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Influence of chemical and thermal treatment methods on the mechanical and micro-structural characteristics of coconut shell based concrete

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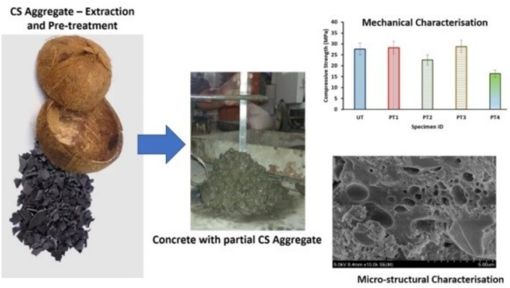
Graphical abstract



Abstract

In this study, an attempt is made to understand the effectiveness on initial treatment of coconut shell on the strength of concrete. The coconut shell materials obtained from the agricultural wastes are used as a replacement for coarse aggregate in conventional concrete. From the particle size distribution graph, the CS aggregates follow a similar trend of smooth grain distribution when compared to conventional aggregates. Coconut shell aggregates were treated using different method with the solutions of sodium silicate, calcium hydroxide, polyvinyl alcohol and with heat. Treated coconut shells were tested for water absorption and their resistance to crushing and impact. Water absorption of PVA treated aggregates was reduced from 17.7% to 4.0% portraying the effectiveness of pre-treatment procedure. Compared to the untreated coconut shell aggregates, the impact and crushing values of heat treated ones reduced by 75.8% and 87.8% respectively. Coconut shell concrete specimens were tested for 28-day compressive strength, split tensile strength and flexural strength. The results of treated coconut shell concrete were compared with untreated coconut shell concrete. Compressive and split tensile strengths of CS concrete also increased with heat treatment whereas the flexural strength improved due to the calcium hydroxide treated aggregates. Micro-structural characterisation using Scanning Electron Microscope (SEM) analysis showed the presence of strong interface between the aggregate particles and concrete.

Keywords: Treated coconut shells, water absorption, crushing; impact, compression strength, split tensile strength, flexural strength

1. Introduction

Concrete is the second most consumed material after water (Kanojia and Jain, 2017). In concrete, aggregates constitute for 55-75% of their total volume (Chi *et al.*, 2003). Moreover, the use of natural river sand from the beds of perennial rivers can result in depletion of resources and cause sustainable imbalance (Benyamina *et al.*, 2020; Revilla-Cuesta *et al.*, 2021). Hence, it is important to discover an alternative resource for the natural aggregates. Substantial research efforts were made in the past on understanding the durability and strength characteristics of concrete using artificial aggregates such as copper slag, pond ash, recycled aggregates and industrial by-products (Seeni *et al.*, 2023; Arunachelam *et al.*, 2022a; Arunachelam *et al.*, 2022b; Maheswaran *et al.*, 2022; Arunachelam *et al.*, 2023). Lightweight aggregates are one such alternative. Lightweight aggregates can be either natural or artificial products from agriculture and construction industry. Agricultural wastes as aggregates in concrete contribute to sustainability, preservation of natural resources and cost reduction in construction materials (Prusty and Patro, 2015). Coconut shell an agricultural waste resulting from the oil mills and domestic use. Coconut tree (Cocos Nucifera) is one of the major and oldest tree crops cultivated in India. Its contribution to the country's GDP is about 15,000 crore rupees (Raghavi *et al.*, 2019). The white inner part in the coconut called the copra is used in extracting oil. The outer surface of the nut is the shell, covered with fibres. The shell occupies 15.18 ± 2.4 % of the whole coconut fruit (Bellow *et al.*, 2016) and often discarded as waste. Disposal of this agricultural waste on land impose environmental issues. Hence, the researchers in the past have used this agro waste as a lightweight aggregate in lieu of natural aggregates in concrete. In addition, the presence of high lignin content in the coconut shells (CSs) makes them a suitable material for the production of concrete (Chanap, 2012). Moreover, the low cellulose content of coconut shells could make them less moisture absorbent and weather resistant (Chanap, 2012). Hence, its high strength and modulus properties (Chanap 2012), the absence of sugar in free form, which does not affect the setting and strength of concrete (Gunasekaran 2011), its low inhibitory index (Gunasekaran *et al.*, 2012), the presence of smooth surface on concave side that gives better workability and its binding with concrete matrix without leaching (Gunasekaran *et al.*, 2011a).

