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The Effect of Adding Coconut Shell Charcoal Ash as an Additive to the Compressive Strength of Fc'30 Quality Concrete

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Abstract

Concrete remains one of the most widely used materials in construction, driving continued interest in supplementary materials that can enhance its mechanical performance while promoting the utilization of locally available waste. Coconut shell charcoal ash has emerged as a potential additive for this purpose. This study aimed to investigate the effect of coconut shell charcoal ash addition on the compressive strength of concrete with a specified compressive strength (f'c) of 30 MPa and to determine the most effective ash content among the proportions evaluated. Three concrete mixtures were prepared: a control mixture without ash and two experimental mixtures containing 5% and 10% coconut shell charcoal ash by cement mass, respectively. Three cylindrical specimens measuring 150 mm in diameter and 300 mm in height were prepared for each mixture. Compressive strength tests were conducted after 14 and 28 days of curing, while slump tests were performed to assess the workability of the fresh concrete. At 28 days, the mixture containing 5% ash achieved the highest average compressive strength of 53.354 MPa, representing an 8.47% increase compared with the control mixture, which recorded 49.191 MPa. Conversely, the mixture containing 10% ash achieved an average compressive strength of 42.973 MPa, representing a 12.64% reduction relative to the control. These findings indicated that incorporating 5% coconut shell charcoal ash produced the most favorable compressive strength among the mixtures investigated. The reduction in strength at the higher ash content may be associated with the material's porous structure and water absorption characteristics, which could affect the effective water-to-cement ratio and concrete microstructure. Further investigation is required to verify these mechanisms and assess the consistency of the observed results.

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INTRODUCTION

Indonesia's construction sector continues to expand in response to increasing demand for buildings, bridges, and other infrastructure (Solihin et al., 2024). Concrete remains one of the most widely used structural materials because of its relatively low cost, availability of

constituent materials, high compressive strength, and resistance to weathering and fire (Akbar et al., 2013; Bheel et al., 2021). Conventional concrete consists primarily of cement, fine aggregate, coarse aggregate, and water, with supplementary materials or admixtures incorporated to modify specific properties. During hardening, cement hydration produces binding compounds that contribute to the development of concrete strength and structural integrity (Artika et al., 2021).

Indonesia's tropical climate supports abundant coconut (Cocos nucifera) production, providing opportunities to utilize various coconut-derived materials, including coconut meat, water, coir, and shells (Artika et al., 2021). However, coconut shells are frequently used as conventional fuel or discarded without further processing (Riyanto et al., 2018), potentially contributing to waste accumulation and environmental management challenges (Irawan & Khatulistiani, 2021). One potential utilization method involves converting coconut shells into charcoal through pyrolysis, followed by further processing to produce ash suitable for incorporation into concrete (Chelvia et al., 2024; Langitan et al., 2022). Depending on its combustion conditions and chemical composition, coconut shell charcoal ash may contain reactive silica capable of participating in pozzolanic reactions with calcium hydroxide released during cement hydration (Bheel et al., 2021; Ranatunga et al., 2023). Such reactions can produce additional calcium silicate hydrate (C-S-H), potentially improving the density and mechanical properties of the cementitious matrix (Sun et al., 2023; Thomas et al., 2021).

Previous studies have investigated the incorporation of coconut shell-derived materials into concrete, although their findings have varied according to material characteristics, replacement proportions, and experimental conditions (Bheel et al., 2022; Damodaran et al., 2025; Mahindra & Kartikasari, 2021; Santosa et al., 2023). Santosa et al. (2023) examined coconut shell ash as a partial cement replacement and reported a high silica content, suggesting potential pozzolanic properties. However, increasing replacement proportions were associated with reduced slump values and, beyond certain levels, decreased compressive strength. Other investigations involving coconut shell charcoal as a partial fine aggregate replacement have reported reductions in compressive strength, potentially associated with the material's high porosity and water absorption capacity (Artika et al., 2021). Conversely, Riyanto et al. (2018) identified a coconut shell charcoal proportion of 7.5% as producing the most favorable performance under their experimental conditions, whereas Saputra et al. (2025) obtained the highest strength with 2% coconut shell ash combined with 2% silica fume. These differences suggest that the effectiveness of coconut shell-derived materials depends on their processing methods, physical and chemical characteristics, incorporation proportions, and interactions with other concrete constituents (Novitasari et al., 2022; Ramdhany et al., 2025).

