Semarak International Journal of Material Research

Journal homepage:
https://semarakilmu.my/index.php/sijmr/index
ISSN: 3083-8908

Performance Autoclaved Aerated Concrete of Crushed Coconut Shell (AAC-CCS) for AAC Board Panels

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ARTICLE INFO

Article history:
Received 10 January 2025
Received in revised form 11 February 2025
Accepted 18 February 2025
Available online 28 February 2025

Keywords:
Autoclaved aerated concrete (AAC); crushed coconut shell; agricultural waste; strength; fire resistance; lightweight panel

ABSTRACT

This study investigates the feasibility of incorporating crushed coconut shell (CCS) as a partial replacement for quartz sand in autoclaved aerated concrete (AAC). It highlights the dual benefits of reducing environmental waste and enhancing AAC's material properties, presenting a sustainable approach to construction. The integration of CCS into AAC aligns with global sustainability goals by addressing resource depletion, high energy demands, and environmental concerns linked to quartz sand extraction. Furthermore, this research emphasizes the potential of agricultural waste utilization, such as CCS, to promote eco-friendly construction practices, offering innovative solutions to meet the increasing demand for sustainable building materials. By replacing quartz sand with varying proportions of CCS (0%, 2.5%, 5%, 7.5%, 10%, 12.5%, and 15%), the research evaluates its effects on the mechanical, fire resistance, and surface properties of AAC. The findings reveal that a 2.5% CCS substitution demonstrated the highest compressive strength of 3.7 MPa, as well as improved Young's modulus and modulus of rupture, while maintaining lightweight characteristics. Additionally, fire resistance tests revealed that 2.5% CCS achieved the highest fire resistance rate of 92%, indicating superior thermal insulation and heat diffusion properties. Surface analysis demonstrates minimal damage post-fire exposure for formulations below to 7.5% CCS. The findings demonstrate that CCS not only provides a viable replacement for traditional aggregates but also enhances the fire resistance and structural durability of AAC, particularly at optimal levels of substitution.

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https://doi.org/10.37934/sijmr.2.1.5265a

1. Introduction

The global surge in construction activities has heightened the demand for sustainable construction materials, particularly fine aggregates, which form a vital component in concrete production. Annually, the construction industry utilizes over 7.23 billion tonnes of concrete, requiring vast quantities of aggregates to meet global infrastructural needs [1]. Traditional reliance on quartz sand as a primary fine aggregate has led to significant environmental concerns, including habitat destruction, resource depletion, and high energy consumption during extraction and processing [2]. To address these challenges, researchers have explored agricultural by-products, such as coconut shell, rice husk, palm kernel shell, and sugarcane bagasse, as potential substitutes for conventional aggregates in construction materials [3]. Among these alternatives, crushed coconut shell (CCS) has emerged as a promising material due to its strength, durability, and availability in tropical regions where coconut production is abundant [5].

Crushed coconut shell, a by-product of the coconut industry, is often discarded as waste, contributing to environmental pollution. However, the unique properties of CCS, such as high carbon content, strength, and durability, make it a viable replacement for traditional aggregates like quartz sand [6]. Research has shown that integrating CCS into construction materials, particularly autoclaved aerated concrete (AAC), can enhance their mechanical and thermal properties while promoting environmental sustainability [7]. The incorporation of CCS in AAC production not only reduces waste disposal challenges but also lowers production costs, addressing economic and ecological concerns simultaneously [8]. These advantages make CCS an innovative solution for sustainable construction, particularly in lightweight panel applications [9].

Autoclaved aerated concrete (AAC) is a lightweight, precast building material renowned for its superior thermal insulation, fire resistance, and soundproofing capabilities, making it a preferred choice in modern construction [10]. Traditionally, AAC consists of cement, quartz sand, water, and aluminum paste, which react during autoclaving to produce a porous structure that defines its lightweight characteristics [12]. Despite its widespread use, the reliance on quartz sand in AAC production raises sustainability concerns, prompting interest in replacing traditional aggregates with eco-friendly alternatives [13]. Studies have demonstrated that replacing a portion of quartz sand with CCS can enhance the porosity of AAC, improve its lightweight properties, and potentially increase its thermal and mechanical performance [14].

One of the most important mechanical characteristics for assessing the performance of concrete using sand substitutes is compressive strength. The compressive strength of traditional AAC typically ranges between 3 to 7 MPa, depending on the formulation and curing conditions [15]. The research on AAC-CCS confirms that compressive strengths ranging between 1 and 4 MPa are sufficient for applications in non-load-bearing and low-load structural elements, aligning with the performance demands of these use cases. From the data obtained, the AAC mix with 2.5% CCS content achieved the highest compressive strength value of 3.706 MPa. This indicates its potential for use in applications like interior partition walls, thermal insulation, and infill material in framed structures. The impact of different sand replenishment techniques on the compressive strength of concrete has been the subject of numerous studies conducted between 2018 and 2024. However, other studies have shown more varied results [17]. Noshin *et al.,* (2023) explored the use of quarry dust as a sand replacement and observed that although the compressive strength was comparable to conventional concrete at 2.5 MPa, further replacement of sand led to a decrease in strength. For example, at 50% replacement, the compressive strength dropped to 2.0 MPa. The irregular particle size distribution of quarry dust was identified as a contributing factor to the reduction in strength, as it negatively affected the workability and compaction of the mix [18].

