Development of a novel sustainable concrete from waste coconut shell with alccofine supplements

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Abstract:
The infrastructure of a country depends significantly on cement concrete as the primary construction material. The aggregate comprises a significant proportion of the overall volume of concrete. However, the ongoing extraction of granite rock to obtain coarse aggregate contributes to the escalating need for natural resources among future generations. Due to its high carbon dioxide (CO2) footprint, the cement industry is a significant contributor to global warming. An appropriate reduction in the amount of cement in concrete without affecting its key properties can result in economical and sustainable development of the construction industry. In this investigation, agricultural waste coconut shell is considered as a substitute for conventional aggregate in concrete to produce lightweight coconut shell concrete. The alccofine-1203 contains ultrafine particles with a distinctive composition that enhances the pozzolanic and hydration process in concrete. Alccofine ranging from 5 % to 15 % were added to cement. The results demonstrated that the 10 % alccofine enhanced the fresh and mechanical properties of the lightweight coconut shell concrete. Using a combination of coconut shell and alccofine in concrete would be the most environmentally sustainable option in the construction industry.

Keywords:
alccofine; coconut shell; supplementary cementitious materials; sustainability; water absorption

1 Introduction

Concrete is the most commonly used building materials worldwide after potable water [1]. The manufacturing process involves the utilisation of substantial amounts of natural resources. According to Srividhya et al. [2], a substantial quantity of waste can be recycled as substitutes for aggregates and binders in concrete. According to Alexander and Mindess [3], aggregates comprise approximately 78 % of the volume in concrete. The utilisation of natural coarse aggregates is significantly challenging in terms of sustainability, leading to several ecological concerns [4]. Waste and byproducts are the best alternatives to natural materials for achieving sustainable development in concrete production [5].

Crushed coconut shells are viable materials for concrete manufacturing [6, 7]. Coconut shells are commonly found in several coconut-producing countries including India. According to official data provided by the Indian Ministry of Agriculture and Farmer's Welfare, the total coconut production in India in 2021 was 20,736 million units [8]. The use of coconut shells as a substitute for coarse aggregates in concrete has several advantages, such as mitigating environmental consequences and lowering manufacturing costs. Olanipekun et al. [9] estimated that if coconut shells were substituted for gravel in concrete, a 30 % cost reduction can be attained. Coconut shells decrease the reliance of concrete on natural resources. Additionally, the recycling and dispersal of coconut-shell waste in concrete is advantageous and straightforward. Therefore, they are effective and ecofriendly concrete materials. According to Basri et al. [10], wood-based materials of organic origin incorporated into a concrete matrix do not contaminate or percolate to produce toxic substances. The bond between the coconut-shell aggregate and cement composite was observed to be compatible, requiring no pretreatment and minimal inhibition. Gunasekaran et al. [11] reported that the durability properties of coconut-shell concrete are comparable to those of conventional lightweight concrete. Because the coconut shell is a lightweight aggregate, it reduces the density of concrete, thereby reducing the dead load of the structure [12]. Owing to the lower rigidity of lightweight concrete and uniform distribution of microcracks, its durability in severe environments increases [13]. Moreover, coconut-shell coarse aggregates improve the sound absorption coefficient of lightweight concrete compared to that of regular-weight concrete [14].

Cement production is one of the leading causes of environmental pollution due to the emission of vast quantities of carbon dioxide into the atmosphere. Using supplementary cementitious materials (SCMs) as partial or complete replacements for cement, the consumption of large quantities of cement in concrete production can be reduced. SCMs include fly ash, ground granulated blast furnace slag (GGBS), silica fume, pond ash, limestone particles, rice husk ash, metakaolin, etc.

Alccofine-1203 is an eco-friendly, low-calcium silicate-based microfine material comprising a large amount of glass with high reactivity. Alccofine-1203 is a highly processed material obtained from GGBS, which is a waste material generated by the iron ore industries in India. Hence, the production volume of alccofine depends on iron ore production in India, which was 255 million tons in the 2022-2023 fiscal year. Leading cement manufacturers in India also produce alccofine additives. The customised particle size distribution offers special properties that improve the "concrete performance" in both the fresh and hardened phases. As alccofine is partially replaced with cement in concrete, it reduces the consumption of cement; hence, the CO_2 emissions due to cement production are reduced. Owing to the controlled granulation process, alccofine-1203 contains ultra-fine particles with a fineness of 12,000 cm^2/gm and distinctive chemistry [15-18]. The use of alccofine-1203 in the production of concrete not only enhances its compressive strength, but also its flowability and workability [19]. Alccofine-1203 material particles are significantly finer than those of cement, GGBS, silica, and fly ash. Therefore, alccofine-1203 can be used to fill the cavities formed between the cement particles. Alccofine-1203 outperforms all other mineral admixtures owing to the presence of CaO (lime). Because of its high glass content, the XRD pattern of alccofine-1203 is nearly amorphous [20].

