

Cockle Shell as Mixing Ingredient in Concrete: A Review

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ABSTRACT – The demand for the population is boosting the production of edible and non-edible products that produce by-products that result in emissions being thrown as waste. The successful cockle trade also creates vestiges of cockle shell that are thrown away as waste. Despite the effects of climate change, industrial activity including calcareous and granite mining to satisfy the need for cement and concrete production, respectively, cannot be prevented as more structures are developed worldwide. The mechanical properties of concrete containing crushed cockle shell as partial fine aggregate, coarse aggregate and cement replacement were examined and reported in this paper. Cockle shell powder was used as cement replacement up to 75%. To sum up, the use of cockle shell is an appealing option for the construction industry and sustainable green climate.

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INTRODUCTION

Actually, concrete is the most consumed commodity in the world among human-made products, with about three tonnes per capita every year [1]. Concrete is a material that involves the processing of cement, fine aggregate, coarse aggregate, and water as its raw material [2]. In order to achieve a solid form and a load bearing building material, the hydration of the cement connects the other components [3]. These raw materials have been taken from natural resources such as quarries, river beds, etc. [4]. Many forms of concrete are used annually in significant amounts [5]. Overall, concrete annual consumption reaches 25 billion tonnes [6], and with a total production volume of about 6 billion m³ in 2017 [7]. In Belgium, the total annual amount of concrete manufactured is estimated at 40.8 million tonnes (equal to 3.6 tons per capita), while precast concrete products are estimated at 12 million tons per annum (equal to 1.1 tonnes per capita) [8]. Due to its flexibility in strength, longevity and low maintenance costs, concrete is now regarded as the most important construction material. However, because of the extensive use of cement, natural fine and coarse aggregate, and energy, it has become one of the least sustainable commodities, increasing carbon dioxide (CO₂) emissions and depleting natural resources [9]. Continuous production of cement-based concrete is harmful and unsustainable, since it depletes available natural resources [10]. It should be remembered that 70-80% of the concrete consists of lower inert carbon and lower cost aggregates [11]. Even a little gain in resource efficiency has a significant mitigating impact on the environmental impact of concrete manufacturing owing to its large size and ubiquity [12].

Cement acts as a binder in concrete. It is a compound that hardens and binds alternative items [13]. The cement sector plays a central part in developing nations' economic development. Demand for cement in construction drives production and, on the demand side, the production of cement is expected to continue to increase [14]. Ordinary Portland cement (OPC) production is progressively 9% per annum worldwide and about 4 billion tons are made [15,16]. The global production of cement output reaches 4.20 billion tonnes in 2019, 2.35 in China and 1.83 in the rest of the world [17,18] with 54-200 kg of cement kiln dust produced by each ton of Portland cement [19]. Cement production in Brazil was also about 55,000 thousand tonnes in 2019 (United States Geological Survey [20]). Global cement production reached 82,000 million tons in 2018, including 35,700 million tons in China, 12,460 million tons in the United States, 25,640 million tons in Thailand, 540 million tons in Turkey, 388 million tons in Brazil and 6976 million tons in other countries [21,22,23] suggesting that enormous cement production is increasing. Cement manufacturing is the second largest carbon dioxide (CO₂) industrial emitter, with about 7% of global emissions [24,25]. The cement industry is one of the major contributors to global climate change, releasing 2.2 Gt of CO₂ annually or 7% of total anthropogenic CO₂ emissions, due to the energy-intensive manufacturing process [26]. OPC production greenhouse gas emissions are approximately 1.5 billion tons (7-8% of total emissions) annually from various industries around the world [27]. These environmental degradations can also disrupt certain animal habitats, causing them to relocate, which in turn destroys the current ecosystem. However, this is an important issue because cement is often listed as a crucial material due to the large volume needed in building energy technologies and its high effect on the environment [28].

