Exploring Geo-polymer Concrete with Recycled Steel Slag as Primary Aggregate

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Abstract:

Concrete production has been revolutionized by the advent of geopolymer concrete, which eliminates the need for traditional cement and offers a sustainable alternative for the construction industry. This paper investigates the feasibility and performance of incorporating recycled steel slag as the primary coarse aggregate in geopolymer concrete. The study aims to address the environmental challenges posed by conventional concrete production by utilizing industrial by-products. Experimental investigations involve analyzing the mechanical behavior, durability, and flexural properties of geopolymer concrete with scrap steel slag. Additionally, analytical investigations using ANSYS software are conducted to validate experimental findings. The results indicate improved compressive strength, resistance to acid and sulfate attacks, enhanced durability, and cost savings compared to conventional concrete. The paper concludes with suggestions for future research focusing on long-term properties, dynamic loading behavior, and alternative fine aggregate materials.

Keywords: Geopolymer concrete, steel slag, sustainable construction, compressive strength, durability, finite element analysis, ANSYS.

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1. Introduction:

The evolution of concrete composition over the years has witnessed a significant departure from traditional ingredients towards incorporating industrial byproducts once deemed as waste. Among the notable advancements is the emergence of Geopolymer concrete, revolutionizing the conventional cement-dominated landscape. As the global demand for concrete continues to surge, there's a pressing need for sustainable alternatives to mitigate environmental impacts and resource depletion. This research paper delves into the feasibility of integrating scrap steel slag as a coarse aggregate in low-calcium fly ash-based geopolymer concrete. Against the backdrop of India's burgeoning construction sector, poised to become the world's third-largest market, the study aims to offer insights into sustainable practices while addressing the escalating challenges of industrial waste generation and environmental degradation. By exploring the uncharted territory of utilizing scrap steel slag in concrete production, this research endeavors to contribute towards fostering eco-friendly construction methodologies and enhancing the sustainability quotient of the built environment.

2. Objectives:

The study aims to:

- Evaluate the feasibility of using scrap steel slag as coarse aggregate in concrete.
- Compare experimental results with analytical investigations using ANSYS software.

3. Experimental Investigations:

In the realm of concrete production, binders play a crucial role in holding the mixture together, while coarse aggregates provide structural integrity. In this study, cement, fly ash, and GGBS act as binders, imparting strength and stability to the concrete matrix. Scrap steel slag and natural gravel are employed as coarse aggregates, contributing to the bulk and robustness of the concrete. Additionally, river sand serves as the fine aggregate, enhancing the workability and cohesiveness of the mixture. An alkaline activator solution, comprising sodium hydroxide and sodium silicate, facilitates the activation of pozzolanic materials, promoting the formation of geopolymer bonds and further strengthening the concrete. Structural RC beams are reinforced with high yield strength steel bars, ensuring the structural integrity and load-bearing capacity of the concrete elements. Detailed reports encompassing material properties, mix proportions, and experimental procedures are meticulously documented, providing comprehensive insights into the fabrication and testing processes employed in this research endeavor.

Figure 1.1 Class F Fly Ash

Figure 1.2 GGBS

Figure 1.3 Coarse Aggregate

Table 1 Chemical Composition of Fly Ash

SI. No.	Element	Weight %	Atomic %
1	Si	66.63	66.59
2	Al	27.56	28.67
3	K	3.15	2.26
4	Mg	1.35	1.56
5	Ca	1.31	0.92

Table 2 Chemical Composition of GGBS.

SI. No.	Element	Weight %	Atomic %
1	Si	42.2	43.15
2	Al	16.87	17.11
3	K	1.69	1.13
4	Mg	5.09	5.24
5	Ca	34.15	33.36

Table 3 Physical Properties of Coarse Aggregate

SI. No.	Parameter	value	Test Method Reference
1	Bulk density (kg/m^3)	1380	IS 2386 : 1963 Part 3
2	Specific gravity	2.66	IS 2386 : 1963 Part 3
3	Water absorption %	1	IS 2386 : 1963 Part 3
5	Fineness Modulus	6.23	IS 2386 : 1963 Part 1

4. Analytical Investigation:

Finite Element Analysis (FEA) using ANSYS software is conducted to analyze the behavior of the reinforced concrete beams studied experimentally. Load-deflection responses obtained from ANSYS analysis are compared with experimental results to validate the findings.

Figure 2 ANSYS Model of Beam

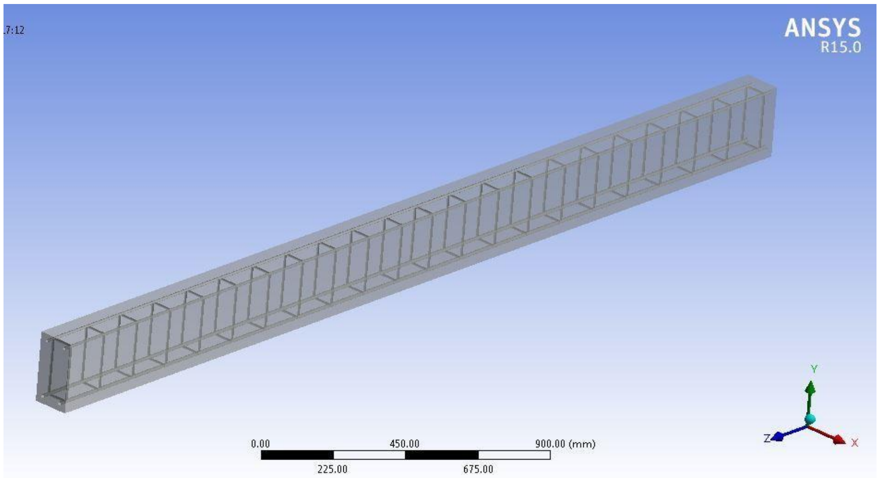

Table Load Deflection values for beams from ANSYS

SI. No.	Beam ID	Yield Load (kN)	Ultimate Load (kN)	Max. Deflection (mm)
1	CCGA20	45.00	47.00	47
2	CCSA20	44.75	47.25	59
3	CCGA40	47.25	50.00	47
4	CCSA40	48.70	51.25	65
5	CCGA60	51.00	52.25	56
6	CCSA60	51.25	52.75	60
7	GCGA20	46.50	49.00	51
8	GCSA20	47.75	49.25	63
9	GCGA40	48.00	50.00	47
10	GCSA40	48.50	50.25	60
11	GCGA60	49.25	53.25	58
12	GCSA60	50.00	53.50	71