Most previous investigations have focused on using coconut shell ash or charcoal as a partial replacement for cement or fine aggregates (Diana & Zainah, 2023; Rhamadhani et al., 2026). Comparatively limited attention has been devoted to evaluating coconut shell charcoal ash as an additional material incorporated without reducing the original cement or aggregate quantities (Merdana et al., 2025; Samen et al., 2024). This distinction is important because the effects of additive incorporation may differ from those of material replacement. When cement content is maintained, the potential influence of coconut shell charcoal ash on compressive strength may involve particle packing, filler effects, water demand, and possible pozzolanic reactions, depending on the ash's chemical reactivity and physical characteristics (Adhikary et

al., 2022). Nevertheless, the presence of silica alone does not establish pozzolanic activity, and the contribution of additional reaction products requires experimental verification. Accordingly, investigating coconut shell charcoal ash additions of 0%, 5%, and 10% by cement mass in concrete with a specified compressive strength (f'c) of 30 Mpa, evaluated at curing ages of 14 and 28 days, provides an opportunity to assess its influence on concrete performance under controlled experimental conditions.

Based on these considerations, this study employed an experimental approach to investigate the effect of coconut shell charcoal ash addition on the compressive strength of concrete with a specified strength of 30 Mpa. The investigation compared conventional concrete with mixtures containing different proportions of coconut shell charcoal ash to determine whether the additive improved or reduced compressive strength. Particular attention was given to identifying the most favorable addition level among the proportions investigated. The study also sought to contribute preliminary experimental evidence concerning the potential utilization of coconut shell waste in concrete production and its relevance to more sustainable construction material practices.

Specifically, the study aimed to evaluate the compressive strength of concrete containing 0%, 5%, and 10% coconut shell charcoal ash by cement mass after 14 and 28 days of curing. The compressive strength of the control mixture was compared with that of the experimental mixtures to determine the relative effects of ash incorporation. Furthermore, the study sought to identify the addition proportion that produced the highest compressive strength within the investigated range and assess the preliminary technical potential of coconut shell charcoal ash as an alternative concrete additive. The investigation focused on compressive strength performance rather than establishing comprehensive field suitability or long-term durability.

From a theoretical perspective, the study was expected to contribute to research on alternative cementitious and filler materials by providing experimental evidence regarding the relationship between coconut shell charcoal ash content and concrete compressive strength. The findings could also inform subsequent investigations into the physical characteristics, chemical reactivity, particle size distribution, and water absorption behavior of coconut shell charcoal ash, particularly in relation to concrete mixture design and strength development. Such investigations would be necessary to clarify the mechanisms underlying any observed changes in mechanical performance.

From a practical perspective, the findings were expected to provide preliminary information for construction material researchers, concrete producers, and engineering practitioners regarding the potential incorporation of coconut shell charcoal ash into concrete mixtures. Utilizing this agricultural byproduct could create opportunities for waste recovery and alternative material development. However, its practical application would require further evaluation of workability, durability, material consistency, production costs, and compliance with applicable concrete standards. Moreover, environmental and economic benefits should be verified through appropriate assessments rather than inferred solely from waste utilization. Subject to these considerations, coconut shell charcoal ash could contribute to resource efficiency and support circular economy initiatives within the construction industry (Ahmed et al., 2024; Ranatunga et al., 2023).

