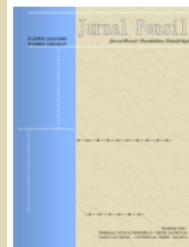


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THE EFFECT OF SUPERPLASTICIZER AND ACCELERATOR ON THE EARLY-AGE PERFORMANCE OF FAST TRACK CONCRETE CONTAINING RICE HUSK ASH

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Abstract

The utilization of high-performance fast-track concrete has become a crucial solution to meet the demands of efficiency and accelerated schedules in modern construction. This study aims to analyze the optimal combination of Rice Husk Ash (RHA) substitution as a pozzolanic material, alongside the utilization of a superplasticizer additive (Viscocrete 1050 HE) and an accelerator (Sika Rapid 505) in high-strength concrete with a target compressive strength of 60 MPa. The experimental method involved the partial substitution of cement with RHA at variations of 0%, 5%, 10%, and 15% by weight of the total binder. The evaluation encompassed workability and the mechanical performance of the hardened concrete specifically compressive, flexural, and splitting tensile strengths tested at curing maturities of 1, 2, 3, and 28 days. The results indicate that increasing the RHA content beyond 5% significantly degrades workability due to the high specific surface area of the RHA particles. At 1 day of testing, the cement dilution effect reduced the compressive strength from 30.3 MPa (0% RHA) to 25.3 MPa (15% RHA). Nevertheless, the inclusion of Sika Rapid 505 effectively and synergistically mitigated this reduction, maintaining the early-strength acceleration of the concrete matrix. At 28 days of maturity, the 5% RHA substitution was identified as the optimum composition, yielding a maximum compressive strength of 52.2 MPa and a flexural strength of 7.1 MPa, whereas the highest splitting tensile strength of 4.3 MPa was achieved at 10% RHA. This study concludes that integrating 5% RHA, supported by Viscocrete 1050 HE and Sika Rapid 505, provides the best synergistic performance in maintaining fresh properties while maximizing the ultimate mechanical performance of the concrete.

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Introduction

Due to its exceptional longevity, great compressive strength, and adaptability to different structural shapes, concrete remains the most used building material. (Rahma et al., 2025; Sudarsono et al., 2023). The demand for high-performance concrete capable of achieving optimal strength in a short time has increased in tandem with the evolving needs of modern construction. One implemented solution is the use of fast-track concrete, which is formulated to achieve high early-age strength, making it suitable for projects requiring rapid execution, such as highways and airports. A primary challenge in developing this concrete is maintaining adequate workability without compromising compressive strength. To address this issue, incorporating chemical admixtures, such as superplasticizers and accelerators, is an effective solution to enhance casting fluidity and accelerate setting.

Superplasticizers, or HRWR, make it possible to drastically lower the w/c ratio without sacrificing the concrete's workability (Aghaee et al., 2023; Alam & Siddique, 2025; Alsadey & Omran, 2022; Bashir, 2021; Frediyansyah et al., 2024; Paktiawal & Alam, 2021; Pang et al., 2024). This reduction can markedly increase compressive strength, often by 25–35%, by facilitating a denser particle packing (Ho et al., 2023; Ji et al., 2024; Sadegh-Zadeh et al., 2023). Superplasticizers make casting and compaction easier by increasing flowability, especially in complicated geometries or regions with high reinforcement density (Aicha et al., 2022). Superplasticizers also have a major impact on the slump flow values of self-compacting concrete. (Alagarsamy et al., 2025; Patowary & Siddique, 2023; Rustendi et al., 2025). Precise doses, usually not exceeding 2-3% by weight of cement, provide maximum performance without causing long-term negative consequences such as excessive segregation or shrinkage (Rustendi Iwan et al., 2024; Susilowati et al., 2025).

Accelerators are essential for quickening the hydration process and guaranteeing a notable increase in concrete strength during the initial stages (Bali et al., 2023; Luo et al., 2021; Xie et al., 2023; Yang & He, 2021; Yoneyama et al., 2021; Yuan et al., 2020; Zhang et al., 2024). Rapid-setting concrete's mechanical qualities and durability may be improved by a variety of accelerator kinds and doses that reduce setting and hardening times, underscoring its significance in construction (Kos et al., 2023; Song et al., 2025; Wan et al., 2023; Winnefeld et al., 2021). Furthermore, the variety of accelerator types including powder accelerators based on alkali may affect the microstructural properties and workability of UHPC (Su et al., 2021).