CS aggregates have low bulk density compared to normal aggregates making it suitable for producing lightweight concrete (Gunasekaran *et al.*, 2011b). Coconut shell concrete (CSC) is classified as structural lightweight concrete as its density is less than 2000 kg/m^3 (Gunasekaran *et al.*, 2011a; Regin *et al.*, 2017). CSC can reduce the dead load in structures by 18–21% compared to ordinary concrete (Regin *et al.*, 2017). Studies from Nigeria show cost reduction of 30% and 48% when coconut shells replace normal aggregates (Olanipekun *et al.*, 2006; Abubakar and Abubakar, 2011). The bond strength and impact resistance of CSC is higher than conventional aggregate concrete (Gunasekaran *et al.*, 2011a). Gunasekaran *et al.* (2013a, 2013b, 2014) have observed good ductility behavior in CSC beams. Also, CS aggregate is recommended in beams subjected to torsion (Gunasekaran *et al.*, 2014). CSC beam has shear behavior similar to other lightweight concretes (Gunasekaran *et al.*, 2013b). It is observed that the compressive strength development of CSC happens predominantly in the early stages and proceeds to increase with age (Maheswaran *et al.*, 2022). Regin *et al.* and Raghavi *et al.* (2019) recommends up to 10% of partial replacement of cement with silica fume and fly ash in CSC. Coconut shell and oil palm shells belong to the palm family (Arecaceae). The ability of these shells to withstand aggressive environments when used as aggregates and their bonding with the cement paste is reported in few studies.

Mannan *et al.* (2003) have investigated the improvement in the quality of OPS aggregates by subjecting the aggregates to severe acidic, alkaline and strong sulphate solutions. It was reported that pre-treating the aggregates with poly vinyl alcohol (PVA) solution is the most suitable pre-treatment to OPS aggregates. Yew *et al.* 2014 have succeeded in producing high strength lightweight concrete of strength 49.0 MPa using heat treatment at a temperature of 60°C for 0.5h on OPS aggregates. It was also pointed out that subjecting the OPS aggregates to high temperature for longer period can decrease the density of the concrete. Treore *et al.* 2018 studied the properties and behaviour of oil palm shell aggregates by treating with lime, sodium silicate, PVA, heat and pre-wetting. OPS aggregates showed a deposition of lime, silica and PVA after treatment with lime, sodium silicate and PVA respectively. Loss in mass was observed in heat treated aggregates. It was found that among the various treated concretes, the lime treated OPS concrete showed an increase in the propagation speed of ultrasonic waves, improvement in the compressive strength and increased elastic modulus. Mechanical properties of concrete decreased with the use of saturated OPS but gave better thermal conductivity and reduced shrinkage. Regin *et al.* (2020) studied on the quality improvement of coconut shell aggregates by exposing the aggregates to severe acidic, alkaline and sulphate solutions. It was shown that pre-treated coconut shell concrete show increase in density of concrete and the concrete made of PVA treated aggregates gave optimum compressive strength.

From the thorough literature review carried out in the past (Bari *et al.*, 2021; Sukontasukkul *et al.*, 2019; Prakash *et al.*, 2021; Natarajan *et al.*, 2022; Liu *et al.*, 2023), it can be seen that no previous studies have worked on identifying the efficiency of different treatment methods for coconut shell aggregates to be used for the development of light weight aggregate concrete. Moreover, the previous study on the quality improvement of CSC shows lack of information regarding the influence of heat treatment on the properties and strength of CSC. Also, the flexural and tensile strength of chemically treated CS material have not been studied. The aim of this study was twofold. First, enhancing the properties of coconut shell aggregates by subjecting them to two different treatment methods and second, to study the performance of treated coconut shell lightweight concrete under compression, flexure and tension. Figure 1 depicts the overall objective of the proposed work. The coconut shell aggregates are used as a complete replacement for the conventional granite based coarse aggregates in the development of light weight concrete. The replacement is aimed without much compromise in the strength of the developed mix and to be used for structural as well as non-structural applications.

