

Development of Eco-Friendly Concrete Using Binary Blends and Recycled Construction Waste

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Abstract

This study examines the mechanical properties of sustainable concrete that includes agro-industrial by-products, specifically fly ash (FA) and rice husk ash (RHA), used as partial substitutes for cement in binary blended mixtures. Experimental evaluation was carried out by replacing cement at varying proportions (5%, 10%, 15%, and 20%) and assessing compressive strength and split tensile strength at 7 and 28 days. The results indicate that the incorporation of fly ash significantly enhances the strength characteristics, with the optimum performance observed at 10% replacement, achieving a maximum compressive strength of 43.93 N/mm² and split tensile strength of 2.95 N/mm² at 28 days. Rice husk ash mixes also demonstrate improvement, particularly at 10–15% replacement levels, with peak compressive and tensile strengths of 39.80 N/mm² and 2.64 N/mm², respectively. However, a decline in strength is observed at higher replacement levels (20%) for both materials due to reduced cementitious content. Comparative analysis reveals that fly ash-based blends outperform RHA mixes in terms of strength development, while RHA provides stable and consistent results. The study highlights that an optimum level of partial replacement can effectively enhance mechanical properties while promoting sustainable construction practices through the utilization of industrial and agricultural waste materials.

Keyword: *Binary blended concrete, Fly ash and rice husk ash, Construction Demolition Waste (CDW), Sustainable construction materials, Mechanical performance*

I. Introduction

Concrete continues to be the backbone of modern infrastructure due to its adaptability, compressive strength, and economic viability. It is traditionally composed of cement, aggregates, and water, where cement acts as the primary binding material. However, the production of cement is energy-intensive and contributes significantly to global carbon dioxide emissions, accounting for nearly 7–8% of total emissions worldwide. This has encouraged the exploration of alternative materials that can partially replace conventional constituents without compromising performance. Recent advancements emphasize the use of industrial by-products and agricultural residues as sustainable substitutes, improving both environmental and mechanical performance of concrete (Neville, 2011; Mehta & Monteiro, 2014; Woldeesenbet et al., 2025).

1.1. Sustainable Green Concrete

Sustainable green concrete focuses on minimizing environmental impact by making better use of available resources and integrating waste materials into its composition. The inclusion of supplementary cementitious materials (SCMs), such as fly ash and rice husk ash, plays a key role in reducing the overall carbon emissions associated with conventional concrete. At the same time, these materials contribute to improved durability and strength over longer periods. Research in this area shows that green concrete not only helps in conserving natural resources but also enhances resistance to harmful conditions like chloride ingress and chemical exposure. Furthermore, life cycle assessment studies indicate that partial replacement of cement with waste-based materials can significantly lower energy usage and reduce the overall environmental burden of construction practices (Naik, 2008; Malhotra, 2002; Onyelowe et al., 2022; Barragán-Ramírez et al., 2024).

1.2 Binary Blended Concrete

Binary blended concrete refers to the practice of partially replacing cement with a single pozzolanic material, commonly fly ash or rice husk ash. During the hydration process, these materials react with calcium hydroxide released from cement and form additional calcium silicate hydrate (C–S–H), which contributes to improved strength and durability. Studies have shown that such binary blends enhance the internal microstructure of concrete and reduce its permeability, making it more resistant to harsh environmental conditions. Rice husk ash has attracted particular interest because of its high amorphous silica content and strong pozzolanic activity, while fly ash is known for improving workability and supporting long-term strength gain. Together, these materials help in producing concrete that is both high-performing and environmentally sustainable (Siddique, 2004; Ganesan et al., 2008; Ordoñez et al., 2024; Indumathi et al., 2024).

1.3. Construction and Demolition Waste (CDW)

Construction and Demolition Waste (CDW) forms a significant share of the total solid waste produced worldwide, mainly due to building construction, renovation, and demolition activities. Converting this waste into recycled aggregates provides an effective way to reduce the burden on landfills while conserving natural resources. Research has shown that aggregates obtained from CDW can be used in concrete production; however, they tend to have higher porosity and greater water absorption compared to natural aggregates. To overcome these drawbacks, recent studies emphasize the use of supplementary cementitious materials along with recycled aggregates to improve the quality of the interfacial transition zone and enhance overall performance. This combined approach has demonstrated notable improvements in both the strength and durability of recycled aggregate concrete (Poon et al., 2004; Rao et al., 2007; Al-Naghi et al., 2025).

