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REVIEW ARTICLE

Use of Seashell as Cement Replacement in Construction Material: A Review

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ABSTRACT - Growing construction industry boost cement manufacturing industry which consume a large amount of natural resources and releases greenhouse gases during cement production affects the environment. A lot of researchers attempt to find alternatives in integrating waste into concrete mixes and can be reused in cementitious construction material. Seashells are one of the waste materials that would give harm to their own biodiversity as it would occupy the landfills and seashores. Seashell is known to be very hard and protective on the outer layer produced by an animal that lives in the sea. This review paper is focused in using seashells as cement replacements in construction material. This academic review paper examines the potential of utilizing seashells, including various types such as a cockle, clam, oyster, and scallop as a sustainable and environmentally beneficial alternative to traditional usage in construction. By exploring the practical applications and economic viability of seashell-based concrete, this research aims to contribute to the broader discourse on eco-friendly construction practices and sustainable resources utilization in the construction industry.

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1.0 INTRODUCTION

Concrete is the most frequent and regular substance used for building materials, and its demand is rising year by year as construction progresses. According to the Statista Research Department [1], it is estimated that 4.1 billion tons of the total volume of cement in 2022 were produced worldwide. In terms of concrete demand forecasts, the Global Cement and Concrete Association (GCCA) [2], said that 14.0 billion m³ in 2020 volume of concrete globally, and it is expected that it will increase to approximately 20 billion m³ in 2050. According to Dinga and Wen [3], to current the data, "the annual worldwide cement output is around 4.5 gigatonnes, with consumption ranging around 4.27 gigatonnes." China is the highest country in producing cement with 22,489 thousands of tonnes followed by India (20,850 thousands tonnes) in 2020. Cement plays a crucial role as a binding element in the concrete matrix, contributing to the construction of buildings and structures essential for the development of a country [4]. The waste that produced from cement industry is predominantly categorized into non-biodegradable and biodegradable materials and is often disposed of in landfills [5], [6]. Environmental anxieties arising from the elevated energy costs and CO2 emissions linked to cement production have led to calls for the reduction of cement consumption by employing Supplementary Cementitious Materials (SCMs) [7]. It is reported that, the production of cement is an exceptionally energy-intensive undertaking as the cement industry accounts for approximately 2-5% of the world's overall energy consumption [8], [9]. Due to the increasing in the production of cement, the sector's carbon emissions are increasing by 4.7% each year which this accounted to the serious environmental issues.

The increasing appearance of environmental problems is due to a combination of factors, especially the significant impact on the environment caused by the substantial growth in the global population, consumption habits, and industrial activities [10]. Industrial activities consume natural resources and also generates wastes that need to be disposed. Improper disposal causes undesirable environmental pollution. Most human activities contribute to four primary categories of harm, namely global warming gases, ozone-depleting substances, gaseous pollutants, and microbiological hazards. The accumulation of these gases that come from man-made activities including mining activities precipitates a rise in the global temperature by 30^{o}C [8]. When making cement, dust is a major source of pollution. For example, dust is created when moving and unloading clinker, and it ends up outside the storage silo where this dust pollution is also posing a risk to the air and water quality [11]. As highlighted by the Centres for Disease Control and Prevention, the drainage of dust has the potential to contaminate water sources, posing a detrimental impact on human health and, in some cases, on animals [11]. Water supplies from rivers or groundwater sources are contaminated because wastewater discharge which is one of the factors that will lead to pollution [11]. According to Ding et al. [12], the concerns about soil degradation increase in areas that experiencing population growth, construction, and urbanization with poor land management practices which can worsen the situation by allowing water to flow over the land instead of soaking in, leading to soil erosion. According to Guo et al. [13], improper land management said that construction will be a worry as the average

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tonne of cement produced emits 0.5-0.6 tonne of CO_2, and the exact carbon emissions depend on a variety of parameters such as the clinker-to-cement ratio, manufacturing method, heat recovery, and raw materials and fuels. The statement supported as well as by Ephraim et al. [14].

The emissions intensity of cement has maintained a relatively stable level since 2018, hovering just below 0.6 metric tons of CO2 per tonne of cement produced. This follows a period of slight increases in the preceding years, primarily attributed to a rising clinker-to-cement ratio in China [15]. Malaysia also mostly relies on non-renewable energy such as fossil fuel and coal to generate production activities yet if the economy is too dependent on this energy, it will cause an expansion in CO_2 then will have an impact on global warming [16]. Getting on track with the Net Zero Scenario necessitates fast decarbonization and enhanced global policies [4]. Moreover, the cement industry faces various challenges, including the depletion of natural raw material resources, the imperative to enhance cement production, the necessity to curtail energy consumption in Portland cement clinker production, and growing environmental apprehensions related to greenhouse gas [17]. The increased of concern about the depletion of the Earth's natural resources and global pollution has prompted the construction industry to explore the utilization of byproducts and waste materials as construction elements. This emphasis on reducing, reusing, and recycling waste, including materials like seashells, where it has become crucial for environmental preservation.

