JURNAL TEKNIK SIPIL DAN LINGKUNGAN| EISSN:2549-1407
https://journal.ipb.ac.id/index.php/jsil

Vol. 10 No. 02 October 2024
DOI: 10.29244/jsil.10.2.259-266

Compressive Strength Performance of Rice Husk Ash-Based Geopolymer Concrete with Fly Ash as a Secondary Material

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Abstract: Concrete production heavily relies on cement, whose manufacturing significantly contributes to carbon emissions, necessitating alternative materials for sustainable construction. This study investigates the effect of varying compositions of rice husk ash (RHA) and fly ash on the compressive strength and workability of concrete. Five variations of RHA and fly ash ratios (80:20, 75:25, 70:30, 65:35, and 60:40) were tested to identify the optimal mixture. The results show that the 60:40 ratio produced the highest compressive strength of 16.66 MPa and a slump value of 9.5 cm, indicating enhanced workability and mechanical performance. This finding highlights the complementary roles of RHA, which contributes to pozzolanic activity, and fly ash, which enhances hydration and cementitious properties. Excessive RHA content, however, leads to reduced strength due to its lower reactivity. The exponential trend observed in the compressive strength characteristics (R^2 = 0.91) confirms the nonlinear relationship between material composition and performance. This research aligns with previous studies demonstrating the benefits of using industrial by-products in concrete. The findings underscore the potential of combining RHA and fly ash as an eco-friendly solution for high-strength concrete, promoting waste utilization and sustainability in the construction industry. Future studies should investigate the long-term durability and scalability for industrial applications.

Keywords: Rice husk ash; fly ash; compressive strength; sustainable construction; pozzolanic

Submitted : 17 June 2025
Revised : 07 July 2025
Accepted : 29 July 2025

1. Introduction

The construction industry is pivotal in global development, yet it is one of the largest contributors to environmental degradation (Olii, et al., 2023). Ordinary Portland cement (OPC), essential for concrete, is a major contributor to greenhouse gas emissions [2], [3]. Cement production is responsible for about 7-8% of global CO_2 emissions, mainly from limestone calcination and fossil fuel combustion in kilns [4]. The extraction of raw materials and energy-intensive processes worsen resource depletion and environmental pollution [5]. Rising global demand for infrastructure development has raised concerns about the environmental impacts of OPC production, questioning the sustainability of traditional construction methods [6], [7]. Researchers and engineers are exploring alternative construction materials and methods to reduce the environmental impact of cement-based products [8], [9]. A promising solution is eco-friendly concrete, which reduces dependence on OPC by using industrial by-products and agricultural waste [10]. This approach promotes environmental sustainability and improves waste management by repurposing materials that would otherwise be thrown away [11]. Among the various innovations in this field, geopolymer concrete has emerged as a sustainable alternative to traditional concrete [3], [12], [13].

Geopolymer concrete is a binder system that eliminates the need for OPC, utilizing aluminosilicate materials activated by alkaline solutions [14], [15]. It is renowned for its lower CO_2 emissions, enhanced durability, and resistance to chemical attacks [16]. Fly ash, a by-product from coal combustion in power plants is widely researched as a key ingredient in making geopolymers [17], [18]. The limited availability of fly ash in some areas and its rising demand have led to the search for alternative materials. Rice husk ash (RHA), made from burning rice husks, is valued for its high silica content and pozzolanic properties [19]. Using RHA as the main ingredient in geopolymer concrete supports a circular economy by turning waste into a valuable building material and lowering environmental impact [20], [21]. Despite the promising potential of RHA-based geopolymer concrete, limited research has focused on its performance when fly ash is used as a secondary binder. Combining RHA and fly ash in geopolymer concrete creates a strong synergy by utilizing RHA's high silica content and the aluminosilicate properties of fly ash [22]. This blend has the potential to enhance the mechanical properties, particularly compressive strength, of geopolymer concrete. Compressive strength is crucial for structural applications, and knowing how precursor combinations affect this property is vital for enhancing geopolymer concrete performance [23].