The current study was conducted to investigate the effect of alccofine as a cement replacement on the mechanical parameters of lightweight concrete (LWC) made using coconut-shell aggregate, including the compressive strength, split tensile strength, flexural strength, elastic modulus, and impact resistance. Several studies on alccofines in conventional concrete are available in literature. However, the standard literature on alccofines in coconut–shell concrete is scarce. This study considers the effect of alccofine at 5 %, 10 %, and 15 % by weight as a partial substitute for cement on the properties of coconut shell light weight concrete.

2 Methodology

2.1 Materials

In this study, IS:12269-1987-compliant conventional Portland cement (Grade 53) with a specific surface area of 3,350 cm^2/g and specific density of 3,13 was utilized. The initial and final setting periods of the cement were 65 min and 140 min, respectively. Alccofine with a specified surface area and density of 12,500 cm^2/g and 900 kg/m^3 was utilised as the supplementary cementitious material. Sand from the Cauvery River meeting the Zone II specifications was used as the fine aggregate. The specific gravity was 2,36, and the fineness modulus was 2,91. Figures 1a, 1b, and 1c show the alccofine pack, alccofine sample, and SEM images of alccofine, respectively. Table 1 presents the chemical constituents of OPC, Class F fly ash, and Metakaolin.

a) b) c)

Figure 1. a) Alccofine pack, b) Alccofine sample, c) SEM image

Table 1. Chemical constituents of OPC and alccofine

Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
cement	20,90	4,70	3,4	65,4	1,2	2,7	0,370	0,71	0,75
alccofine	35,00	22,10	2,1	33,0	7,5	0,3	0,032	0,61	0,58

A CS sample was obtained from a local copra preparation yard in Thanjavur, Tamil Nadu, India. After being hammered and crushed into small fragments, the CS samples were sieved. Crushed CS samples with particle sizes ranging from 12,5 to 4,75 mm were employed as a coarse aggregate. Subsequently, the prepared CS aggregate was rinsed with clear water and dried under sunlight. Because of their exceptional ability to retain moisture, CS aggregates must be soaked in water for 24 h. The soaked CS were dried before being used in concrete to remove surface water, matching the aggregate saturated surface dry (SSD) condition. When the CS is in the SSD state, it does not absorb additional water from the concrete; thus, the workability of the concrete is not compromised. The CS trash accumulated in the copra preparation yard is shown in Figure 2a. The CS waste was collected and crushed into aggregates (Figure 2b).

a) b)

Figure 2. a) Discarded CS waste from copra preparation yard, b) Aggregates crushed from CS shell

Tables 2 and 3 list the physical and mechanical parameters of the CS. Conplast SP430 was used as the water-reducing additive, and accessible borehole water from the college was used for concrete mixing.

Table 2. Physical properties of CS aggregate

Max/min size (mm)	**Thickness** (mm)	**Water absorption** (%)	**Spec. gravity**	**Fineness modulus**	**Bulk density** (g/cm^3)	**Void ratio**	**Moisture content** (%)
12 / 4,75	3-8	25	1,11	6,25	0,65	0,64	3,8

Table 3. Mechanical properties of CS aggregate

Mechanical properties	**Crushing value** (%)	**Abrasion value** (%)	**Impact value** (%)
Values	2,59	2,00	7,90

2.2 Concrete mix proportions

The trial mixes were formulated in accordance with the guidelines outlined in ACI 211.2-98. Subsequently, the mixture that exhibited superior performance was selected for further investigation. Alccofine-1203 was substituted with cement in varying proportions of 10 %, 20 %, and 30 % by weight. These mixtures were designated CSA5, CSA10, and CSA15, respectively. The binder-to-water ratio in all mixtures was maintained at 0,33. To attain the desired workability of concrete, a high-range water-reducing agent, Conplast SP430, was used at a dose of 1,2 % relative to the weight of the binder. The mix proportions for all concrete mixes generated in this study are listed in Table 4. The mixing process involved combining the CS aggregate and M-sand in a rotary drum mixer for approximately three minutes. Subsequently, cement and Alccofine were added and stirred for an additional six minutes. Subsequently, water and a superplasticiser were introduced into the drum, followed by a further 8-minute mixing. The mixture was then introduced into moulds and subjected to compaction. The specimens were removed from the moulds after 24 h and subsequently subjected to water curing until the designated testing day.

Table 4. Mix proportions of various concrete mixes designed in this study

Mix ID	**Alccofine** (%)	**Cement** (kg/m^3)	**Fine aggregate** (kg/m^3)	**Coconut Shell Aggregate**	**w/b**	**Super plasticizer** (% by weight of cement)
CSA	0	510	749,7	331,5	0,33	1,2
CSA5	5	459	749,7	331,5	0,33	1,2
CSA10	10	408	749,7	331,5	0,33	1,2
CSA15	15	357	749,7	331,5	0,33	1,2

