerns over the depletion of natural sand sources and environmental impact have prompted the exploration of alternative materials and composite blends.

Geopolymerization of Flyash Sand

Flyash was brought from KPCL Raichur Thermal Power Plant located at Yadlapur (Shaktinagar) in the raichur district of the state of Karnataka.

Known volumes of NaOH solutions were mixed with fly ash batches at varying Solid: Solution ratio and Na_2SiO_3 / NaOH ratio. The moist mixes were compacted into specimen dimensions of 70.6 mm x 70.6mm x 70.6mm motor cubes and varying oven curing period at different temperatures.

Figure: Casted flyash Geopolymer Specimen

Figure: Oven curing of flyash Geopolymer Specimen

Preparation of alkaline activation i.e. Sodium Hydroxide Solution.

To avoid the interference of minerals distilled water is used for preparation of Sodium Hydroxide (NaOH) Solution. The small circular shaped Sodium Hydroxide pellets were mixed with distilled water to form different Molarity of Sodium Hydroxide Solution. The quantity of chemical required for 1 molar calculation is shown below.

1 molarity NaOH Solution = 40gms of NaOH pellets / 1ltr of Distilled water.

Molar Mass NaOH= 40g/mol (Na= 22g/mol + O = 16g/mol + H = 1g/mol)

8M NaOH Solution = (8*40) = 320gms of NaOH pellets / 1ltr of Distilled water.

As per the above calculation 8M, 10M, 12M, 14M NaOH solution was prepared and kept for cooling at room temperature for 24hrs as the addition of NaOH with Distilled Water undergoes Exothermic reaction, where heat will be released.

Formulation of fly ash geopolymer sand (FGPS):

A mixture containing 1kg of fly ash was mixed with 172 ml of sodium silicate and 114ml of 12 M NaOH solution (solids: solution ratio = 3.5:1; Na2SO4: NaOH ratio = 1.5:1). The slurry was initially cured in an oven for 20 min at 100°C and then the sample was taken out of the oven and kept for cooling for 10 min and was sieved through 4mm IS (Indian Standards) sieve to obtain the fine aggregate. The fine aggregates were further cured at 100°C for 2h in a temperature-controlled oven (±2°C accuracy) to complete the geopolymer reactions. This fine aggregate particle obtained is termed Fly ash geopolymer sand (FGPS).

Table: Conditions for synthesis of fly ash based Geopolymer specimens by varying Molarity of NaOH Solution.

Pozzolana	NaOH concentration (M)	Solid to Solution ratio	Na_2SiO_3 / NaOH ratio	Oven Curing period, h	Curing temperature, °C	Compressive Strength, MPa
Fly ash (Class F)	8M	3:1	2:1	2	100	11.32
	10M					12.41
	12M					21.29
	14M*					32.21*

Table: Conditions for synthesis of fly ash based Geopolymer specimens by varying Na2SiO3 / NaOH ratio.

Pozzolana	NaOH concentration, (M)	Na_2SiO_3 / NaOH ratio	Solid to Solution ratio	Oven Curing period, h	Curing temperature, °C	Compressive Strength, MPa
Fly ash (Class F)	12M	0.5:1	3:1	2	100	11.50
		1:1				17.13
		1.5:1				20.95
		2:1				21.50
		2.5:1				16.70

Table: Conditions for synthesis of fly ash based Geopolymer specimens by varying Solid to Solution ratio.

Pozzolana	NaOH concentration, (M)	Na_2SiO_3 / NaOH ratio	Solid to Solution ratio	Oven Curing period, h	Curing temperature, °C	Compressive Strength, MPa
Fly ash (Class F)	12M	1.5:1	2:1	2	100	12.53
			2.5:1			16.50
			3:1			21.00
			3.5:1			26.57

Table: Conditions for synthesis of fly ash based geopolymer specimens by varying oven curing period with constant temperature.

Pozzolana	NaOH concentration, (M)	Na_2SiO_3 / NaOH ratio	Solid to Solution ratio	Oven Curing period, h	Curing temperature, °C	Compressive Strength, MPa
Fly ash (Class F)	12M	1.5:1	3.5:1	1.5	100	16.38
				2		26.56
				2.5		30.36
				3		27.23

Table: Conditions for synthesis of fly ash based geopolymer specimens by varying temperature with constant oven curing period.