Quarries that are often utilised in the processing of igneous, sedimentary, and metamorphic rock deposits are often utilised to produce natural aggregates [29]. The aggregate makes up around 70-80% of the overall concrete volume. Computed to be over 48 billion metric tonnes of aggregate materials, the world's construction sector is believed to use this amount of aggregate [30]. The components are comprised of about half river and ocean fine and coarse aggregates and about half from mountains, which make up more than 50% of the overall mixing components. Approximately 9

billion tonnes of this resource will be needed annually by 2050 [31]. rising at an average annual rate of 7.7% through 2022, aggregate demand for concrete production is projected to increase to 66.2 billion metric tonnes [31]. The need for building is growing in many regions of the globe, which causes the sand supply sector to rise. Generally, sand is collected from land quarries, river beds or from marine and coastal mining. To date, it takes about 50 billion tons of sand per year [32]. Owing to the high demand on the construction side, sand is becoming scarce in certain regions of the world and as human consume sand more quickly than their stocks replenish with natural creation [3].

The lack of natural mineral resources is expected to become even more prevalent in 2019, when total annual consumption of natural aggregates is estimated to surpass 51.7 billion tonnes [33,34]. Almost all nations have a lack of natural aggregates and rising pricing [35]. A case may even be made to point out that in certain nations, aggregates are imported to help ease the problem of localised natural aggregate scarcity [12]. It's now becoming more and more difficult to find big amounts of high-quality limestone, which is why cement is harder and more expensive to make. Today, the Earth is short on landfill space and there are imbalances in the ecosystem [36]. River sand is the most often utilised construction material because of its exceptional characteristics. Unrestricted usage of local natural resources in small geographic regions will, however, fail to meet future demands, and hence will be lost in the future [11]. Aggregate mining threatens to decimate the natural beauty that is teeming with plants and wildlife, transforming it into a desolate landscape that faces erosion during the rainy seasons [37]. One of the most important protein sources in the South East Asian zone is the South East Asian cockle (*Anadara granosa*), which lives mostly on intertidal mudflats. Sea mollusk meat is a common ingredient in South East Asian dishes [38]. Europe produced an average of 14,000 to 26,000 tonnes of cockles per year from 2014 to 2017 (Table 1), with UK, Spain, Portugal, and Denmark accounting for more than half of this output [39]. Clams have a wildly fluctuating value, mostly depending on the supply-demand balance. Their value relative to other forms of shellfish is low. Generation of \$6.3 million yearly comes from the harvest of around 5543 tonnes of cockle shell, which might be used as shell aggregate [39].

Table 1. Annual reported European harvest (tonnes) of *Cerastoderma edule* by country for 2014 to 2017

Country	Year			
	2014	2015	2016	2017
UK	10 171	11 169	5036	5997
Denmark	6081	7699	5917	7924
Portugal	1991	4700	1835	5063
Spain	1195	2410	1561	2846
France	228	145	80	259
Ireland	3	0	222	441
Sweden	0	2	0	0
European total	19 669	26 125	14 651	22 530

Sources: FAO [40]

MATERIAL CHARACTERISTICS

Physical Aspect

A family category of double-shelled *cardiidae* called "cockle shell" is made in a variety of ways, including on the exterior [41]. A shell's ridges grow more uniformly with time, and the older cockles have more consistent patterns of ridges than the younger ones, which causes the number of ridges to reveal the age of the cockle. They may grow to between 60 and 60 millimetres in width, and can survive up to 20 years. When the shell grows, it makes the cockle stronger and heavier, so protecting it from damage [42]. As observed in Figure 1, the outside surface is white, yellowish, or brownish. Once lines of development have been established, they are not reversible. The adductor muscle scar's inside surface is greyish white with a brownish or light purple tinge on or around the muscle scar's back [43]. In the other hand, when cockle shell waste was used as a gross aggregate in plain concrete, these shells were typically in uncrusted shape with a maximum size of between 10 and 20 mm. As seen in Table 3, the specific gravity of the aggregate cockle shells was observed to be within the range of 2.09-2.64, which is close to standard aggregates [44,45]. In general, crushed cockle shell powder and cockle shell ash have been used as a cement substitute with a scale of less than 75µm (Table 2). The scale of the samples taken in this analysis ranged from 25 to 50 mm prior to sea shell grinding [46]. Cockle shell powder appears in a white colour while cockle shell ash appears in a light greyish colour due to a burning reaction (Figure 2). The composition of cockle shell ash is also rougher than cockle shell powder. Other properties of the cockle shell as a cockle shell mixture, powder and ash are seen in Table 2. In comparison, Figure 3 to Figure 5 displays the morphologies of the cockle shell before and after pulverisation.