The seafood and aquaculture sectors, like many others, generate large volumes of solid waste and byproducts such as shells, possibly in the range of 10-20 million tonnes per year in several regions of the world [18]. Bivalve mollusc production is an important component of worldwide aquaculture, which is critical to the future of food security. This sector generates a considerable quantity of trash in the form of shells, which is either underutilized or disposed of in landfills [19]. Many types of seashells have been disposed of such as oyster shells, clam shells, queen scallop shells, and cockle shells. Shell waste is a major issue for shellfish producers, sellers, and consumers, both in practice and economically [19], [20], [21]. Pinpointing the precise global quantity of seashell waste is challenging. Nevertheless, it is evident that the volume of seashell waste is substantial and on the rise. According to the Department of Fisheries Malaysia [22], 57,544 tonnes of cockles were harvested along the west coast of Peninsular Malaysia. Oyster farming is a quickly growing economy [23]. Farming oysters in the open sea increases particle deposition on the seafloor, decreases marine currents, and decreases dissolved oxygen concentrations in the region near the farming area [24]. More than 6 to 8 million tonnes of leftover crab, prawn, and lobster shells are generated worldwide, with over 1.5 million tonnes occurring in Southeast Asia alone [25]. Waste shells are sometimes merely thrown into the sea or disposed of in landfills. Seashell dumping generates a variety of environmental issues including foul odours, harm to natural landscapes, and sanitation issues [19]. In industrialized nations, the cost of disposal might reach USD 150 per tonne in Australia, for instance [25]. Thus, approach of utilizing these shells for product manufacturing would save the waste management cost of the seafood related industries and preserve the landfill space for better use. Realizing the importance of a cleaner environment, researchers have integrated seashells namely cockle shell, oyster shell, clam shell, queen scallop and mussel shell as the replacement materials for concrete ingredients as shown in Table 1.

Table 1. Summary from previous work in integrated seashells in construction material

Research Reference	Country	Type of Shells	Usage of Seashells
[26]	Malaysia	Cockle	Coarse aggregate replacement
[27]	Malaysia	Cockle	Cement and filler replacement
[28]	Indonesia	Ground cockle	Cement replacement
[7]	Nigeria	Oyster Seashell	Cement replacement
[29]	Palestine	Clam Seashells	Cement replacement
[30]	India	Mixed Seashells	Cement and aggregate replacement
[31]	China	Oyster Seashell	Recycled aggregate porous concrete for artificial reef
[32]	France	Queen Scallop	Replacement for metakaolin
[33]	India	Clam Seashell	Coarse aggregate replacement for basalt fibre-reinforced concrete
[34]	Malaysia	Anadara Granosa	Sand replacement in mortar
[35]	South Korea	Cockle Shell	Pervious concrete pavement
[36]	China	Mussel shell	Replacement of aggregate

2.0 PROPERTIES OF SEASHELL

Seashell are used in concrete for replacement material because of the huge amount of the waste and easy to get. The properties of seashell itself is that high in the hardness and the toughed. Moreover, seashells have high calcium content which can improve the mechanical and physical properties of concrete. exhibit various properties that make them interesting materials for various applications, including construction and manufacturing. When selecting seashells for certain applications, it is critical to understand their qualities as well as how they may be handled and changed to fulfill the needed specifications.

2.1 Chemical Composition of Seashells

Seashells, composed primarily of calcium carbonate ($CaCO_3$) where the chemical compositions of seashells are determined by the shell kinds and collecting sites [37]. Basically, when the seashell is calcinate or heated over 840 ^oC in around 30 minutes, normally it will release carbon dioxide, forming calcium oxide, popularly known as quicklime or burnt lime. According to Rashidi et al. [38], the optimal point is basically at 850^oC, duration time of 40 minutes, heating rate of 20^oC/min and the size of <1.25mm. The process of calcination can transform $CaCO_3$ into calcium oxide (CaO). The key distinction is that raw seashells have a lot of $CaCO_3$, whereas burned seashells have a lot of CaO. The shell type, treatment chlorides, treatment technique, and burning temperatures which vary from 500°C to 1000°C all affect the CaO concentrations [37]. According to Dampang et al. [39], Fourier Transform Infrared Spectroscopy (FTIR) results suggest that the calcination time did not gave major alternation to the functional groups, however the temperature of calcination takes the major influence in calcination process. Many researchers have investigated the composition of chemicals in every type of seashell. Table 2 shows the chemical compositions of seashell ash that have been investigated by past researchers. To start with, the cockle shell has the highest amount of in term of CaO, followed by oyster and mussel shells. This may be due to the great mechanical properties both of their nanoscale structures and the combination of inorganic and organic materials.

Table 2. Chemical composition of seashell ash and OPC

Chemical Composition (%)										
References	Type of seashells	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	TiO2	SO3
[29]	OPC	19.01	4.680	3.200	66.89	0.810	0.09	1.17	0.220	3.660
[40]	OPC 53	21.27	8.790	3.560	58.66	1.940	-	-	1.350	2.520
[27]	Cockle	0.07	0.030	0.050	99.00	-	0.490	0.06		0.140
[41]	Oyster	2.00	0.500	0.200	51.06	0.510	0.580	0.06	0.020	0.600
[29]	Clam	0.25	0.047	0.009	97.80	-	0.290	0.02	0.099	0.270
[7]	Oyster	2.10	0.590	0.160	54.55	0.580	0.730	0.03	0.060	0.520
[31]	Oyster	1.05	0.210	0.270	95.06	0.670	1.280	-	-	0.560
[32]	Queen Scallop	0.70	-	0.100	61.10	0.400	-	-	-	0.600
[42]	Scallop	0.46	0.130	0.320	94.61	0.280	0.380	0.16	-	0.550
[40]	Not specified	-	-	-	47.49	0.619	1.119	-	-	0.403
[42]	Mussel	2.26	0.010	0.040	94.53	0.230	0.480	0.02	-	0.380

