Fly Ash-Based Geopolymer Concrete

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Abstract

This paper investigates the properties and applications of fly ash-based geopolymer concrete (GPC) using sodium hydroxide (NaOH), sodium silicate (Na2SiO3), and coarse and fine aggregates. The focus is on understanding the chemical interactions, mechanical properties, and durability of this sustainable construction material. Additionally, results from a rebound hammer test are discussed to evaluate the in-situ strength over time.

Keywords : - Fly Ash, Geopolymer Concrete, Sodium Silicate, Sodium Hydroxide, Sustainable Construction, Mechanical Properties, Durability

Introduction

Geopolymer concrete represents a promising eco-friendly alternative to conventional Portland cement concrete. Traditional concrete production is associated with high carbon emissions due to the calcination process required for producing Portland cement. Geopolymer concrete, however, utilizes industrial by-products such as fly ash and GGBS, which are activated by alkaline solutions like sodium hydroxide and sodium silicate. This not only reduces the carbon footprint but also repurposes industrial waste materials. This study aims to explore the potential of geopolymer concrete in reducing carbon emissions and enhancing construction sustainability. The research includes the results of a rebound hammer test to evaluate the in- situ strength of the geopolymer concrete over time.

Literature Review

Recent studies have demonstrated the feasibility and advantages of using geopolymer concrete. For instance, research by Singh et al. (2023) showed that geopolymer concrete exhibits superior mechanical properties and durability compared to conventional concrete. Additionally, the use of sodium hydroxide and sodium silicate as activators significantly improves the early strength of the material.

Other studies have focused on the environmental benefits, noting substantial reductions in CO2 emissions when using fly ash and GGBS instead of Portland cement.

Materials and Methods Materials

- Fly Ash: A by-product from coal combustion in power plants, characterized by its fine particles and rich aluminosilicate content.

- Coarse Aggregate: Crushed stone with a nominal size of 20 mm, providing the necessary mechanical stability.

- Fine Aggregate: River sand, serving as a filler and contributing to the overall workability of the concrete.

- Alkaline Activators: Sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) solutions, which initiate the geopolymerization process.

Mix Design

The mix proportions were optimized based on the ratio of fly ash to alkaline activators, concentration of sodium hydroxide, and the sodium silicate to sodium hydroxide ratio. The mix was designed as M15 grade concrete with a chemical to fly ash ratio of 1:6.25. The primary mix components included:

- Fly Ash: 60%
- Coarse Aggregate: 20 mm nominal size
- Fine Aggregate: River sand
- NaOH Solution: 10M concentration
- Na2SiO3 to NaOH Ratio: 2.5

Cubicmeter Material for M15 (1:2;4), Weights (Kg)

FLYASH/SOLUTION- (4:1)

FLYASH	290.4
FINE AGGREGATES	704
COARSE AGGREGATES	2112
CHEMICAL SOLUITION	72.5

FLYASG/SOLUTION -(6:1)

FLYASH	290.4
FINE AGGREGATES	704
COARSE AGGREGATES	2112
CHEMICAL SOLUITION	48.33

The mix design aimed to achieve a balance between workability, strength, and durability, ensuring that the geopolymer concrete meets the necessary structural requirements for construction applications.

Preparation and Curing

The preparation process involved thoroughly mixing the dry materials (fly ash, coarse, and fine aggregates). The alkaline solutions were prepared separately and then combined with the dry materials. This process ensures a uniform distribution of the activators throughout the mixture, promoting effective geopolymerization. The resulting paste was poured into molds and cured at 110°C for 24 hours. The elevated curing temperature accelerates the geopolymerization process, leading to early strength development.

Table 1. Physical properties of aggregates.

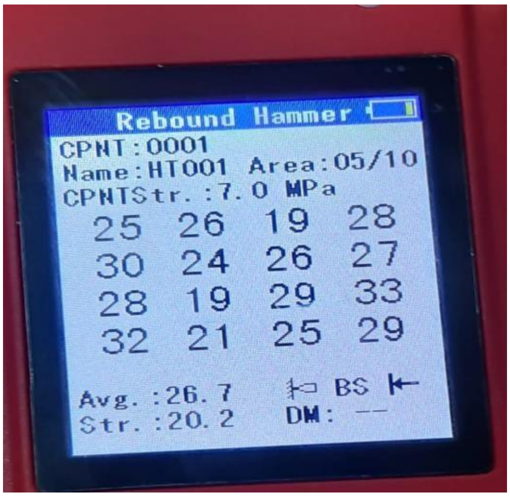
Aggregate Source	Aggregate Type	Bulk Specific Gravity	Moisture Content (%)	Absorption (%)	Dry Rodded Unit Weight (kg/m³)	Fineness Modulus
Placitas (NSC mixture)	Coarse Agg.	2.53	0.2	1.7	1565	-
	Pea Gravel	2.52	0.9	2.0	1476	-
	Sand	2.61	1.1	1.4	-	2.77
Moriarty (NSC mixture)	Coarse Agg.	2.65	0.2	1.7	1572	-
	Pea Gravel	2.66	0.2	1.3	1530	-
	Sand	2.70	0.9	1.2	-	3.40
Las Cruces (UHPC mixture)	Sand	2.51	0.7	1.6	-	2.81