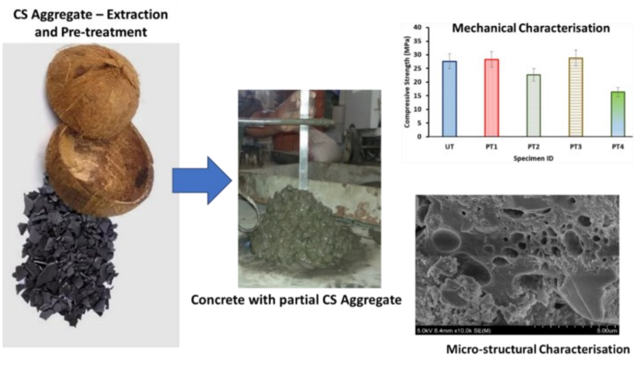


Figure 1. Schematic representation of the objective of proposed work

2. Materials and mix proportioning

Ordinary Portland cement (OPC) of grade 53 was used as a binder. The properties of cement were tested to check its properties satisfy the limits of Indian standards. The adopted OPC 53 grade cement had a specific gravity of 3.13. To ensure sustainability, manufactured sand was used as fine aggregate which had a fineness modulus and specific gravity values as 2.80 and 2.58 respectively. Coconut shells were collected from local industry and sundried for one month before being crushed manually. In India, the by-products of coconut are available in abundant volume. Being a waste material and resembling similar to the conventional aggregates, the use of coconut shell can be a potential option in replacing the conventional coarse aggregates. The crushed shells had a maximum size of 12 mm as shown in Figure 2. This was done to achieve the reduction in size of the aggregates which in turn reduces the flakiness. The movement of water through the capillaries of coconut shell can affect the hydration of cement when added directly (Gunasekaran *et al.*, 2011). Therefore, the crushed coconut shells were soaked in water for 24h for achieving the saturated surface dry (SSD) condition. Saturated Surface Drying (SSD) refers to a condition where the aggregates are treated/soaked in water and dried for 24 hours to ensure the filling of pores with water. SSD condition is essential for lightweight aggregates like coconut shell as they can absorb a large amount of water re-quired for the concrete mixing process. The use of the lightweight aggregates after SSD condition is also recommended by Trarore et al. and Olanipekun *et al.* (2006).

Table 1. Physical and mechanical properties of aggregates

Properties	M-Sand	Coarse Aggregate (20 mm)	Coconut shell (12.5 mm)
Specific gravity	2.58	2.78	1.16
Bulk Density (kg/m^3)	1644	1644	695
Fineness modulus	2.80	7.68	6.56
Water absorption (%)	2.0	1.5	17.7
Impact value (%)	-	19.8	6.6

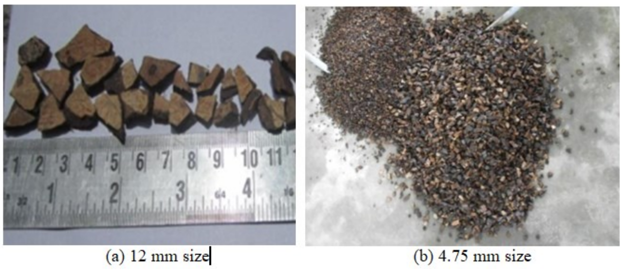


Figure 2. Different size of Coconut shell aggregates used

The physical and mechanical properties of sand and granite and untreated coconut shell aggregates are shown in Table 1. Moreover, Figure 3 depicts the particle size distribution comparison of conventional coarse aggregate and coconut shell aggregates used in this work. From the figure, it is clear that the size of coconut shell follows a similar trend of distribution when compared to the conventional granite aggregates. All the tested aggregates showed a smooth s-shape transition in the particle size distribution diagram.

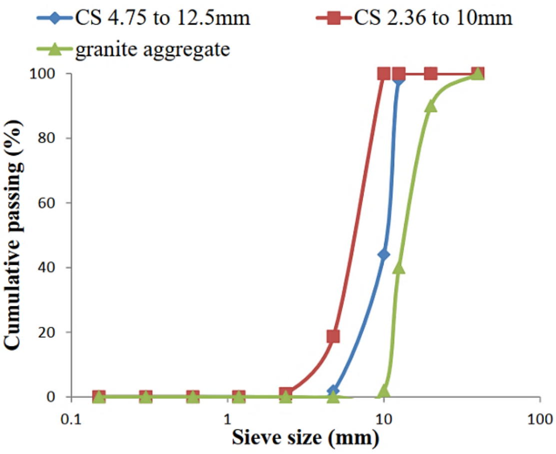


Figure 3. Particle size distribution curve comparison for coconut shell and conventional aggregates.