Pozzolana	NaOH concentration, (M)	Na_2SiO_3 / NaOH ratio	Solid to Solution ratio	Oven Curing period, h	Curing temperature, °C	Compressive Strength, MPa
Fly ash (Class F)	12M	1.5:1	3.5:1	2.5	70	4.80
					100	26.56
					120	34.93
					150	32.96

Design Specifications for Manufacture Fly ash Geopolymer Sand (FGPS) Particle:

Sodium hydroxide (NaOH) Concentration: 12 Molar.

Sodium Silicate Liquid (Na_2SiO_3)/ Sodium hydroxide (NaOH) Ratio: 1.5:1.

Solid (fly ash) to Solution (Na_2SiO_3 / NaOH) ratio: 3.5:1.

Oven Curing Period: 2 hours 30 minutes.

Oven Curing Temperature: 120°C.

Characteristics of Geopolymer Flyash Sand

Specific Gravity

Table: Specific Gravity

Property	Trial 1	Trial 2	Trial 3
Specific gravity	1.85	1.92	1.92

Grain Size Analysis

Grain size analysis is used to determine the particle size distribution of the sample. The RFA conforms to grading zone I as per table 9 of IS 383 and is considered to be coarser as the FM is 3.4.

Table: Grain size analysis – Trial 1

Sieve size (mm)	Weight Retained	% By Weight Retained	% Cumulative Weight Retained	% Finer
4.75	3	0.3	0.3	99.7
2.36	334	33.4	33.7	66.3
1.18	219	21.9	55.6	44.4
0.60	135	13.5	69.1	30.9
0.30	174	17.4	86.5	13.5
0.15	94	9.4	95.9	4.1
Pan	41	4.1		
	∑= 1000		∑= 341.1	

Fineness modulus = $\frac{\sum \% \, Cumulative\ Weight\ Retained}{100}$

FM = $\frac{341.1}{100}$ = 3.41

Table: Grain size analysis – Trial 2

Sieve size (mm)	Weight Retained	% By Weight Retained	% Cumulative Weight Retained	% Finer
4.75	3	0.3	0.3	99.7
2.36	298	29.8	30.1	69.9
1.18	318	31.8	61.9	38.1
0.60	115	11.5	73.4	26.6
0.30	157	15.7	89.1	10.9
0.15	81	8.1	97.2	2.8
Pan	28	2.8		
	∑= 1000		∑= 352	

Fineness modulus = $\frac{\sum\%\ Cumulative\ Weight\ Retained}{100}$

FM = $\frac{352}{100}$ = 3.52

Table: Grain size analysis – Trial 3

Sieve size (mm)	Weight Retained	% By Weight Retained	% Cumulative Weight Retained	% Finer
4.75	6	0.6	0.6	99.4
2.36	265	26.5	27.1	72.9
1.18	310	31.0	58.1	41.9
0.60	119	11.9	70	30
0.30	171	17.1	87.1	12.9
0.15	95	9.5	96.6	3.4
Pan	34	3.4		
	∑= 1000		∑= 339.5	

Fineness modulus = $\frac{\sum\%\ Cumulative\ Weight\ Retained}{100}$

FM = $\frac{339.5}{100}$ = 3.39

Lime Reactivity

This method of test covers the procedure determining the lime reactivity of flyash with hydrated lime, as indicated by the compressive strength of standard mortar test cubes prepared and tested under specific conditions.

pH Test

Indian standard code book used for determination of pH is IS 2720(part026) -1997. According to code book pH is done using Elico L 120, by unsettling specimens in deionised water. The obtained result for the sample is found to be 11.58 which is strongly Alkaline Ash.

Test standard: IS 1727:1967
Ration, M = 2.06 = 0.936
Fly ash required = 2×M×150
= 2×0.936×150
=280.8g
Standard sand = 450+450+450 = 1350g
250 ml of water is required to mix the materials.
After 50 ml increase i.e, 300ml →150ml
310ml→ 173.5 mm.

Total Dissolved Solids

TDS test is done to know total dissolved concentration of all inorganic and organic substances present in sodium hydroxide. TDS can be done by 2 methods; one is gravity metric analysis and other is by conductivity. Gravity metric analysis is a more accurate method; the procedure involved is evaporating solvent of the liquid and measuring the residual mass left. Conductivity meter method TDS method involves electrical conductivity that can pass through liquid by concentration of dissolved ionized solids present in the solution.TDS for fly ash was done by TDS meter. The TDS value for the sample was found to be 4.78x10^3ppm.

