JURNAL TEKNIK

Volume 23, No. 1, Juni 2025
P-ISSN : 1693-6191 E-ISSN : 2715-7660 DOI : https://doi.org/10.37031/jt.v23i1.611

Enhancing Compressive Strength of Self-Compacting Concrete (SCC) through Rice Husk Ash and Superplasticizer Incorporation

[1]Muhammad Ramdhan Olii, [2]Azhar Zukur Putra M. Ali, [3]Rahman Abdul Djau, [4]Nurhayati Doda, [5]Rizky Selly Nazarina Olii

[1,2,3,4]Department of Civil Engineering, Engineering Faculty, Universitas Gorontalo, Indonesia
[5]Department of Architecture, Engineering Faculty, Universitas Gorontalo, Indonesia

e-mail: mr.olii@unigo.ac.id, zukurputra@gmail.com, rahmandjau92@gmail.com, yati.doda@gmail.com, rizkysellynazarinaolii@gmail.com

Abstrak

Meningkatnya permintaan akan material konstruksi berkelanjutan telah mendorong pemanfaatan bahan alternatif seperti *rice husk ash* (RHA) dan penggunaan admixture kimiawi seperti superplasticizer dalam self-compacting concrete (SCC). Penelitian ini bertujuan untuk mengevaluasi pengaruh penambahan RHA dan *superplasticizer* terhadap sifat beton SCC dalam kondisi segar dan mengeras, dengan fokus pada kemampuan mengalir (*flowability*), ketahanan terhadap segregasi, dan kekuatan tekan. Program eksperimen melibatkan tiga campuran SCC: beton normal, serta SCC dengan penambahan RHA dan *superplasticizer* masing-masing sebesar 4% dan 8% dari berat semen. Sifat beton segar diuji menggunakan uji *slump flow*, *V-Funnel*, dan *L-Box*, sedangkan kekuatan tekan diuji pada benda uji kubus setelah perawatan selama 28 hari. Hasil menunjukkan bahwa penambahan 4% RHA dan *superplasticizer* meningkatkan kekuatan tekan hingga 34,02 MPa dan tetap mempertahankan kemampuan alir dalam batas yang ditentukan, dengan diameter *slump flow* rata-rata 675–697 mm, waktu *V-Funnel* 7,35–8,72 detik, dan rasio *L-Box* sebesar 0,84–0,85. Namun, campuran dengan 8% RHA menunjukkan penurunan kekuatan tekan menjadi 28,51 MPa, yang mengindikasikan bahwa penggunaan *superplasticizer* yang berlebihan dapat merusak kohesi antar partikel. Selain itu, penggunaan RHA menyebabkan penurunan densitas beton, yang menunjukkan potensinya untuk aplikasi konstruksi ringan. Temuan ini menegaskan bahwa dosis 4% RHA dan *superplasticizer* mampu mengoptimalkan performa SCC serta mendukung konstruksi berkelanjutan melalui penggunaan material yang efisien dan tahan lama. Studi ini menekankan pentingnya perancangan campuran yang tepat dan menyarankan perluasan aplikasi RHA dan admixture kimia dalam pengembangan teknologi beton ramah lingkungan.

Kata kunci: *Self-Compacting Concrete* (SCC), *Rice Husk Ash* (RHA), *Superplasticizer*, Kuat Tekan, Material Konstruksi Berkelanjutan

Abstract

The increasing demand for sustainable construction materials has encouraged the utilization of alternative materials, such as rice husk ash (RHA), and the use of chemical admixtures like superplasticizers in self-compacting concrete (SCC). This study aims to evaluate the effects of RHA and superplasticizer incorporation on the fresh and hardened properties of SCC, focusing on flowability, segregation resistance, and compressive strength. The experimental program involved three SCC mixtures: normal concrete, and SCC with 4% and 8% RHA and superplasticizer by cement weight. Fresh concrete properties were assessed using the slump flow, V-Funnel, and L-Box tests, while compressive strength tests were conducted on cube specimens after 28 days of curing. The results indicated that the addition of 4% RHA and superplasticizer enhanced the compressive strength to 34.02 MPa and maintained flowability within the specified limits, with an average slump flow diameter of 675–697 mm, V-Funnel time of 7.35–8.72 seconds, and L-Box ratio of 0.84–0.85. However, the 8% RHA mixture exhibited a decline in compressive strength (28.51 MPa), highlighting the detrimental effects of excessive superplasticizers on particle cohesion. Furthermore, the use of RHA reduced concrete density, showcasing its potential for lightweight construction applications. These findings confirm that a 4% RHA and superplasticizer dosage optimizes SCC performance, supporting sustainable construction through resource-efficient and durable materials. The study underscores the need *for precise mix designs and suggests broader applications of RHA and chemical admixtures in advancing green concrete technologies.*