Table 2. Physical properties of cockle shell used in previous studies

Reference	Replacement type	Size	Specific gravity (%)	Blaine-specific surface area	Fineness modulus (%)	Water absorption (%)
[47]	Cement	75µm	2.82	8299 cm ² /g	4.22% passing	0.15
[48]	Cement	23.97µm	2.07		-	-
[46]	Cement	60µm	1.39	3800 cm ² /g	-	12.10
[49]	Cement	75µm	-	-	-	-
[49]	Cement	75µm	-	-	-	-
[45]	Coarse	10-14mm	-	-	-	-
[44]	Coarse	20mm	2.50	-	7.53	20.15
		6.30-9.50mm	2.09	-	-	1.8
[51,52]	Coarse	4.75-6.30mm	2.64	-	-	2.5
[53]	Coarse	-	2.43	-	-	0.1
[54]	Cement	0.6µm	-	-	-	-
[55]	Cement	5.77µm	2.33	-	-	-



Figure 1. Cockle shell sample before crushing (left) and cockle shell texture and colour (right)



Figure 2. Cockle shell powder (left) and cockle shell greyish ashes (right)

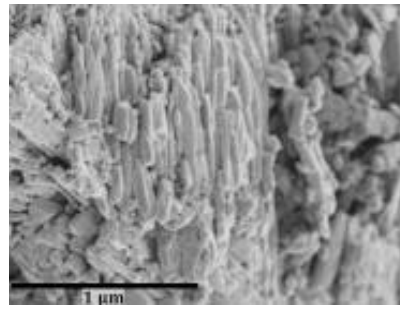


Figure 3. SEM picture of cockle shell powder [47]

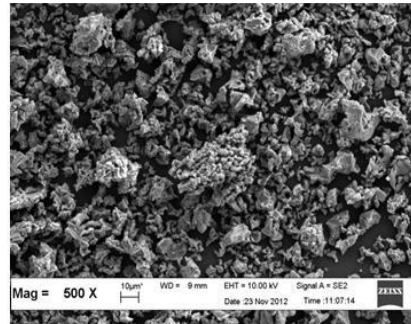


Figure 4. SEM picture of cockle shell ashes [55]

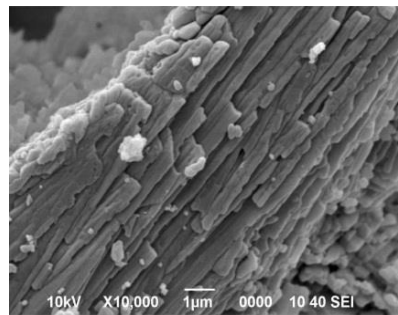


Figure 5. SEM picture of cockle shell aggregate [52]

Chemical composition of Cockle Shell

Cockle shell has a very high calcium content. The material is so important that it is typically composed of calcium carbonate of prismatic layers giving the shell structure a high strength, low mass and low coefficient of thermal conductivity [56,47]. The chemical structure of the raw cockle shell is shown in Table 3. Calcium carbonate content CaCO_3 is more than 90% by weight in cockle shells [56,57,58,49,50,59] and is almost equivalent to limestone [48,46]. Interestingly, CaCO_3 is one of the four main raw materials making cement [60] while the other major cement compounds are dicalcium silicate (C_2S), tricalcium silicate (C_3S), tricalcium aluminate (C_3A) and tetracalcium aluminoferrite; (C_4AF).

Table 3. Chemical properties of raw cockle shell in percentage (%)

Reference	Mineral Composition (%)								
	CaC	Mg	Si	Na	P	Al	Si	Sr	Others
[56]	98.99	0.51	0.078	-	-	-	-	-	<0.1
[61]	98.70	0.05	-	0.9	-	-	-	-	<0.1
[41]	98.7	0.05	-	0.9	0.02	-	-	-	0.2
[54]	97.23	0.54	0.63	-	-	1.02	0.63	0.34	0.24

MECHANICAL PROPERTIES OF COCKLE SHELL CONCRETE

Table 4 summarises previous research on cockle shell's effect on concrete characteristics. Using cockle shell affects the compressive, flexural, tensile, and elastic strengths of concrete, as well as its modulus of elasticity. An abundance of relevant data is available on the compressive strength of concrete. Effect on each of these mechanical characteristics is explored in the following sub-sections. As reported by [62] and has also been observed by the author that the behavior of concrete depending on the source and the proportions of its individual components. Environmental conditions, sample hardening history, and non-standardized test parameters and procedures make it difficult to obtain general results on the mechanical properties of concrete.