Potable water from the laboratory was used both for mixing and curing. In order to improve the workability due to the addition of lightweight aggregates, Sulpho-napthalene formaldehyde (SNF) based water reducing admixture (Conplast SP430) with a specific gravity of 1.18 was used in this work. Un-treated CSC (UT) was prepared to compare the properties of treated CSC. Proportioning of CSC was achieved based on trial mixes as there is no standard mix design method for lightweight concrete. In this study, the mix proportion were obtained by casting and testing more than 10 trails to arrive at the optimum quantities. The optimum mix proportion arrived was 1:1.58:0.6 (cement: sand: CS) with a water cement ratio of 0.4. The mix proportion consisted of 510 kg/m^3 of cement, 805.8 kg/m^{3}of manufactured sand (M-sand) and 306 kg/m^{3}of treated coconut shells and 204 litres of water. The mix design was performed not complying with the Indian standards as the proposed one is a light weight concrete. Hence, the maximum quantity of cement content is not followed to achieve desired strength characteristics in light weight concrete. Super plasticizer was added at a dosage of 1% by the weight of cement.

3. Pre-treatment of coconut shell

Coconut shell is a ligno-cellulose material. When used in concrete, the presence of cement makes it highly susceptible to degradation due to the high alkalinity environment (Cechin *et al.*, 2018). Pre-treatment process helps in ensuring their performance and prevents against any kind of degradation (Regin *et al.*, 2020; Premkumar *et al.*, 2022). Coconut shells are pre-treated using different methods to accomplish two major objectives which includes: (a) improvement in strength properties through the increase in surface area and hardness and (b) reduction of water absorption which in turn does not react with the free water required for the hydration reaction. Two different treatment types were used in this study namely chemical treatment and heat treatment. The chemicals used in treating coconut shell aggregates were solutions of sodium silicate, calcium hydroxide and poly vinyl alcohol (PVA). Sodium silicate (Na_2SiO_3) or water glass is a water-soluble and extremely alkali solution. Treating wood with sodium silicate changes the properties of wood and gives improved resistance against fire, termite, rot and decay. Also, wood treated with silica has superior bonding with cement paste (Traore *et al.*, 2018). Calcium hydroxide ($Ca(OH)_2$) also called as slaked lime is a white powder used in the paper industry to convert wood into wood pulp. It improves the mechanical strength of the wood-cement composites (Traore *et al.*, 2018). Poly vinyl alcohol is a water-soluble polymer. PVA forms a thin-film on the aggregates, prevents water penetration into the aggregates thereby making them waterproof (Bellow *et al.*, 2016; Chanap, 2012; Gunasekaran, 2011). It also has excellent adhesion property (Yaowarat *et al.*, 2018). The effects of heat treatment on wood are (a) darkening of the wood color, (b) reduction in shrinkage and swelling, (c) improved equilibrium moisture content and (d) resistance to decay and rot (Rapp 2001). Heat treatment enhances the surface quality of aggregates, leading to better adhesion between the aggregate and cement paste (Yew *et al.*, 2014).

3.1. Pre-treatment method

Treatment with sodium silicate (PT1) involved immersing coconut shells in a solution of sodium silicate for two hours. Dosage of the chemical used was 100 grams of sodium silicate in 1 litre of water. Lime treatment (PT2) of coconut shells involved immersing the aggregates in a solution of calcium hydroxide for two hours. For this purpose, 40gm of calcium hydroxide was dissolved in one litre of water. Coconut shells were immersed for three minutes in a solution of 5% polyvinyl alcohol (PT3). Heat treatment involved heating the coconut shell aggregates at 60°C for 0.5h similar to observations made by Yew *et al.* 2014. Table 2 shows method of treatment given to coconut shell aggregates in this study and their dosages.