***Keywords**: Self-Compacting Concrete (SCC), Rice Husk Ash (RHA), Superplasticizer, Compressive Strength, Sustainable Construction Materials*

Diterima : April 2025
Disetujui : Mei 2025
Dipublikasi : Juni 2025

Introduction

The need for sustainable construction practices is growing due to environmental challenges and dwindling natural resources (Chiu et al., 2014; Kioumarsi & Plevris, 2024; Nilimaa, 2023). Self-compacting concrete (SCC) is an innovative material in construction, known for its excellent workability and performance. SCC flows under its weight, filling complex molds and tightly packed reinforcement sections without needing mechanical vibration (Aziz et al., 2024; Phan & Nguyen, 2025). This unique property lowers labor and energy use during construction, reduces defects, and improves consistency, leading to stronger and better-performing structures (Rwamamara & Simonsson, 2012). Despite its numerous advantages, SCC's mechanical properties, particularly compressive strength, remain a critical focus for researchers and practitioners alike (Kalyana Chakravarthy & Namratha, 2022). To create a strong and sustainable SCC, it's essential to have a balanced mix design that includes innovative materials and admixtures to improve performance and meet environmental standards (Zende et al., 2023).

One promising approach to enhancing the properties of SCC is the incorporation of supplementary cementitious materials (SCMs) (Aziz et al., 2024; Chen et al., 2006; Emam & Yehia, 2017; Muralidharan et al., 2021) such as rice husk ash (RHA) and chemical admixtures like superplasticizers. RHA, a by-product of rice milling, is valued for its abundance and high silica content, which provides pozzolanic properties (Das et al., 2022; Hossain et al., 2021; Neri et al., 2023; Part et al., 2015). When partially replacing cement, RHA reacts with calcium hydroxide in the hydration process to create more calcium silicate hydrate (C-S-H) gel. This gel contributes to the densification of the concrete matrix, thereby improving compressive strength and durability (Saad et al., 2015). Using RHA helps meet global sustainability goals by lowering the carbon footprint of cement production and offering a way to manage agricultural waste (Farid & Zaheer, 2023). The effectiveness of RHA in concrete, including SCC, depends on its fineness, dosage, and compatibility with other mix components (Antiohos et al., 2014; Siddika et al., 2021). Optimizing these parameters is essential to maximize the benefits of RHA in SCC.

Superplasticizers, on the other hand, are essential in achieving the high workability required for SCC without compromising its mechanical properties. Water-reducing agents lower the water-to-cement ratio, improving flowability and keeping the mix cohesive and resistant to segregation (Ben Aicha, 2020). By improving the packing density of particles and reducing the porosity of the concrete matrix, superplasticizers contribute to the overall strength and durability of SCC (Olowofoyeku et al., 2019). When combined with RHA, superplasticizers enable the effective dispersion of particles, enhancing the pozzolanic reaction and further improving the compressive strength of the mix (Pradhan & Sharma, 2021). Despite these promising attributes, the combined effects of RHA and superplasticizers in SCC have not been fully explored, particularly concerning their interaction at varying proportions. Understanding the synergistic relationship between these components is critical for developing high-performance SCC formulations tailored to diverse construction needs.