Table 4. Effects of cockle shell on mechanical properties of concrete

Reference	Cockle shell content (%)	Replacement type	Result			
			Compressive Strength	Flexural Strength	Tensile Strength	Modulus of Elasticity
[46]	0, 4, 5, 6, 7, 8, 9, 10, 15, 20, 30	Cement	Increase at 8% replacement	Decreased for all replacement	-	-
[55]	0, 5, 10, 15, 25, 50	Cement	Decreased for all replacement	-	Increase at 5% replacement	Increased at 10% replacement
[47]	0, 5, 10, 15, 20	Cement	Decreased for all replacement	-	-	-
[49]	0, 2, 4, 6, 8	Cement	Decreased for all replacement	Increase for all replacement	Increase for all replacement	Decreased for all replacement
[45]	0, 5, 10, 15, 20, 25, 30		Decreased for all replacement	-	-	-
[50]	4	Cement	Decreased for all replacement	-	Decreased for all replacement	-
[44]	0, 10, 20, 30	Coarse aggregate	Decreased at 30%	-	Decreased at 30% replacement	-
[51]	0, 25, 50, 75	Coarse aggregate	Decreased for all replacement	-	-	-
[53]	0, 5, 10, 15, 20, 25	Coarse aggregate	Decreased for all replacement	-	-	-
[54]	0, 10, 25, 40, 50	Cement	Increase for all replacement	-	-	-
[52]	0, 25, 50, 75	Coarse aggregate	Decreased for all replacement	-	-	-
[63]	0, 5, 10, 15, 20	Fine aggregate	Increase for all replacement	Increase for all replacement	-	-
[41]	0, 5, 10, 15, 20, 25, 30	Fine aggregate	Increase at 10% replacement	-	Decrease for all replacement	-
		Coarse aggregate	Increase at 25% replacement	-	Decrease for all replacement	-

Compressive Strength

Compressive strength is the most common mechanical behaviour studied in concrete science. The findings of previous research on the integration of cement substitution are seen in Table 4. Most of the studies indicated that the addition of cockle shells to concrete contributes to a decrease in early concrete strength (Table 4). If a cockle shell is replaced as a partial cement substitute in concrete, the strength of a cockle shell ash mixture is stated to be lower than regular concrete [49,55,47]. However, the percentage of strength increased over a long curing period (up to 90 days) relative to regular concrete, particularly with CSA5 and CSA15 [55]. Hazurina [15] have showed that the compressive strength of concrete declined with a higher volume of cockle shell ash used. However, CSA5 and CSA10 showed compressive strength above 35N/m at 28 days. It can be inferred that the substitution of 5% to 10% of cement by a cockle shell with a low amorphous content and low LOI values, as well as a high CaCO_3 , has proven to be an effective new concrete [55]. Meanwhile, Al-Zubaidi [54] showed an improvement in compressive strength with an increase in cockle shell powder ratio. This activity is thought to be related to the intrinsic hardness of the powder particules. Each powder particle in the volume of the specimen is known to be a centre of resistance to external compression. As a result, the increase in these tolerance centres would result in a homogeneous distribution of external force over the whole specimen system and, eventually, an increase in compressive power. This indicates that the inclusion of coke shell powder has contributed to a decrease in the failure process under external load [54]. Another analysis came to the same conclusion that it can be argued that cockle shell concrete is more able to tolerate load resistance than control specimens. For the initial 14 days of the evaluation, all cockle shell concrete achieved rapid strength growth as presented in Figure 6. However, the drop in intensity was significantly detected from day 14 to day 28. There was no substantial growth of cockle shell concrete after 28 days, although the control specimens tended to improve their intensity to a limited degree. These findings suggest that the strength of the cockle shell concrete depends on the volume of the replacement material of which the lower quantity of the replacement material yields at higher strength. Cockle shell concrete with a reduced volume of sand is assumed to contribute to isolation and bleeding of concrete. Adding more sand makes the concrete thicker and heavier. Apart from that, the disproportionate volume of sand used induces high cement use in concrete [64].