This research focuses on the compressive strength of geopolymer concrete made primarily from RHA and supplemented with fly ash. Few studies have examined the combined effects of RHA and fly ash on the compressive strength of geopolymer concrete, despite much research on fly ash-based geopolymer concrete [23]. This study aims to fill this research gap by examining the influence of precursor ratios, alkaline activator concentrations, and curing conditions on the compressive strength of RHA-based geopolymer concrete. Furthermore, this research contributes to the broader goals of sustainable construction by promoting the utilization of agricultural and industrial by-products. The findings aim to help develop high-performance, eco-friendly geopolymer concrete that meets the mechanical standards for structural use. This study improves geopolymer technology by using RHA and fly ash while tackling environmental issues related to waste management and CO_2 emissions. The objectives of this study are twofold: first, to investigate the compressive strength behavior of RHA-based geopolymer concrete with varying proportions of fly ash; second, to optimize the mix design for achieving maximum compressive strength while maintaining sustainability. This research is expected to benefit the construction industry, especially in areas rich in RHA and fly ash. This study enhances our understanding of geopolymer concrete's performance, promoting its use as a sustainable alternative to traditional cement.

2. Methods

This study uses experiments to analyze the properties of coarse and fine aggregates used in making geopolymer concrete. Laboratory tests were conducted by relevant Indonesian National Standards (SNI) to ensure the quality and suitability of materials. The materials used in this study were sourced from specific locations to ensure quality and consistency. RHA was sourced from the Mananggu District in Gorontalo, an area renowned for its agricultural products ideal for use as supplementary cementitious materials. Fly ash was obtained from the Anggrek Power Plant in Gorontalo, providing a by-product with pozzolanic properties. PT provided coarse aggregate. CMP Crusher Plant, ensuring uniformity and adherence to standard specifications for construction materials. Fine aggregate was sourced from the Bone River, offering natural sand with appropriate grading and cleanliness. These materials were selected to achieve optimal performance in concrete production and reflect locally available resources.

2.1. Aggregate Characteristic Tests

(a) Gradation was performed using sieving methods from SNI 03-1968 (1990) to find the particle size distribution of aggregates. (b) Moisture Content was measured according to SNI 03-1971 (1990), drying until a constant weight was achieved. (c) Bulk Density was evaluated based on SNI 1973 (2016) by weighing the aggregate in loose and compacted conditions. Specific Gravity and Absorption tests were performed according to SNI 1968 (2008) to assess the aggregate's density and water absorption. (e) Clay Content was assessed following SNI 03-4428 (1997) to determine the cleanliness of sand from clay particles. Abrasion resistance was tested with a Los Angeles machine, per SNI 03-2417 (1991), to evaluate the aggregate's durability.

2.2. Tests on RHA and Fly Ash

(a) Bulk Density tests for RHA and fly ash were conducted according to SNI 1973 (2016), using methods to measure both loose and compacted states. (b) Specific Gravity and Absorption measurements adhere to SNI 1968 (2008) for determining density and water absorption. Gradation involved using a No. 100 sieve (0.15 mm mesh) to filter out only fine and reactive particles for the study.

2.3. Binder Preparation Method

The binder for geopolymer concrete was prepared through a series of steps integrating RHA and fly ash as primary materials, along with an alkaline activator solution as the binder: (a) Preparation of Alkaline Activator Solution involved dissolving NaOH in water at a concentration of 12 M. The NaOH and Na_2SiO_3 were mixed at a ratio of 1:2.5 and stirred until fully homogenized using either a mechanical or manual mixer. This ratio is widely used in the literature because it provides a balance between alkalinity and silica content, supports the formation of strong geopolymer gels, and maintains good workability [24], [25], [26], [27], [28]. The aging process required the alkaline solution to sit for 24 hours at room temperature to stabilize the initial reactions. (c) Combine RHA, fly ash, and the activator solution according to the geopolymer concrete mix design, ensuring a consistent and uniform mixture through meticulous mixing. (d) Storage and Readiness ensured the binder was used immediately after preparation to prevent premature drying or hardening.