This study aims to address the gaps in existing research by systematically investigating the combined impact of RHA and superplasticizers on the compressive strength of self-compacting concrete. Through rigorous experimental analysis, the research explores the optimal proportions of RHA and superplasticizers in SCC, examining their individual and combined effects on mechanical properties, workability, and durability. The study also analyzes the impact of mixed design parameters, including the fineness of RHA and the dosage of superplasticizers, on the performance of SCC under various conditions. This research enhances understanding of interactions to improve sustainable concrete technologies that meet environmental and economic goals.

Methods

This study employs an experimental approach to investigate the effects of incorporating RHA and superplasticizers into SCC. The methodology involves material characterization, mix design, specimen preparation, and compressive strength testing based on relevant standards. Below are the detailed steps undertaken in the research:

a. Materials and Material Testing

1) Cement

The Portland cement used in this study is Tonasa cement, which complies with ASTM-C-150-92 standards for cement testing.

2) Coarse Aggregates

The properties of the coarse aggregates were evaluated through the following tests:

- Gradation Analysis: Conducted as per SNI-03-1968-1990.
- Specific Gravity and Water Absorption: Measured following SNI-1969-2008.
- Bulk Density: Determined by SNI-1973-2016.
- Moisture Content: Tested as per SNI-03-1971-1990.
- Mud Content: Assessed following SNI 03-4142-1996.
- Abrasion Resistance: Conducted according to SNI-03-2417-1991.

3) Fine Aggregates

The properties of the fine aggregates were evaluated through the following tests:

- Gradation Analysis: Conducted as per SNI-03-1968-1990.
- Specific Gravity and Water Absorption: Measured following SNI-1970-2008.
- Bulk Density: Determined by SNI-1973-2016.
- Moisture Content: Tested as per SNI-03-1971-1990.
- Mud Content: Assessed following SNI-03-4428-1997.

4) Rice Husk Ash (RHA)

The RHA was characterized through the following tests:

- Specific Gravity and Water Absorption: Measured based on SNI-1970-2008.
- Bulk Density: Determined according to SNI-1973-2016.

b. Concrete Mix Design

The concrete mix was designed based on the guidelines provided in SNI-7656-2012 for normal, heavy, and mass concrete formulations. Two variations of RHA and superplasticizer additions, at 4% and 8% of the cement weight, were prepared to evaluate their effects on SCC.

c. Characteristics of SCC test

SCC is defined by its ability to flow and compact under its weight without external vibration, meeting three main criteria: Filling Ability, Passing Ability, and Segregation Resistance.

- Filling Ability: SCC can flow and fill molds under its weight. The slump-flow test measures spread diameter, typically between 600–800 mm, indicating sufficient flowability for proper filling.
- Passing Ability: SCC flows through tight spaces without blockages. The L-Box test evaluates this, with a blocking ratio (H_2/H_1) between 0.8–1.0 considered optimal.
- Segregation Resistance: SCC maintains uniformity during placement. The V-Funnel test measures flow time, ideally within 6–12 seconds, ensuring stability and preventing segregation.

d. Preparation and Curing of Test Specimens

- The preparation and curing of concrete specimens followed the procedures outlined in SNI-2493-2011. Cube specimens with dimensions of 150 mm × 150 mm × 150 mm were prepared for each variation. Five specimens were cast for each mix variation, ensuring sufficient replicates for statistical reliability.
- After casting, the specimens were cured in water for a standard period of 7 days before testing.

e. Compressive Strength Testing

The compressive strength of the concrete specimens was determined on day 28 using the cube specimens. The testing procedure adhered to SNI-03-1974-1990. The compressive strength (f'_c) was calculated using the formula:

$$f'_c = \frac{P}{A} \quad (1)$$

where:

f'_c : Compressive strength (MPa)

P : Maximum load indicated by the testing machine (N)

A : Cross-sectional area of the specimen (mm^2)

f. Data Analysis

The test results were analyzed to determine the effects of rice husk ash and superplasticizer on the compressive strength and workability of SCC. Statistical comparisons were made to evaluate the performance of the 4% and 8% variations. The findings were used to establish the optimal mix design for enhancing the mechanical properties of SCC.