Rice Husk Ash (RHA) can significantly improve durability and compressive strength in a range of environmental conditions by replacing 15–20% of cement (Agboola et al., 2022; Dhanalakshmi et al., 2023; Endale et al., 2022; Lo et al., 2021; Shastri et al., 2025; Suclupe et al., 2024; Sutama et al., 2025). Moreover, the integration of RHA in concrete mixtures has proven effective in reducing shrinkage and minimizing the heat generated during the hydration process (Adnan et al., 2022; Al-Alwan et al., 2024; Amin et al., 2019; P BALAJI, 2025). This positions RHA as an environmentally friendly supplementary cementitious material aligned with sustainable construction practices. Furthermore, studies on the combined use of RHA and superplasticizers in high-strength concrete have shown significant increases in 28-day compressive strength (Basman et al., 2025; Devi et al., 2024; Poerwodihardjo & Rustendi, 2021). These findings underscore that the synergy between RHA and chemical admixtures can yield concrete with optimal mechanical performance. Therefore, research into integrating superplasticizers, accelerators, and rice husk ash into fast-track concrete is essential to optimize early-age performance while supporting faster, more efficient, and sustainable construction.

Research Methods

This study investigates the early-age and ultimate performance of high-performance fast-track concrete incorporating Rice Husk Ash (RHA) as a partial cement replacement, combined with 2.0% Sika Rapid 505 accelerator and 1.1% Viscocrete 1050 HE superplasticizer. The

concrete mixtures were proportioned with a low water-to-cement (w/c) ratio of 0.25 to achieve a target compressive strength of 60 MPa. Cement was partially substituted by RHA at dosages of 0% (control), 5%, 10%, and 15% by weight of the binder. Prior to mixing, the quality of all constituent materials, including coarse and fine aggregates, was evaluated in accordance with the Indonesian National Standards (SNI). The evaluation of concrete mechanical properties utilized a total of 96 cylindrical specimens (150 mm × 300 mm) for compressive and splitting tensile tests, alongside beam specimens (150 mm × 150 mm × 600 mm) for flexural testing. To comprehensively evaluate the mechanical performance, tests were conducted at curing ages of 1, 2, 3, and 28 days.

Research Results and Discussion

Fine Aggregate

Figure 1 illustrates the characterization results for the fine aggregate sourced from Mount Merapi sand, demonstrating that the material meets the technical specifications required for high-quality concrete mixtures. According to SNI 03-2834-2000, the gradation distribution, which was examined using sieves with a diameter of 0.15 mm to 4.75 mm, is classified as medium sand. Physical characteristics studies show that the fine aggregate has a water absorption rate of 0.86% and an average SSD specific gravity of 3.05 and 3.00. Additionally, the aggregate's ideal particle size distribution to enhance the concrete mixture's workability is shown by its average fineness modulus of 2.79.

Coarse Aggregate

The coarse aggregate characterization findings from the Kedung Randu quarry indicate complete adherence to the specified combination criteria shown in Figure 2. The aggregate's physical properties include an average SSD specific gravity of 2.71, an oven-dry specific gravity of 2.66, and a water absorption rate of 1.77%. Furthermore, 1.478 g/cm³, or 1.478 kg/m³, was the average bulk density.

Rice Husk Ash (RHA)

The silica SiO₂ content of the RHA samples was ascertained by triplicate testing based on the chemical composition analysis carried out at the Biochemistry Laboratory, Faculty of Mathematics and Natural Sciences. The recorded silica concentrations were 81.28%, 80.93%, and 81.21%, yielding an average silica content of 81.14%.