Table 2. Type of treatment to coconut shell aggregates

Method of treatment adopted	Designation	Treatment dosage/temperature
Un-treated	UT	-
Sodium silicate	PT1	100 grams in 1 litre of water
Calcium hydroxide	PT2	40 grams in 1 litre of water
Poly vinyl alcohol	PT3	5%
Heat	PT4	60°C


(a) Before pre-treatment process (b) After pre-treatment process

Figure 4. Comparison of coconut shell aggregates using pre-treatment process

Figure 4 compares the visual appearance of coconut shell aggregates before and after treatment process. From the visual observation, it can be seen that the coconut shells went change in color due to the pre-treatment process. This can be attributed due to the removal of surface impurities present in the natural coconut shells. Moreover, their surface roughness was significantly improved which in turn could improve the bonding capability when used as aggregates in the concrete mix.

4. Results and discussion

The experimental results obtained using the treated coconut shell based concrete were compared and presented in the following section.

4.1. Properties of treated coconut shells

4.1.1. Water absorption

As per the American Concrete Institute (ACI) standards, the water absorption of coconut shell aggregates was performed. Table 3 shows the results of water absorption test conducted on un-treated and treated aggregates. The water absorption capability was 17.67% for the untreated coconut shell (CS) aggregates. This large water absorption capacity of CS aggregates signifies their porous nature and eagerness to absorb water for filling in the pores. The high pore content in coconut shells absorbs more water. However, the water absorption value of conventional granite aggregate was only about 1.5%. Hence, care has been taken to reduce the water absorption levels of coconut shells. Otherwise, these aggregates may absorb the water required for the concrete mixing process and reduce the workability to a significant extent. The water absorption capacity of CS aggregate was satisfying the permissible limit prescribed for the light weight aggregates i.e., 5–20% (ACI Education Bulletin E1-07). Similar results of water absorption value more than 20% is obtained for other lightweight aggregates used (Shafigh *et al.*, 2013) and volcanic pumices, have values of almost 37% (Hossain 2004). Mannan *et al.*, 2006 reported that the water absorption capacity of light weight aggregate can be reduced through chemical pre-treatment process i.e., use of 20% PVA solution. Due to the pretreatment process, the coconut shell aggregates showed a drastic reduction in water absorption from 23.3 to 4.2%. In this study, the water absorption values of CS aggregates were reduced through two means: (a) pre-treatment of aggregates by different methods and (b) application of saturated surface dry conditions to fill the pores by water. From the results obtained for different treatment methods, it can be seen that the percentage of water absorption of treated coconut shells is significantly lower than the untreated one. Treatments PT1 and PT2 have a water absorption values of 5.0% which is 72% lower than the untreated coconut shell based aggregates. As expected, water absorption in PVA treated shells was the lowest with 77% lesser than the untreated shells due to its nature of forming a thin layer on the coated aggregates. PT4 treated aggregates had water absorption 66.5% less than the un-treated ones.

4.1.2. Impact value and crushing value

Crushing value and impact tests were conducted to determine the strength of treated CS aggregates. Treated CS aggregates showed improved resistance to crushing and impact loads. The impact values of PT1, PT2, PT3 and PT4 treatments were 54%, 67%, 59% and 72% respectively when compared to the untreated ones. Heat treated aggregates showed the highest impact resistance value with reduced powder content. The crushing values of PT1, PT2, PT3 and PT4 treatments were 37%, 28%, 37% and 66% respectively lower than the untreated ones. This indicated that heat treated aggregates have superior resistance to crushing. The physical and mechanical properties of treated coconut shell aggregates are shown in Table 3.

Table 3. Properties of treated coconut shells

Properties	Treatment method				
	UT	PT1	PT2	PT3	PT4
Water absorption (%)	17.8	5.0	5.0	4.0	6.0
Impact value (%)	19.8	3.0	2.2	2.7	1.85
Crushing value (%)	8.6	0.48	0.54	0.48	0.26

