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Sustainable Construction Revolution: Fly Ash as Artificial Fine Aggregate and Fiber Glass as Innovative Additive in Lightweight Concrete

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Abstract

The paradigm of sustainable construction is undergoing a revolutionary transformation with the integration of novel materials. This study explores the use of fly ash as an artificial fine aggregate and fiber glass as an innovative additive in the formulation of lightweight concrete. The research aims to enhance the sustainability of construction practices by reducing the environmental impact associated with traditional concrete production. The final compressive strength and absorption tests were conducted, and the results were compared with those of conventional lightweight concrete. The collected data will undergo analysis to ascertain the strength of lightweight concrete across various content ratios while maintaining consistent size. As a result of various compositions, the concrete revealed different properties. The density ranged from 1804 to 2070 kg/m^3, and the corresponding strength ranged from 13.5 to 29.6 MPa. The durability research results of tested lightweight concretes showed that, despite considerably higher water absorption, a comparable water permeability and comparable or better freeze-thaw resistance in relation to normal-weight concrete may be present. Through a series of experiments and analyses, the study investigates the mechanical properties, durability, and environmental benefits of the developed lightweight concrete. The findings reveal a synergistic effect between fly ash and fiber glass, resulting in a lightweight concrete that not only exhibits improved performance but also contributes to the overall sustainability goals of the construction industry. This abstract provides a glimpse into the transformative potential of adopting fly ash and fiber glass in lightweight concrete, paving the way for a more eco-friendly and resilient future in construction.

Keywords: - Sustainable construction, compressive strength, absorption tests

1. Introduction

Lightweight aggregates (LWA) are specified in international standards like EN 13055, ASTM C330M, ASTM C331M, and ASTM C332. The ASTM standards distinguish between LWA for structural lightweight concrete, LWA for the application in masonry lightweight concrete and LWA for insulating concrete. Besides their origin, the definition of the aggregate properties, mainly the density, is important to distinguish between normal weight and lightweight aggregate. ASTM C330M and ASTM C331M give upper limits for the loose bulk density 1120 kg/m3 for fine LWA, 880 kg/m3 for coarse LWA and 1040 kg/m3 for the combination of fine and coarse LWA (Thienel, Haller & Beuntner, 2020).

The surge in popularity of lightweight concrete in recent years can be attributed to its myriad advantages, presenting a compelling alternative to traditional concrete. Technological advancements, coupled with an enhanced understanding of concrete properties, have played a pivotal role in the widespread adoption of lightweight concrete (Kayali, 2005; Chandra & Berntsson, 2002; Clarke, 1993 and Domagała, 2015).

Similar in composition to conventional concrete, the distinguishing factor lies in the use of lightweight aggregates or a combination of lightweight and normal-weight aggregates. Unlike standard lightweight concretes that rely on natural sand as fine aggregates, our project endeavors to address this norm by introducing a specialized lightweight concrete that not only upholds structural integrity but also contributes to resource conservation (Hossain, Ahmed & Lachemi, 2011; Liu, Chia & Zhang, 2011 and Lotfy, Hossain & Lachemi, 2016).

The primary motivation behind this project is to overcome the challenges associated with reinforcing lightweight concrete while simultaneously addressing the critical issue of conserving natural resources, particularly the scarce materials of coarse aggregates and sands. In doing so, this study aims to strike a balance between structural for roof decks performance and environmental responsibility.

Beyond its utilitarian aspects, our study extends into the realm of aesthetics, envisioning lightweight concrete as a versatile material capable of serving as a decorative panel. This dual-purpose approach not only enhances the practical applications of lightweight concrete but also adds an artistic dimension to its potential uses in construction and design (Zhang & Gjvorv, 1991).

Moreover, this research project takes a bold step towards sustainability by incorporating waste and recyclable materials, notably fly ash, at optimal levels. By doing so, we aspire to curtail the quantity of waste generated annually, aligning our efforts with broader initiatives aimed at promoting responsible waste management practices and reducing environmental impact.

