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Mix Design of Ultrafine Fly Ash and Ultrafine GGBS Based Geopolymer Concrete

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ABSTRACT

Mix design procedure for geopolymer concrete (GPC) using ultrafine fly ash and ultrafine Ground Granulated Blast-furnace Slag as the primary binder material, in combination with sodium hydroxide and sodium silicate as alkaline activator solutions. The main objective is to develop a methodology that optimizes compressive strength in a for different alkaline solution-to-binder (AAS/FA) ratios. This proposed mix design method serves as a foundational step for advancing GPC production by providing a structured approach to achieving desirable strength properties with an emphasis on sustainability and economic viability. The use of ultrafine fly ash and ultrafine Ground Granulated Blast-furnace Slag not only contributes to waste minimization but also enhances the eco-friendly nature of the concrete industry.

Keywords: Geopolymer concrete (GPC), Ultrafine fly ash, ultrafine Ground Granulated Blast-furnace Slag, compressive strength

Introduction

The mix design methodologies for geopolymer concrete (GPC) proposed by different researchers primarily aim to optimize the concrete's properties, such as strength and workability, by adjusting the proportions of ultrafine fly ash and ultrafine Ground Granulated Blast-furnace Slag, aggregates, and alkaline activators. The mix design of ultrafine fly ash and ultrafine Ground Granulated Blast Furnace Slag (GGBS) based geopolymer concrete requires careful selection of materials, ratios, and processing methods. This type of geopolymer concrete leverages the reactivity of ultrafine particles to achieve improved mechanical and durability properties, without using Ordinary Portland Cement (OPC). The primary activators for this mix design are typically alkaline solutions such as sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). ypically a by-product of coal combustion, ultrafine fly ash is used due to its high pozzolanic activity. It should have a particle size smaller than 20 microns. A by-product from the blast furnace process of the iron industry, ultrafine GGBS contributes to the strength and durability of the geopolymer. Its particle size should be less than 20 microns. Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) are commonly used. The molarity of NaOH should be between 8M and 16M, depending on the desired strength and setting time. Coarse and fine aggregates should conform to IS 383 specifications or ASTM C33 for optimal performance. They are typically selected based on the target density and workability of the mix. High-range water reducers may be added to achieve desired workability without compromising strength. The sum of ultrafine fly ash and ultrafine GGBS typically ranges from 400 to 600 kg/m³, depending on the desired strength.

Avinash Ojha et al (2023) the study you described addresses a critical gap in mix design guidelines for low calcium fly ash-based geopolymer concrete (FA-GPC). Given the focus on utilizing waste materials and reducing environmental impact, the use of FA-GPC as an alternative to traditional cement concrete is gaining traction. With the selected parameters, the mix achieved rapid strength, making it suitable for precast applications like kerb stones and paver blocks. The controlled ratios of alkaline activators and molarity adjustments directly influenced the workability and strength, which are critical for production and handling.

Parmender Gill et al (2022) this study proposes a systematic mix-design approach for developing Rubberized Geopolymer Concrete (RGPC), focusing on a blend of high-strength, low-calcium fly ash-based geopolymer concrete and crumb rubber as a partial replacement for fine aggregates. The binder composition used in this research includes 80% fly ash and 20% Ordinary Portland Cement (OPC), with varying binder contents (350, 375, and 400 kg/m³). The study considers key variables such as crumb rubber content (0, 5, 10, and 15%) and NaOH molarity (8, 10, and 12 M) under heat curing at 60 °C. The compressive strength of the RGPC varied significantly with changes in binder content, crumb rubber percentage, and NaOH molarity. An optimal combination of these variables resulted in compressive strengths that met or exceeded the targeted values. The slump value was observed to decrease as the crumb rubber content increased. However, with careful adjustment of the mix proportions, the targeted workability was achievable. The inclusion of crumb rubber in geopolymer concrete led to a reduction in density, which is advantageous for applications where a lightweight concrete is desirable. The proposed mix-design procedure effectively balances the compressive strength and workability of RGPC. The developed method can be used as a guideline for producing rubberized geopolymer concrete with tailored properties for specific construction applications. The trial experiment validates the reliability of the mix design and demonstrates its applicability in real-world scenarios. This study highlights the potential of incorporating waste materials like crumb rubber into geopolymer concrete, promoting sustainability while achieving desirable mechanical properties.

Methodology

These methodologies offer different perspectives on GPC mix design, but the specific gravity of materials and the selection of the activator solution to ultrafine fly ash and ultrafine Ground Granulated Blast-furnace Slag ratio remain critical factors that influence the mix design's effectiveness.

Table 1 Mix Design of M30 Grade of ultrafine fly ash and ultrafine ggbs based geopolymer concrete

M-30 CONCRETE MIX DESIGN		
As per IS 10262-2009 & MORT&H		
A-1	**Stipulations for Proportioning**	
1	**Grade Designation**	**M30**
2	Type of Cement	OPC 53 grade confirming to IS-12269-1987
3	Maximum Nominal Aggregate Size	20 mm
4	Minimum Cement Content (MORT&H 1700-3 A)	310 kg/m^3
5	Maximum Water Cement Ratio (MORT&H 1700-3 A)	0.45
6	Workability (MORT&H 1700-4)	50-75 mm (Slump)
7	Exposure Condition	Normal
8	Degree of Supervision	Good
9	Type of Aggregate	Crushed Angular Aggregate
10	Maximum Cement Content (MORT&H Cl. 1703.2)	540 kg/m^3
11	Chemical Admixture Type	Superplasticiser Confirming to IS-9103
A-2	**Test Data for Materials**	
1	Cement Used	Coromandal King OPC 53 grade
2	Sp. Gravity of Cement	3.15
3	Sp. Gravity of Water	1.00
4	Chemical Admixture	BASF Chemicals Company
5	Sp. Gravity of 20 mm Aggregate	2.884
6	Sp. Gravity of 10 mm Aggregate	2.878
7	Sp. Gravity of Sand	2.605
8	Water Absorption of 20 mm Aggregate	0.97%
9	Water Absorption of 10 mm Aggregate	0.83%
10	Water Absorption of Sand	1.23%
11	Free (Surface) Moisture of 20 mm Aggregate	nil