2.4. Making Geopolymer Concrete Samples

(a) Material preparation includes binder, coarse aggregates, fine aggregates, cement, and water. (b) Mix Design follows SNI 7656 (2012) to find the best proportions of binder, aggregates, alkaline solution, and water for the required compressive strength. (c) The mixing process starts by blending coarse and fine aggregates in a mixer. Then, the prepared binder is added, and water is gradually mixed in to adjust the consistency for proper workability. (d) The molding requires lightly greased cylindrical molds (15 cm in diameter and 30 cm in height) for easy removal, into which the geopolymer concrete is poured. Each layer was compacted using a rod or vibrator to eliminate trapped air. Each mix proportion was cast into five cylindrical specimens to ensure consistency and allow for reliable statistical analysis of the compressive strength results. (e) A Slump Test was conducted on fresh concrete to assess its workability and verify that the mix met the flowability requirements of SNI 1972 (2008). (f) Curing Process, following SNI 03-2847-2002, consisting of demolding the specimens after 24 hours, curing them in a controlled environment for 24 hours to accelerate polymerization, and then exposing them to normal environmental conditions for further curing. (g) Compressive Strength Testing was conducted at specific intervals (e.g., 7 or 28 days) to evaluate the performance of the geopolymer concrete specimens using a compressive strength testing machine per SNI 03-2847-2002. This study uses systematic methods to characterize materials, precisely formulate binders, and reliably produce geopolymer concrete specimens, ensuring they meet desired properties and performance standards (Figure 1).

3. Result and Discussion

3.1. Test Results for Coarse, Fine Aggregates, Fly Ash, and RHA

Table 1 details the physical properties of materials used to create concrete, including fine aggregate, coarse aggregate, RHA, and fly ash. These properties are critical for evaluating their suitability for producing durable, high-performance concrete. The fineness modulus of the fine and coarse aggregates is 2.81 and 8.39, respectively, indicating that lower values correspond to finer particle sizes. The water content of fine and coarse aggregates is 3.80% and 1.32%, respectively, affecting workability and mix proportions.

The specific gravity values are 2.87 for fine aggregate, 2.76 for coarse aggregate, 1.25 for RHA, and 2.11 for fly ash, showing their relative densities. The bulk specific gravity of aggregates is provided for both saturated surface dry (SSD) and dry conditions, indicating their volumetric density in water and dry states. The absorption capacities of fine and coarse aggregates are 3.84% and 1.52%, respectively. These values are important for adjusting mix designs based on their water absorption ability. The bulk densities of the materials are: fine aggregate 1.55 kg/l, coarse aggregate 1.70 kg/l, RHA 0.70 kg/l, and fly ash 1.18 kg/l, indicating their compactness. The mud content of fine and coarse aggregates is relatively low (0.99% and 0.60%), ensuring material cleanliness. The wear and tear percentage of coarse aggregate is 22.86%, indicating its durability under mechanical stress, which is crucial for structural use. These detailed properties collectively guide the selection of materials to achieve optimal performance in concrete.