Electronic Conductivity

Electrical conductivity was done by fermentation process of all measured quantity of specimen in distilled water in a solid to water ratio of 1:2 for half an hour. Arrangements and measurement of the value for electrical conductive was done using a controlled dynamic meter. Electronic Conductivity for the sample was found to be 7.28mS.

Loss on ignition (%)

Loss on ignition test for fly ash was conducted in accordance to IS 1727(1999). The procedure involved heating 1g of the oven- dried specimen in a muffle furnace at 1000 ± 25°C for about 1hr. after heating, the specimen was cooled and weighed. The percentage loss on ignition is given by following formula, Loss on ignition, % = (loss in weight) / (mass of dry sample taken for test) x 100.

Hydrometer Analysis

To know the particle size distribution of Fly ash, Hydrometer analysis was done. Test was done according to IS-2720:1985 (Part 4), result shows that fly ash contain67% of silt, 29% of sand and 4% of clay.

Micro Structural Analysis

X-RAY.DIFFRACTION.ANALYSIS (XRD) FOR FLY ASH: Crystalline structure of materials can be effectively determined by X-ray diffraction (XRD). Materials whose crystal sizes 3 to 5 nm can be detected in X-ray diffraction. X-ray diffraction for fly ash was done in BMS College, Bangalore. Analysis was done by passing CuKα radiation from 10° to 80°. Result shows that Quartz, Chabazite – Mg and Mullite are the major chemicals present in fly ash.

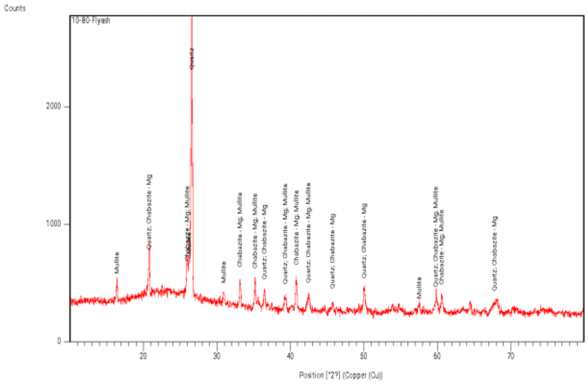
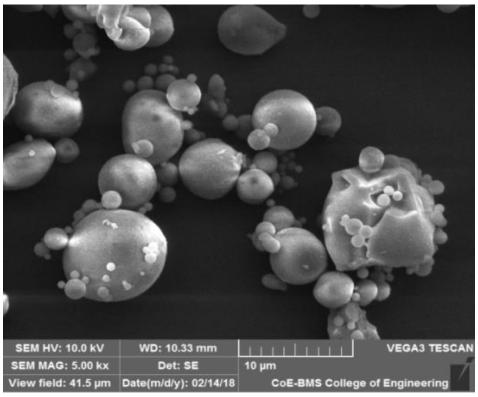


Figure: XRD for Fly ash

SCANNING ELECTRON MICROSCOPE (SEM) FOR FLY ASH:

Detailed external morphology and chemical composition are more precisely done in scanning electronic microscope. SEM produces variety of signals using focused beam of high-energy electron, which are made to hit specified surface. Data collected from signals are in the form of two-dimensional image, which give information about texture, orientation and characterization of materials. SEM analysis was done for fly ash. Results were as shown in the figure.