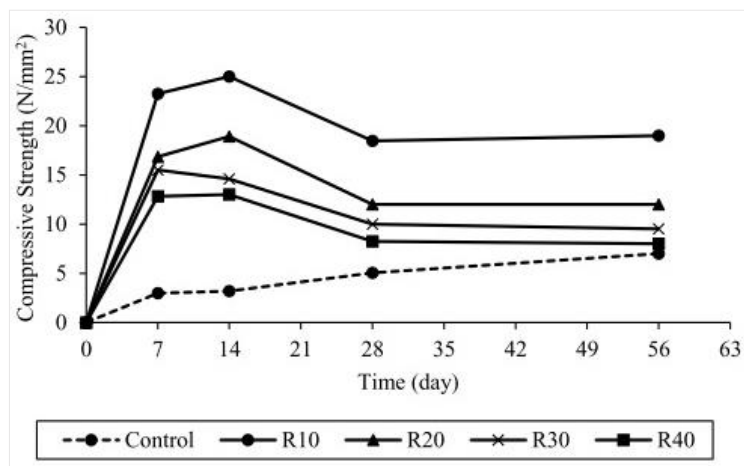


Figure 6. The effect of cockle shell as cement replacement on compressive strength [64]

The coarse aggregate, when mixed proportionally with cockle shell, may boost the concrete strength, according to researchers who study the use of cockle shell as a gross aggregate substitute. It is possible to demonstrate that a blend formed of a 20% cockle shell replacement displays the greatest compressive strength when compared to concrete created just from the cement and the aggregate. The rougher surface roughness of the coke shell lends strength to the bond and contributes to inter-particle friction, both of which contribute to the concrete's compressive strength. It can be shown in Figure 7 that a cockle shell content of too much greatly reduces the concrete's compressive strength [41,45]. It is justified because the cement paste won't be able to bind adequately if there is too much cockle shell, which increases the effective surface area [45]. In the paper by Raju [53], it has been discovered that when 15% of the coarse aggregate and 20% of the fine aggregate are used, the maximum compressive strength of concrete is found. The compressive power of this combination is 43.7 MPa while that of standard concrete is 30 MPa. The potential explanation for this effect may be that the C-S-H gel (formed due to the high content of silica in granite powder) strengthens the properties of the cockle shell by forming a coating over it [53].

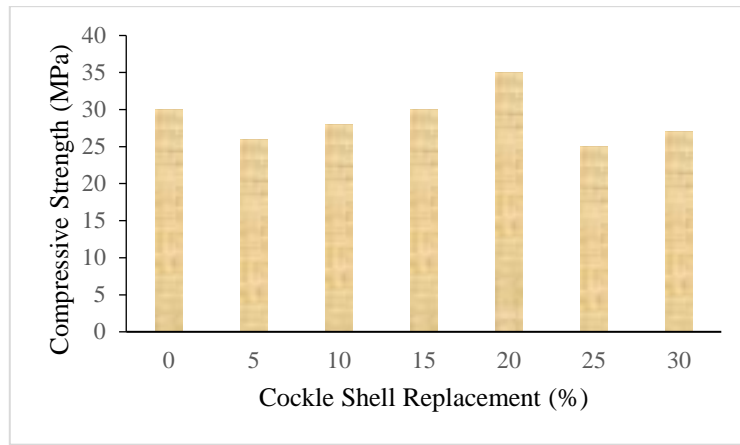


Figure 7. Compressive strength results for all replacement at 28 days [45]

In the other hand, by referencing Figure 8, it can be seen that integrating up to 20% crushed cockle shell waste improves compressive strength. Finely crushed aggregate is presumed to serve as a filler to make the inside of the concrete construction more compact. The more weight it can carry, the more concrete may be used [63].