METHOD

Research Design

This study employed a quantitative experimental approach to investigate the effect of coconut shell charcoal ash addition on the compressive strength of concrete with a specified compressive strength (f'c) of 30 Mpa. The independent variable was the proportion of coconut shell charcoal ash added by cement mass, comprising 0% (control), 5%, and 10%, while the dependent variable was concrete compressive strength measured at curing ages of 14 and 28 days. Coconut shell charcoal ash was incorporated as an additive rather than as a partial replacement for cement or aggregates, with the original cement and aggregate quantities maintained consistently across all mixtures. The experiments were conducted at the Materials Technology Laboratory, Civil Engineering Study Program, Faculty of Engineering, Universitas Swadaya Gunung Jati, Cirebon, Indonesia.

Materials and Equipment

The materials used include Portland Type I cement, coarse aggregate in the form of natural gravel, fine aggregate from Cimalaka, water from the laboratory, and coconut shell charcoal ash obtained from traditional market waste in Karangsembung District. Before use, coconut shells are crushed through controlled combustion, then crushed and sifted using a No. 200 sieve to obtain a uniform fine grain size.

The main equipment used includes a digital scale, drying oven, concrete mixer, an aggregate sieve set, an Abrams cone for slump testing, a 15 cm × 30 cm cylinder mold, and a compression testing machine.

Test Pieces

The 15 cm × 30 cm cylindrical test specimen with a total of 18 samples was divided into six groups of combination of mixed variation and test age (3 samples per group), as presented in Table 1.

Table 1. Test Specimen Code and Number

LIFESPAN OF THE TEST PIECE (Day)	VARIETY MIX (%)	CODE TEST PIECES	QUANTITY SAMPLE
	0	PB-14-0	3
14	5	PB-14-5	3
	10	PB-14-10	3
	0	PB-28-0	3
28	5	PB-28-5	3
	10	PB-28-10	3
TOTAL SAMPLE			18

Material Characteristics Inspection

Prior to mixing planning, all concrete constituent materials are checked for characteristics to ensure conformity with quality standards. Fine and coarse aggregates are tested through granular gradation analysis (multi-tiered sieve) to obtain Grain Fine Modulus, specific gravity and water absorption testing of the SSD (*Saturated Surface Dry*) method, content weight testing (loose and solid), and sludge content. Cement is checked for fineness

using No. 100 and No. 200 sieve, as the fineness of cement affects the rate of hydration reaction. All inspection procedures refer to the relevant Indonesian National Standard (SNI).

Concrete Mix Design

The mix *design is* prepared to achieve the planned compressive strength of 30 Mpa, with stages including: determination of standard deviation values, calculation of the average compressive strength of the target (f'cr = f'c + M), determination of water-cement factor (FAS) of 0.4, determination of free water needs and cement needs, and calculation of the proportion of fine and coarse aggregates based on the combined specific gravity. Coconut shell charcoal ash is added at the final stage of mixing according to the proportion of variation (0%, 5%, 10% of the cement weight), without reducing the planned cement or aggregate requirements.

Test Specimen Manufacturing and Testing

The process of making the test specimen is carried out through stages: (1) measuring all materials according to the *results of the mix design*; (2) mixing using a concrete mixer until homogeneous; (3) *slump testing* with Abrams cone following the PBI 1971 procedure to determine the level of workability of fresh mixtures; and (4) casting and compaction into cylindrical molds, with punctures 25 times per layer to minimize air cavities.

Concrete treatment (*curing*) is carried out by the immersion method. After molding, the test specimen is stored at room temperature for the first 24 hours with the surface covered with plastic to prevent premature evaporation of the cement water. After dismantling from the mold and assigned an identity code according to the variation, the test specimen is fully immersed in a water bath at a temperature of ±25–28 °C until it reaches the planned test life (14 or 28 days), and then the surface is dried (SSD condition) before testing.

Compressive strength testing is carried out using a pressure testing machine with a gradually and stable increased axial load until the test piece collapses (*failure*). The maximum recorded load is converted into a compressive strength value (Mpa) by dividing the load by the cross-sectional area of the test piece.