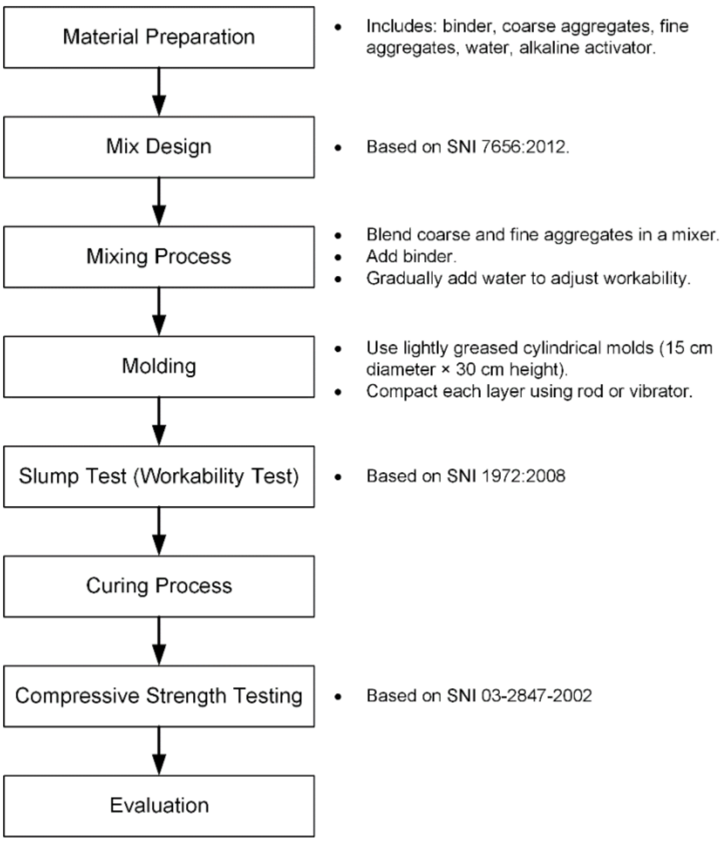

Figure 2. Geopolymer Concrete Procedure

Table 1. Characteristics of concrete materials

Characteristics	Fine Aggregate	Coarse Aggregate	RHA	Fly Ash
Fineness modulus	2.81	8.39	-	-
Water content (%)	3.80	1.32	-	-
Apparent spesific gravity	2.87	2.76	1.25	2.11

Bulk specific gravity (SSD basic)	2.69	2.68	-	-
Bulk specific gravity (on dry basic)	2.59	2.64	-	-
Absorption (%)	3.84	1.52	-	-
Density (kg/l)	1.55	1.70	0.70	1.18
Mud content (%)	0.99	0.60		
Wear and tear (%)		22.86		

3.2. Comparison of concrete material composition based on variations in the proportion of RHA and fly ash in the mixture

Table 2 presents the composition of concrete materials for five variations of RHA and fly ash percentages. These variations, expressed as RHA to fly ash ratios based on weight of sample (80:20, 75:25, 70:30, 65:35, and 60:40), illustrate the proportional changes in binder materials and their effects on other concrete components, such as the activator, fine aggregate, and coarse aggregate. In all variations, the RHA quantity remains constant at 1.00 (normalized for comparison), while the fly ash proportion increases progressively with each variation. At the 80:20 ratio, fly ash is 0.15, and it increases steadily to 0.39 in the 60:40 ratio, demonstrating the impact of a higher fly ash percentage in the binder composition.

Table 2. Comparison of Concrete Material Composition

Variations of RHA and Fly Ash (%)	*RHA*	Fly Ash	Activator	Fine Aggregate	Coarse Aggregate
80 : 20	1.00	0.15	0.50	3.55	3.50
75 : 25	1.00	0.20	0.54	3.33	3.73
70 : 30	1.00	0.25	0.58	3.10	4.00
65 : 35	1.00	0.32	0.62	2.88	4.30
60 : 40	1.00	0.39	0.67	2.66	4.66

The activator quantity increases correspondingly, from 0.50 in the 80:20 ratio to 0.67 in the 60:40 ratio. This reflects the greater demand for alkali activator solutions to ensure sufficient geopolymerization as fly ash content rises. The fine aggregate proportion decreases as the fly ash ratio increases, starting from 3.55 in the 80:20 mix and reducing to 2.66 in the 60:40 mix. Conversely, the coarse aggregate proportion shows a complementary increase, ranging from 3.50 in the 80:20 ratio to 4.66 in the 60:40 ratio. This shift indicates adjustments in the aggregate balance to maintain overall mix consistency. This table underscores how varying RHA and fly ash proportions influence the composition of other materials, ensuring that the concrete mix maintains optimal workability and structural integrity.