4.2. Strength comparison of treated coconut shell concrete

4.2.1. Compressive strength

Before the compression tests, cube specimens were weighed to determine the reduction in density due to the addition of coconut shell as a replacement for conventional coarse aggregates. From the results obtained, the density of concrete was found to vary from 1800 kg/m^3 to 2000 kg/m^3. The variation in compressive strength of treated coconut shell concrete and untreated coconut shell concrete is shown in Table 4 and Figure 5. The test fixture and the failure mode observed for the CS based concrete is shown in Figures 5a and 5b respectively. The compressive strength of untreated CS concrete at 28 days of curing was 16.33 N/mm^2. All treatments on coconut shell aggregates showed a significant improvement on the compressive strength after 28 days when compared to the untreated CS concrete. This increase in the compressive strength after treatment may be due to an improvement in adherence between the treated CS and the cement matrix. Heat treated (PT4) CS concrete had an average compressive strength of 28.83 N/mm^2 after 28 days of curing. Breakage of CS aggregate was observed on the failure surfaces of the concrete (Figure 5b). This shows that the strength of concrete is also dependant on individual shell strength. Compressive strength of calcium hydroxide treated (PT2) CSC increases 73.5% compared to untreated CSC. The increase in mechanical strength may be due to the changes on the surface of the aggregates by lime. Compressive strength of sodium silicate treated (PT1) CSC increases 69.5% compared to untreated CSC. The presence of amorphous silica on the CS aggregates improved the bonding with cement paste. The test results of properties of treated shells satisfy the requirements of lightweight aggregates as per ASTMC330. Compressive strength of PVA (PT3) treated CSC increases 38.8% compared to untreated CSC. It forms a thin layer and absorbs less water which improves the bonding and strength of CSC. Compressive strength of heat treated CSC increases by 76.5% compared to untreated CSC. This may due to the rough surface of shells which improve proper bonding and mechanical adhesion between the CS and the cement paste.

Table 4. Strength of treated coconut shell based concrete

Treatment	28 days strength in N/mm^2		
	Compressive	Split tensile	Flexural
PT1	27.66	2.70	3.67
PT2	28.33	2.04	3.83
PT3	22.66	2.30	3.57
PT4	28.83	2.54	3.01
UT	16.33	1.59	3.64

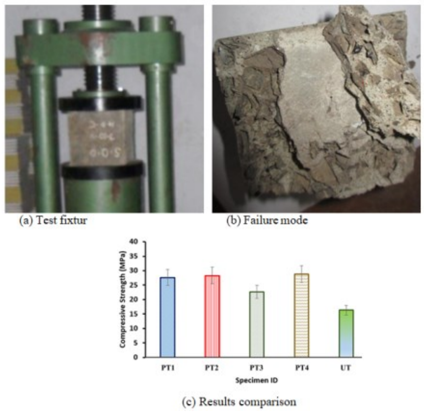


Figure 5. Compressive strength of CSC under various treatment methods

4.2.2. Split tensile strength

The variation of split tensile strength of treated coconut shell concrete and untreated coconut shell concrete is shown in Table 4. Figure 6 shows the comparison of split tensile strength with different treatment methods of coconut shell aggregates. The spilt tensile strength of specimens was in the range of 2.0 N/mm^2 to 3.0 N/mm^2. This satisfied the ASTM C330 minimum requirement for the split tensile strength of lightweight concrete of 2.0 N/mm^2. All the treatments on CS showed improvement in split tensile strength after 28 days compared to untreated CSC. The test fixture and the failure mode observed for the CS based concrete is shown in Figures 6a and 6b respectively. Sodium silicate (PT1) treated coconut shell concrete has an average split tensile strength of 2.7 N/mm^2 after 28 days of curing. Sodium silicate treated CSC obtained the optimum split tensile strength. Split tensile strength of calcium hydroxide treated (PT2) CSC increases 28% compared to untreated CSC. This may be due to limiting the amount of shrinkage that occurs when a cement paste is dried. Split tensile strength of sodium silicate treated (PT1) CSC increases by 70% compared to untreated CSC. This may due to the increase of fibre volume and increase with age. Split tensile strength of polyvinyl alcohol treated (PT3) CSC increases 45% compared to untreated CSC. This may be due to improvement in the chemical resistance properties of the coconut shell. Split tensile strength of heat treated (PT4) CSC increases 60% compared to CSC. An early age strength increase may be attributed to the reason behind this Yew *et al.*, 2014. Tensile strength of concrete depends largely on the stiffness of the aggregate rather than the pre-treatment methods used. The adoption of pre-treatment methods could just improve the surface hardness for achieving better bonding which in turn could increase only the compressive strength.