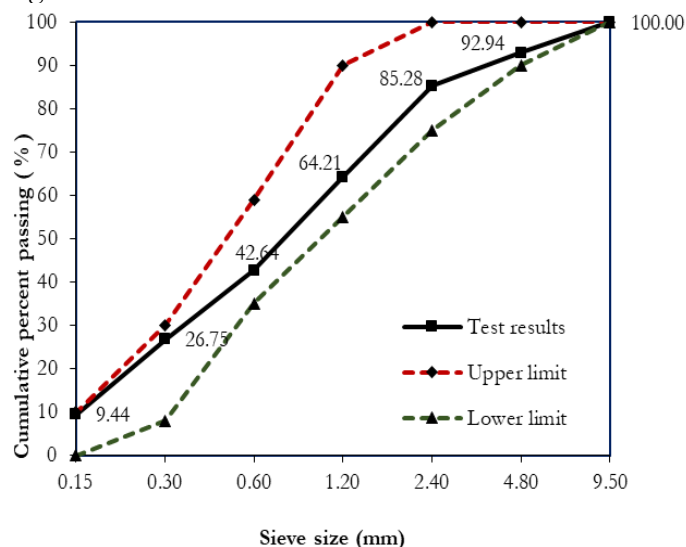


Figure 1. Fine Aggregate Gradation

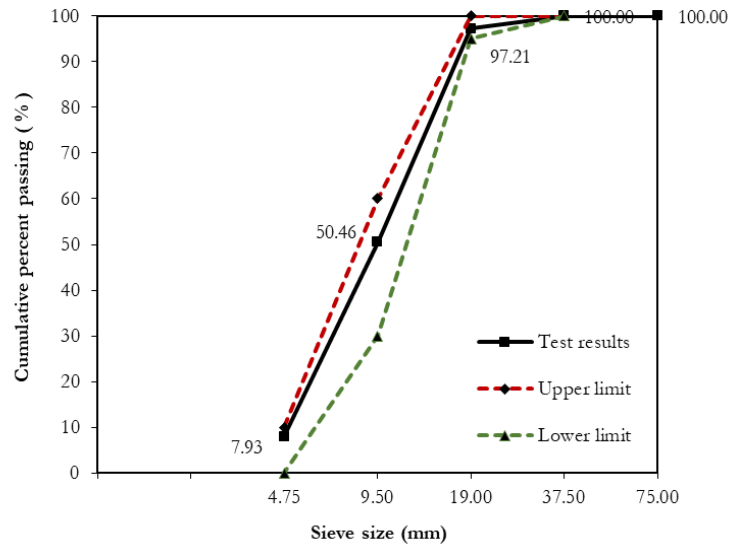


Figure 2. Coarse Aggregate Gradation

Concrete Mix

The fast-track concrete mixtures were formulated by substituting cement with RHA at weight fractions of 0%, 5%, 10%, and 15%, while maintaining a constant total mixture volume. The detailed mix proportions per cubic meter (1 m³) of concrete are presented in Table 1, utilizing a fixed WCR of 0.25.

Table 1. Fast Track Concrete Mix Requirements (1 m³)

Materials (kg/ m ³)	RHA 0 %	RHA 5 %	RHA 10 %	RHA 15 %
Water	190	190	190	190
PCC type I	760	722	684	646
RHA	0	38	76	114
Fine Aggregate	1052.62	1052.62	1052.62	1052.62
Coarse Aggregate	485.09	485.09	485.09	485.09
Viscocrete 1050 HE	8.36	7.94	7.52	7.11
Sika Rapid 505	15.20	14.44	13,68	12.92

Compressive Strength Analysis of Rice Husk Ash (RHA) Concrete

The average compressive strength of concrete at different curing ages and Rice Husk Ash (RHA) concentration levels is shown in Figure 3. The experiment's findings show that the development of compressive strength is significantly impacted when RHA is partially substituted for cement. Both early ages and the 28-day mark exhibit this impact (Al-Alwan et al., 2024; Halim & Amiruddin, 2024). The control mixture (0% RHA) had the maximum compressive strength at 30.35 MPa throughout the one-day test. An increase in the RHA substitution proportion tends to decrease the initial compressive strength, indicating limited pozzolanic contribution during the early hydration phase. Specifically, the 5% RHA variation produced a strength of 28.3 MPa, while the 10% RHA variation yielded 26.0 MPa.

At 25.31 MPa, the 15% RHA variation recorded the lowest value. This problem happens as a result of RHA's pozzolanic response not yet reaching an ideal state during the first phase. Despite this reduction, the early-age compressive strength across all RHA variations remains high for the fast-track concrete category, proving the synergistic effectiveness of the accelerator and superplasticizer additives in the mixture (Mehta, 2014).

Concrete with 5% and 10% RHA content begins to exhibit compressive strengths nearly equivalent to those of the control concrete at early ages. At 2 days, the 5% and 10% RHA variations reached strengths of 39.99 MPa and 40.76 MPa, respectively. These results indicate that at low to medium dosages, RHA increases microstructural density by initiating pozzolanic reactions. Conversely, a higher substitution level at 15% RHA causes a decrease in the effective cement content, which subsequently lowers the compressive strength. This reduction is primarily attributed to the restricted production of primary calcium silicate hydrate (C-S-H) gel due to the dilution of the clinker phase (Agboola et al., 2022).