2.2 Physical Properties of Seashells

When assessing the applications of seashells as mineral admixtures in concrete, it is crucial to take into account specific gravity, surface area, and mean particle size. These physical variables play a significant role in influencing the mechanical strength and durability of the concrete [37]. Table 3 shows the physical properties of seashell with various sources. Seashells are naturally hard and rigid due to the presence of calcium carbonate [43]. This hardness can vary among different species of seashells. When considering seashells for specific applications, it’s essential to understand their properties and how they can be processed and modified to meet the desired requirements. Their exterior surfaces can be smooth, rough, or textured, and they can have complex species-specific designs and patterns. Seashells are available in a wide range of colors and sizes, as well as densities ranging from lightweight to dense. When strained, they can become brittle and break. The surface can be hydrophobic to some extent, causing water droplets to form. They may also have a porous structure, which makes them useful in applications such as water filtration, and they are biodegradable, degrading gradually over time. Seashells are well-known for their varied forms and structures, which offer habitat for marine organisms and contribute to the diversity of coastal ecosystems.

Table 3. Physical properties of seashell ash

Properties	Cockle Shell	Oyster Shell	Mussel shells	Periwinkle shells	Mixed Seashells
References	[35]	[42]	[42]	[44]	[45]
Uniformity coefficient	-	-	-		-
Fineness modulus (%)	1.90	3.09	3.01	-	-
Specific gravity	2.82	2.64	2.86	2.56	2.82

Table 3. (cont.)

Properties	Cockle Shell	Oyster Shell	Mussel shells	Periwinkle shells	Mixed Seashells
Bulk density (g/cm³)	-	2.16	2.41	-	2.485
Moisture content (%)	0.15	1.72	3.18	-	-
Water absorption (%)	-		-	-	0.7
Bulk porosity (%)	-	67	62	-	7.1
Ave. particle size (µm)	20	18	25	-	-

3.0 SEASHELLS PREPARATION

Many researches dealt with the waste from seashells in various ways, such as gathering the waste, cleaning, drying, and calcining the powdered seashells, which were then gathered from the coast and utilized to make concrete. Seashells have piqued human interest for centuries owing to their unusual structures and mineral content. They are not just a symbol of seaside beauty, but they also have practical value in a range of applications. The seashell powder is a versatile product derived from the calcareous shells of marine creatures that have applications in agriculture, construction, art, and nutrition. The production of seashell powder is an important step in harnessing the intrinsic properties of these natural wonders, and this introduction provides the framework for additional research into the methods, applications, and relevance of seashell powder in a variety of areas. There is a step that need to be undergone before the seashell is use for cement replacement. Initially, the seashells underwent a washing and drying process to eliminate any apparent traces of flesh and contaminants [32]. Clean water was used for the cleansing process of the seashells [35]. Muthusamy et al. [26] also use tap water for washing the seashells and removing the dirt before drying. It was discovered that washing seashells reduces contaminants, salt content, and organic debris, particularly chloride ions. The shell was crushed into raw white seashell powder using a crusher so that it could pass the 2.36 mm sieve size for aggregate replacement. The powder passing through the 90 µm sieve size was used for the replacement of OPC in the concrete [30]. Omer [7] stated that the procedure involved immersing the oyster shells in water for approximately 48 hours, followed by a thorough washing to eliminate any remaining flesh adhering to the shells. Subsequently, the shells were sun-dried and the sun-dried shells were mechanically crushed with the aid of a Hammer Mill Machine of brand TRF400, with Motor 2.0CV-50Hz-2poles, Voltage 220v-Monophase. The resulting material underwent multiple screenings to obtain fine particles, ultimately passing through a 150µm sieve. Another researcher Othman et al. [27], after cleaning to get rid of any dirt, the seashells were dried in an oven set at 105±5^{o}C for a whole day. Using a cone crusher, the shells were crushed into a powder that could pass through a 5 mm screen. They were then burned at 1000^{o} for one hour at a heating rate of 10^{o}C/min in a gas furnace. Attah et al. [44] also air dried and calcined the shell to a temperature of 1000^{o}C and allowed the shell to cool and ground to powder. Figure 1 shows the preparation of seashell waste powder sieved through a 63 µm sieve. Tayeh et al. [29] prepared seashells by washing the seashell with water after immersing it in the vinegar-water bath for 24 hours and heated at 105^{o}C for 2 hours until reached a full dry level. After that, the seashells are crushed into a raw white seashell powder. According to Afolayan et al. [46], there are different methods of calcination they use, they were washed clean and allowed to dry before being poured into an open perforated pan where it is subjected to fire to be burned locally using firewood. More research by various researchers on seashell preparation as shown in Table 4.