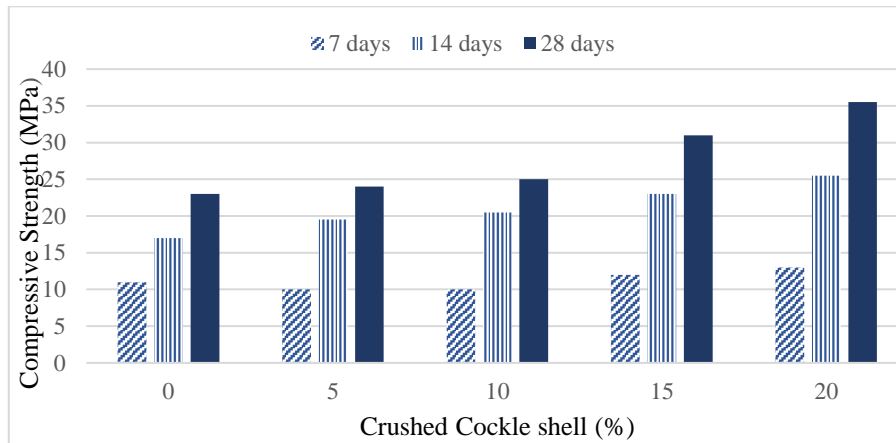


Figure 8. Compressive strength results for all replacement as sand replacement [63]

Flexural Strength

Cement replacement with flexural strength integration research is included in Table 4. It may be inferred from the Olivia [49] study that seashell concrete continues to gain strength after 28 and 91 days (refer Figure 9). Because of the calcium component of the cement, the paste and aggregate bonds were made stronger. Bonding has reduced tension qualities like as tensile and flexural strength. This will assist enhance the composite motion between steel reinforcing bars and concrete [49]. Meanwhile, the findings reveal that the flexural intensity declines with the ash of the cockle shell. At 90 days of curing, a decrease of around 10% for concrete with a cockle shell ash content from 5% to 10% compared to OPC concrete [55].

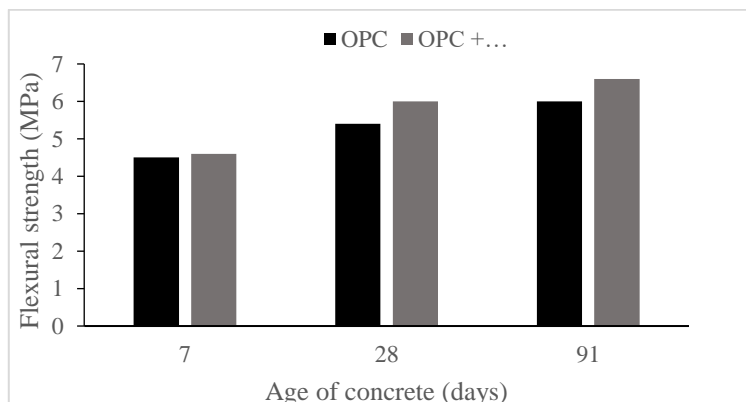


Figure 9. Flexural strength of concrete with 4% cockle shell powder replacement as cement [49]

According to researchers that handle cockle shell as a fine aggregate in concrete, the inclusion of crushed cockle shell waste up to 20% impacts flexural strength, as seen in Figure 10 [63]. However, flexural strength on cockle shell as coarse aggregate substitution in concrete are not investigated yet.

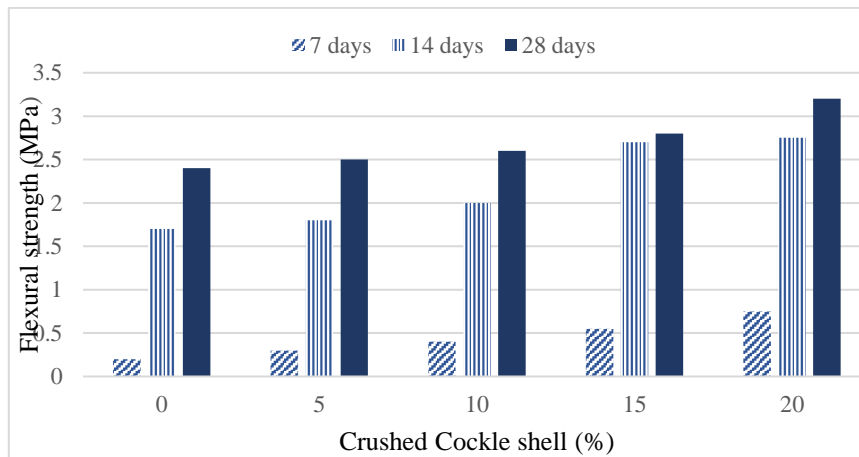


Figure 10. Flexural strength of crushed cockle shell as fine aggregate in concrete [63]