1.4. Research Significance and Gap

Although extensive research has been carried out on green concrete, binary blended systems, and recycled aggregates independently, there is still limited understanding of their combined behavior when used together in a single concrete system. Recent studies emphasize the need for integrated approaches that combine CDW aggregates with binary blended binders to achieve optimal performance and sustainability. However, the influence of such combinations on early-age and long-term compressive strength, particularly with varying proportions of fly ash and rice husk ash, remains insufficiently explored. Therefore, this study aims to address this gap by experimentally evaluating binary blended sustainable green concrete incorporating CDW, with a focus on identifying optimal mix proportions that balance strength, durability, and environmental benefits.

2. Objectives

- To prepare M30 grade sustainable concrete by partially replacing cement with fly ash and rice husk ash, while keeping a fixed 20% replacement of natural coarse aggregates with Construction and Demolition Waste (CDW) in accordance with IS 10262:2019 guidelines.
- To study the mechanical performance of the developed mixes by testing compressive strength and split tensile strength at 7 and 28 days for different proportions of fly ash and rice husk ash, with CDW content maintained at 20%.
- To identify the most effective combination of fly ash and rice husk ash in binary blended concrete with a constant 20% CDW replacement, aiming to achieve maximum strength along with improved sustainability in construction.

3. Materials and Methodology

The present experimental investigation was carried out to evaluate the performance of binary blended sustainable green concrete incorporating Construction and Demolition Waste (CDW) as partial replacement of coarse aggregates. The materials used in this study include Ordinary Portland Cement (OPC) of 53 grade conforming to IS 12269, natural river sand as fine aggregate conforming to Zone II of IS 383:2016, and crushed stone as conventional coarse

aggregate. Processed Construction and Demolition Waste (CDW) aggregates were used as partial replacement for natural coarse aggregates. Fly ash (FA) obtained from a thermal power plant and rice husk ash (RHA) produced under controlled burning conditions were used as supplementary cementitious materials. Clean potable water was used for both mixing and curing of concrete. The study was designed based on M30 grade concrete, and the mix proportions were developed in accordance with the guidelines of IS 10262:2019 and IS 456:2000.

The mix design for M30 grade concrete was carried out by adopting a target mean strength approach as per IS 10262:2019, considering standard deviation and exposure conditions. A constant water-cement ratio was maintained for all mixes to ensure uniformity in comparison. The reference mix (control concrete) was prepared without any replacement of cement or aggregates. For the experimental program, two sets of binary blended mixes were prepared: one with fly ash and the other with rice husk ash as partial replacement of cement. Cement was replaced at levels of 5%, 10%, 15%, and 20% in both series, while the replacement of natural coarse aggregates with CDW was maintained constant at 20% for all mixes.

Concrete mixing was carried out using a standard mechanical mixer to ensure proper blending of materials. The dry components, including cement, fine aggregates, coarse aggregates, CDW aggregates, and supplementary materials (FA/RHA), were first mixed thoroughly to achieve uniform distribution. Water was then added gradually, and mixing was continued until a homogeneous mix was obtained. Workability of fresh concrete was assessed using the slump cone test as per IS 1199:2018 to ensure consistency among different mixes.

For strength evaluation, standard cube specimens of size 150 mm × 150 mm × 150 mm were cast for compressive strength testing, while cylindrical specimens of size 150 mm diameter and 300 mm height were prepared for split tensile strength testing. The concrete was placed in moulds in layers and compacted properly using a tamping rod to remove entrapped air. After casting, the specimens were kept undisturbed for 24 hours at room temperature, then demoulded and transferred to a curing tank containing clean water maintained under standard curing conditions.

Compressive strength tests were conducted at curing ages of 7 days and 28 days in accordance with IS 516:2018 using a calibrated compression testing machine. In addition, split tensile strength tests were performed on cylindrical specimens at 7 and 28 days as per IS 5816:1999 to evaluate the tensile behavior of concrete. For each mix proportion, three specimens were tested, and the average value was reported to ensure accuracy and consistency. The experimental program was structured to compare the performance of binary blended mixes with the reference mix, thereby assessing the influence of fly ash and rice husk ash in combination with a constant 20% CDW aggregate replacement on both compressive and tensile strength characteristics of sustainable green concrete. The below table 1 gives mix proportions used in present study.