5. Conclusions:

The study yields several key conclusions:

Geopolymer concrete incorporating scrap steel slag demonstrates heightened compressive strength when compared to conventional concrete. Furthermore, geopolymer concrete exhibits outstanding resistance against acid and sulfate attacks, indicative of its durability and longevity. In addition to its resistance properties, geopolymer concrete with scrap steel slag showcases improved durability, displaying lower Sorptivity and chloride penetrability. Moreover, structural elements composed of geopolymer concrete beams with scrap steel slag exhibit superior behavior under stress and strain, demonstrating enhanced structural integrity and displacement ductility.

Analytical values derived from ANSYS analysis closely align with experimental findings, validating the accuracy and reliability of the study's results.

Cost analysis indicates notable production cost savings associated with geopolymer concrete utilizing scrap steel slag as compared to conventional concrete, further highlighting its economic viability and potential for widespread adoption in construction projects.

6. Scope of Future Study:

Future research should focus on long-term properties, behavior under dynamic loading, fatigue strength, and fire resistance of geopolymer concrete. Additionally, replacing river sand with M-sand and evaluating its properties in concrete could further enhance sustainability. This research paper provides a comprehensive analysis of utilizing recycled steel slag in geopolymer concrete, offering insights into sustainable construction practices and avenues for future research.

References:

1. Ashadi, H.W.; Aprilando, B.A.; Astutiningsih, S. (2015). Effects of Steel Slag Substitution in Geopolymer Concrete on Compressive Strength and Corrosion Rate of Steel Reinforcement. International Journal of Technology, 2, 227-235.

2. Ionescu, B.A.; Lăzărescu, A.-V.; Hegyi, A. (2020). The Possibility of Using Slag for the Production of Geopolymer Materials and Its Influence on Mechanical Performances—A Review. Proceedings, 63, 30.

3. Zhang, Y.; Chen, J.; Xia, J. (2023). Compressive Strength and Chloride Resistance of Slag/Metakaolin-Based Ultra-High-Performance Geopolymer Concrete. Materials, 16(1), 181.

4. Dao, D.V.; Trinh, S.H.; Ly, H-B; Pham, B.T. (2019). Prediction of Compressive Strength of Geopolymer Concrete Using Entirely Steel Slag Aggregates: Novel Hybrid Artificial Intelligence Approaches. Applied Sciences, 9(6), 1113.

5. Esparham, A.; Vatin, N.I.; Kharun, M.; Hematibahar, M. (2023). A Study of Modern Eco-Friendly Composite (Geopolymer) Based on Blast Furnace Slag Compared to Conventional Concrete Using the Infrastructures. Infrastructures, 8(3), 58.

6. Bajpai, R.; Choudhary, K.; Srivastava, A.; Singh Sangwan, A.; Singh, M. (2020). Environmental impact assessment of fly ash and silica fume based geopolymer concrete. Journal of Cleaner Production, 254, 120147.

7. Schneider, M. (2019). The cement industry on the way to a low-carbon future. Cement and Concrete Research, 124, 105792.

8. Benhelal, E.; Zahedi, G.; Shamsaei, E.; Bahadori, A. (2013). Global strategies and potentials to curb CO2 emissions in cement industry. Journal of Cleaner Production, 51, 146-161.

9. Frischknecht, R.; Wyss, F.; Büsser Knöpfel, S.; Lützkendorf, T.; Balouktsi, M. (2015). Cumulative energy demand in LCA: The energy harvested approach. International Journal of Life Cycle Assessment, 20, 957-969.

10. Salas, D.A.; Ramirez, A.D.; Ulloa, N.; Baykara, H.; Boero, A.J. (2018). Life cycle assessment of geopolymer concrete. Construction and Building Materials, 190, 170-177.

11. Tempest, B.; Sanusi, O.; Gergely, J.; et al. (2021). Strength characteristics of granulated ground blast furnace slag-based geopolymer concrete. Advances in Concrete and Construction, 11, 219-229.

12. Ashadi, H.W.; Aprilando, B.A.; Astutiningsih, S. (2016). Effects of Steel Slag Substitution in Geopolymer Concrete on Compressive Strength and Corrosion Rate of Steel Reinforcement. International Journal of Technology, 2, 227-235.

13. Ionescu, B.A.; Lăzărescu, A.-V.; Hegyi, A. (2020). The Possibility of Using Slag for the Production of Geopolymer Materials and Its Influence on Mechanical Performances—A Review. Proceedings, 63, 30.

14. Zhang, Y.; Chen, J.; Xia, J. (2023). Compressive Strength and Chloride Resistance of Slag/Metakaolin-Based Ultra-High-Performance Geopolymer Concrete. Materials, 16(1), 181.

15. Dao, D.V.; Trinh, S.H.; Ly, H-B; Pham, B.T. (2019). Prediction of Compressive Strength of Geopolymer Concrete Using Entirely Steel Slag Aggregates: Novel Hybrid Artificial Intelligence Approaches. Applied Sciences, 9(6), 1113.