12	Free (Surface) Moisture of 10 mm Aggregate	nil
13	Free (Surface) Moisture of Sand	nil
14	Sieve Analysis of Individual Coarse Aggregates	Separate Analysis Done
15	Sieve Analysis of Combined Coarse Aggregates	Separate Analysis Done
15	Sp. Gravity of Combined Coarse Aggregates	2.882
16	Sieve Analysis of Fine Aggregates	Separate Analysis Done
A-3	**Target Strength for Mix Proportioning**	
1	Target Mean Strength (MORT&H 1700- 5)	42N/mm^2
2	Characteristic Strength @ 28 days	30N/mm^2
A-4	**Selection of Water Cement Ratio**	
1	Maximum Water Cement Ratio (MORT&H 1700-3 A)	0.45
2	Adopted Water Cement Ratio	0.42
A-5	**Selection of Water Content**	
1	Maximum Water content (10262-table-2)	186 Lit.
2	Estimated Water content for 50-75 mm Slump	160 Lit.
3	Superplasticiser used	0.5 % by wt. of cement
A-6	**Calculation of Cement Content**	
1	Water Cement Ratio	0.42
2	Cement Content (160/0.42)	380 kg/m^3
		Which is greater then 310 kg/m^3
A-7	**Proportion of Volume of Coarse Aggregate & Fine Aggregate Content**	
1	Vol. of C.A. as per table 3 of IS 10262	62.00%
2	Adopted Vol. of Coarse Aggregate	62.00%
	Adopted Vol. of Fine Aggregate (1- 0.62)	38.00%
A-8	**Mix Calculations**	
1	Volume of Concrete in m^3	1.00
2	Volume of Cement in m^3	0.12
	(Mass of Cement) / (Sp. Gravity of Cement)x1000	
3	Volume of Water in m^3	0.160
	(Mass of Water) / (Sp. Gravity of Water)x1000	
4	Volume of Admixture @ 0.5% in m^3	0.00160

	(Mass of Admixture)/(Sp. Gravity of Admixture)x1000	
5	Volume of All in Aggregate in m^3	0.718
	Sr. no. 1 – (Sr. no. 2+3+4)	
6	Volume of Coarse Aggregate in m^3	0.445
	Sr. no. 5 x 0.62	
7	Volume of Fine Aggregate in m3	0.273
	Sr. no. 5 x 0.38	
A-9	**Mix Proportions for One Cum of Concrete (SSD Condition)**	
1	Mass of Cement in kg/m^3	**380**
2	Mass of Water in kg/m^3	**160**
3	Mass of Fine Aggregate in kg/m^3	**711**
4	Mass of Coarse Aggregate in kg/m^3	1283
	Mass of 20 mm in kg/m^3	**924**
	Mass of 10 mm in kg/m^3	**359**
5	Mass of Admixture in kg/m^3	**1.90**
6	Water Cement Ratio	0.42

Geopolymer concrete quantity calculation

According to graph for target mean strength 42 N/mm^2 quantity of fly ash is approx. 380 kg/m^3

Solution to fly ash ratio = 0.35

Mass of [Na_2Sio_3 + NaOH] / Fly ash = 0.35

[Na_2Sio_3 + NaOH] / 380 = 0.35

Mass of [Na_2Sio_3 + NaOH] = 133

Take the sodium silicate to sodium hydroxide ratio by mass is 1

So Mass of sodium hydroxide (NaOH) = 66.50 Kg/m^3

Mass of sodium silicate solutions (Na_2Sio_3) = 66.50 Kg/m^3

In this study that involves replacing Ultra Fine Fly Ash (UFFA) with Ultra Fine Ground Granulated Blast Furnace Slag (GGBFS) in your concrete mixture. The replacement is being done at intervals of 0%, 5%, 10%, 15%, 20%, and 25%. This substitution can have significant effects on the concrete's properties, including its compressive strength, durability, and workability. For m30 grade concrete.

Table 2 Quantity of geopolymer concrete ingredient in Kilogram per meter cube

Replacement	**UFFA**	**UFGGBS**	**Aggregate**	**Sand**	**Na_2Sio_3**	**NaOH**
0%	**380**	**0**	**1280**	**710**	**66.50**	**66.50**
5%	**361**	**19**	**1280**	**710**	**66.50**	**66.50**
10%	**342**	**38**	**1280**	**710**	**66.50**	**66.50**
15%	**323**	**57**	**1280**	**710**	**66.50**	**66.50**

20%	**304**	**76**	**1280**	**710**	**66.50**	**66.50**
25%	**285**	**95**	**1280**	**710**	**66.50**	**66.50**

CONCLUSION

Ultrafine fly ash and ultrafine Ground Granulated Blast-furnace Slag -based geopolymer concrete represents a promising advancement in sustainable construction materials. Its superior mechanical properties, durability, and environmental benefits position it as a viable alternative to traditional OPC concrete. While challenges remain, particularly in terms of cost and curing methods, continued research and development are likely to make geopolymer concrete a more prevalent choice in the construction industry. Detailing the dimensions, concrete mix design, reinforcement placement, and curing method for each specimen Specify equipment and tools used for testing.

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