Table 1. Mix proportions used in study

Sl No	Binary Mixes	Binary Mixes
1	Ref Mix	Ref Mix
2	95% Cement + 5% fly ash	95% Cement + 5% RHA
3	90% Cement + 10% fly ash	90% Cement + 10% RHA
4	85% Cement + 15% fly ash	85% Cement + 15% RHA
5	80% Cement + 20% fly ash	90% Cement + 20% RHA

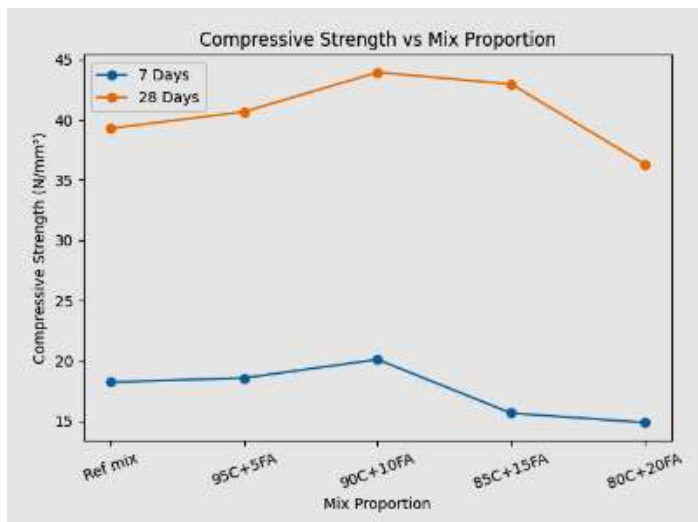
4. Experimental Results and Discussion

4.1 Compressive strength of binary blended concrete with Flyash

Table 2 summarizes the compressive strength results of concrete cube specimens prepared with fly ash (FA) as a partial replacement for cement. The variation in strength for different mix proportions can be clearly understood from the graphical representation provided below, which highlights the trend in strength development across the mixes.

Table 2: Overall compressive strength (7 and 28 days) of binary blended concrete with Flyash

Sl. No	Mix proportion	7 days compressive strength(N/mm ²)	28 days compressive strength(N/mm ²)
1	Ref mix	18.23	39.28
2	95C+5FA	18.58	40.66
3	90C+10FA	20.11	43.93
4	85C+15FA	15.66	42.95
5	80C+20FA	14.88	36.30


Graph 1: Variation of overall compressive strength (7 and 28 days) of binary blended concrete with FA

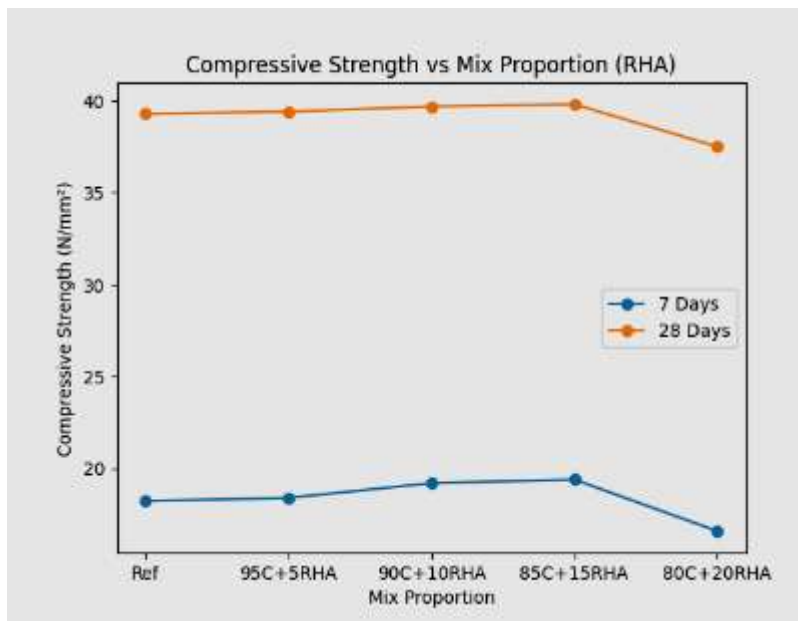
The results show that replacing cement with fly ash enhances compressive strength up to an optimum level of about 10%, with the 90C+10FA mix achieving the highest strength at both 7 and 28 days. When the replacement level exceeds this percentage, a reduction in strength is observed. This decline can be attributed to the lower cement content, which slows down the hydration process and affects the overall development of strength, particularly at early ages.