2.3 Testing methods

A slump test was conducted in accordance with the ASTM C143/C143M-12 standards. The compressive strength of the 100-mm cube specimens was determined following the guidelines specified in IS 456:2000. Three cylindrical specimens measuring 100 × 200 mm and three prismatic specimens measuring 100 × 100 × 500 mm were used to evaluate the split tensile and flexural strengths after a curing period of 28 days. The experiment utilised a compression testing apparatus with a maximum capacity of 2000 kN and loading rate of 2,3 kN/s. The concrete specimens underwent water absorption and sorptivity tests following the guidelines stated in ASTM C1585. The rapid chloride permeability test (RCPT) was conducted following the guidelines provided in ASTM C 1202. Figure 3 shows the tests conducted in this experiment.

a)

b)

c)

Figure 3. a) RCP test, b) sorptivity Test, c) flexural strength test

3 Results and discussion

3.1 Slump

The workability of fresh concrete during transportation, placement, and compaction, in addition to the quality of its constituents, determines the quality of the concrete structure. The lightweight aggregates drift away from the heavier cementitious matrix owing to the significant slump of LWC. This separation was followed by compaction and poor finishing. For satisfactory finishing and compaction, ACI 213R-87 can be leveraged to limit the slump of LWC to a maximum of 100 mm [2]. A 50-75 slump is thought to be sufficient for LWC to achieve good compaction and finishing [2]. Hossain [21] claimed that because the work performed by lightweight aggregates by gravity was noticeably less, a high slump was not necessary for good finishing and compaction of LWC.
Although CS aggregates typically have a high water absorption rate, they were employed in the current investigation under saturated surface dry conditions, which prevented them from absorbing water during the mixing process. Consequently, the capacity of the mixture to work may not be affected. The amounts of water and superplasticiser in the mixtures used in this study were maintained constant. Figure 4 demonstrates how lightweight concrete made from coconut shells was replaced by a slump of alccofine. The slump was reduced by 7 %, 21 %, and 28 %, respectively, with the addition of 5%, 10%, and 15% Alccofine. Higher alccofine content tended to absorb more water. This characteristic results from the larger particle size of alccofine, which has a larger surface area and can absorb more water.

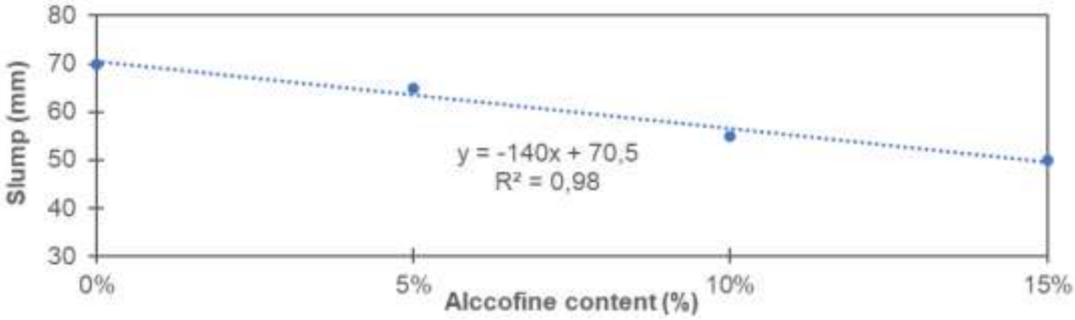

Figure 4. Influence of Alccofine content on slump of CS concrete

3.2 Density

According to Newman and Choo [22], structural LWC has a density of 1600-2000 kg/m^3. Notably, when the amount of alccofines was increased, the concrete density marginally increased. This increase in density is the result of the alccofine particles being packed more tightly between the cement particle spaces.

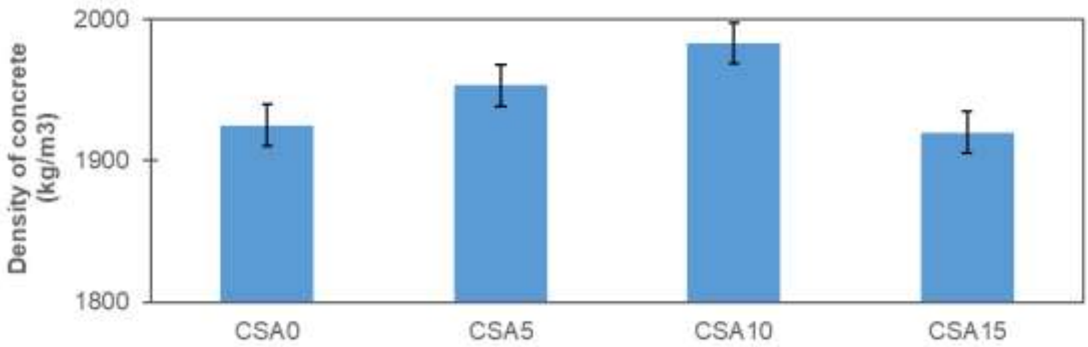

Figure 5. Influence of alccofine content on density of CS concrete

All mixes had densities below 2000 kg/m^3, which met the LWC requirements for density. The density of the alccofine-replaced CS concrete is shown in Figure 5. The addition of 10 % Alccofine resulted in a maximum 3 % density increase. Alccofine increases the density of lightweight concrete made from coconut shells, but the difference is negligible; therefore, the overall weight of the structure is not affected.