(a) (b) (c)

Figure 1. Preparation of seashell waste powder [32]

Table 4. Burning period, temperature, and seashell preparation

Seashell type	Burning period, and temperature	Seashell cleaning and crushing process	References
Cockle	7 days, 50^{o}C	Cockle shells were washed, scrubbed dirt, and boiled for 50 min. The shells were thoroughly washed with distilled water and dried in the oven.	[47]

Table 4. (cont.)

Seashell type	Burning period, and temperature	Seashell cleaning and crushing process	References
Anadara Granosa (blood clam)	3 days, 500°C	Cleaned using tap water, dried, and burnt at the brick furnace. The shell was crushed into small pieces using LA machines and then ground with a blender.	[28]
Molluscs, periwinkle, oyster, and snail.	2 hours, 800°C	Not stated	[48]
Periwinkle	1000°C	Thoroughly washed using tap water, and air dried in an open space before burning.	[49]
Cockle/blood clam, and marsh clam	3 days, 600°C	Shells id produced by washing, grinding, milling, and calcining.	[50]
Clam	2 hours, 800°C	Undergoes cleaning process using tap water and drying before crushing manually.	[51]
Mussels, oysters, and scallops	1 hour, 220°C	Seashells were cleaned and washed with tap water before it is boiled for approximately 20 min.	[42]

4.0 PROPERTIES OF CEMENT BASED COMPOSITE

A good quality concrete for construction application is determined based on its workability, strength and durability [52]. A good hardened concrete needs a low permeability criterion as it needs to keep water or any chemicals from passing through the concrete and a good shrinkage is needed to avoid the concrete shrinking too much as it dries [53]. The properties of the mixing ingredient used are among the factor that influences the properties of cement-based composites. In relation to that, setting time test, slump test, compressive strength test, splitting tensile test and flexural strength test is among the common types of testing conducted when waste materials are integrated as partial cement replacement in concrete.

4.1 Setting Time

The setting is the term used to describe the transition of the mix's consistency from a fluid to a hard condition brought on by the cementitious ingredient hydration. Early concrete strength growth can be indirectly estimated using the setting time test [41] and to ascertain the rate at which newly mixed concrete may become hardened concrete. The first setting time is the amount of time that newly mixed concrete may be worked for a minimum of 45 minutes specified for OPC [7]. Ubachukwu and Okafor [7] reported that the first and last setting times increase in proportion to the amount of oyster shell powder. The decrease in the cement paste's strength-forming components, C_3S, C_2S, and C_3A, is the cause of this. When concreting in hot weather, this increase in the beginning and final setting durations is advantageous. According to Tayeh et al. [29], setting times lengthen when the proportion of OPC substituted with seashell cement rises. The extension observed in both the initial and final setting durations of seashell cement blends can be attributed to the delayed reactivity of seashell cement when mixed with water. The presence of CaO, a primary constituent of seashells, is likely responsible for the delayed initial and final setting times, as the shells introduce a diluting effect within the cement matrix [29]. Additionally, it can be concluded that the utilization of seashell cement is viable in hot regions, where the extended setting durations provide an advantageous increase in the available time for concrete casting [54], initial and final setting time are increase with the influence of higher replacement. This supported by the data from Ubachukwu and Okafor [7]. As well as Tayeh et al. [29]. Table 5 shows the tabulated data of setting time of concrete contain seashells from the researchers.

Table 5. Setting time of concrete seashell

References	Seashells	Replacement %	Initial Setting Time (mins)	Final Setting Time (mins)
[54]	Cockle shell	0	90	210
		5	150	250
		10	180	270
		15	180	290
		25	190	310
		30	200	340

Table 5. (cont.)

References	Seashells	Replacement %	Initial Setting Time (mins)	Final Setting Time (mins)
[7]	Oyster Shell	0	45	105
		5	50	120
		10	55	135
		15	60	140
		20	65	150
		25	70	155
[29]	Clam seashell	0	130	170
		5	135	182
		10	142	187
		15	149	192
		20	155	201

4.2 Workability

Researchers have conducted slump tests in accordance to existing standards namely BS EN 12350-2 [55] or ASTM-C 143 [56] to investigate the effect of seashell ash as cement replacement on concrete's workability. Based on the data of concrete workability with various seashells as cement replacements in Table 6, it can be seen that blending seashell ash as partial cement has an influence on the concrete workability. It has been noted that newly made OSP-cement concrete has greater workability than OPC concrete [7]. The workability rises by an additional 19 mm when the replacement level of OSP goes from 5% to 25% (80 mm to 99 mm, respectively). Concrete has less bleeding and segregation overall because of the increased workability brought about by using oyster shell particles. Even while oyster shell powder cement concrete became more workable over time, it also became more durable. Comparable outcomes were witnessed by Ephraim et al. [14] with oyster shell ash. Nevertheless, the slump of concrete that includes oyster shell ash rises as the water-to-cement ratio increases as there are three water-to-cement ratios considered in the experiment which are 0.22, 0.25, and 0.27 [14]. However, as the water-to-cement ratio increases, there is a decrease in compressive strength and it stated that the highest compressive strength to be at 0.22 water-to-cement ratio. A researcher elsewhere Afolayan et al., (2019), discovered a diminishing trend in slump values for concrete incorporated with 5–30% periwinkle shell ash as a substitute for cement, with a consistent 1% inclusion of fixed Sisal fibre for reinforcement. According to [5], shell ash from periwinkles (PSA) is superior than oysters (OSA) and snails (SSA). This trend was caused by the lower silica concentration of OSA and SSA when compared to PSA. However, according to Othman et al. [54], the workability of concrete that has been substituted with cockle shell ash is significantly impacted by water absorption, which causes the slump value to fall proportionately as the rate of replacement increases. The poor water consistency in SSA might be due to the high lime concentration. The inconsistencies in the morphologies of seashell particles are thought to reduce concrete workability as seashell ash percentages increase. However, the opposite occurs. Increased seashell percentages improve workability. This was ascribed to the seashell cement's hydration duration while retaining the same water/cement ratio as OPC cement. The advantage of this is that when utilizing seashell cement, the water/cement ratio may be reduced while maintaining the same workability as the normal mix [57].