4.2 Compressive strength of binary blended concrete with Rice Hush ash

Table 3 presents the overall compressive strength results of concrete cubes prepared using Rice husk ash (RHA). The changes in compressive strength across different mixes are clearly illustrated through the graphical representation shown below.

Table 3: Overall compressive strength (7 and 28 days) of binary blended concrete with Rice Hush ash

Sl. No	Mix proportion	7 days compressive strength(N/mm ²)	28 days compressive strength(N/mm ²)
1	Ref mix	18.23	39.28
2	95C+5RHA	18.40	39.40
3	90C+10 RHA	19.20	39.68
4	85C+15 RHA	19.40	39.80
5	80C+20 RHA	16.60	37.50



Graph 2: Variation of overall compressive strength (7 and 28 days) of binary blended concrete with RHA

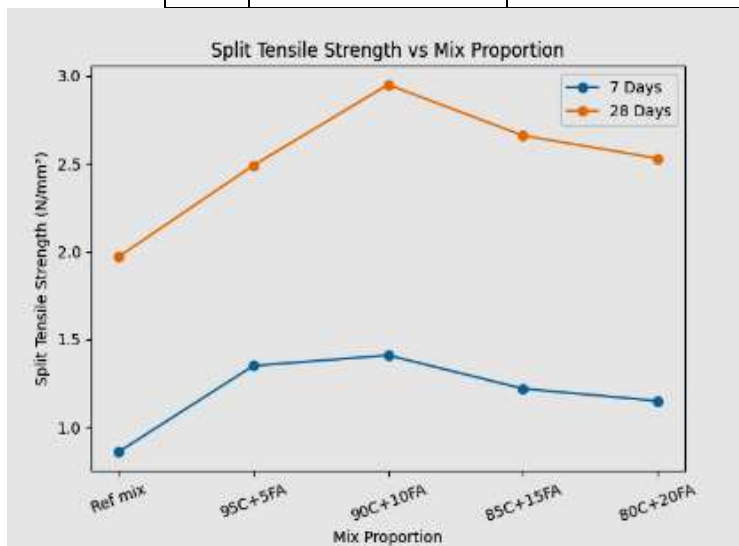
The graph 2 shows gradual strength improvement with increasing RHA content up to 15%, after which strength decreases. The 85C+15RHA mix exhibits optimum performance, indicating effective pozzolanic activity and improved concrete properties.

4.3 Split Tensile strength of binary blended concrete with Flyash

Following table 3 gives the overall results of Split Tensile strength of concrete cube produced by using Fly ash (FA). The variation of Split Tensile strength can be depicted in the form of graph as shown below.

Table 3: Overall Split Tensile strength (7 and 28 days) of binary blended concrete with FA

Sl. No	Mix proportion	7 days Split Tensile strength(N/mm ²)	28 days Split Tensile strength(N/mm ²)
1	Ref mix	0.86	1.97
2	95C+5FA	1.35	2.49
3	90C+10FA	1.41	2.95
4	85C+15FA	1.22	2.66
5	80C+20FA	1.15	2.53



Graph 3: Variation of overall Split tensile strength (7 and 28 days) of binary blended concrete with FA

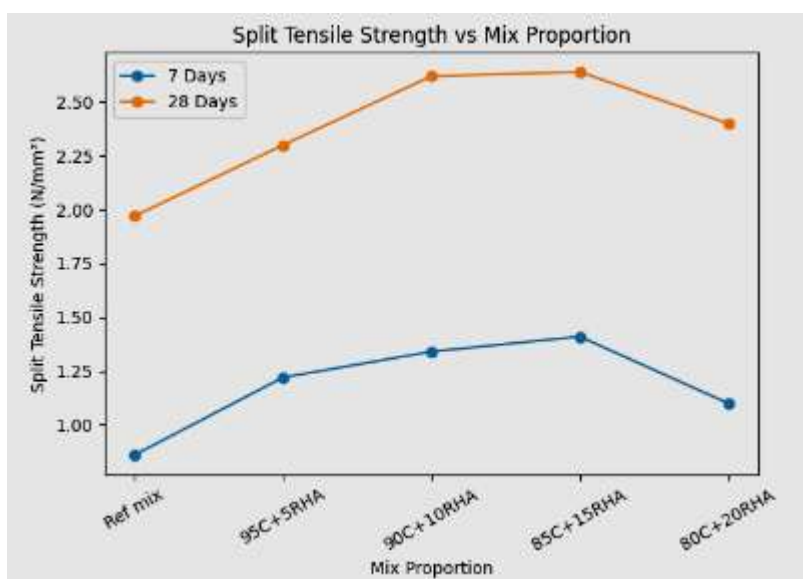
Graph 3 clearly indicates that the split tensile strength increases with the addition of fly ash up to 10% replacement (90C + 10FA) at both 7 and 28 days of curing. The highest 28-day split tensile strength of 2.95 N/mm² is recorded at this level, suggesting better bonding within the concrete matrix and an improved microstructure due to pozzolanic activity. When the replacement level is increased to 15% and 20%, a slight drop in tensile strength is observed. This reduction may be due to the decrease in cement content and the slower rate of strength development. Hence, 10% fly ash replacement can be considered the optimum level for achieving better tensile performance.