3.3 Compressive strength

The compressive strength of concrete is a fundamental property that plays a crucial role in determining the structural integrity and durability of concrete structures. It is a measure of the ability of concrete to withstand axial loads or forces that tend to squeeze or crush materials. Sagar and Sivakumar [23] observed a maximum 17 % improvement in compressive strength of conventional concrete. Pawar and Saoji [18] discovered that self-compacting concrete (SCC) containing 10 % alccofine-1203 had superior workability and compressive strength. Kavitha and Felix Kala [24] discovered that replacing cement with 10 % alccofine-1203 and 30% GGBS resulted in the highest compressive and split tensile strengths for SCC compared with the other replacement levels of alccofine-1203. Kavyateja et al. [25] determined that a proportion of 25 % fly ash and 10 % alccofine-1203 is optimal for partially replacing cement in SCC with superior tensile properties. In this study, the addition of alcofine increased the compressive strength by up to 10 %, after which it decreased. Among the various alccofine addition percentages, the mixture containing 10 % alccofine exhibited the highest compressive strength. At 28 days, the compressive strength increased by 20 % compared to the control CS concrete mix and the results are shown in Figure 6. This result is comparable to that of the compressive strength improvement in conventional concrete reported by previous researchers. With the incorporation of ultra-fine particles of alccofine-1203, the particle density of the binder mass increased, resulting in a high-strength concrete. The addition of lime (CaO) enhanced and facilitated the formation of secondary hydrated C-S-H gel products, leading to increased early age strength development and reduced heat generation throughout the hydration process. The observed reduction in compressive strength of concrete mixes containing 15 % alcofine can be attributed to the instability of the binder caused by an increase in the presence of free lime (CaO), alumina (Al_2O_3), and magnesia (MgO). When hydrated, these compounds result in excessive expansion and formation of microcracks within the concrete. Consequently, the concrete exhibited diminished resistance to compressive loads.

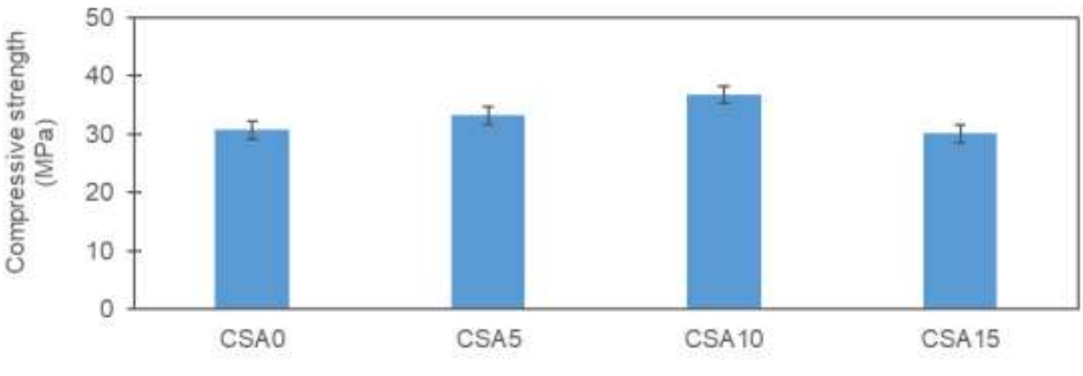

Figure 6. Compressive strength alccofine supplemented CS concrete

3.4 Split tensile strength

Tensile strength holds significant importance in the context of concrete, primarily because concrete elements are prone to cracking when subjected to tensile loads such as the weight of the structure itself. Generally, LWC exhibits low tensile strength. Hence, the incorporation of SCMs presents a viable approach for addressing the inherent weaknesses in the strength characteristics of concrete, including crushed sand (CS), specifically in terms of the split tensile strength, while ensuring that the density limit for LWC is not surpassed. Sagar and Sivakumar

[23] observed a maximum 22 % improvement in split tensile strength of conventional concrete. In their study, Kavitha and Kala [24] observed that the incorporation of 10 % alccofine-1203 and 30 % GGBS as substitutes for cement yielded the highest split tensile strengths in SCC when compared with alternative degrees of alccofine-1203 replacement. Kavyateja et al. investigated the mechanical properties of SCC [25]. This investigation focused on the effects of partial replacement of cement with blends of fly ash and alccofine-1203. The specimens, comprising 25 % fly ash and 10 % alccofine-1203, demonstrated the highest split tensile strengths. Table 5 presents the split tensile strength values of CS concrete reinforced with sisal fibres. In general, the incorporation of alccofine improves the split tensile strength of CS concrete. At the 28-day mark, the CSA10 mixture exhibited a maximum increase of 12 % in split tensile strength, reaching a value of 3,46 MPa. This increase is equivalent to approximately 9,8 % of the compressive strength of the equivalent mixture. This result is comparable to that of the split tensile strength improvement in conventional concrete reported by previous researchers. According to the specifications outlined in ASTM C330, the use of LWC in structural applications requires a minimum split tensile strength of 2,0 MPa. Hence, it is plausible to use all combinations of experimental mixtures as LWC. This study aims to demonstrate the empirical relationships between the split tensile strength and compressive strength using regression analysis, as depicted in Figure 7. The correlation between the split tensile strength and compressive strength can be established by regression analysis using the following equation:

$$f_t = 0{,}5586\sqrt{f_c} \tag{1}$$

Figure 8 presents a comparison of the experimental and theoretical results based on the split tensile strength. The experimental findings closely aligned with the anticipated theoretical results derived from Equation 1.