Table 6. Workability of seashell concrete

References	Seashells type	Replacement %	Slump value (mm)
[54] *Targeted slump – not mentioned	Cockle shell	0	90
		5	60
		10	30
		15	10
		25	5
		50	0
[29] *Targeted slump – not mentioned	Clam seashells	0	60
		5	70
		10	85
		15	100
		20	110

Table 6. (cont.)

References	Seashells type	Replacement %	Slump value (mm)
[7] *Targeted slump – 75 – 100mm	Oyster shell	0	80
		5	82
		10	86
		15	89
		20	95
		25	99

4.3 Density

Water absorption and specific gravity, often known as particle density, are significant characteristics of seashell aggregate that typically impact the density of concrete [58]. Water to binder ratio or w/b refers as the ratio of water consumptions to the cementitious material consumptions in concrete. A decrease in the water to binder ratio the higher density of the seashell waste powder in comparison to the metakaolin resulted in a significant increase in their density when the incorporation rate of the powder was increased [32]. According to Neville and Brooks [58], density is readily determined by weighing the freshly compacted concrete in a standardized container with a known volume and mass. ASTM C 138-01a [59], BS 1881-107: 1983 [60], and BS 12350-6:2000 [61] provide guidelines for this test. The influence of substituting ground seashells for cement on the concrete density at 7, 28 and 91 days is presented in the Figure 2. It is evident that as concrete ages, density rises [50]. The findings indicated that concrete density, when incorporating marsh clam, surpasses that of the standard mix, whereas the concrete density is lower when cockle is used compare to the standard mix across all concrete ages [37]. However, according to Tayeh et al. [29], all the seashell cement cubes exhibited approximately the same unit weight as the SC0 mix cubes. This implies that the substitution of OPC with 5%, 10%, 15%, and 20% seashell cement does not have a discernible effect on the unit weight of the concrete [29]. As concrete ages, the density of clam shell concrete with varying percentages of clamshell ash replacement rises; among the others, the maximum density is found with 6% of clamshell replacing OPC (SC6%). However, the further increment of clam shell will be reducing the density as there is the present of the porosity in the concrete [51]. On overall, the incorporation of seashell ash influences the concrete density.

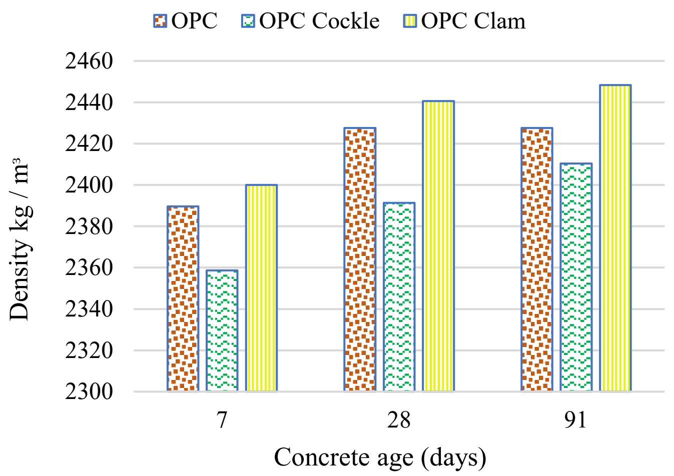
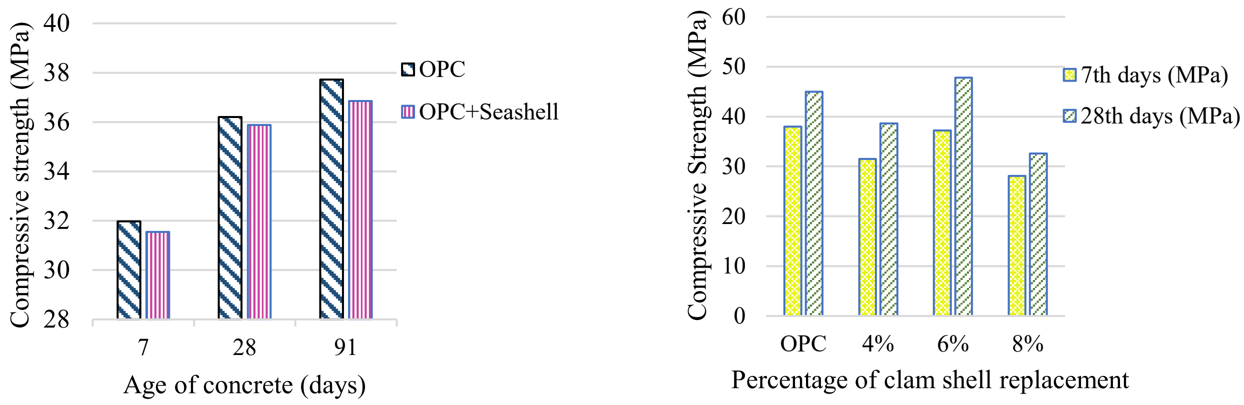