4.4 Split Tensile strength of binary blended concrete with Rice Husk ash

Following table 4 gives the overall results of Split Tensile strength of concrete cube produced by using Rice Husk ash (RHA). The variation of Split Tensile strength can be depicted in the form of graph 4 as shown below.

Table 4: Overall Split Tensile strength (7 and 28 days) of binary blended concrete with RHA

Sl. No	Mix proportion	7 days Split Tensile strength(N/mm ²)	28 days Split Tensile strength(N/mm ²)
1	Ref mix	0.86	1.97
2	95C+5RHA	1.22	2.30
3	90C+10 RHA	1.34	2.62
4	85C+15 RHA	1.41	2.64
5	80C+20 RHA	1.10	2.40



Graph 4: Variation of overall Split tensile strength (7 and 28 days) of binary blended concrete with RHA

Split tensile strength increases with fly ash content up to 15%, with 85C+15FA showing maximum values. Beyond this level, strength decreases, indicating an optimum replacement level for improved tensile performance.

6.0 Conclusions

The experimental study focused on assessing the behavior of binary blended concrete in which Fly Ash (FA) and Rice Husk Ash (RHA) were used as partial substitutes for cement. The performance of the mixes was examined by analyzing their compressive strength and split tensile strength at curing periods of 7 and 28 days.

1. Compressive Strength Analysis

- The compressive strength results clearly show that both fly ash (FA) and rice husk ash (RHA) have a noticeable impact on the mechanical behavior of concrete. In the case of fly ash-based mixes, strength improves as the replacement level increases up to 10%, after which a decline is observed. The mix with 90% cement and 10% fly ash (90C+10FA) recorded the highest 28-day compressive strength of 43.93 N/mm², which is significantly higher than that of the control mix (39.28 N/mm²). This improvement is mainly due to

the pozzolanic action of fly ash, which leads to the formation of additional calcium silicate hydrate (C–S–H) gel and results in a denser and stronger microstructure.

➤ On the other hand, mixes containing rice husk ash showed only a moderate increase in compressive strength. The highest value for RHA-based concrete was obtained for the 85C+15RHA mix, reaching 39.80 N/mm², which is only slightly higher than the reference mix. The comparatively lower improvement may be attributed to variations in particle size, surface characteristics, and reactivity of RHA. At higher replacement levels, such as 20%, both FA and RHA mixes exhibited a reduction in strength, likely due to the decreased cement content, which affects the overall binding capacity of the concrete.

2. Split Tensile Strength Analysis

➤ The split tensile strength results show a trend similar to that observed in compressive strength. Concrete mixes containing fly ash exhibited better tensile performance compared to those with rice husk ash. The highest tensile strength was achieved by the 90C+10FA mix, recording 2.95 N/mm² at 28 days, which is a clear improvement over the reference mix value of 1.97 N/mm². This enhancement can be linked to improved bonding between the aggregates and the cement paste, supported by the fine particles of fly ash that contribute to a denser and more compact matrix.

➤ In the case of rice husk ash, the mixes showed an increase in tensile strength up to a replacement level of 15%. The 85C+15RHA mix reached a tensile strength of 2.64 N/mm² at 28 days. The high silica content in RHA helps improve the interfacial transition zone (ITZ), leading to better bonding, although the overall improvement is not as significant as that observed with fly ash.

➤ Overall, concrete mixes with fly ash perform better than those with rice husk ash in terms of both compressive and split tensile strength. This can be attributed to improved particle packing, higher pozzolanic reactivity, and better microstructural development. However, rice husk ash still shows stable and consistent performance, making it a suitable option when the focus is on sustainability and effective utilization of agricultural waste.