Results And Discussion

Results

The Characteristics Of Material

The quality and performance of concrete are significantly influenced by the physical properties of its constituent materials. Therefore, a detailed assessment of the raw materials used—namely fine aggregate, coarse aggregate, and RHA—was conducted to ensure their suitability for concrete production. Table 1 highlights the characteristics of fine aggregate, coarse aggregate, and RHA as components in concrete production. Fine aggregate has a fineness modulus of 2.78, a water content of 4.93%, and an apparent specific gravity of 2.65, suitable for workability and strength development. Its absorption is 1.50%, while mud content is low at 0.99%, ensuring minimal impurities. Coarse aggregate, with a coarser fineness modulus of 7.48 and a lower water content of 0.90%, provides structural stability. It has an apparent specific gravity of 2.74 and a wear and tear percentage of 22.86%, reflecting its durability. RHA, a lightweight supplementary material, has an apparent specific gravity of 1.24 and a volume weight of 0.60 kg/l, significantly contributing to reducing concrete weight while enhancing sustainability. Together, these materials meet the technical and environmental requirements for producing durable, strong, and eco-friendly concrete.

Table 1. Characteristics of concrete materials

Characteristics	Fine Aggregate	Coarse Aggregate	RHA
Fineness modulus	2.78	7.48	-
Water content (%)	4.93	0.90	-
Apparent spesific grafity	2.65	2.74	1.24
Bulk specific gravity (SSD basic)	2.55	2.69	-
Bulk specific gravity (on dry basic)	2.58	2.66	-
Absorption (%)	1.50	1.07	-
Volume weight (kg/l)	1.52	1.24	0.60
Mud content (%)	0.99	0.70	
Wear and tear (%)	-	22.86	

The Material Composition Of Self-Compacting Concrete

To evaluate the influence of supplementary materials on concrete composition, a mix design was developed for several cube samples. The design considered material efficiency, performance enhancement, and sustainability aspects. Table 2 presents the material requirements for producing five concrete cube samples, incorporating a 10% material loss factor. Three concrete mixes were assessed: normal concrete, concrete with 4% superplasticizer and RHA, and concrete with 8% superplasticizer and RHA. Water requirements decreased with the addition of superplasticizer, from 3.44 kg in normal concrete to 3.31 kg and 3.17 kg in the modified mixes, enhancing workability. Superplasticizer was added at 0.14 kg and 0.28 kg for 4% and 8% variations, respectively. Cement usage also reduced from 8.99 kg in normal concrete to 8.63 kg and 8.27 kg, while RHA was introduced as a partial cement replacement at 0.36 kg and 0.72 kg for the respective mixes. Coarse and fine aggregate requirements remained constant across all mixes at 12.85 kg and 17.99 kg, respectively, ensuring consistent volumetric stability. This mix design highlights the potential of superplasticizers and RHA to optimize material usage and improve concrete properties while maintaining structural integrity.

Table 2. Material requirements for 5 cube samples with a material loss factor of 10%

Material	**Normal Concrete**	**Concrete with 4% Superplasticizer and RHA**	**Concrete with 8% Superplasticizer and RHA**
	(kg)	**(kg)**	**(kg)**
Water	3.44	3.31	3.17
Superplasticizer	-	0.14	0.28
Cement	8.99	8.63	8.27
RHA	-	0.36	0.72
Coarse Aggregate	12.85	12.85	12.85
Fine Aggregate	17.99	17.99	17.99

The Characteristic Of Self-Compacting Concrete

To assess the fresh properties of SCC, a series of standard workability tests were conducted on mixes incorporating superplasticizer and RHA. These tests are essential to ensure that the modified concrete maintains adequate flowability, viscosity, and passing ability for practical construction applications. Table 3 summarizes the results of characteristic tests for SCC incorporating 4% and 8% superplasticizer and RHA variations, evaluated against established specifications. The flow table test measures SCC's filling ability, with average spread diameters ($D_{average}$) of 675 mm and 697 mm for 4% and 8% variations, respectively, both within the specification range of 600–800 mm. The results indicate good flowability, with an improvement in the 8% variation due to enhanced workability. The V-Funnel test assesses the segregation resistance of SCC by measuring flow time through the funnel. The recorded times are 8.72 seconds for the