Autoclaved Aerated Concrete (AAC) is valued for its low Young's modulus, enabling flexibility and crack resistance under load. This study found that incorporating 2.5% CCS resulted in a Young's modulus of 1.042 GPa, exceeding the typical range of traditional AAC (0.4–0.6 GPa) [19]. This increase in stiffness enhances resistance to deformation without significantly compromising flexibility, aligning with findings by Jing *et al.,* (2020), where partial replacement of sand with agricultural waste improved stiffness in cementitious materials. This balance between rigidity and elasticity is crucial for lightweight panels, enabling them to support structural loads while adapting to minor movements [20]. The CCS addition reinforces AAC's suitability for advanced non-load-bearing applications, combining improved performance with its inherent lightweight and insulating properties.

The findings of this research are expected to have significant implications for the construction industry, particularly in developing regions where coconut production is abundant, and sustainable building practices are increasingly prioritized. By promoting the utilization of agricultural waste in construction, this study highlights the potential of CCS to revolutionize AAC production, paving the way for greener, more resource-efficient construction technologies [23]. The outcomes of this study will contribute to the advancement of lightweight, eco-friendly building materials, addressing both environmental and economic challenges in the construction sector.

2. Methodology

2.1 Preparation of AAC-CCS Sample

The preparation material of crushed coconut shell as shown in Figure 1. CCS are sourced and dried to remove moisture. The shells are then ground into a granular form using a high-efficiency mill, such as the Fritsch's Planetary Mono Mill Pulverisette 6 Classic Line, ensuring uniformity in particle size of 0.5 ± 0.1 mm. The ground coconut shell material is subjected to a sieving process using a sieve shaker that complies with the British Standard Specification for Test Sieves (BS 410). The target particle size is set at 0.6 ± 0.05 mm, utilizing appropriate sieves to achieve this granulation. Any material that does not meet this specification is discarded. To integrate CCS as a sustainable alternative to sand, mix designs were formulated with varying replacement levels of CCS at 0%, 2.5%, 5%, 7.5%, 10%, 12.5 and 15% by weight. Each component of the AAC-CCS mixture is weighed according to predetermined proportions, ensuring accuracy as tabulated in Table 1. The production process utilized core raw materials, including sand, lime, cement, gypsum, water, and a small amount of aluminum powder, with the aluminum acting as a foaming agent to generate the characteristic cellular structure of AAC. Measurement tolerances are maintained within ±0.1g for powder materials and ±0.01g for aluminum powder.

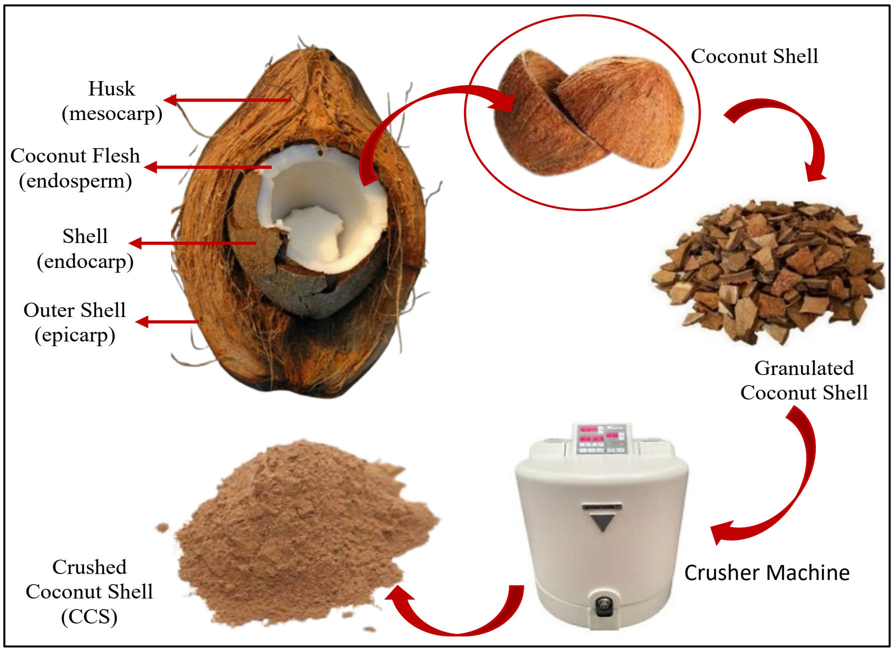

Fig. 1. Material preparation process of Crushed Coconut Shell (CCS)

Table 1
Mix design proportion of AAC-CCS as sand replacement

Materials/ Sample	Control (kg)	CCS 5% (kg)	CCS10% (kg)	CCS15% (kg)	CCS20% (kg)	CCS25% (kg)	CCS30% (kg)
Slurry 70%	10.416	9.895	9.375	8.854	8.333	7.812	7.291
CCS	-	0.336	0.672	1.008	1.344	1.680	2.016
Cement 18%	1.727	1.727	1.727	1.727	1.727	1.727	1.727
Lime 12%	1.151	1.151	1.151	1.151	1.151	1.151	1.151
Aluminum 0.01%	0.010	0.011	0.011	0.011	0.011	0.011	0.011
Water	2.060	2.246	2.431	2.616	2.800	2.983	3.170