In essence, our project stands at the intersection of technological innovation, structural reinforcement, environmental stewardship, and aesthetic enhancement, envisioning a future where lightweight concrete emerges not just as a practical choice but as a sustainable and versatile solution for the construction industry (Srinivasan et al., 2016 and Vijay, 2015).

Fly ash, a byproduct of combustion, traditionally relegated as waste, is now assuming a pivotal role in sustainable construction. This introduction explores how this artificial fine aggregate, rich in pozzolanic properties, not only diverts waste from landfills but also enhances the durability and strength of lightweight concrete, aligning structures with environmental responsibility (Thienel, Haller & Beuntner, 2020).

Fig. 1. Rapid identification method of fly ash quality (Alpa, 2022)

Integrating fiber glass as an innovative additive in lightweight concrete brings forth a host of possibilities, enhancing both the structural and environmental aspects of the material. Here are some ideas for utilizing fiber glass in lightweight concrete which combine fiber glass strands within the concrete mix to reinforce its tensile strength. This not only improves the overall durability of the lightweight concrete but also allows for the creation of thinner and lighter structures for roof decks without compromising structural integrity. It also introduces microfiber glass particles to enhance the crack resistance of lightweight concrete. The fibrous nature of glass can act as a barrier to crack propagation, leading to a more resilient and long-lasting material. Fiber glass can be an impact-resistant additive, especially in applications where lightweight concrete may be exposed to external forces. The flexibility and strength of fiber glass can absorb and distribute impact energy effectively, minimizing potential damage (Priyadharshini, Ganesh & Santhi, 2011; Nadesan & Dinakar, 2018 and Wasserman & Bentur, 1996).

Fig. 2. Fiber glass Chopped Strand

The study aims to achieve the following objectives:

1. To produce Eco-Friendly and decorative lightweight concrete by incorporating fly ash and fiber glass as additive mixtures and substituting fly ash as the artificial aggregate simultaneously.
2. To assess the compressive strength and water absorption characteristics of the lightweight concrete produced with the mentioned additives.
3. To compare the compressive strength of the lightweight concrete incorporating fly ash and fiber glass with that of conventional lightweight concrete.

In summary, the study aims to develop a sustainable and aesthetically pleasing lightweight concrete using eco-friendly materials, evaluate its mechanical properties such as compressive strength and water absorption, and make a comparative analysis with conventional lightweight concrete.

2. Methodology

The methodology for the research project "Sustainable Construction Revolution: Fly Ash as Artificial Fine Aggregate and Fiber Glass as Innovative Additive in

Lightweight Concrete" follows a systematic and comprehensive approach.

2.1 Literature Review

Conduct an extensive review of existing literature on the use of fly ash and fiber glass in lightweight concrete. Explore properties, strengths, and weaknesses of lightweight concrete with these additives. Identify gaps in knowledge to understand the state of the art in sustainable lightweight concrete.

2.2 Material Characterization

Characterize properties of raw materials (fly ash and fiber glass) through laboratory testing. Examine particle size distribution, chemical composition, and physical properties of fly ash. Evaluate fiber glass properties, including length, diameter, and tensile strength.

2.3 Mix Design Optimization

Develop various lightweight concrete mix designs with different ratios of fly ash and fiber glass. Conduct trial mixes to determine optimal combinations for strength, durability, and sustainability. Consider variations in fly ash percentages, fiber glass lengths, and other relevant factors.

2.4 Concrete Sample Preparation

Prepare concrete samples based on optimized mix designs.

2.5 Mechanical Testing

Perform comprehensive mechanical testing on concrete samples, including compressive strength. Conduct tests at various curing periods to analyze strength development over time.

2.6 Data Analysis and Interpretation

Analyze collected data using statistical tools. Interpret results in the context of research objectives.