Data Analysis Techniques

The compressive strength data from each variation and test age were analyzed descriptive-quantitative by calculating the average value of each sample group, then comparing between variations (0%, 5%, 10%) and between ages (14 and 28 days) to identify the trend of the effect of the addition of coconut shell charcoal ash on the compressive strength of concrete, as well as determine the percentage of additions that resulted in optimal compressive strength values.

RESULTS AND DISCUSSION

The results of the matrial testing of the concrete constituent show that all materials have met the required quality standards. The fine aggregate has a fine grain of 2.821% in the requirement range of 1.5-3.8. The Type 1 Portland cement used meets the ASTM C184-66 standard with a retention percentage in the No. 100 filter of 0.4% and the No.200 filter of 10% The coconut shell charcoal ash used has a very high level of fineness, with the percentage of passing the No.200 filter reaching 88.5% far above the minimum threshold of 66% required ASTMC618, so it has the potential to be good for filling micro-cavities (pore-filling effect) in the concrete paste.

The results of the slump test showed that all mixed variations (0%, 5%, and 10%) met the planned tolerance range of 12 ± 2 cm. With the true slump collapse profile, there were indications of segregation and bleeding, which indicated that the matrial proportion and semen water factor were well controlled during the stirring process.

The results of the compressive strength test at 14 and 28 days of age are presented in Table 1. Concrete with the addition of 5% coconut shell charcoal ash consistently produced the highest compressive strength on all test objects, both at 14 and 28 days of age, compared to normal concrete and concrete with a 10% additive. At 28 days of age, the compressive strength of normal concrete (0%) reached an average of 49.191 Mpa. It increased to 53.354 Mpa (up ± 8.47%) at the 5% variation, but decreased to 42.973 Mpa (down ± 12.64%) at the 10% variation. A similar pattern was also consistently seen in the results of the 14-day age test.

Table 2. Average Compressive Strength of Concrete per Variation

Variasi	14-day average (kg/cm²)	28-day average (kg/cm²)	Average 28 Hari (Mpa)	Difference thd Normal
Normal (0%)	359,288	491,907	49,191	—
Ash 5%	389,694	533,536	53,354	+8,47%
Ash 10%	313,872	429,727	42,973	−12.64%