The process begins with the precise weighing of raw materials, the weighed materials are combined using an electric mixer which is Allefix 2100W, for approximately 15 minutes to ensure a homogeneous mixture. After this initial mixing, aluminum powder (0.01%) is added and stirred for an additional 15 seconds to integrate it into the slurry. The resulting slurry is poured into molds, filling them to two-thirds capacity. The molds are gently shaken to release trapped air bubbles, promoting a more uniform structure in the final product. The initial reaction phase is 30 minutes, during which the slurry expands to fill the molds completely. After this, the samples undergo a pre-curing process at room temperature for 2 hours. Finally, the pre-cured samples are transferred to an autoclave machine, where the AAC-CCS samples undergo hydrothermal curing at a temperature of 180°C to 200°C, control pressure of 13 bar for 12 hours and 2 hours of buffer to produce AAC-CCS as show in Figure 2.

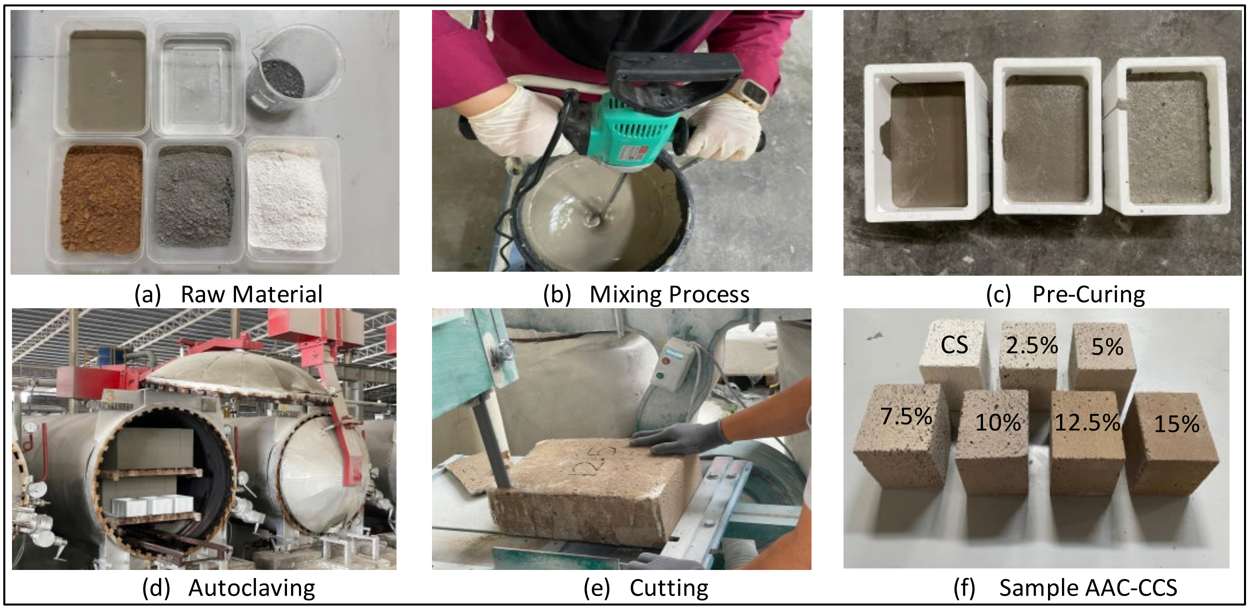

Fig. 2. Fabrication process of sample Autoclaved Aerated Concrete-Crushed Coconut Shell (AAC-CCS)

2.2 Testing Sample of AAC-CCS
2.2.1 Compressive strength

The compressive strength test of the AAC-CCS samples was conducted at Kim Hoe Thye Industries Sdn. Bhd. using a Controls' Automax Pro Compact-Line, Super-Automatic EN Tester (model 50-C56F02, Italy), which is specifically designed for testing the compressive strength of concrete specimens such as cubes, cylinders, and blocks. The samples were prepared with precise dimensions of 100 mm × 100 mm × 100 mm and were labeled according to their different mix ratios as show in Figure 3. The test procedure began by powering on the machine and placing the sample at the center of the loading area. The relevant sample details were entered into the software's 'Report' tab, and the test settings were confirmed in the 'Graph' tab under the 'Settings' icon. The test was initiated by selecting the 'Run' icon, which lowered the piston until it contacted the top of the sample.