2.7 Conclusion and Recommendations

Summarize findings and draw conclusions based on research outcomes. Provide recommendations for practical application of sustainable lightweight concrete. Suggest areas for future research and development in the field.

3. Result and Discussion

The research involved the analysis of data obtained from a series of tests, including compressive strength and water absorption tests, conducted on lightweight concrete with different ratios. Each test was performed on individual sample test cubes, allowing for a comprehensive evaluation of the durability of the lightweight concrete under varying ratios. The aim was to assess how changes in composition influenced both compressive strength and water absorption, providing valuable insights into the overall performance and robustness of the concrete under different conditions. The standard for water absorption in lightweight concrete is less than 12%. Based on the data obtained in Table 1, the entire testing ratio is consistent.

Table 1. Water absorption test

Ratio	Cube size (mm)	Sample	Day	Density (kg/m^3)	Weight (kg)		Percentage of absorption (%)	Percentage average of absorption (%)
					Before	After		
Concrete Control 1:2	100 x 100 x 100	1	7	2014	2.014	2.067	2.632	2.650
		2		1912	1.912	1.963	2.667	
		3	28	2040	2.040	2.102	3.039	3.011
		4		1978	1.978	2.037	2.983	
1:2:1		1	7	1784	1.784	1.875	5.100	4.516
		2		1704	1.704	1.771	3.932	
		3	28	1778	1.778	1.850	4.049	4.145
		4		1769	1.769	1.844	4.240	
1:2:2		1	7	1750	1.750	1.875	7.143	5.827
		2		1774	1.774	1.854	4.510	
		3	28	1756	1.756	1.825	3.929	4.201
		4		1766	1.766	1.845	4.473	
1:2:3		1	7	1731	1.731	1.798	3.871	3.945
		2		1817	1.817	1.890	4.018	
		3	28	1743	1.743	1.816	4.188	4.339
		4		1715	1.715	1.792	4.490	

Table 1 and Fig. 3 shows that the 1:02:02 admixture ratio absorbs 5.112% more water after seven days compared to the other three ratios. However, after twenty-eight days, the water absorption percentages for the 1:02:01, 1:02:02, and 1:02:03 ratios are similar, ranging from 4.145% to 4.339%. In contrast, the concrete control has the lowest water absorption percentages at 2.650% for seven days and 3.011% for twenty-eight days.

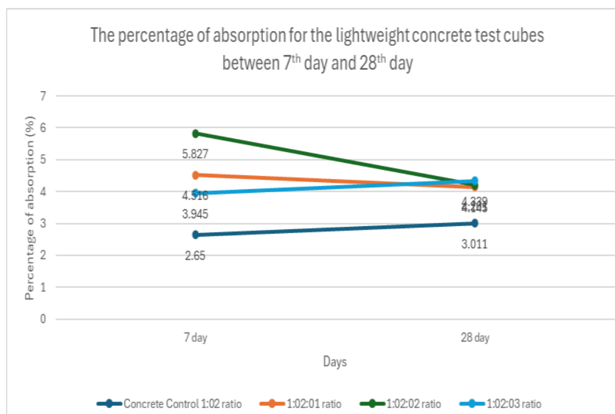

Fig. 3. The percentage of absorption for the lightweight concrete test cubes between 7th day and 28th day

Based on Table 2 and Fig. 4, the 1:02:02 admixture ratio exhibits the highest compressive strength, measuring 23.12 MPa at seven days and 29.61 MPa at twenty-eight days, surpassing the other three ratios. In contrast, the 1:02:01 admixture ratio shows the lowest compressive strength at 13.50 MPa for the seven-day test. The compressive strength drops significantly for the 1:02:03 admixture ratio, recording 17.14 MPa at seven days and 18.43 MPa at twenty-eight days. Notably, the concrete control demonstrates superior strength at twenty-eight days, surpassing both the 1:02:01 and 1:02:03 admixture ratios with a strength of 16.78 MPa.