Figure 2. Density of OPC and seashell concrete [50]

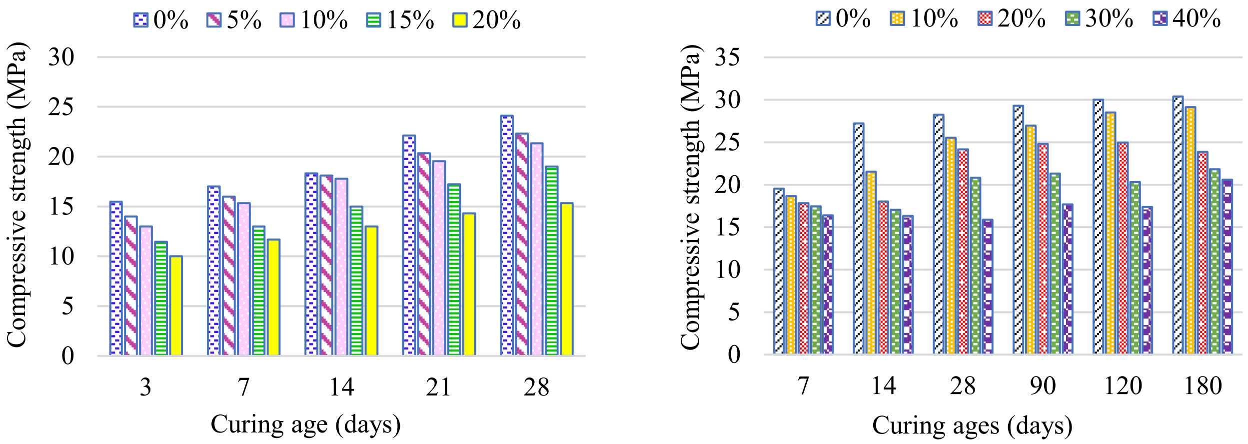
4.4 Compressive Strength Test

Numerous researchers have undertaken assessments on the compressive strength of concrete produced through the partial replacement of cement with seashell waste in accordance with BS EN 12390-3 [62]. It is observed that the compressive strength of the concrete at age 28 days, with bleeding of oyster shell (OS), is not less than the value of a typical combination. Adewuyi et al. [48] claimed that after 28 days of curing, the concrete with periwinkle shell used as a partial substitute for cement had the highest compressive strength when compared to snail and oyster shells, measuring 19 MPa, greater than the measurement for the control sample, which was 17.5 MPa. Olivia et al. [28] have conducted research using ground cockle as a partial cement replacement. Figure 3 (a) displays the table of compressive strength of mixes with cement replacement. The proposed optimum mixture was the mixture with ground cockle shell content of 4% with the highest strength 32.24 MPa at 28 days. According to Olutuge et al. [63], the strength of the concrete decreases as a larger percentage of periwinkle ash level is used. A similar observation has been reported by [64], [49], [44]. Overall, the strength increases with longer curing times. A compressive strength result as it shows in Figure 4 (a) and (b) shows that when the age of curing is longer, the higher the value of compressive strength. However, the graph in Figure 3 (b) shows the compressive strength of the mixture using 4% of ground cockle shell that shows the increase of compressive strength of all samples at 7, 28, and 91 days for both types of concrete with OPC and concrete with OPC + Seashell. The OPC sample showed slightly higher strength than the seashell concrete. However, using of clam shell as cement replacement (6%) has the highest compressive strength at 28 days higher than the control mix as it shows in Figure 3 (b). It indicates that the replacement of the clam shell improved the latest strength of concrete as well as the density of concrete. Similar findings were reported by [65].



(a) (b)

Figure 3. (a) Compressive strength of OPC and seashell concrete at 7, 28, and 91 days [28] (b) percentage of OPC and clam seashell concrete at 7, and 28 days [51]



(a) (b)

Figure 4. (a) Compressive strength result [63] (b) compressive strength result [64]

4.5 Splitting Tensile Strength Test and Flexural Strength Test

The use of seashells as cement replacement influences the splitting tensile strength and flexural strength of concrete. The test was conducted in accordance to BS EN 12390 -6 [66]. As shown in Figure 5 (a), it is determined that the tensile strength of concrete is increased when clam seashell cement (5% and 10%) is substituted for OPC. This is most likely due to the fiber content of seashell cement and its superior aggregate binding properties. Furthermore, seashell cement strengthens the bond between the concrete particles by functioning as a filler. Tensile strength, however, decreases as the replacement proportion rises. This suggests that the increased replacement % weakens the connection between the aggregates and cement paste [29]. As shown in Figure 5 (b) it has been discovered that the water-cement ratio of the mix determines the ideal percentages of silica fume replacement for tensile strengths. While the range for flexural strength was 15% to 25%, the optimal 28-day split tensile strength was found to be within the range of 5–10% silica fume replacement level [67]. Specimen with 6% of cement replacement of clam shell has the highest splitting tensile strength as shown in Figure 5 (c). It shows that 6% of OPC replacement has good adhesion between aggregate and cement paste compared to other cement replacements [51]. Olivia et al. [50] found that the tensile strength of OPC is higher than OPC seashells concrete as shown in Figure 5 (d). According to Olivia et al. [50], the difference of tensile strength in every replacement along the curing age is may be due to the bonding of aggregate and cement being disrupted by the cement replacement.