Fig. 3. Compressive strength test

A load rate of 0.7 MPa/s was applied for a duration of up to 60 seconds. If cracking occurred before the 60-second mark, the machine automatically stopped the load application. If the sample did not crack, the test continued for the full 60 seconds, and the maximum load applied was recorded in MPa. After the test, the piston was returned to its starting position, and the broken sample was removed for inspection. The machine was cleaned to prevent contamination for subsequent tests. The collected data was cross-checked for accuracy, and Eq. (1) was employed to determine the Young's modulus of the material. The automated, computerized nature of the test ensures precise and reliable results.

$$\text{Young's Modulus, E} = (\frac{F}{A})/(\frac{\Delta_L}{L}) \tag{1}$$

2.2.2 Fire resistance test

The fire resistance test for AAC-CCS samples was conducted at Kim Hoe Thye Industries Sdn. Bhd, following ASTM E-119 standards, which focus on evaluating the material's ability to withstand exposure to direct fire. The samples, labeled with seven different mix ratios, were prepared with precise dimensions of 100 mm × 100 mm × 100 mm. For the fire exposure test, key parameters such as temperature, duration of exposure, and visual changes were closely monitored and recorded.

Figure 4 shows the experimental setup for the fire resistance test of AAC-CCS is to evaluate the rate of fire resistance under direct fire exposure as Eq. (2). The sample is positioned between insulating fire bricks to minimize heat loss and ensure consistent exposure to the fire source. A controlled fire source is applied directly to one side of the sample, simulating high-temperature conditions. The samples were positioned 40 cm away from the fire source and heated for 5 minutes at a temperature between 500°C and 600°C. Two thermocouples, $Temp_1$ and $Temp_2$, are placed on opposite sides of the composite to measure the surface temperatures during the test. $Temp_1$ records the temperature on the fire-exposed side, while $Temp_2$ measures the temperature on the opposite side, providing a gradient indicating rate of fire resistance through the material. A timer is used to monitor the duration of flame exposure.

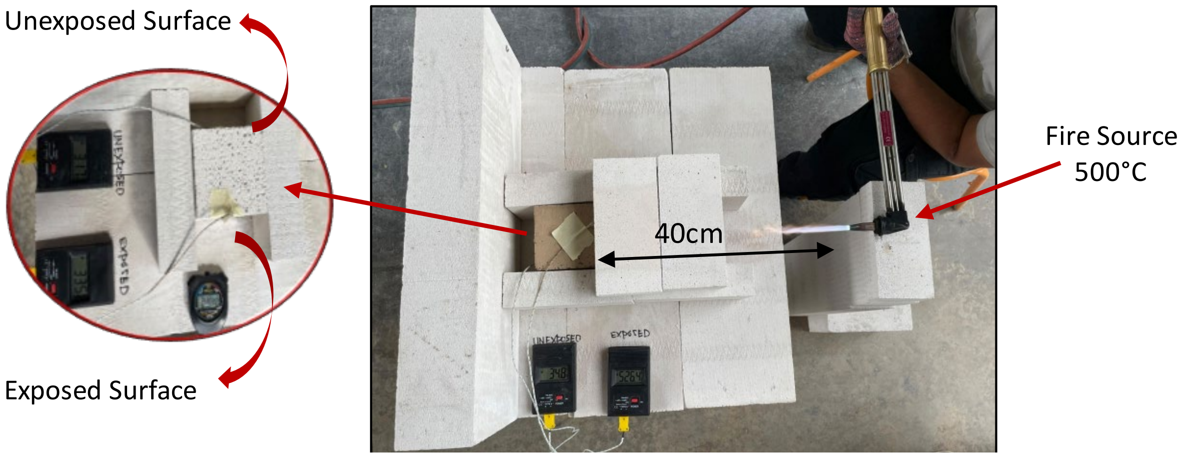

Fig. 4. Direct fire testing of AAC-CCS with different proportion

$$\text{Rate of fire resistance, \%} = \frac{\text{Exposed, T1} - \text{unexposed, T2}}{\text{Exposed, T1}} \text{ x } 100 \tag{2}$$

3. Results

3.1 Compressive Strength Analysis with and without Drying

Figure 5 shows the compressive strength of autoclaved aerated concrete incorporating crushed coconut shell (AAC-CCS) at varying replacement percentages 0–15% by weight under two conditions: with and without a drying process. Initially, the compressive strength increases with the addition of CCS up to 2.5%, reaching its maximum value under both drying and non-drying conditions. At 2.5% CCS, the compressive strength is approximately 3.7 MPa for dried samples and 2.3 MPa for non-dried samples, indicating a slight improvement compared to the control sample, 0% CCS. This improvement can be attributed to the enhanced compatibility of a small amount of CCS with the cementitious matrix, promoting better bonding and reducing porosity within the material. The increase in compressive strength was to be the effect of CCS which has a higher percentage of silica and alumina. According to Tural *et al.,* (2024), a higher percentage of silica, alumina, and calcium oxide are responsible for pozzolanic reactivity and cementitious properties [25]. In addition, Elyasigorji *et al.,* (2023) stated the pozzolanic material can improve the long-term strength of Poland cement binder by pozzolanic reaction among Ca(OH)2 remaining from cement hydration [26]. The compressive strength of the sample increased linearly with the increased ratio of CCS addition.