Table 5. Split tensile strength of sisal fibre-reinforced CS concrete

Mixture ID	Split tensile strength (MPa)
CSC	3,10
CSA5	3,22
CSA10	3,46
CSC15	2,98

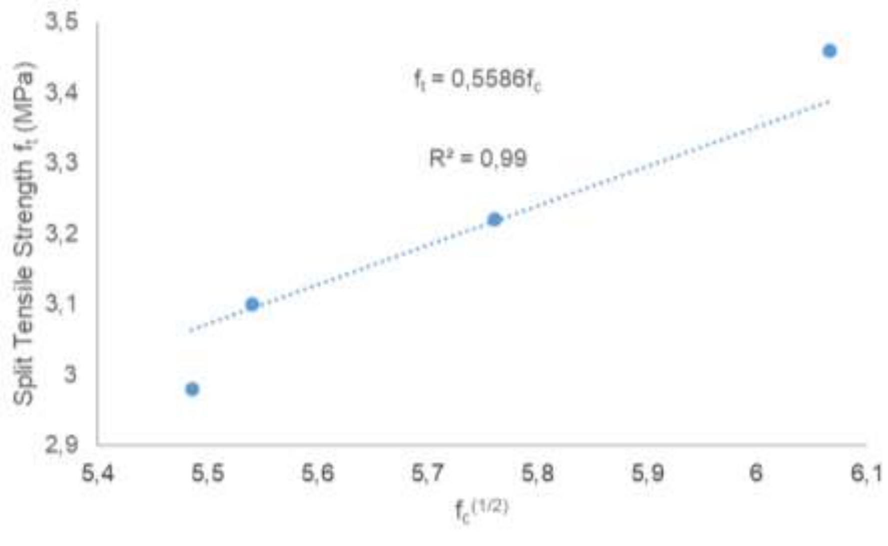

Figure 7. Correlation between compressive strength and split tensile strength of alccofine supplemented CS concrete

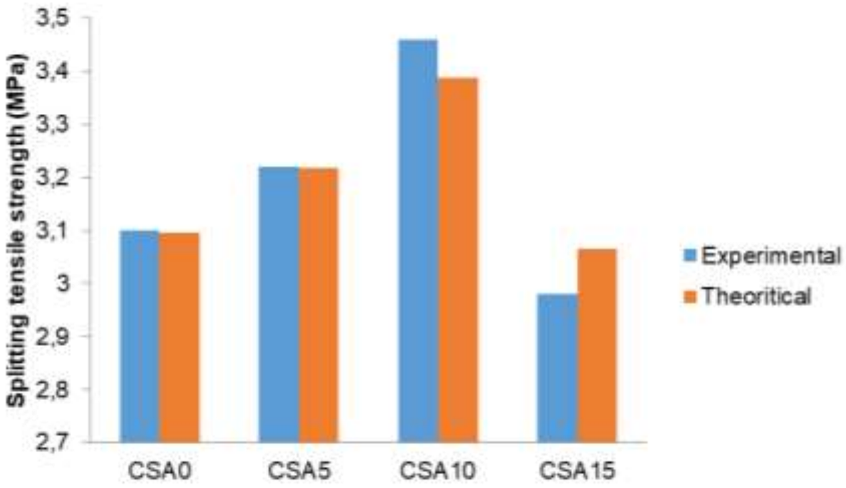

Figure 8. Experimental and theoretical split tensile strength of alccofine supplemented CS concrete

3.5 Flexural strength

Table 6 presents data pertaining to the flexural strength of the CS concrete. The flexural strength of the control concrete specimen was measured to be 4,95 MPa, which corresponds to approximately 14,5 % of its compressive strength. In this study, the incorporation of alccofine into CS LWC resulted in a notable enhancement in the flexural strength of concrete. In a study conducted by Kavyateja et al. [25], it was observed that the incorporation of 15 % alccofine into steel fibre-reinforced SCC resulted in a notable enhancement in flexural strength. In a study conducted by Kumar et al. [26], it was observed that the use of alccofine in lightweight concrete led to a substantial enhancement in its flexural strength. In their study, Reddy and Ramadoss [27] employed a proportion of 8% alccofine in the composition of high performance concrete. The findings revealed a significant improvement in the flexural strength of the material.