At the 28-day curing age, the effect of RHA on the concrete's compressive strength becomes highly pronounced. The 5% RHA variation achieved the maximum compressive strength of 52.2 MPa, representing an approximate 12.2% increase compared to the control concrete (46.5 MPa). This enhancement indicates that at this specific dosage, the silica within RHA reacts optimally with free calcium hydroxide Ca(OH)_2 to form secondary calcium silicate hydrate (C-S-H) gels, which efficiently refine the pore structure and densify the microstructure. In contrast, the compressive strengths dropped to 42.8 MPa and 45.3 MPa for the 10% and 15% RHA levels, respectively, demonstrating that higher replacement dosages exceed the optimal pozzolanic threshold, as reported by Poerwodihardjo and Rustendi (2021). This reduction at higher concentrations (10–15%) is primarily attributed to the dilution effect, where the diminished effective cement content available for primary hydration restricts the long-term strength development. Consequently, incorporating a 5% RHA content is determined as the optimum percentage for high-performance fast-track concrete, establishing the finest compromise between early-age workability and ultimate strength enhancement (Farhan et al., 2023).

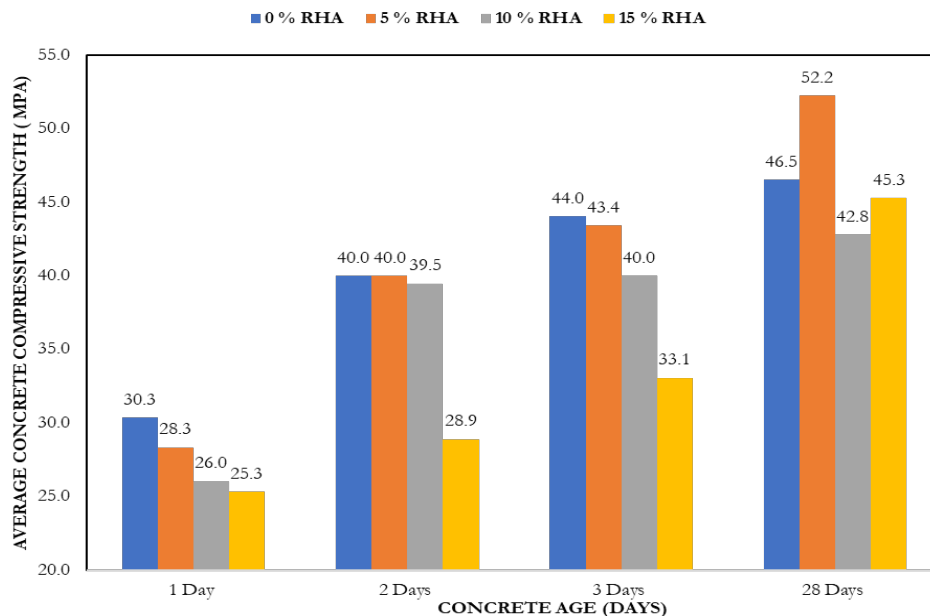


Figure 3. Average Compressive Strength of Concrete at Different RHA Substitution Levels

Although the experimental compressive strength at 28 days did not fully achieve the initial target design of 60 MPa, the underlying mechanism offers critical insights into the hydration kinetics of high-performance concrete. The inclusion of the chemical accelerator explicitly generated an excessive acceleration of the initial cement hydration, driving a rapid precipitation of hydration products predominantly calcium silicate hydrate (C-S-H) gel at early curing ages. This accelerated hydration kinetics triggers the premature formation of a dense, low-permeability shell of hydration products around the unhydrated cement grains. Consequently, further water

diffusion into the unhydrated core is significantly restricted, hindering subsequent long-term hydration and preventing the concrete from reaching the targeted strength of 60 MPa at 28 days. These findings highlight that the dosage of chemical accelerators in high-strength concrete design must be carefully optimized, as excessive early acceleration potentially disrupts the development of a homogeneous, highly densified microstructure at later maturities (Su et al., 2021).