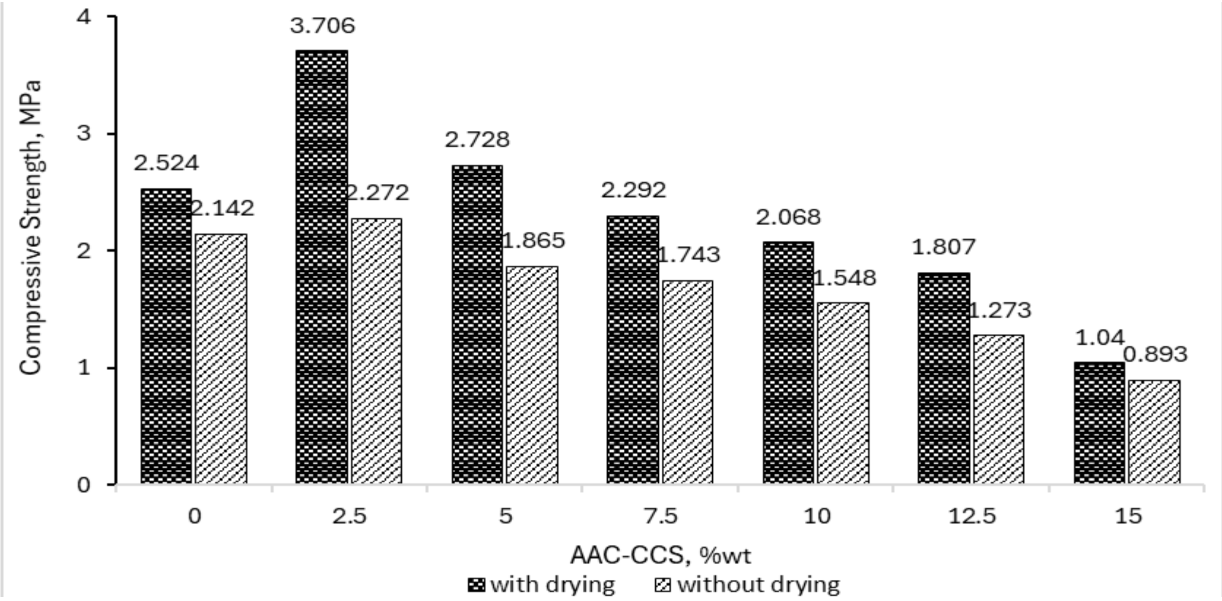

Fig. 5. The compressive strength with and without drying of AAC-CCS with different CCS contents

However, as the replacement percentage increases beyond 2.5%, the compressive strength begins to decline significantly. At 5% CCS, the compressive strength decreases to approximately 2.7 MPa for dried samples and 1.9 MPa for non-dried samples. The reduction becomes more pronounced at higher replacement levels, with the compressive strength dropping to its lowest value of approximately 1.0 MPa (dried) and 0.9 MPa (non-dried) at 15% CCS. This trend indicates that while a small proportion of CCS contributes positively to strength, excessive replacement levels introduce weaknesses in the matrix due to increased porosity and reduced cement hydration efficiency. The reduction in compressive strength at higher CCS percentages can be attributed to the physical and chemical characteristics of CCS. The lower density and higher organic content of CCS compared to quartz sand lead to increased voids and reduced cohesion in the mix. Additionally, the introduction of CCS beyond optimal levels likely disrupts the balance of fine aggregates in the mix, weakening the structural properties of the material.

Previous study the effectiveness of CCS in enhancing AAC compressive strength was found to be more evident compared to prior studies. Rajkohila *et al.,* (2024) has been investigated the AAC based on fiber as addition and compressive strength was enhanced between 12.67% and 15.12% compared to control sample, respectively [27]. This enhancement was attributed to the pozzolanic effect of CCS, owing to its higher silica and alumina content. Previous studies by Bhagath Singh *et al.,* (2022) have highlighted that higher percentages of silica, alumina, and calcium oxide contribute to pozzolanic reactivity and cementitious properties, supporting the formation of C-S-H and tobermorite as major phases in AAC, thereby enhancing compressive strength [28]. Additionally, pozzolanic materials have been shown to improve the long-term strength of Portland cement binder through pozzolanic reactions. The positive impact of pozzolanic material on the compressive strength of AAC and aerated concrete has been explored in the literature [29].

The drying process consistently enhances the compressive strength of AAC-CCS across all replacement levels. On average, dried samples exhibit a 10–20% improvement in strength compared to non-dried samples. This improvement is due to the elimination of excess moisture, which facilitates better cement hydration and matrix consolidation during the curing process. In general, most of AAC-CCS was qualified as grade-2 AAC except for AAC-2.5CCS, which is reached grade 3 according to ASTM C1693. In summary, the compressive strength of AAC-CCS increases with the incorporation of CCS only up to 2.5%, after which it steadily decreases with higher replacement levels from 5% to 15%. The results highlight the importance of maintaining an optimal CCS proportion to balance strength, lightweight properties, and sustainability. The drying process also plays a critical role in improving the material's mechanical performance, reinforcing the need for controlled curing conditions in the production of AAC-CCS.