3.3 Results of Concrete Characteristic Compressive Strength Test

Table 3 summarizes the compressive strength test results for concrete with varying percentages of RHA and fly ash (80:20, 75:25, 70:30, 65:35, and 60:40). The table also includes slump values, average compressive strength, and characteristic compressive strength to evaluate the performance of each mix. Slump values range from 7.8 cm for the 80:20 mix to 9.5 cm for the 60:40 mix, showing that workability increases with more fly ash. This trend suggests that higher fly ash content enhances the concrete's flowability. The average compressive strength shows a significant increase as the fly ash percentage grows. Starting at 6.25 MPa in the 80:20 ratio, the strength gradually rises to 16.87 MPa in the 60:40 ratio. Similarly, the characteristic compressive strength improves from 5.87 MPa in the 80:20 mix to 16.66 MPa in the 60:40 mix. The data demonstrate that increasing fly ash content, up to 40%, contributes positively to the mechanical strength of the concrete. The 65:35 and 60:40 variations stand out with notably higher compressive strength values, exceeding 15 MPa. The results show that using RHA and fly ash together as cement additives improves the polymerization process and overall strength when used in the right proportions. This table highlights the significance of material proportions in obtaining desired mechanical properties, guiding the selection of RHA and fly ash ratios for concrete mixes in structural applications.

Table 3. Results of Concrete Characteristic Compressive Strength Test

Variations of RHA and Fly Ash (%)	*Slump* (cm)	Average Compressive Strength (MPa)	Compressive Strength Characteristics (MPa)
80 : 20	7.8	6.25	5.87
75 : 25	8.3	7.78	7.24
70 : 30	8.6	8.80	8.70
65 : 35	9.2	15.85	15.83
60 : 40	9.5	16.87	16.66

Figure 2 depicts the relationship between compressive strength characteristics (MPa) and the variations in the ratio of RHA to fly ash (%). The exponential trendline, expressed as y = 552.02$^{e-0.05x}$ with a coefficient of determination (R^2 = 0.91), demonstrates a strong inverse correlation. The compressive strength significantly improves as the proportion of fly ash increases relative to RHA. The highest compressive strength is observed at the 60:40 ratio, with a characteristic strength of approximately 16.66 MPa. Conversely, higher RHA proportions (e.g., 80:20 ratio) result in lower compressive strength values, around 5.87 MPa. The graph highlights the importance of balancing RHA and fly ash ratios to optimize concrete compressive strength. The strong R^2 value indicates that the exponential model effectively represents the observed data, suggesting that fly ash is critical in enhancing concrete properties.

The study results highlight the influence of varying RHA and fly ash compositions on the compressive strength and workability of concrete. As shown in the data, a higher proportion of fly ash relative to RHA significantly improves both the compressive strength and slump values of concrete. At an 80:20 ratio of RHA to fly ash, the compressive strength is the lowest (5.87 MPa), and the slump is relatively low (7.8 cm). In contrast, the 60:40 ratio yields the highest compressive strength (16.66 MPa) and slump value (9.5 cm). This trend aligns with previous findings that fly ash enhances the hydration process and reduces voids within the concrete matrix, contributing to higher strength and better workability. The relationship between compressive strength and the RHA-fly ash ratio follows an exponential trend, with a high correlation coefficient (R^2 = 0.91).