Workability

The workability of the geopolymer concrete was assessed using the slump test. The slump test measures the consistency and flowability of the concrete mix. The results indicated a slump value of 85mm, which is within the acceptable rang for good workability. The inclusion of GGBS significantly improve the workability, making the mix easier to handle and place.

Rebound Hammer Test

The rebound hammer test, a non-destructive testing method, was conducted to determine the in-situ strength of the geopolymer concrete. This test is useful for assessing the uniformity of concrete strength and estimating the compressive strength based on surface hardness. The test results indicated a 7-day strength of 13, 14-day strength of 20 MPa and a 28-day strength of 30.5 MPa, demonstrating significant early strength gain. Average strength is 26.7Mpa



Results and Discussion Mechanical Properties

- **Compressive Strength**: The compressive strength of the geopolymer concrete was evaluated at different curing ages. The inclusion of coarse and fine aggregates improved the mechanical properties of the concrete. These results are comparable to conventional concrete, making geopolymer concrete a viable alternative for structural applications.

- **Flexural Strength**: The flexural strength showed similar trends, with geopolymer concrete exhibiting superior performance compared to traditional concrete. The enhanced flexural strength can be attributed to the strong bonding between the geopolymer matrix and the aggregates.

Creep

Creep, the long-term deformation under sustained load, was measured over a period of 90 days. The results indicated that geopolymer concrete exhibited lower creep compared to traditional Portland cement concrete. This reduced creep is likely due to the dense and stable microstructure of the geopolymer matrix, which provides greater resistance to deformation.

Durability

- **Water Absorption**: The water absorption test revealed lower permeability, indicating enhanced durability. Lower water absorptionreduces the risk of freeze-thaw damage and ingress of harmful chemicals, thereby prolonging the lifespan of the concrete.

Chemical Resistance:

Oven dried cubes are used after the curing period of 28 days for both Acid and Sulphate attacks. Initial weight of cubes is recorded.

Specimens are immersed in 2% concentrated H_2SO_4, for Acid attack and 2%Sodium sulphate for Sulphate attack. Specimens are placed in solution for 28 days and specimens oven dried to remove the water content and final weight is recorded. Percentage loss in weight is calculated

SAMPAL	RATIO (FLYASH/SOLUTION)	COMPRESSIVE STRENGTH(KN/CM^2)			WATER/FLY ASH
		7 DAYS	14 DAYS	28 DAYS	
SAMPAL: 1	4/1	14	23	27	0.4
SAMPAL: 2	6/1	11	19.5	25	0.4

Microstructural Analysis

Scanning electron microscopy (SEM) and X-ray diffraction (XRD) analyses confirmed the

formation of a compact and homogeneous geopolymer matrix. The SEM images showed a dense and well-bonded matrix with minimal porosity, while XRD patterns indicated the presence of geopolymer gel phases. The presence of unreacted fly ash particles was minimal, indicating high reactivity and efficient geopolymerization.

Rebound Hammer Test Results

The rebound hammer test provided valuable insights into the in-situ strength of the geopolymer concrete. The test results indicated a 7-day strength of 13 MPa, 14-day strength of 19 MPa and a 28-day strength of 30.5 MPa, Average strength is 26.7Mpa. These findings are consistent with the compressive strength results obtained from destructive testing methods, validating the reliability of the rebound hammer test for assessing geopolymer concrete strength.

Conclusion

Fly ash-based geopolymer concrete with sodium hydroxide, sodium silicate, and coarse and fine aggregates presents a viable alternative to traditional concrete. It offers superior mechanical properties, enhanced durability, and environmental benefits due to the utilization of industrial by-products and reduced CO2 emissions. The rebound hammer test results corroborate the significant early strength gain, making this material suitable for various construction applications. The study concludes that geopolymer concrete is a promising sustainable building material that can potentially replace conventional concrete in many structural applications.

Future Work

Future research should focus on optimizing mix designs for different applications, exploring the long-term performance of geopolymer concrete in various environmental conditions, and developing standardized testing methods for this new material. Additionally, the scalability of geopolymer concrete production should be investigated to ensure its feasibility for large- scale construction projects.

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