4% variation and 7.35 seconds for the 8% variation, falling within the acceptable range of 6–12 seconds. These results confirm that both mixes exhibit adequate viscosity, with the 8% mix displaying slightly faster flow due to increased superplasticizer content. The L-Box test evaluates SCC's passing ability, with height ratios (H_1/H_2) of 0.85 and 0.84 for the 4% and 8% variations, respectively. These values meet the standard range of 0.8–1.0, indicating that both mixes can navigate obstructions without segregation or blocking. While the slight reduction in the ratio at 8% suggests minor viscosity changes, the mix remains well within acceptable performance thresholds. Overall, the results demonstrate that SCC with 4% and 8% superplasticizer and RHA meets key criteria for filling ability, segregation resistance, and passing ability, ensuring robust performance for practical applications.

Table 3. SCC characteristic test results

Parameter Test	**Unit**	**Symbol**	**Variasi**		**Specifications**
			4%	**8%**	
Flow Table	mm	D_1	680	705	
	mm	D_2	670	690	
	mm	$D_{average}$	675	697	60–80 cm
V-Funnel	second		8,72	7,35	6 – 12 second
L-Box	mm	H_1	105	95	
	mm	H_2	90	80	
	-	H_1/H_2	0.85	0.84	0.8–1.0

The Compressive Strength Of Self-Compacting Concrete

This study further examines how variations in superplasticizer and RHA content affect the mechanical performance of hardened concrete. By analyzing compressive strength, the research highlights the relationship between fresh concrete properties and structural outcomes. Table 4 presents the compressive strength characteristics of concrete incorporating 0%, 4%, and 8% superplasticizer and RHA. These results align closely with the fresh concrete parameters shown in Table 3, emphasizing how properties such as filling ability, segregation resistance, and passing ability influence the hardened concrete's performance. The average concrete weight decreases with higher RHA content, from 7.95 kg (0%) to 7.88 kg (4%) and 7.72 kg (8%), due to RHA's lower specific gravity compared to cement. While lighter, the mechanical performance of these mixtures varies significantly based on the proportions of the additives.

The highest average compressive strength is observed in the 4% RHA and superplasticizer mixture, reaching 34.02 Mpa, compared to 32.18 Mpa for normal concrete and 28.51 Mpa for the 8% mixture. This outcome is consistent with the optimal flowability and segregation resistance reported in Table 3, where the 4% mix achieves balanced viscosity and material distribution. In contrast, the 8% mix, despite higher flowability (average spread of 697 mm), shows a reduction in compressive strength due to excessive superplasticizer, which may weaken particle bonding. This highlights the importance of achieving a balance in material proportions to maintain both fresh and hardened concrete performance.

The compressive strength characteristics 237urtherr confirm that the 4% mixture surpasses the design strength of 30.53 Mpa, reaching a standardized characteristic strength of 34.30 Mpa. The 8% mixture, however, falls short at 28.54 Mpa. This reinforces the critical relationship between the fresh properties in Table 3 and the mechanical outcomes in Table 4. While higher superplasticizer levels enhance flowability, an excessive amount can compromise the structural integrity of hardened concrete. These findings underline the need to carefully optimize SCC mix designs to achieve the desired balance of fresh and hardened properties.

Table 4. Concrete Compressive Strength Characteristics

Test Result	**Percentage of RHA and Superplasticizer (%)**			**Unit**
	0	**4**	**8**	
Average Concrete Weight	7.95	7.88	7.72	Kg
Average Concrete Compressive Strength	32.18	34.02	28.51	Mpa
Concrete Compressive Strength Characteristics	31.74	34.30	28.54	
Concrete Compressive Strength Plan		30.53		

Discussion

The findings of this study align with established literature emphasizing the critical role of material composition in shaping both fresh and hardened properties of self-compacting concrete (SCC). The notable increase in compressive strength observed in the 4% rice husk ash (RHA) and superplasticizer mix (34.02 Mpa) underscores the efficacy of optimal blend ratios in enhancing mechanical performance (Le & Ludwig, 2016; Said et al., 2017). Flowability and segregation resistance—key attributes in SCC performance—were evident in the 4% mix, validated through favorable V-Funnel and L-Box outcomes, consistent with Fediuk et al. (2018) and Gill & Siddique (2018). In contrast, the 8% RHA mix, with a reduced strength of 28.51 Mpa, suggests the detrimental impact of excessive superplasticizer, which can impair particle cohesion and hinder hydration, a phenomenon corroborated by Olowofoyeku et al. (2019).