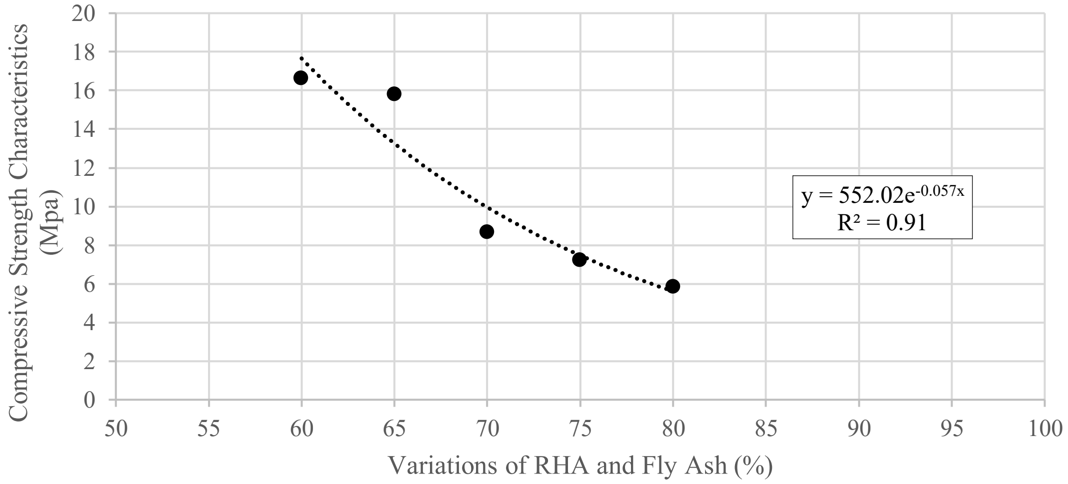

Figure 2. The relationship between compressive strength characteristics (MPa) and the variations in the ratio of RHA to fly ash (%)

This demonstrates the critical role of fly ash as a supplementary cementitious material in optimizing concrete properties. Excessive RHA, despite its pozzolanic properties, leads to diminished strength due to its high porosity and lower reactivity compared to fly ash. These findings corroborate earlier studies, such as those by [29], [30], [31], which emphasize the importance of balancing pozzolanic materials for enhanced durability and strength. The slump test results further support the hypothesis that fly ash improves workability due to its spherical particle shape, which reduces internal friction. This is crucial for practical applications, ensuring ease of placement and compaction without compromising structural performance.

4. Conclusion

This study explores how different amounts of RHA and fly ash affect the compressive strength and workability of concrete. The results show that the optimal RHA-to-fly ash ratio is 60:40, achieving the highest compressive strength of 16.66 MPa and a slump value of 9.5 cm, indicating improved strength and workability. Fly ash plays a crucial role in improving hydration and cementitious reactions, while RHA offers valuable pozzolanic properties. However, excessive RHA reduces compressive strength due to its lower reactivity. These findings align with previous studies that emphasize the synergistic effects of combining pozzolanic materials for sustainable concrete production. This study suggests that using the right amounts of RHA and fly ash improves concrete performance and helps recycle waste materials, reducing environmental impact. This approach can be applied to develop sustainable, high-strength concrete for various structural applications in modern construction.

Acknowledgements

We would like to express my sincere gratitude to the Faculty of Engineering, Universitas Gorontalo, for their financial and laboratory support, as well as to all parties who have contributed to this work.

References

[1] M. R. Olii, A. S. Hidayat, M. Saliko, T. Santoso, M. A. Hippy, and R. Pakaya, "Environmentally Friendly Concrete Using Waste Glass Powder (WGP) As a Partial Substitute of Cement," *J. Tek. Sipil*, vol. 12, no. 2, pp. 140–146, 2023.

[2] S. S. Hossain, P. K. Roy, and C. J. Bae, "Utilization of waste rice husk ash for sustainable geopolymer: A review," *Constr. Build. Mater.*, vol. 310, no. August, p. 125218, 2021, doi: 10.1016/j.conbuildmat.2021.125218.

[3] M. Amran, S. Debbarma, and T. Ozbakkaloglu, "Fly ash-based eco-friendly geopolymer concrete: A critical review of the long-term durability properties," *Constr. Build. Mater.*, vol. 270, p. 121857, 2021, doi: 10.1016/j.conbuildmat.2020.121857.

[4] S. Barbhuiya, F. Kanavaris, B. B. Das, and M. Idrees, "Decarbonising cement and concrete production: Strategies, challenges and pathways for sustainable development," *J. Build. Eng.*, vol. 86, no. September 2023, p. 108861, 2024, doi: 10.1016/j.jobe.2024.108861.

[5] L. Valentini, "Sustainable sourcing of raw materials for the built environment," *Mater. Today Proc.*, no. July, pp. 26–29, 2023, doi: 10.1016/j.matpr.2023.07.308.