The present study demonstrates that the incorporation of alccofine into CS concrete results in a notable improvement in its flexural strength, with enhancement of up to 20 %. The incorporation of alccofine at concentrations of 5 % and 10 % resulted in respective enhancements of 8 % and 18 % in the flexural strength of CS concrete. This result agrees with that of the split tensile strength improvement in conventional concrete reported by past researchers. Nevertheless, the incorporation of a 15 % alccofine admixture resulted in a marginal decrease in the flexural strength of CS concrete.

$$f_r = 0{,}514 {f_c}^{2/3} \tag{2}$$

Table 6. Flexural strength

Mixture ID	Flexural strength (MPa)
CSA0	4,95
CSA5	5,30
CSA10	5,84
CSA15	4,90

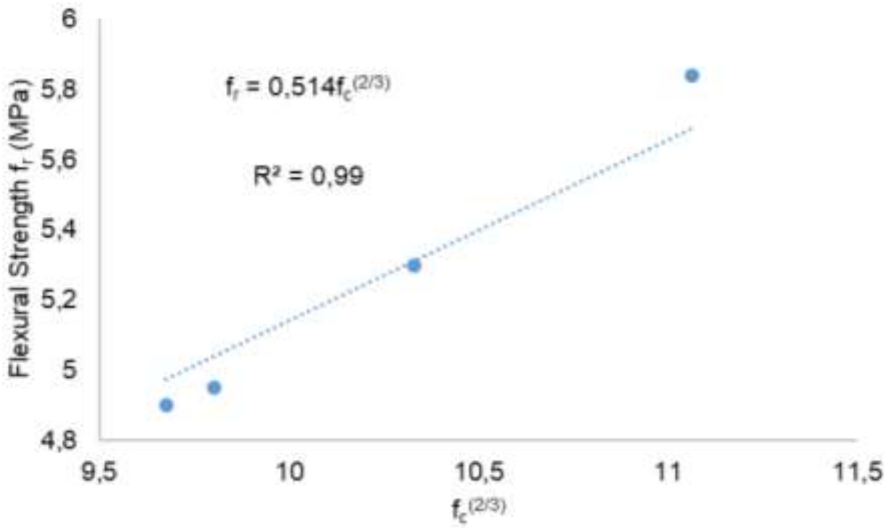

Figure 9. Correlation between compressive strength and flexural strength of alccofine supplemented CS concrete

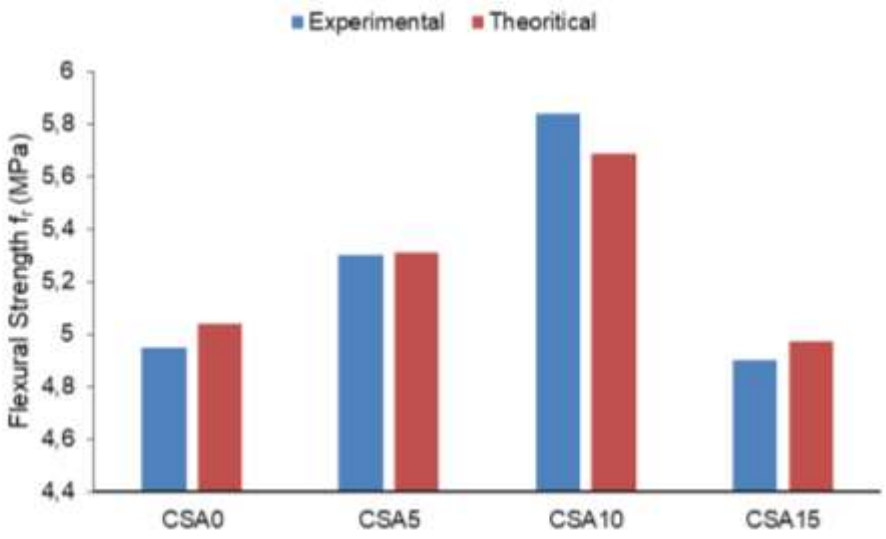

Figure 10. Experimental and theoretical flexural strength of alccofine supplemented CS concrete

3.6 Water absorption

The durability of concrete can be determined by analysing its absorption characteristics. This phenomenon can be characterised as the movement of fluids within permeable substances as a result of the capillary action exerted by surface tension [28]. The open-pore volumes of the specimens were determined by measuring their absorption in water [29]. Studies have shown that the addition of alccofine to concrete reduces water absorption, and thus increases the durability [30]. Vivek et al. [31] found that an alccofine-admixed fibre-reinforced SCC mix has less water absorption than that of control concrete. Figure 11 illustrates the water absorption characteristics of all mixtures. In the control mixture, the water absorption rate was determined to be 10,7 % after 28 days. This rate decreased to 8,3 %, 7,2 %, and 5,7 % when fly ash was used as a replacement in 5 %, 10 %, and 15 % of the mixture, respectively. This outcome can potentially be attributed to the total evaporation of water from the CS, which was retained by CS during the concrete immersion process. Subsequently, it was demonstrated that the water absorption of the mixtures containing alccofine was lower than that of the control mixtures. The water absorption of the mixture increased when a smaller quantity of alccofine was added and decreased when a larger quantity of alccofine was added. The inclusion of alccofine in concrete resulted in a reduction in the pore size owing to its fine particle size. The relationship between alccofine and water absorption is inversely proportional, resulting in a decrease in the available area for water storage within the specimen.