Flexural Strength Analysis of Rice Husk Ash (RHA) Concrete

Figure 4 displays the average flexural strength of concrete at various RHA concentration levels. All investigated mixes exhibit a steady rise in flexural strength as the curing age increases. RHA-incorporated mixes, however, show lower flexural strengths than the control combination in the early age phase. This pattern suggests that it takes longer for RHA-substituted concrete to reach structural stability during the first hardening period.

These experimental results confirm that flexural strength is significantly more sensitive to reductions in active cement content than compressive strength. In the early phases of the hydration process, this behavior is very noticeable. Despite the use of accelerators to accelerate hydration and superplasticizers to maintain a low w/c ratio, the early-age tensile strength disadvantage remained. The application of these chemical admixtures was evidently insufficient to fully offset the loss in cement weight during the initial phase.

Such conditions suggest that the accelerated hydration of the remaining cement was not sufficient to overcome the concrete's microstructural vulnerability. The cement dilution effect resulting from RHA substitution directly impacts the integrity of the tensile bonds within the concrete matrix (Mehta, 2014). Furthermore, the matrix densification produced by the superplasticizer is not robust enough to replace the role of active cement at this early stage. This microstructural weakness renders the concrete more susceptible to flexural loads before the chemical reactions are fully realized.

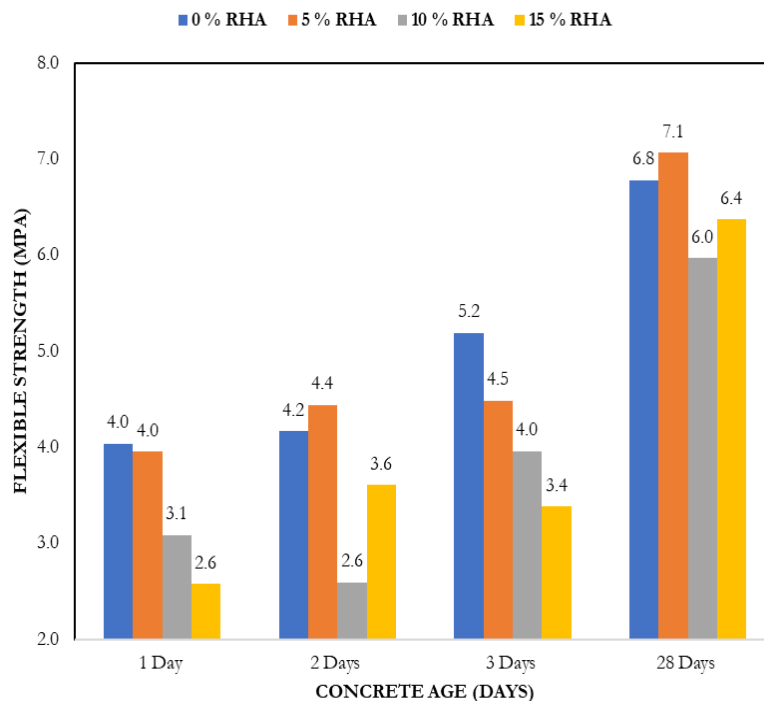


Figure 4. Average Flexural Strength of Concrete at Different RHA Substitution Levels

At 28 days, the 5% RHA variation outperformed the control concrete in terms of flexural strength. This improvement shows that the Interface Phase (IP) between the cement paste and

the aggregates is much improved by the pozzolanic reaction of RHA (Suclupe et al., 2024). The IP region's micropores are efficiently filled by the production of secondary C-S-H. This pore-filling procedure improves the overall flexural stress transmission mechanism and increases the homogeneity of the concrete structure.

Flexural strength decreases with increasing RHA content, particularly at 10% and 15%. This decline indicates that at higher dosages, the cement dilution effect and matrix composition imbalance diminish the effectiveness of strength enhancement. Although pozzolanic reactions continue to occur in these mixtures, an excessive RHA content weakens interparticle bonding in the concrete (Mehta, 2014). Consequently, an optimal RHA utilization level is required to maintain a positive contribution to the mechanical strength of the concrete

Splitting Tensile Strength Analysis of Rice Husk Ash (RHA) Concrete

Figure 5 displays the average splitting tensile strength data for concrete at various RHA content levels. The experimental findings show that as concrete ages, splitting tensile strength rises. On the other hand, splitting tensile strength is significantly reduced during the early-age phase when RHA replacement levels rise. This pattern suggests that the first contribution of RHA is not enough to equal the tensile strength produced by pure cement.