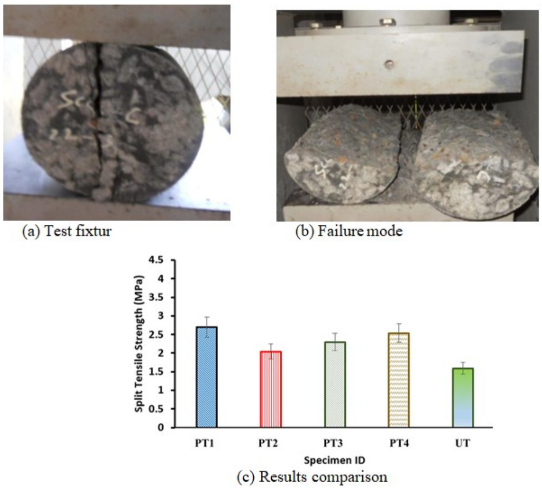


Figure 6. Split tensile strength of CSC under various treatment methods

4.2.3. Flexural strength

Table 4 shows the variation in flexural strength of coconut shell concrete. The test fixture and the failure mode observed for the CS based concrete is shown in Figures 7a and 7b respectively. The treated coconut shell concrete has better flexural strength than untreated coconut shell concrete. Calcium hydroxide (PT2) treated CSC had an average flexural strength of 3.83 N/mm^2 after 28 days of curing. Calcium hydroxide treated CSC obtained the optimum flexural strength. Flexural strength of calcium hydroxide treated CSC increases by 5.1% compared to untreated CSC. This may be due to the presence of fibres in the coarse aggregate. Flexural strength of sodium silicate (PT1) treated CSC increases by 1% compared to untreated CSC. This may due to reduction in pores which aids in reducing water penetration. Flexural strength of polyvinyl alcohol (PT3) treated CSC decreases by 3% compared to untreated CSC. This may due to formation of water proof coating on the surface of CS thereby preventing the entry of water. Flexural strength of heat treated (PT4) CSC decreases by 2.1% compared to untreated CSC (Figure 7c). This may due to the increase in duration of heating.

4.2.4. Micro-structural examination using FESEM

Figure 8 shows the comparison of field emission scanning electron microscope (FESEM) analysis for coconut shell based concrete. The FESEM images shows the presence of various characteristic features such as pores, interfacial transition zone (ITZ), calcium hydroxide crystals, etc. Figure 8(a) highlights the FESEM image of conventional concrete captured at a magnification of 1000 x. The image presents the presence of large number of coarse aggregates in the control specimens along with thick ITZ in most cases. Moreover, the image captures a number of large sized potholes which could be the regions where the aggregates might have present earlier before and during loading. Figure 8(b) highlights the FESEM image of concrete specimen captured at a larger magnification of 3000 x. From the image, it can be seen that the concrete specimen contains a large number of pores with few micro-cracks. Moreover, the Figure 8(b) represents the micro-structure image at a very large magnification scale where the dimension of the largest interface can be measured to a level of 1 μm. The image highlights the presence of a number of hydrated particles and crystals of $Ca(OH)_2$ which is responsible for the strength development in the concrete specimens (Hari *et al.*, 2022; Ragul *et al.*, 2022; Maheswaran *et al.*, 2023; Liu *et al.*, 2022).

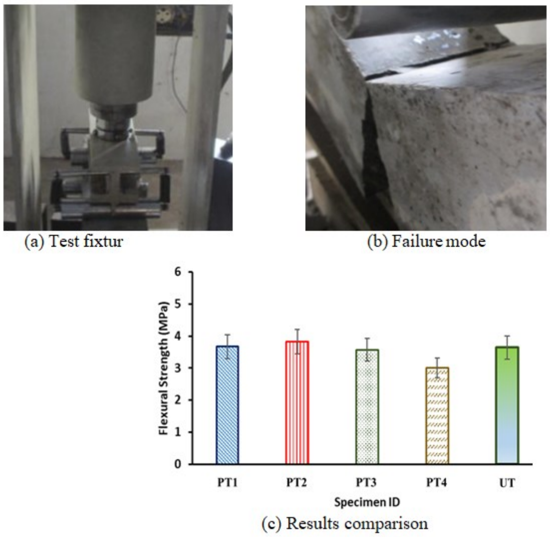


Figure 7. Flexural strength of CSC under various treatment methods

Figure 8(c) represents the SEM image of light weight aggregate concrete. From the Figures, it can be observed that the light weight concrete contains no major interfacial transition zone or a thin ITZ which is responsible for the lower strength characteristics compared to the conventional concrete. Moreover, the representation of micro-structure in different locations of the sample (Figures 8(c) and 8(d)) highlights the gap or thick interface to the order of 3 μm - 5 μm. In addition, the light weight concrete contains numerous micro pores which could affect the strength of the developed concrete. Liu *et al.* (2022) studied the micro-structural characteristics of biomass recycled concrete made using coconut shells. They added that the reduction in strength of developed LWC was due to the presence of loose C-S-H gels and pores adjacent to the coconut shells.