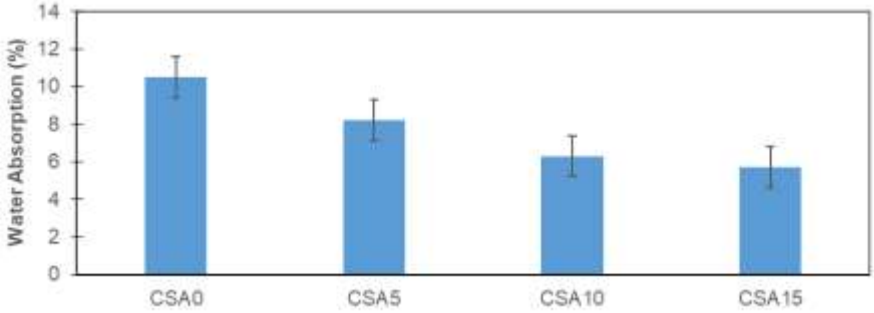

Figure 11. Water absorption of alccofine supplemented CS concrete

3.7 Sorptivity

The measurement of sorptivity offers valuable insights into the permeability characteristics of concrete [29]. Low sorptivity levels indicate a high level of resistance to water absorption. In general, concrete possesses a high grade if its sorptivity value below 0,1 mm/min^{0,5} [11]. Researchers have found that alccofine in concrete decreases the sorptivity coefficient and thus increases the durability [30]. It was found that the alccofine-admixed fibre-reinforced SCC mix had a lower sorptivity value than that of the control concrete [31]. Figure 12 shows the sorptivity values of the concrete mix containing alccofine with the addition of CS. The sorptivity of the CSA0 mixture at 28 days was measured to be in the range of 0,095-0,098 mm/min^{0,5}. The addition of alccofine further decreased these values. This can be attributed to the high specific surface area of alccofine, which resulted from its fine particle size. The presence of alccofine lowered the transition zone between the aggregates. The sorptivity values for the alccofine replacement at 15 % were determined to be within the range of 0,089-0,093mm/min^{0,5}, indicating the lowest levels of sorptivity. The sorptivity values observed in this study are consistent with those of previous studies conducted on various types of lightweight concrete, such as sintered pulverised fuel ash and expanded shale. These materials have been found to exhibit sorptivity values of 0,06 mm/min^{0,5} and 0,03 mm/min^{0,5}, respectively.