Table 5: Overall comparison of both binary mixes

Parameter	Fly Ash (FA) Based Concrete	Rice Husk Ash (RHA) Based Concrete
Optimum Replacement Level	10% (90C + 10FA)	15% (85C + 15RHA)
Maximum Compressive Strength (28 days)	43.93 N/mm ²	39.80 N/mm ²
Improvement in Compressive Strength	Significant increase	Slight increase
Maximum Split Tensile Strength (28 days)	2.95 N/mm ²	2.64 N/mm ²
Improvement in Tensile Strength	High improvement	Moderate improvement
Strength Trend	Increases up to 10%, then decreases	Increases up to 15%, then decreases
Pozzolanic Activity	High	Moderate
Workability	Better due to spherical particles	Slightly lower due to finer particles
Overall Performance	Superior in strength and durability	Stable and sustainable alternative
Suitability	High-performance structural concrete	Sustainable and eco-friendly applications

References

- [1]. Al-Naghi, A. A. A., Ali, T., Inam, I., et al. (2025). An innovative approach to enhancing the strength and durability of recycled aggregate concrete through fly ash-silica fume coating and rice husk ash supplementation. *Scientific Reports*, 15, 32780.
- [2]. Barragán-Ramírez, R., González-Hernández, A., Bautista-Ruiz, J., et al. (2024). Enhancing concrete durability and strength with fly ash, steel slag, and rice husk ash for marine environments. *Materials*, 17(12), 3001.
- [3]. Ganesan, K., Rajagopal, K., & Thangavel, K. (2008). Rice husk ash blended cement: Assessment of optimal level of replacement. *Construction and Building Materials*, 22(8), 1675–1683.
- [4]. Indumathi, M., Nakkeeran, G., Roy, D., et al. (2024). Innovative approaches to sustainable construction: A detailed study of rice husk ash as an eco-friendly substitute in cement production. *Discover Applied Sciences*, 6, 597.
- [5]. Malhotra, V. M. (2002). Introduction: Sustainable development and concrete technology. *ACI Concrete International*, 24(7), 22–23.
- [6]. Mehta, P. K., & Monteiro, P. J. M. (2014). *Concrete: Microstructure, properties, and materials* (4th ed.). McGraw-Hill Education.
- [7]. Naik, T. R. (2008). Sustainability of concrete construction. *Practice Periodical on Structural Design and Construction*, 13(2), 98–103.
- [8]. Neville, A. M. (2011). *Properties of concrete* (5th ed.). Pearson Education.
- [9]. Onyelowe, K. C., Ebid, A. M., & Mahdi, H. A. (2022). Optimization of green concrete containing fly ash and rice husk ash based on hydro-mechanical properties and life cycle assessment. *Civil Engineering Journal*, 8(12).
- [10]. Ordoñez, L. M., Borrachero, M. V., Monzó, J., et al. (2024). Binary and ternary blended Portland cements containing different types of rice husk ash. *Materials*, 17(12), 2923.
- [11]. Poon, C. S., Shui, Z. H., & Lam, L. (2004). Effect of microstructure of ITZ on compressive strength of concrete prepared with recycled aggregates. *Construction and Building Materials*, 18(6), 461–468.
- [12]. Rao, A., Jha, K. N., & Misra, S. (2007). Use of aggregates from recycled construction and demolition waste in concrete. *Resources, Conservation and Recycling*, 50(1), 71–81.
- [13]. Woldesenbet, D. T., Mohammed, J. J., Negedu, S. D., et al. (2025). Experimental investigation on partial cement replacement with binary blended materials for enhanced concrete performance. *Scientific Reports*, 15.
- [14]. Mehta, P. K. (1992). Rice husk ash—A unique supplementary cementing material. *Proceedings of the International Symposium on Advances in Concrete Technology*, Athens, Greece, pp. 407–430.
- [15]. Malhotra, V. M., & Mehta, P. K. (2005). *High-Performance, High-Volume Fly Ash Concrete: Materials, Mixture Proportioning, Properties, Construction Practice, and Case Histories*. Ottawa: Supplementary Cementing Materials for Sustainable Development Inc.
- [16]. Habeeb, G. A., & Mahmud, H. B. (2010). Study on properties of rice husk ash and its use as cement replacement material. *Materials Research*, 13(2), 185–190.
- [17]. Siddique, R. (2004). Performance characteristics of high-volume Class F fly ash concrete. *Cement and Concrete Research*, 34(3), 487–493.