Table data reference source: Personal Documentation

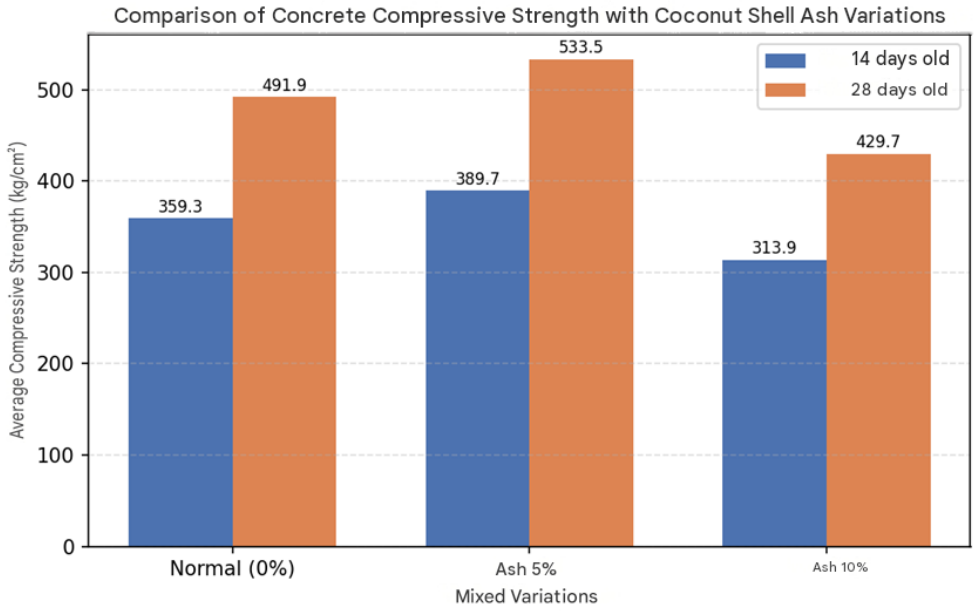

Figure 1. Compressive Strength Comparison

The increase in compressive strength at 5% is thought to occur because the fine sized coconut shell charcoal ash particles are able to fill the micro-cavities (filler effect) between the cement and the aggregate, so that the concrete structure becomes denser and the porosity is reduced. In addition, the silica content in the charcoal ash is suspected to react pozzolanic with calcium hydroxide from cement hydration, forming a secondary calcium silicate hydrate (C-S-H) that closes the micropores of the concrete. On the other hand, at the 10% variation, a larger

amount of additives is suspected to reduce the level of workability of the mixture and interfere with the effectiveness of the cement hydration process due to the porous nature of charcoal ash which absorbs more water, so that the compressive strength produced is lower than the 5% or normal variation.

CONCLUSION

The experimental findings indicated that incorporating coconut shell charcoal ash as an additive influenced the compressive strength of concrete with a specified compressive strength (f'c) of 30 Mpa, exhibiting a nonlinear trend across the proportions investigated. Compressive strength increased at the lower addition level but decreased at the higher proportion. At 28 days of curing, the control mixture achieved an average compressive strength of 49.19 Mpa, while the mixture containing 5% coconut shell charcoal ash reached 53.35 Mpa, representing an increase of approximately 8.47%. Conversely, the mixture containing 10% ash achieved 42.97 Mpa, corresponding to a reduction of approximately 12.64% compared with the control. A similar trend was observed at 14 days, suggesting a consistent relationship between ash content and compressive strength across the two curing ages. However, the statistical significance of these differences could not be established without further inferential analysis.

Among the proportions evaluated, the 5% addition produced the highest compressive strength. This improvement may have been associated with the filler effect of fine ash particles, with 88.5% passing the No. 200 sieve (75 μm), potentially improving particle packing and reducing voids within the cementitious matrix. Additional pozzolanic reactions may also have contributed to strength development, although this mechanism requires verification through chemical and microstructural analyses. At the 10% addition level, the reduction in compressive strength may have resulted from increased water demand, changes in particle packing, or interference with cement hydration. Nevertheless, these mechanisms remain hypothetical and require further investigation. Slump test results of 11, 13, and 12.5 cm for the 0%, 5%, and 10% mixtures, respectively, remained within the specified target range of 12 ± 2 cm, indicating that the investigated ash additions did not substantially impair fresh concrete workability under the experimental conditions.

Overall, the findings suggested that coconut shell charcoal ash had potential as an additive for concrete production, with the 5% addition yielding the most favorable compressive strength among the proportions tested. However, this proportion should be regarded as the best-performing experimental level rather than a definitively established optimum. Although all mixtures exceeded the specified compressive strength of 30 Mpa at 28 days, their suitability for structural applications requires further evaluation of durability, long-term performance, material consistency, and compliance with applicable concrete standards. Additional research should investigate intermediate ash proportions, microstructural characteristics, and environmental performance to establish appropriate application limits and assess the potential contribution of coconut shell charcoal ash to sustainable concrete production.

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CONFLICT OF INTEREST

The authors state that this research was conducted without any commercial or financial relationship that can be interpreted as a potential conflict of interest.

AUTHOR CONTRIBUTION

If relevant, statements regarding the contributions of each author may be included in this section.

GENERATIVE ARTIFICIAL INTELLIGENCE USAGE STATEMENT

The authors state that generative artificial intelligence (AI) was used in the preparation of this manuscript. The authors acknowledge the use of generative AI to help improve language clarity and improve the grammatical structure of manuscripts. The use is carried out in compliance with applicable ethical guidelines regarding the use and disclosure of generative AI in scientific research. Each author has made substantial intellectual contributions to this work. The entire content of the manuscript has been carefully reviewed to ensure its accuracy, and the authors are solely responsible for the integrity and final content of the manuscript.

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