Figure 6 (b) shows the seashell concrete's flexural strength will increase after 28 and 91 days. After a period of 28 days, a significant strength was added, most likely because of the cement's calcium content, which improved the link between the paste and aggregates. The bonding promoted the tension qualities. Enhancing composite action between steel reinforcing bars and concrete is worth the extra gain in tension characteristics [68]. However, in self-compacting concrete as shown in Figure 6 (a) when oyster shell powder is substituted with 7.5% cement, the greatest increase in flexural strength is 7.45 N/mm^2 and 8.92 N/mm^2 at 7 and 28 days, respectively. Furthermore, as shown in Figure 7 (a) and (b), there is a visual interpretation on the age-related flexural strength of concrete. it shows that, the higher the age of curing the higher the flexural strength. This statement also supported by another researcher as it is shown in Figure 7 (a) and (b). Moreover, the MSA15% reported that has the highest mix among the other substitutions. The reason of MSA15% has the highest flexural strength among of others because of seashell cement serves as a filler that reinforces the concrete's binding between individual particles. Therefore, all the types of seashell binder's flexural capacity enhance with the initial cement replacement [42]. Most of the researcher conducted the test by using BS EN 12390-5 [69].

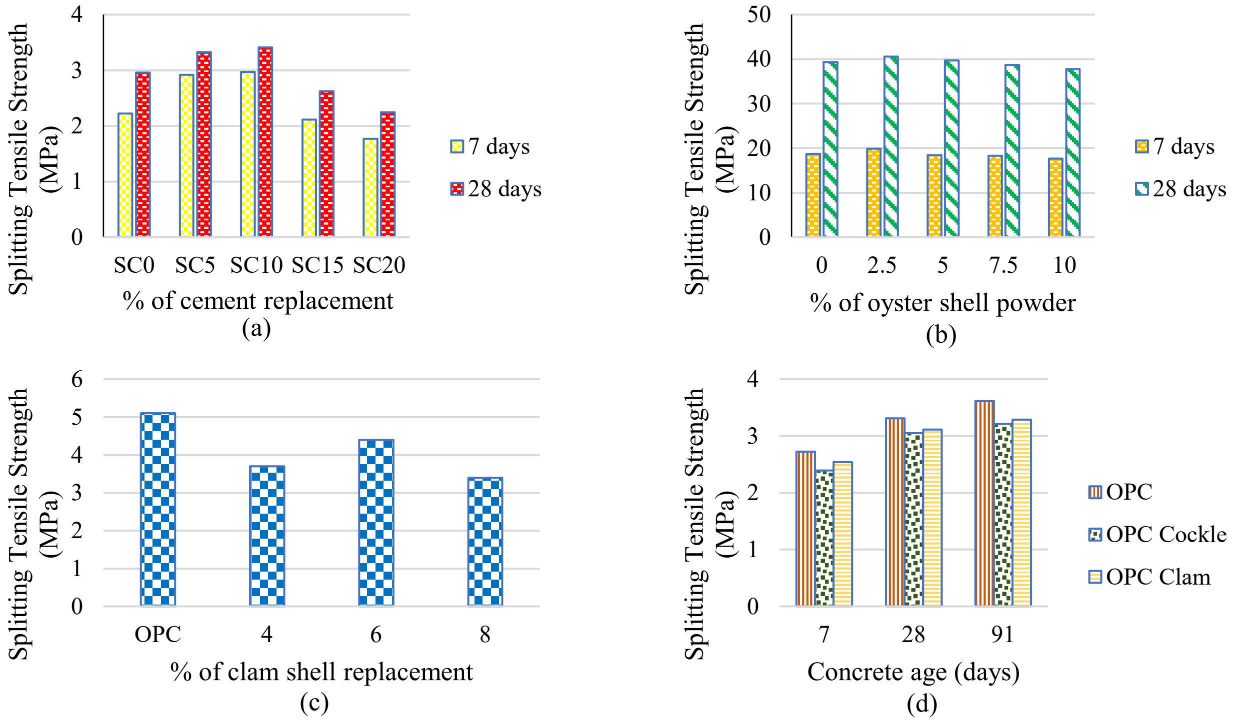


Figure 5. (a) A bar chart of the tensile strength of standard and bivalve clam seashell cement concretes [29], (b) oyster powder on split tensile strength of self-compacting concrete [67] (c) tensile strength of clam shell replacement as OPC in concrete [51] (d) Tensile strength of OPC and seashells concrete [50]