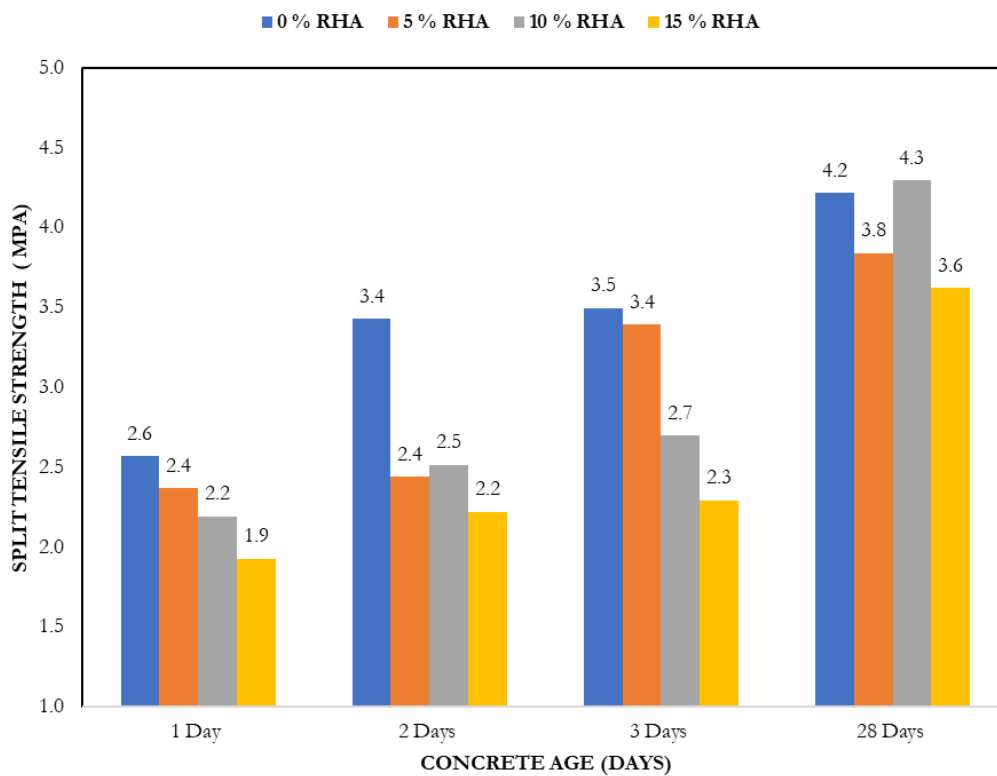


Figure 5. Average Splitting Tensile Strength of Concrete at Various Levels of RHA Substitution

This early-age strength decline suggests that the tensile capacity of concrete during the initial hydration stage is significantly influenced by the formation of primary C-S-H and the quality of the Interface Phase (IP). Although the inclusion of superplasticizer allowed for a low w/c ratio and the accelerator sped up the hydration rate of the remaining cement, this chemical acceleration effect was inadequate to overcome the innate vulnerability of the concrete matrix. Such vulnerability arises from the reduced proportion of active cement, which leads to higher concentrations of splitting tensile stress during the early hydration phase.

After 28 days, the 10% RHA variation outperformed the control concrete by having the highest splitting tensile strength. This result shows that RHA is very successful in improving IP

quality at a certain dosage by creating secondary C-S-H via the pozzolanic reaction. This micro-pore-filling process by secondary minerals increases the concrete's resistance to crack propagation under tensile stress (Adnan et al., 2022). Consequently, by the age of 28 days, the role of RHA shifts from a mere filler to a primary contributor to mechanical strength.

Increasing RHA content to 15% again reduces splitting tensile strength. This phenomenon demonstrates that an excessively high cement substitution ratio negatively affects the formation of the internal bonding network in concrete. Although pozzolanic reactions continue to occur sustainably, the loss of cement cannot be fully compensated for by the presence of RHA at such high levels. This reinforces the existence of an optimal limit for RHA utilization to maintain structural integrity and balance the concrete matrix composition.