SEM HV: 10.0 kV
WD: 10.33 mm
VEGA3 TESCAN
SEM MAG: 5.00 kx
Det: SE
10 µm
View field: 41.5 µm
Date(m/d/y): 02/14/18
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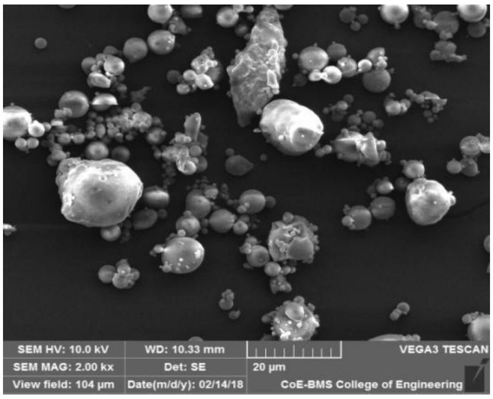
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VEGA3 TESCAN
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20 µm
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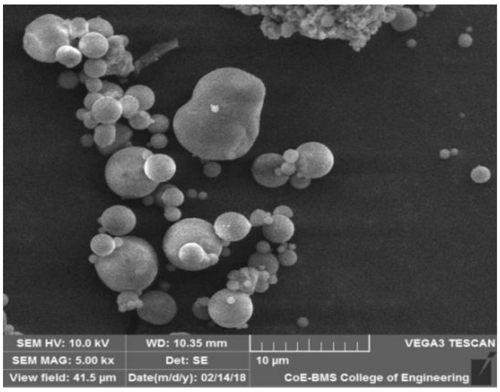
SEM HV: 10.0 kV
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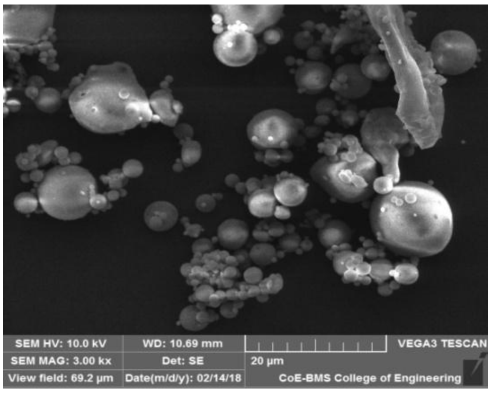
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VEGA3 TESCAN
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20 µm
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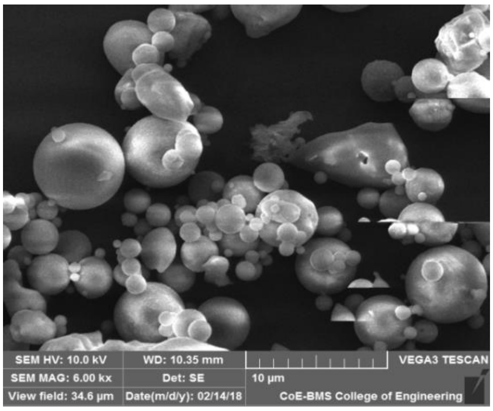

Figure: SEM for Fly ash

MIX DESIGNS USED IN THIS STUDY

Concrete mix design used for casting of concrete of M30, M40 & M50 grade concrete in table is done using IS 10262 (2019) and IS 456 (2000).

Table: Mix design of M30, M40 & M50 Grade concrete

Materials	M30	M40	M50
Cement	403 Kg/m^3	426 Kg/m^3	440 Kg/m^3
Water	149 Kg/m^3	149 Kg/m^3	174.40 Kg/m^3
Manufactured fine aggregates	727.66 Kg/m^3	712.44 Kg/m^3	650 Kg/m^3
Coarse aggregates	1208.94 Kg/m^3	1204.095 Kg/m^3	1178 Kg/m^3
Super Plasticizer	2.821 Kg/m^3	2.982 Kg/m^3	1.32 Kg/m^3
Additional water for absorption	152.81 Kg/m^3	178.11 Kg/m^3	143 Kg/m^3

TESTS CONDUCTED

Compression Test Conducted on concrete

To examine the hardened property the compressive strength of the concrete specimens is prepared using fly ash geopolymer sand and are tested according IS-456. Compressive strength of cubes with 100% sand replacement.

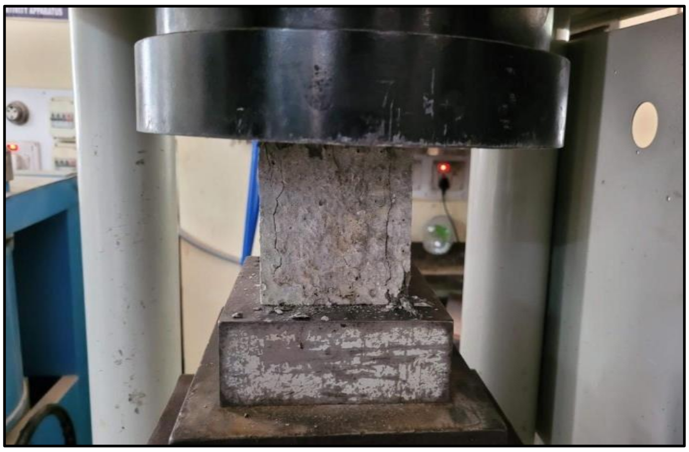

Figure: Testing for Compressive strength of concrete

Table: Compressive strength of concrete casted using Manufactured fine aggregates

Grade	Average compressive strength		
	7 days	14 days	28 days
M30	12.30 Mpa	13.93 Mpa	17.08 Mpa
M40	12.71 Mpa	14.12 Mpa	18.52 Mpa
M50	13.20 Mpa	15.64 Mpa	23.61 Mpa

Compression Test on Geopolymer Flyash Sand Self Compacting Concrete

Compressive test is one of the most basic tests that is carried on the hardened concrete. Compressive strength is qualitatively related to maximum number of the desired characteristic properties of concrete. The SCC cube specimens were of size 150x150x150mm are tested in the machine.