[6] M. R. Olii, A. A. Wahab, I. Ichsan, R. A. Djau, and S. Nento, "Beton Hijau Menggunakan Fly ash sebagai Subtitusi Parsial Semen," *Siklus J. Tek. Sipil J. Tek. Sipil*, vol. 9, no. 1, pp. 11–20, 2023.

[7] M. R. Olii, I. . Poe, I. Ichsan, and A. Olii, "Limbah Kaca Sebagai Penganti Sebagian Agregat Halus Untuk Beton Ramah Lingkungan," *Teras J.*, vol. 11, no. 1, pp. 113–124, 2021, doi: http://dx.doi.org/10.29103/tj.v11i1.407.

[8] N. A. A. Al-Jburi, K. J. H. Hasan, N. Azline, and N. Ostovar, "Waste glass as partial replacement in cement - A review," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 357, no. 1, 2019, doi: 10.1088/1755-1315/357/1/012023.

[9] L. Imtiaz, S. K. Ur Rehman, S. A. Memon, M. K. Khan, and M. F. Javed, "A review of recent developments and advances in eco-friendly geopolymer concrete," *Appl. Sci.*, vol. 10, no. 21, pp. 1–56, 2020, doi: 10.3390/app10217838.

[10] H. Afrin, N. Huda, and R. Abbasi, "An Overview of Eco-Friendly Alternatives as the Replacement of Cement in Concrete," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1200, no. 1, p. 012003, 2021, doi: 10.1088/1757-