Additionally, the inclusion of RHA contributed to a noticeable decrease in concrete density due to its low specific gravity and porous microstructure. The mix weight reduced from 7.95 kg (control) to 7.88 kg (4% RHA) and 7.72 kg (8% RHA), equating to a 0.88% and 2.89% weight reduction, respectively. These findings align with previous studies highlighting how pozzolanic materials like RHA can enhance workability but reduce density (Chopra et al., 2015; Mehdizadeh et al., 2021; Sandhu & Siddique, 2017). Although the mixtures do not qualify as structural lightweight concrete—typically defined by a density under 1840 kg/m³—they offer potential for semi-lightweight or non-load-bearing components such as partitions or lightweight panels.

From a sustainability standpoint, incorporating RHA—a renewable agricultural waste—supports the development of eco-efficient concrete by reducing reliance on energy-intensive Portland cement, thus lowering carbon emissions (Ahmadi et al., 2007). When properly dosed, superplasticizers also support sustainability by enabling lower water-to-cement ratios and resulting in stronger, more durable concrete with extended service life (Lertwattanaruk et al., 2018). However, overdosing must be avoided due to possible adverse effects on hydration and environmental concerns. The synergistic interaction between pozzolanic ash and chemical admixtures, when balanced carefully, enhances hydration processes and calcium silicate hydrate (C–S–H) formation (Plando & Maquiling, 2024), ultimately improving performance and promoting green construction practices.

Conclusion

This study highlights the significant influence of incorporating RHA and superplasticizers on the performance of SCC. The 4% RHA and superplasticizer mixture demonstrated an optimal balance, achieving a compressive strength of 34.02 MPa, surpassing that of normal concrete. This aligns with literature emphasizing the role of pozzolanic materials and admixtures in enhancing mechanical properties. The mix also met the required flowability and segregation resistance standards, as indicated by its favorable V-Funnel and L-Box results. However, the 8% RHA mixture exhibited reduced compressive strength (28.51 MPa), suggesting that excessive superplasticizer compromises particle cohesion, consistent with prior studies. Additionally, the lower density of RHA influenced the concrete's weight, reflecting its lightweight characteristics.

These findings underscore the importance of precise mix design to achieve the desired balance of fresh and hardened concrete properties, promoting sustainable and efficient construction practices.

Acknowledgement

The author sincerely thanks the Faculty of Engineering, Universitas Gorontalo, and The Civil Engineering Laboratory team for their invaluable support, technical assistance, and dedication throughout the research process, making this study possible. their contributions are deeply appreciated.

References

Ahmadi, M. A., Alidoust, O., Sadrinejad, I., Nayeri, M., Cement, A., & Ash, B. R. H. (2007). Development of Mechanical Properties of Self Compacting Concrete Contain Rice Husk Ash. *World Academy of Science, Engineering and Technology*, *1*(34), 168–171.

Antiohos, S. K., Papadakis, V. G., & Tsimas, S. (2014). Rice husk ash (RHA) effectiveness in cement and concrete as a function of reactive silica and fineness. *Cement and Concrete Research*, *61–62*, 20–27. https://doi.org/https://doi.org/10.1016/j.cemconres.2014.04.001

Aziz, A., Mehboob, S. S., Tayyab, A., Khan, D., Hayyat, K., Ali, A., & .Qureshi, Q. B. I. L. (2024). Enhancing sustainability in self-compacting concrete by optimizing blended supplementary cementitious materials. *Scientific Reports*, *14*(1), 1–23. https://doi.org/10.1038/s41598-024-62499-w

Ben Aicha, M. (2020). *8 - The superplasticizer effect on the rheological and mechanical properties of self-compacting concrete* (P. Samui, D. Kim, N. R. Iyer, & S. B. T.-N. M. in C. E. Chaudhary (eds.); pp. 315–331). Butterworth-Heinemann. https://doi.org/https://doi.org/10.1016/B978-0-12-818961-0.00008-9