3.2 Modulus Young & Modulus Rupture Analysis of AAC-CCS

The results of the study highlight the importance of evaluating the mechanical properties of AAC-CCS, specifically the modulus of elasticity (Young's modulus) and the modulus of rupture, to understand its suitability for structural and lightweight applications. The modulus of elasticity represents the material's stiffness, reflecting its ability to resist deformation under applied stress. This property is critical for determining the load-bearing capacity of AAC-CCS and ensuring minimal elastic deformation in structural applications. On the other hand, the modulus of rupture signifies the material's flexural strength, indicating its resistance to cracking or failure under bending stresses. For AAC-CCS, these properties are particularly relevant for lightweight panels, which are often subjected to flexural forces during handling, installation, and operational use. By analyzing the relationship between these mechanical properties and the varying content of crushed coconut shells, the study provides valuable insights into optimizing the material's performance for sustainable construction.

The correlation between compressive strength, modulus of elasticity (Young's modulus), and modulus of rupture for AAC-CCS with varying CCS contents is illustrated in Figure 6. The results demonstrate how these mechanical properties are influenced by the addition of crushed coconut shell (CCS) at different percentages.

Initially, at 2.5% CCS, the compressive strength and modulus of rupture show an increase, reaching their peak values of approximately 3.5 MPa and 2.0 GPa, respectively. This suggests that a small addition of CCS enhances both the material's compressive and flexural performance. However, as the CCS content increases beyond 2.5%, both compressive strength and modulus of rupture exhibit a declining trend. By 15% CCS, the compressive strength reduces significantly, while the modulus of rupture reduce to nearly negligible levels. This indicates that excessive CCS compromises the structural properties of the AAC-CCS, likely due to the lower bonding strength between CCS particles and the cementitious matrix. Aerated concrete's modulus of elasticity, sometimes referred to as Young's modulus, can be described as a function of both density and compressive strength, with both increasing as the two variables do (Gonglian *et al.,* 2021). Young's modulus and compressive strength in lightweight concrete have also been linked by other researchers, such as Poongodi and Murthi (2021). According to their research, lightweight concrete's Young's modulus rises linearly with its compressive strength. The modulus of elasticity for autoclaved aerated concrete can also be described as a function of density and compressive strength, increasing with increasing density and compressive strength, according to Kothapally *et al.,* (2024).

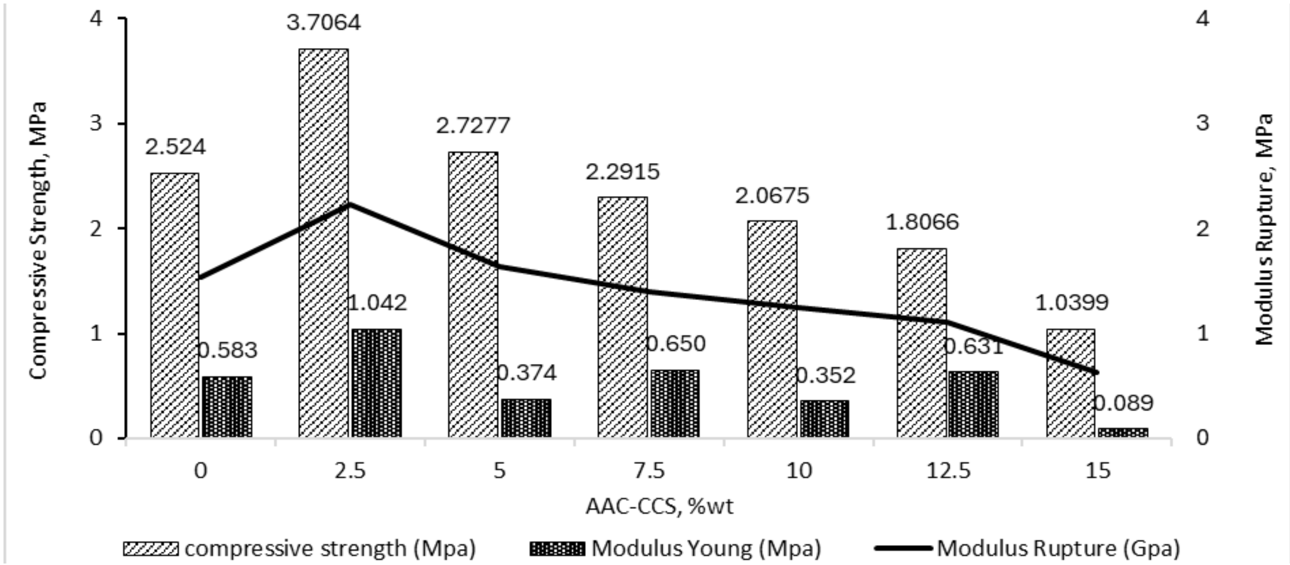

Fig. 6. The correlation between compressive strength with modulus young and modulus rupture with different CCS contents

In contrast, the modulus of elasticity (Young's modulus) follows a slightly different trend. While it remains relatively low compared to the other properties, it peaks at 2.5% CCS and gradually decreases as CCS content increases, showing the material becomes progressively less stiff. This reduction highlights the trade-off between incorporating higher amounts of CCS for sustainability and maintaining the mechanical rigidity of the material. Overall, the results demonstrate that the mechanical properties of AAC-CCS, particularly its compressive strength and flexural performance, are optimal at lower CCS content, with 2.5% providing the best balance for practical applications. Beyond this level, the structural performance reduce, limiting its suitability for load-bearing purposes.