Workability and Slump Characteristic Analysis

Figure 6 presents the slump test values of concrete across various Rice Husk Ash (RHA) content levels. Based on the experimental results, both the control concrete and the 5% RHA variation exhibit high slump values, indicating excellent workability. This condition demonstrates that the application of superplasticizers effectively maintains the workability of fast-track concrete, even with a low w/c ratio (Nugraha et al., 2017). These admixtures function optimally by preserving the mixture's fluidity, ensuring it remains easy to handle without requiring excessive water addition.

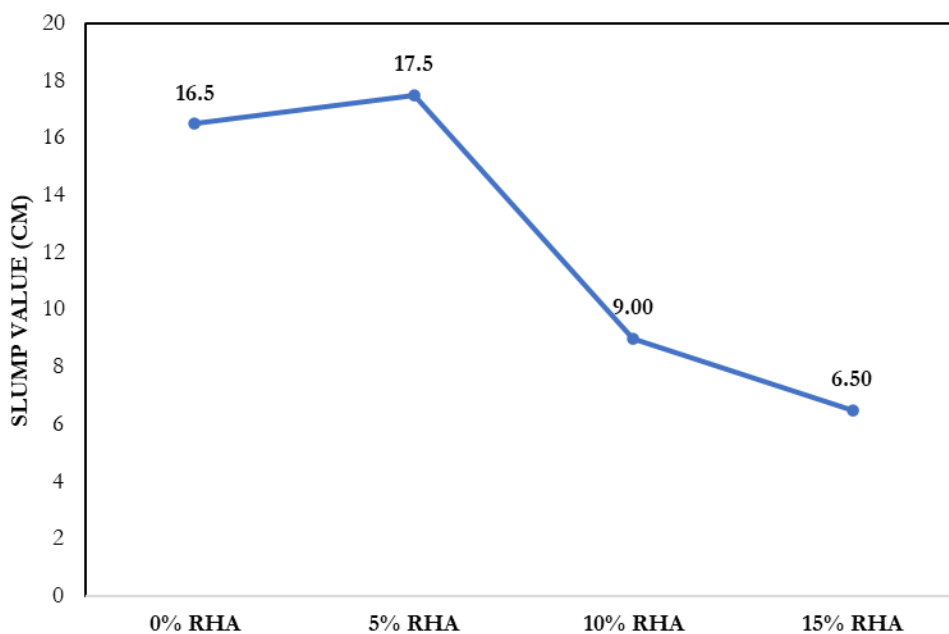


Figure 6. Concrete slump value

RHA levels of 10% and 15% greatly lower the slump values of the concrete mixtures (Sutama et al., 2025). This decline is attributed to the physical characteristics of RHA, which possesses a very high specific surface area, thereby inherently increasing the water demand within the mixture. Furthermore, RHA particles have a natural capacity to adsorb water and superplasticizer molecules into their structure. The quantity of free water that ought to act as a lubricant inside the concrete matrix is reduced as a result of this event. As a result, the mixture stiffens and is unable to flow on its own.

The reduction in workability at high RHA concentrations can complicate casting and compaction in the field, particularly in fast-track concrete applications. Obstructions during compaction can lead to the formation of air voids, which subsequently degrade the concrete's mechanical properties. Therefore, the utilization of high RHA dosages necessitates more precise

mix design modifications. This is crucial to ensure that the balance between hydration rate and ease of placement remains optimally maintained.

Conclusion

This study shows that the use of superplasticizers and accelerators greatly impacts the early-age performance of fast-track concrete. Based on a slump value of 17.5 cm, the research results show that the workability of fast-track concrete using a superplasticizer is best at a 5% Rice Husk Ash (RHA) replacement level. Because of RHA's large specific surface area and the superplasticizer's enhanced adsorption, workability significantly decreases when the RHA concentration is raised over 5%. In terms of early-age strength, the cement dilution effect reduces 1-day compressive strength at higher RHA concentrations. Nonetheless, the minimum compressive strength of 25.3 MPa still demonstrates how well superplasticizers and accelerators work to maintain the essential characteristics of fast-track concrete. The maximum compressive and flexural strengths, 52.2 MPa and 7.1 MPa, respectively, were obtained with 5% RHA replacement at 28 days. This suggests that the Interface Phase (IP) and microstructure have been significantly improved. Meanwhile, the maximum splitting tensile strength of 4.3 MPa was obtained with a 10% RHA dosage. In conclusion, the most effective and balanced formulation for sustainable fast-track concrete applications is a 5% RHA substitution, offering the best trade-off between long-term mechanical performance and fresh properties.

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