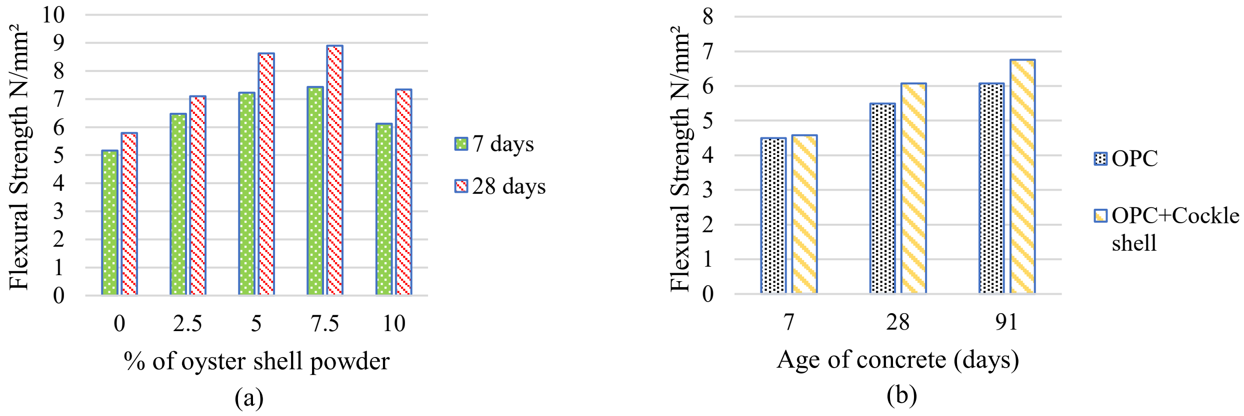
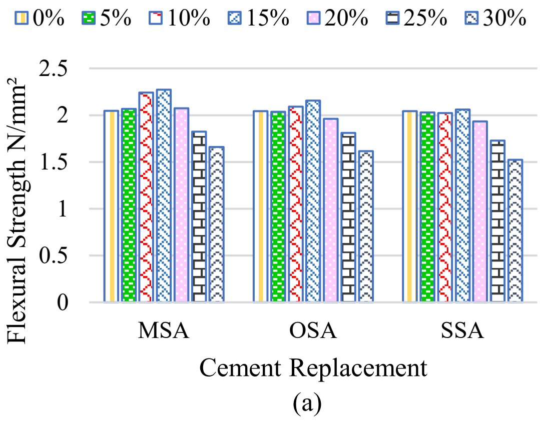
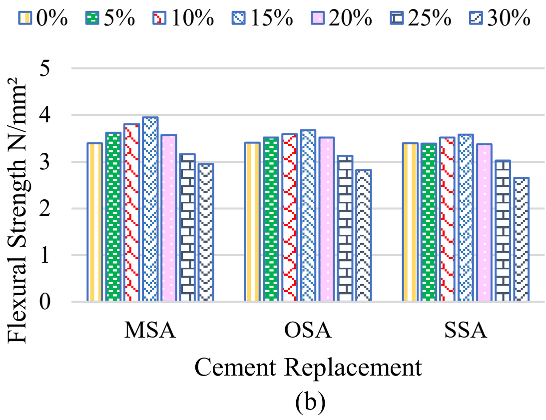


Figure 6. (a) Flexural strength of seashell self-compacting concrete [67], (b) flexural strength of seashell concrete [68]



(a)



(b)

Figure 7. Flexural strength of Mussel Shell Ash (MSA), Oyster Shell Ash (OSA), and Scallop Shell Ash (SSA) at (a) 7 (b) 28 days [42]

5.0 CONCLUSION AND RECOMMENDATIONS

Seashell wastes namely oyster shell, cockle shell, clam shell has the potential to be utilized as partial cement replacement in concrete. The effectiveness of seashells as a cement replacement depends on factors such as shell type, size, and local availability. Seashells must be washed thorough to remove sea salt and dirt. Calcination is an important process to produce seashell ash rich with CaO. Concrete with made with inclusions of seashell ash, or powder still have an acceptable strength as it is possessed above the allowable strength. The optimum substitution levels of replacement are found to be 5-15%. Among the various types of seashells, cockles' shells are the most suitable for producing concrete that is mixed with partial cement replacement. This is followed by mussels' shells and oyster shells. Using seashell cement clearly enhances the splitting tensile and flexural strength of concrete at lower levels of substitutions due to the bonding improvement at the interface of the cement and aggregate. Despite extensive prior research on substituting seashells for cement, numerous inquiries remain unanswered. The effect of seashell ash fineness on concrete strength can be looked into. The durability performance of concrete produced using seashell ash as a cement substitute in terms of resistance towards sulphate attack, ion chloride ingress, alkali silica reaction and acid attack. The long-term performance of seashell ash cement-based concrete upon subjected to seawater curing also another area to be explored. The potential use of seashell ash when blended with industrial pozzolanic ashes namely fly ash, ground granulated blast furnace slag, palm oil clinker powder, coal bottom ash and silica fume in towards mechanical and durability properties of concrete remains to be investigated.

6.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

7.0 AUTHOR CONTRIBUTIONS

Sofia Adibah Jasni: Writing- Original draft preparation
Khairunisa Muthusamy: Conceptualization, Reviewing, Editing
Hanis Nadiah Ruslan: Reviewing, Editing
Hussein Mahmood Hamada: Reviewing, Editing
Ezahtul Shahreen Ab Wahab: Reviewing

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9.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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