3.3 Fire Resistance Analysis of AAC-CCS

The temperature diffusion analysis of AAC-CCS samples reveals that adding crushed coconut shell improves fire resistance, as higher CCS content results in lower peak temperatures and slower heat absorption. Each sample had a volume of 100 mm³, and the temperature was recorded on both the exposed and unexposed surfaces. The results, as shown in Table 2, reveal that the fire resistance of AAC-CCS is significantly influenced by the proportion of CCS incorporated into the mix. The highest rate of fire resistance was observed for the 10% CCS sample, indicating its superior fire resistance compared to other formulations.

Table 2
Temperature diffusion analysis of different proportion of CCS during direct fire testing

Sample of Different ratio	Temperature AAC-CCS		Rate of Fire Resistance, %
	Exposed Surface, T1	Unexposed Surface, T2	
AAC-CCS	373.6°C	37.1°C	90.1%
AAC-2.5CCS	481.2°C	38.7°C	92.0%
AAC-5CCS	362.1°C	37.9°C	89.5%
AAC-7.5CCS	326.8°C	37.3°C	88.6%
AAC-10CCS	389.1°C	37.6°C	91.5%
AAC-12.5CCS	393.4°C	37.2°C	90.5%
AAC-15CCS	409.8°C	37.5°C	90.8%

The temperature diffusion analysis of AAC-CCS samples revealed that increasing the proportion of crushed coconut shell (CCS) enhances fire resistance by reducing peak temperatures and slowing heat transfer. Among the tested samples as shown in Figure 7, the 2.5% CCS achieved the highest fire resistance rate of 92%, while the lowest rate of fire resistance was 7.5% of CCS at 88.8%, demonstrating the thermal insulating potential of CCS. These results align with findings from Jing *et al.,* (2020), who observed that agricultural waste in cementitious materials improves thermal stability, and Nguyen *et al.,* (2019), who reported enhanced fire resistance in bio-based composites due to reduced thermal conductivity. This study confirms that incorporating CCS into AAC optimizes its thermal properties for applications requiring superior fire resistance while maintaining its lightweight and insulating benefits.

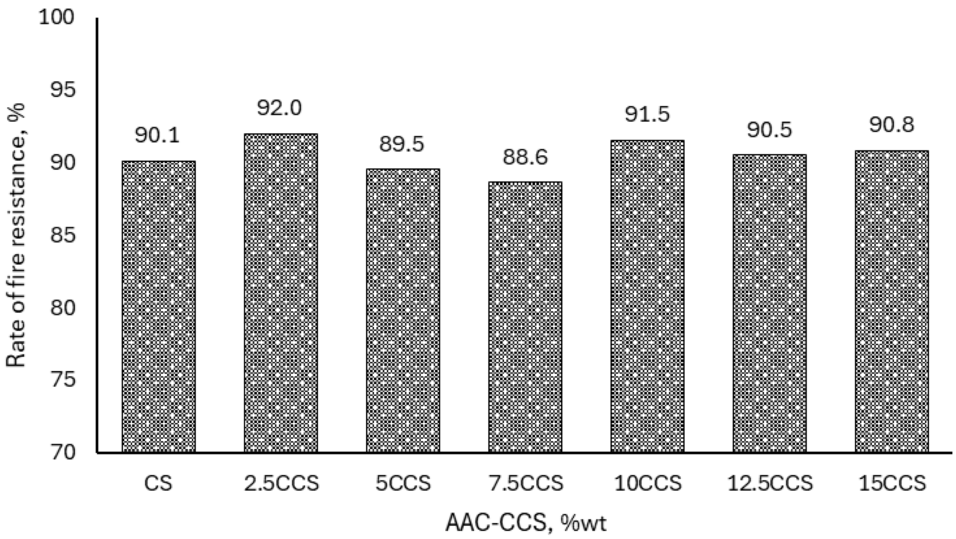

Fig. 7. Rate of fire resistance at different proportion of CCS

3.4 Surface Analysis of AAC-CCS

Figure 8 illustrates the effect of direct fire exposure on the surface of AAC-CCS samples before and after testing. Prior to burning, all samples exhibited a natural brown coloration, characteristic of the coconut shell content. After the fire direct test, the surface of the samples appeared lighter in colour, resembling standard AAC blocks, with slight brownish burn marks visible on some specimens. The absence of severe surface damage or discoloration, even at high temperatures, is consistent with findings from Lam *et al.,* (2020), who reported similar fire resistance in high-performance concrete subjected to temperatures of up to 520°C for 300 seconds [31]. Despite prolonged exposure to direct fire, the AAC-CCS samples remained free from visible cracks or burning, highlighting the positive effect of coconut shell inclusion. Coconut shell, a non-combustible material, contributes to the thermal stability of AAC by enhancing its insulating properties. Furthermore, the AAC-CCS samples did not melt or undergo structural deformation during fire exposure, which demonstrates the effective integration of CCS into the AAC matrix. These results differ from studies by Reena Dewi *et al.,* (2022), where eco-friendly concrete containing recycled plastic displayed significant blackening, cracking, and burning under similar fire testing conditions [32]. This highlights the superior fire resistance of AAC-CCS as a sustainable construction material.