Table. 2. Results of compressive strength test

Ratio	Cube size (mm)	Sample	Day	Weight (kg)	Density (kg/m³)	Load (kN)	Averge Load (kN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
Concrete Control 1:2	100 x 100 x 100	1	7	2.067	2015	168.6	167.75	16.86	16.78
		2		1.963		166.9		16.69	
		3	28	2.102	2070	245.3	229.40	24.53	22.94
		4		2.037		213.5		21.35	
1:2:1		1	7	1.875	1814	125.0	135.00	12.50	13.50
		2		1.771		145.0		14.50	
		3	28	1.850	1847	174.0	229.45	17.40	22.95
		4		1.844		284.9		28.49	
1:2:2		1	7	1.875	1860	232.9	231.20	23.29	23.12
		2		1.854		220.5		22.95	
		3	28	1.825	1835	299.9	296.10	29.99	29.61
		4		1.845		292.3		29.23	
1:2:3		1	7	1.798	1844	163.7	171.35	16.37	17.14
		2		1.890		179.0		17.90	
		3	28	1.816	1804	173.7	184.30	17.37	18.43
		4		1.792		194.9		19.49	

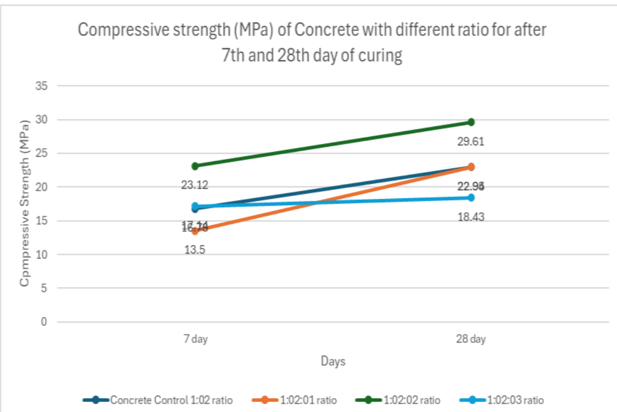

Fig. 4. Compressive strength of concrete with different ratio for after 7th and 28th of curing

In analyzing the compressive strength data from the conducted test, variations among samples are evident. The 1:02:02 admixture ratio stands out with the highest compressive strength for both testing durations compared to the other three samples. The 1:02:01 admixture ratio records the lowest compressive strength at seven days, attributed to its lighter weight than the other cubes. However, its strength equals that of the concrete control at twenty-eight days due to the presence of fiber glass content. The compressive strength peaks at the 1:02:02 admixture ratio but declines rapidly at the 1:02:03 admixture ratio, likely due to the mixture reaching its strength limit.

4. Conclusion

Regarding water absorption, the results indicate varying percentages among the samples. The 1:02:02 admixture ratio exhibits the highest water absorption, attributed to its fiber glass content. In contrast, the 1:02:03 admixture ratio shows lower water absorption due to a higher concentration of fiber glass. The control concrete has the lowest water absorption, as it lacks additional components that readily absorb water. The 1:02:02 admixture ratio emerges as the most suitable choice, effectively controlling water absorption.

In terms of compressive strength, the samples display different values. The 1:02:02 admixture ratio stands out with the highest compressive strength for both seven and twenty-eight days. The 1:02:01 admixture ratio exhibits lower compressive strength at seven days due to its lighter weight but matches the control concrete at twenty-eight days, thanks to its fiber glass content. The compressive strength peaks at the 1:02:02 admixture ratio but decreases rapidly at the 1:02:03 admixture ratio, suggesting a limit to the strength achievable. To ensure the accuracy of the obtained data, the researchers emphasize the importance of conducting future research and tests with precision and care.

The research has demonstrated the transformative potential of incorporating fly ash as an artificial fine aggregate and fiber glass as an innovative additive in lightweight concrete. This sustainable construction revolution not only enhances the structural properties of the material but also contributes significantly to reducing environmental impact and conserving natural resources.

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