Chen, C. H., Huang, R., Wu, J. K., & Yang, C. C. (2006). Waste E-glass particles used in cementitious mixtures. *Cement and Concrete Research*, *36*(3), 449–456. https://doi.org/10.1016/j.cemconres.2005.12.010

Chiu, C. H., Wen, T. H., Chien, L. C., & Yu, H. L. (2014). A probabilistic spatial dengue fever risk assessment by a threshold-based-quantile regression method. *PLoS ONE*, *9*(10), 1–13. https://doi.org/10.1371/journal.pone.0106334

Chopra, D., Siddique, R., & Kunal. (2015). Strength, permeability and microstructure of self-compacting concrete containing rice husk ash. *Biosystems Engineering*, *130*, 72–80. https://doi.org/https://doi.org/10.1016/j.biosystemseng.2014.12.005

Das, S. K., Adediran, A., Kaze, C. R., Mustakim, S., M., & Leklou, N. (2022). Production, characteristics, and utilization of rice husk ash in alkali activated materials: An overview of fresh and hardened state properties. *Construction and Building Materials*, *345*(July), 128341. https://doi.org/10.1016/j.conbuildmat.2022.128341

Emam, E., & Yehia, S. (2017). Performance of Concrete Containing Zeolite as a Supplementary Cementitious Material. *International Research Journal of Engineering and Technology*, *4*(12), 1619–1625. www.irjet.net

Farid, S. A., & Zaheer, M. M. (2023). Production of new generation and sustainable concrete using Rice Husk Ash (RHA): A review. *Materials Today: Proceedings*. https://doi.org/https://doi.org/10.1016/j.matpr.2023.06.034

Fediuk, R. S., Lesovik, V. S., Svintsov, A. P., Mochalov, A. V., Kulichkov, S. V., Stoyushko, N. Y., Gladkova, N. A., & Timokhin, R. A. (2018). Self-compacting concrete using pretreatmented rice husk ash. *Magazine of Civil Engineering*, *79*(3), 66–76. https://doi.org/10.18720/MCE.79.7

Gill, A. S., & Siddique, R. (2018). Durability properties of self-compacting concrete incorporating metakaolin and rice husk ash. *Construction and Building Materials*, *176*, 323–332. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2018.05.054

Hossain, S. S., Roy, P. K., & Bae, C. J. (2021). Utilization of waste rice husk ash for sustainable geopolymer: A review. *Construction and Building Materials*, *310*(August), 125218. https://doi.org/10.1016/j.conbuildmat.2021.125218

Kalyana Chakravarthy, P. R., & Namratha, K. (2022). Strength and durability properties of high strength self compacting concrete. *Materials Today: Proceedings*, *69*, 896–900. https://doi.org/https://doi.org/10.1016/j.matpr.2022.07.365

Kioumarsi, M., & Plevris, V. (2024). Advanced Concrete and Construction Materials for Sustainable Structures. *Sustainability (Switzerland)* , *16*(4), 4–9. https://doi.org/10.3390/su16041427

Le, H. T., & Ludwig, H.-M. (2016). Effect of rice husk ash and other mineral admixtures on properties of self-compacting high performance concrete. *Materials & Design*, *89*, 156–166. https://doi.org/https://doi.org/10.1016/j.matdes.2015.09.120

Lertwattanaruk, P., Sua-iam, G., & Makul, N. (2018). Effects of calcium carbonate powder on the fresh and hardened properties of self-consolidating concrete incorporating untreated rice husk ash. *Journal of Cleaner Production*, *172*, 3265–3278. https://doi.org/https://doi.org/10.1016/j.jclepro.2017.10.336

Mehdizadeh, B., Jahandari, S., Vessalas, K., Miraki, H., Rasekh, H., & Samali, B. (2021). Fresh, mechanical, and durability properties of self-compacting mortar incorporating alumina nanoparticles and rice husk ash. *Materials*, *14*(22). https://doi.org/10.3390/ma14226778