899x/1200/1/012003.
[11] W. K. Part, M. Ramli, and C. B. Cheah, "An overview on the influence of various factors on the properties of geopolymer concrete derived from industrial by-products," *Constr. Build. Mater.*, vol. 77, pp. 370–395, 2015, doi: 10.1016/j.conbuildmat.2014.12.065.
[12] F. Farooq *et al.*, "Geopolymer concrete as sustainable material: A state of the art review," *Constr. Build. Mater.*, vol. 306, no. August, p. 124762, 2021, doi: 10.1016/j.conbuildmat.2021.124762.
[13] K. H. Mo, U. J. Alengaram, and M. Z. Jumaat, "Structural performance of reinforced geopolymer concrete members: A review," *Constr. Build. Mater.*, vol. 120, pp. 251–264, 2016, doi: 10.1016/j.conbuildmat.2016.05.088.
[14] N. Shehata, O. A. Mohamed, E. T. Sayed, M. A. Abdelkareem, and A. G. Olabi, "Geopolymer concrete as green building materials: Recent applications, sustainable development and circular economy potentials," *Sci. Total Environ.*, vol. 836, no. April, p. 155577, 2022, doi: 10.1016/j.scitotenv.2022.155577.
[15] F. N. Okoye, "Geopolymer binder: A veritable alternative to Portland cement," *Mater. Today Proc.*, vol. 4, no. 4, Part E, pp. 5599–5604, 2017, doi: https://doi.org/10.1016/j.matpr.2017.06.017.
[16] P. Risdanareni, P. Puspitasari, and E. J. Jaya, "Chemical and Physical Characterization of Fly Ash as Geopolymer Material," in *MATEC Web of Conferences*, 2017. doi: 10.1051/matecconf/20179701031.
[17] H. K. Shehab, A. S. Eisa, and A. M. Wahba, "Mechanical properties of fly ash based geopolymer concrete with full and partial cement replacement," *Constr. Build. Mater.*, vol. 126, pp. 560–565, 2016, doi: 10.1016/j.conbuildmat.2016.09.059.
[18] A. M. Putra, S. Reni, and H. Maizir, "Studi Eksperimental Sifat Mekanis Bata Ringan CLC Dengan Penambahan Fly Ash," *Siklus J. Tek. Sipil*, vol. 10, no. 2, pp. 215–227, 2024, doi: https://doi.org/10.31849/siklus.v10i2.21182.
[19] S. K. Das, A. Adediran, C. R. Kaze, M. Mustakim, S., and N. Leklou, "Production, characteristics, and utilization of rice husk ash in alkali activated materials: An overview of fresh and hardened state properties," *Constr. Build. Mater.*, vol. 345, no. July, p. 128341, 2022, doi: 10.1016/j.conbuildmat.2022.128341.
[20] G. Mounika, M. Priyanka, Y. Rajasri, T. S. Reddy, S. Srinanda, and G. S. Reddy, "Evaluation of Mechanical Characteristics of concrete incorporating Fly Ash and Rice Husk Ash as sustainable alternatives," *E3S Web Conf.*, vol. 559, 2024, doi: 10.1051/e3sconf/202455904028.
[21] S. A. Zareei, F. Ameri, F. Dorostkar, and M. Ahmadi, "Rice husk ash as a partial replacement of cement in high strength concrete containing micro silica: Evaluating durability and mechanical properties," *Case Stud. Constr. Mater.*, vol. 7, no. October 2016, pp. 73–81, 2017, doi: 10.1016/j.cscm.2017.05.001.
[22] K. Chiranjeevi, M. M. Vijayalakshmi, and T. R. Praveenkumar, "Investigation of fly ash and rice husk ash-based geopolymer concrete using nano particles," *Appl. Nanosci.*, vol. 13, no. 1, pp. 839–846, 2023, doi: 10.1007/s13204-021-01916-2.
[23] S. Joel, "Compressive strength of concrete using fly ash and rice husk ash: A review," *Civ. Eng. J.*, vol. 6, no. 7, pp. 1400–1410, 2020, doi: 10.28991/cej-2020-03091556.
[24] D. Hardjito and B. V Rangan, "Development and Properties of Low-Calcium Fly Ash-Based Geopolymer Concrete," Faculty of Engineering, Curtin University of Technology, Perth, 2005.
[25] P. Duxson, J. L. Provis, G. C. Lukey, and J. S. J. van Deventer, "The role of inorganic polymer technology in the development of 'green concrete,'" *Cem. Concr. Res.*, vol. 37, no. 12, pp. 1590–1597, 2007, doi: 10.1016/j.cemconres.2007.08.018.
[26] A. Fernández-Jiménez, A. Palomo, and M. Criado, "Alkali-activated fly ash binders: A comparative study between sodium and potassium activators," *Cem. Concr. Res.*, vol. 36, no. 10, pp. 1980–1986, 2006, doi: 10.1016/j.cemconres.2006.05.012.
[27] A. Sathonsaowaphak, P. Chindaprasirt, and K. Pimraksa, "Use of palm oil fuel ash and rice husk ash in geopolymer concrete," *Waste Manag.*, vol. 29, no. 2, pp. 539–543, 2009, doi: 10.1016/j.wasman.2008.06.023.
[28] J. Temuujin, A. Minjigmaa, M. Lee, N. Chen-Tan, and A. van Riessen, "Characterization of class F fly ash geopolymer pastes immersed in acid and alkaline solutions," *Cem. Concr. Compos.*, vol. 31, no. 1, pp. 29–34, 2009, doi: 10.1016/j.cemconcomp.2008.09.001.
[29] T. Van Lam, B. Bulgakov, O. Aleksandrova, O. Larsen, and P. Ngoc Anh, "Effect of rice husk ash and fly ash on the compressive strength of high performance concrete," *E3S Web Conf.*, vol. 33, pp. 1–13, 2018, doi: 10.1051/e3sconf/20183302030.
[30] M. N. Al-hashem *et al.*, "Predicting the compressive strength of concrete containing," *Materials (Basel).*, 2022.
[31] A. H. Insyira *et al.*, "Study of using Coal Fly Ash (CFA) and Rice Husk Ash (RHA) on the Compressive Strength of Geopolymer Concrete," *E3S Web Conf.*, vol. 426, pp. 3–7, 2023, doi: 10.1051/e3sconf/202342601011.