The testing is carried out conforming to IS: 516 – 1959 by placing the SCC cubes such that the finished face of cube is facing the load, rather it is turned such that the side face is kept to receive the loading face and the load is applied at a rate of 14 MPa per minute on the specimen gradually, the load is applied until the cracks appear on the specimen and the load gradually decreases. Cylindrical specimens are kept vertically and loading is gradually applied until the crack appears on the specimen. The load at which the specimen fails or cracks are noted down. The specimens were cured in water for 7, 14 and 28-day after that the specimens were tested. The formula used to calculate the compressive strength is given below.

Figure: Compression Test of cube

Results And Discussions

Geopolymer Flyash Sand Concrete

Compression Test

To examine the hardened property the compressive strength of the concrete specimens is prepared using fly ash geopolymer sand are tested according IS-456. Compressive strength of cubes with 100% sand replacement.

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M50	13.20 Mpa	15.64 Mpa	pa

Geopolymer Flyash Sand Self Compacting Concrete

Compressive strength of self-compacting concrete:

Compressive strength of SCC was determined at the beginning by compressive test of cube of size 150x150x150mm under Compression testing machine. After obtaining compressive strength of concrete the axial load is applied on concrete filled steel tubes for determination of compressive strength of CFS tubes of different dimensions, and the comparison with the theoretical values obtained from codes are also provided in the table.

Table: Experimental results of 28 days strength of SCC:

Grade	sample	time	Compressive strength
M25	Sample 1	28 days	33mpa
	Sample 2	28 days	34mpa

Conclusion

Flyash Geopolymer Concrete

Manufactured Aggregate Characteristics:

Manufactured aggregates are noted for their lightweight properties, attributed to their lower specific gravity compared to naturally occurring aggregates. These aggregates exhibit higher water absorption rates compared to natural aggregates, which is an important consideration in concrete mix design.

Particle Size Distribution and Workability Manufactured aggregates boast a more uniform particle size distribution curve, which enhances the workability of concrete mixes. This uniformity contributes to better concrete placement and consolidation during construction activities.

SEM Analysis of Manufactured Aggregates:

Scanning Electron Microscopy (SEM) analysis reveals a higher presence of pores in manufactured aggregates, which correlates with increased water absorption capabilities. The presence of pores can influence the overall durability and permeability characteristics of concrete made with these aggregates.

SEM Analysis on Concrete:

SEM analysis of concrete samples indicates a retardation in the hydration process, with cement particles being only partially hydrated even after 28 days of curing. This partial hydration may contribute to reduced concrete strength over time and necessitates further investigation into curing and hydration processes.

EDAX Studies on Manufactured Fine Aggregate:

Energy Dispersive X-ray Analysis (EDAX) reveals the presence of alumina and silicates in manufactured aggregates, which can contribute to increased concrete strength during later stages of curing. EDAX studies on concrete highlight the presence of SO3 content, which may retard hydration and lead to unreacted CaO, SiO2, and Al2O3 after 28 days of curing. These findings suggest potential challenges in achieving optimal concrete strength and durability.

Self-Consolidating Concrete (SCC) with Geopolymer Aggregates:

Literature review indicates that self-consolidating concrete incorporating geopolymer aggregates meets EFNARC specifications for fresh properties. Utilizing geopolymer aggregates offers environmental benefits such as reduced depletion of natural resources, landfill space conservation, and cost savings.

Mechanical Properties of Manufactured Aggregates:

Manufactured Fine Aggregates exhibit variations from standard values, with higher water absorption and lower specific gravity compared to natural fine aggregates. The fineness modulus of aggregates is higher, implying larger average particle sizes, which can affect concrete properties. As the proportion of aggregates increases in mixes, yield stress decreases while plastic viscosity increases, influencing flow characteristics and inter-particle friction.

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