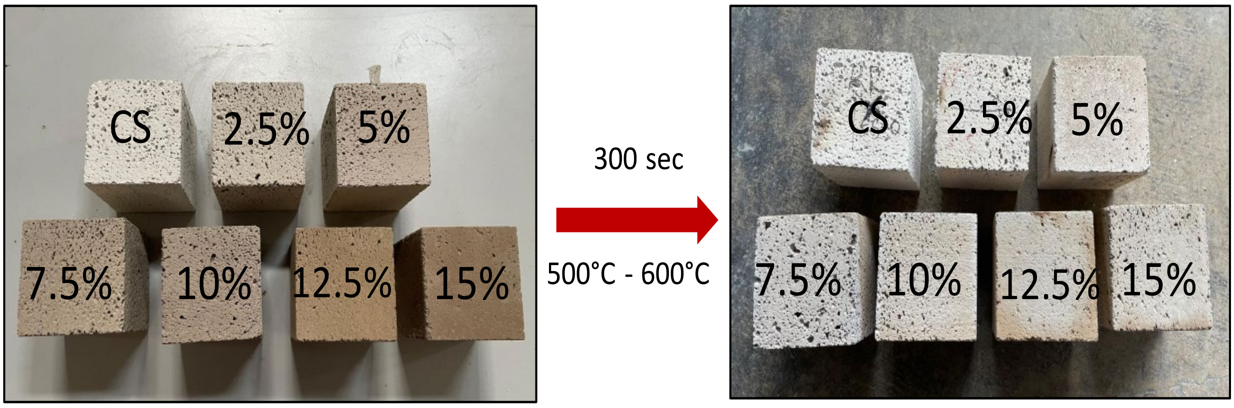

Fig. 8. The surface analysis of AAC-CCS with different proportion after direct fire testing

Among the tested samples, the Control Sample (CS), 2.5% CCS, 5% CCS and 7.5% CCS specimens exhibited minimal surface damage, showing no visible cracks or signs of burning. This result highlights that incorporating CCS at levels below 7.5% effectively improves the material's resilience to high temperatures and thermal stress. The enhanced fire resistance of AAC with CCS can be attributed to the excellent insulating properties of coconut shell particles. Coconut shell's natural low thermal conductivity and structural stability help to dissipate and absorb heat, reducing the risk of rapid temperature buildup that might lead to cracking or burning. However, increasing CCS content beyond an optimal range e.g., 12.5% could potentially compromise other mechanical properties, such as compressive strength. Therefore, CCS proportions of up to 7.5% appear to achieve a balance between thermal resistance and structural durability. This makes AAC-CCS an attractive option for applications requiring fire-resistant building materials, particularly in high-temperature environments.

4. Conclusions

In conclusion, this study demonstrated the potential of crushed coconut shell (CCS) as a sustainable replacement for quartz sand in autoclaved aerated concrete (AAC). The mechanical performance analysis reveals that a 2.5% substitution of CCS achieved the highest compressive strength of 2.27 MPa compared to control sample 2.14 MPa. The dry compressive strength also improved with higher CCS content, reaching 3.71 MPa at 2.5% CCS and shown 38.8% increase over the control sample, highlighting its exceptional mechanical properties and suitable for non-load-bearing applications. Additionally, the Young's modulus and modulus of rupture analysis exhibited a linear correlation with compressive strength, further emphasizing the interrelation of these mechanical properties. The fire resistance testing highlighted that AAC-CCS formulations offer superior thermal insulation, with 5% CCS achieving the lowest exposed surface temperature during direct fire exposure, but the mixed ratio of AAC-CCS 2.5% achieved the highest fire resistance rate of 92% confirming its effectiveness as a fire-resistant material. The fire resistance testing highlighted that AAC-CCS formulations offer superior thermal insulation, with 5% CCS achieving the lowest exposed surface temperature during direct fire exposure, but the mixed ratio of AAC-CCS 2.5% achieved the highest fire resistance rate of 92% confirming its effectiveness as a fire-resistant material. hence, CCS's natural insulating properties contributed to reduced heat transfer and enhanced thermal stability. These outcomes establish AAC-CCS as a viable, eco-friendly construction material capable of reducing reliance on traditional aggregates and promoting sustainability. Hence, the mixed ratio of 2.5% AAC-CCS stands out as the optimal formulation, offering a balanced combination of superior mechanical strength, enhanced fire resistance, and eco-friendly attributes, making it the most suitable choice for sustainable and efficient lightweight construction applications.

Acknowledgement
The authors are grateful for the fruitful discussions and input UTHM staff brought to the project. This research was supported by Ministry of Higher Education (MOHE) through Prototye Research Grant Scheme (PRGS/1/2024/WAS02/UTHM/02/1). We also want to thank to the Government of Malaysia which provide MyBrain15 programme for sponsoring this work under the self-funded grant and L00022 from Ministry of Science, Technology and Innovation (MOSTI). The authors also acknowledge the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM), and Kim Hoe Thye Industries Sdn Bhd for the equipment and technical assistance. The authors are grateful for the fruitful discussions and input UTHM staff brought to the project.

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