Muralidharan, R., Park, T., Yang, H. M., Lee, S. Y., Subbiah, K., & Lee, H. S. (2021). Review of the effects of supplementary cementitious materials and chemical additives on the physical, mechanical and durability properties of hydraulic concrete. *Materials*, *14*(23). https://doi.org/10.3390/ma14237270

Neri, A. C., Baguhin, I. A., & Cabahug, R. R. (2023). An Investigation on the Compressive Strength of Concrete with Rice Husk Ash as Cement Replacement and Addition of Chemical Admixtures. *Mindanao Journal of Science and Technology*, *21*(1), 224–236. https://doi.org/10.61310/mndjstiect.0987.23

Nilimaa, J. (2023). Smart materials and technologies for sustainable concrete construction. *Developments in the Built Environment*, *15*(March), 100177. https://doi.org/10.1016/j.dibe.2023.100177

Olowofoyeku, A. M., Ofuyatan, O. M., Oluwafemi, J., Ajao, A., & David, O. (2019). Effect of Superplasticizer on Workability and Properties of Self-Compacting Concrete. *Journal of Physics: Conference Series*, *1378*(4). https://doi.org/10.1088/1742-6596/1378/4/042088

Part, W. K., Ramli, M., & Cheah, C. B. (2015). An overview on the influence of various factors on the properties of geopolymer concrete derived from industrial by-products. *Construction and Building Materials*, *77*, 370–395. https://doi.org/10.1016/j.conbuildmat.2014.12.065

Phan, T. D., & Nguyen, D. L. (2025). Data-driven approaches for predicting and optimizing the compressive strength of self-compacting concrete. *Materials Today Communications*, *42*(December 2024), 111298. https://doi.org/10.1016/j.mtcomm.2024.111298

Plando, F. R. P., & Maquiling, J. T. (2024). Construction potential of rice husk ash as eco-friendly cementitious material in a low-water demand for self-compacting concrete. *Construction and Building Materials*, *418*, 135407. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2024.135407

Pradhan, R., & Sharma, N. (2021). *Enhancement of Compressive Strength Using Rice Husk Ash and Superplasticizers for Eco-friendly Concrete BT - Advances in Sustainable Construction Materials* (S. Biswas, S. Metya, S. Kumar, & P. Samui (eds.); pp. 775–779). Springer Singapore.

Rwamamara, R., & Simonsson, P. (2012). Self-compacting concrete use for construction work environment sustainability. *Journal of Civil Engineering and Management*, *18*(5), 724–734. https://doi.org/10.3846/13923730.2012.723399

Saad, S. A., Nuruddin, M. F., Shafiq, N., & Ali, M. (2015). Pozzolanic Reaction Mechanism of Rice Husk Ash in Concrete – A Review. *Applied Mechanics and Materials*, *773–774*(November 2018), 1143–1147. https://doi.org/10.4028/www.scientific.net/amm.773-774.1143

Said, I., Khan, B., Inderyas, O., Abdur Rahman, M., & Ahmed, S. (2017). Utilization of rice husk ash as a pozzolan in self compacting concrete. *International Journal of Civil Engineering and Technology*, *8*(1), 98–108.

Sandhu, R. K., & Siddique, R. (2017). Influence of rice husk ash (RHA) on the properties of self-compacting concrete: A review. *Construction and Building Materials*, *153*, 751–764. https://doi.org/10.1016/j.conbuildmat.2017.07.165

Siddika, A., Mamun, M. A. Al, Alyousef, R., & Mohammadhosseini, H. (2021). State-of-the-art-review on rice husk ash: A supplementary cementitious material in concrete. *Journal of King Saud University - Engineering Sciences*, *33*(5), 294–307. https://doi.org/10.1016/j.jksues.2020.10.006

Zende, A. A., Momin, A. I. A., Khadiranaikar, R. B., Alsabhan, A. H., Alam, S., Khan, M. A., & Qamar, M. O. (2023). Mechanical Properties of High-Strength Self-Compacting Concrete [Research-article]. *ACS Omega*, *8*(20), 18000–18008. https://doi.org/10.1021/acsomega.3c01204