5. Summary and conclusions

This study examined the influence of different treatments on the properties of coconut shell aggregates and the behavior of concrete made with treated CSC aggregates.

Different treatment methods such as sodium silicate, polyvinyl alcohol, heat, etc. on the micro-structural and mechanical properties of coconut shell aggregate based light weight concrete was investigated. The following conclusions can be arrived from the limited results presented on mechanical and micro-structural properties of treated coconut shell based concrete.

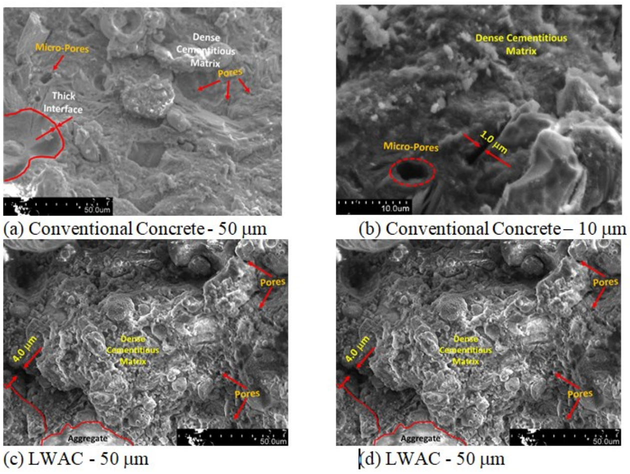


Figure 8. Comparison of SEM Images of conventional and light weight aggregate based concrete

Treated coconut shells have low water absorption due to the formation of thin film coating over the shells and lesser impact and crushing values than untreated shells. Low values of aggregate crushing and impact value proves more shock absorbent nature.

Test results revealed that the mechanical properties of treated coconut shell concrete are better than the untreated coconut shell concrete. 28-day compressive strength of treated coconut shell concrete is more than 17 N/mm^2 which is the minimum recommended value of compressive strength for lightweight concrete as per ASTM C330.

Split tensile strength of lightweight concrete with treated coconut shells is greater than 2 N/mm^2 which is the expected value for light weight aggregate concrete as per ASTMC330.

The flexural strength of lightweight concrete is expected to be 10% of its compressive strength. In this work the flexural strength of treated shell mixes is more than the expected value. Heat-treated coconut shell concrete performs well in compression and split tension. But its flexural strength is lesser than that of untreated one. This may be due to the procedure of treatment adopted such as duration of heating etc.

Sodium silicate and poly vinyl alcohol treated coconut shell concrete gives better results than the calcium hydroxide treated and heat treated coconut shell concrete. Moreover, the mass treatment of coconut shells using 5% PVA solution is feasible. Hence, the proposed coconut shell based light weight concrete can be fabricated for all structural and non-structural applications.

6. Limitations and recommendation for further research

In this study, the effect of different treatment methods on the mechanical and micro-structural characteristics of light weight concrete with 100% coconut shell aggregates as a replacement for the conventional granite aggregate has been examined. Therefore, there are some unexplored areas which have to be studied and the following areas are recommended for further research investigations.

Lightweight self-compacting concrete can be produced using the coconut shell aggregate. However, to ensure the flow property, CS aggregates passing through the 4.75 mm standard sieves shall be used. Studying the mechanical and durability properties of light weight aggregate based SCC with CS aggregates will be the scope for further work.

Fly ash based lightweight geopolymer CS concrete can be produced with a view to reduce the weight and CO_2 emission. Here, fly ash binder will be used to completely replace cement and alkaline activators to replace the water and super-plasticizers. Studying the mechanical and durability properties of light weight aggregate based geopolymer concrete with CS aggregates will be the scope for further work.

Due to the low density, lightweight foam concrete can also be produced using coconut shell aggregates. These concrete has the potential to be used for the applications in pavements and floors since CS aggregate has high resistance to wear and impact. Understanding these parameters will be the scope for further investigation.

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