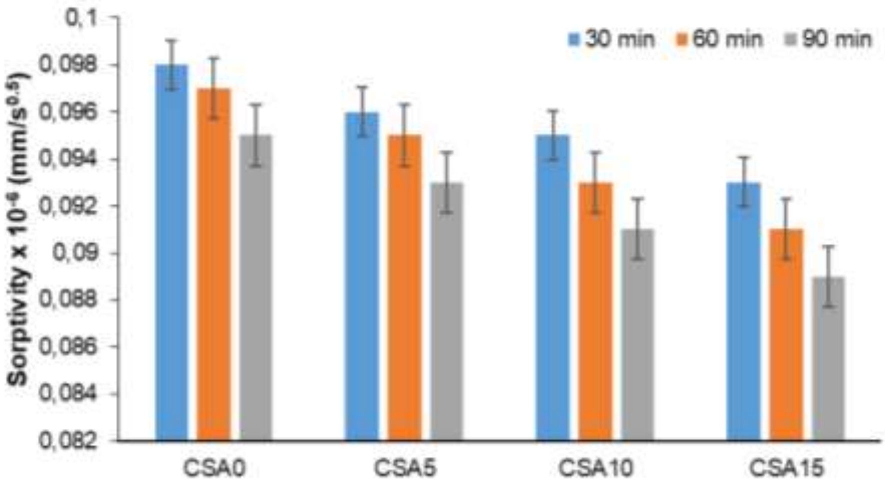

Figure 12. Sorptivity of alccofine supplemented CS concrete

3.8 Rapid chloride permeability test (RCPT)

Chloride ingress is a significant environmental threat to concrete, causing rebar corrosion and leading to a reduction in the structural capacity and serviceability of structural elements. This has the potential to lead to premature degradation and necessitates structural member repair. The primary method employed to mitigate rebar corrosion involves the prevention of chloride infiltration into the concrete or, at the very least, limiting its penetration in the vicinity of the steel reinforcement. This method can be realised by constructing a concrete structure with relatively high impermeability. Determining the extent of chloride penetration in concrete is essential for quality control and design. Nevertheless, direct determination of chloride penetrability within a specific time range is not feasible. Therefore, it is imperative to develop a methodology that expedites the assessment of chloride penetration, thereby enabling the determination of diffusion coefficients within a feasible timeframe. Figure 13 shows the results of RCPT conducted on concrete mixtures with varying levels of alccofine substitution. The CSA0's RCPT value was measured to be 793,7 at the age of 28 days. In addition, concrete mixes containing various amounts of CS (that is, CSA5, CSA10, and CSA15) exhibited a decrease in the charge passed, which was further reduced as the alccofine concentration increased. The observed outcome can be attributed to the alkali-binding properties and reduced permeability of voids in concrete integrated with alccofine. According previous studies, it has been observed that the values of RCPT for expanded clay lightweight aggregate concrete range from 2115 to 3336 C [32]. Patankar and Sandeep [33] revealed that the 10 % Alccofine supplements in conventional concrete decreased the chloride penetration upto 285 C. The results obtained from this study agree with those of conventional concrete studied by previous researchers.

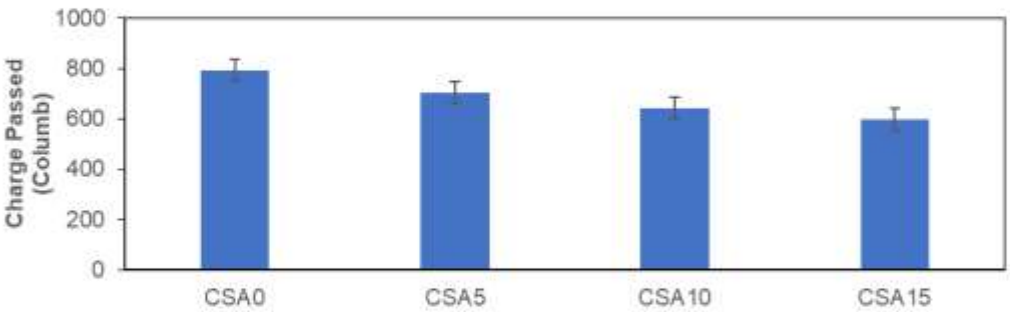

Figure 13. Charge passed of alccofine supplemented CS concrete

3.9 Economic efficiency and sustainability performance

Coconut shells are discarded agro-waste generated in many countries. According to the Ministry of Agriculture and Farmer Welfare, Government of India, 20736 million nuts were generated in 2021. When these wastes are used in concrete to replace crushed granite aggregates, the cost associated with the procurement of coarse aggregates in concrete is reduced. Although alccofine is slightly expensive than cement, when it is replaced at just 10 %, its advantages are numerous, including enhanced mechanical and durability performance. Coconut shell disposal is a serious problem in local environments. When CS is used in concrete production, it offers an effective method for its disposal and preserves granite, which is a rapidly depleting resource. When alccofine is used in concrete production as a partial substitute for cement, the depletion of limestone (a natural resource used in cement manufacturing) is minimised. Thus, the sustainability aspects of the construction industry can be improved. This study will help save limestone for future generations and reduce the release of greenhouse gases such as CO_2 and NO_x into the atmosphere. Therefore, the development of coconut-shell concrete with partial replacement of alccofine will contribute to the sustainability of concrete production.

4 Conclusions

Structural LWC using an agricultural waste coconut shell was prepared by the partial replacement of cement with alccofine. The fine incorporation of alccofine enhances the strength and durability and reduces the cement content in concrete, thus achieving eco-friendliness in concrete production. The following conclusions were drawn from this study:

- Increasing the alccofine content resulted in a linear decreasing trend in slump. However, all mixes satisfied the minimum requirements for lightweight concrete.
- The addition of alccofine to coconut-shell concrete did not result in significant changes in density.
- Enhancement of hardened concrete properties was observed with an increase in alccofine content. The specimen that incorporated 10 % alccofine replacement exhibited the highest values for compressive strength, splitting tensile strength, and flexural strength.
- The addition of 10 % alccofine in the mix resulted in a 20 % increase in compressive strength, 18 % increase in splitting tensile strength, and 17 % increase in flexural strength.
- The addition of fly ash to CS concrete mixes resulted in a significant reduction in water absorption. This can be attributed to the decrease in concrete pores caused by the tiny particles of fly ash and increased formation of hydration products.
- The sorptivity of the CS concrete was reduced by the incorporation of fly ash, which enhanced the interfacial transition zone between the weak aggregate and CS lightweight concrete.
- The addition of alccofine to CS concrete resulted in lower chloride permeability.
- The splitting tensile strength and flexural strength were correlated with the compressive strength of alccofine-replaced CS concrete with a high coefficient of determination.

The results indicate that the use of coconut shell, an agricultural byproduct, as a coarse aggregate, along with alccofine, an SCM, as a partial substitute for cement, is a viable approach for the production of economically efficient and environmentally friendly concrete. Furthermore, this concrete mixture has the potential to be used in structural applications.

Abbreviations

CS – Coconut Shell
CSA – Coconut Shell Aggregate
SCM – Supplementary Cementitious Materials
GGBS – Ground Granulated Blast Furnace Slag
SSD – Saturated Surface Dry

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