Tensile Strength

Table 4 summarises past studies on the integration of cement replacement at tensile strength. According to Olivia [49] experiment, the tensile strength of both OPC and OPC cockle shells increased steadily. After 28 days, the tensile strength of cockle shell concrete increased much more than that of OPC. It has been reported that the addition of 5% cockle ash increased the tensile strength significantly. This high tensile strength was probably achieved by improved interfacial bonding between the cement paste and particles. The field seashell will raise the density of the concrete, thereby altering the ITZ at the interface between the aggregate and the cement paste [49]. Olivia [50] discovered that the tensile strength of OPC cockle with a 4% cockle shell ash replacement was substantially less than that of OPC concrete. Other studies obtained similar findings regarding the tensile strength of OPC sea shells after the interaction of the aggregate-cement paste's bonding strength with the cement replacement [50]. Additionally, Hazurina [55] observed that combining concrete with cockle shell ash results in a significant increase in curing time of up to 90 days (refer Figure 11). As a consequence, the lengthy curing cycle is necessary to assure the uniformity of the concrete's strength as a consequence of the pozzolanic reaction and cement hydration [55].

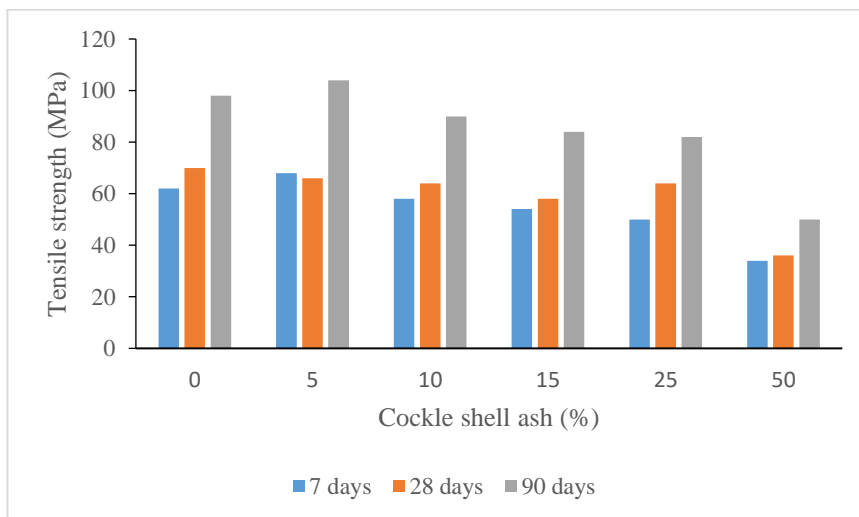


Figure 11. Tensile strength of cockle shell ash as cement replacement in concrete [55]

According to researchers who treat cockle shell as a gross aggregate in concrete, the tensile strength of concrete at 7 days and 28 days is steadily decreased as the percentage of substitution rises. However, a replacement between 10% and 20% is found to be more than conventional concrete and a replacement of 30% is found to be much smaller than anticipated (Table 5) [44]. Similar to Ramakhrishna [41], concrete is extremely fragile under stress as the cockle shell is substituted as a gross aggregate due to its quickly fractured existence and cannot withstand direct tension. It can be seen

through the results shown in Figure 12. Concrete cracks form as the load is exposed to tensile forces. It is therefore important to infer the tensile strength of the concrete at which the concrete member can crack.

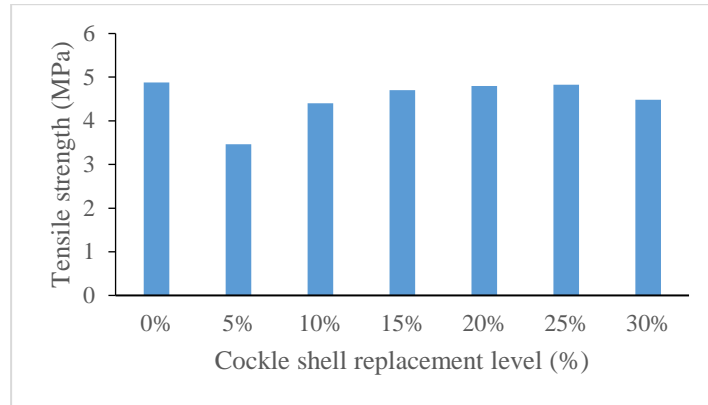


Figure 12. Splitting tensile strength of concrete containing various content of cockle shell as coarse aggregate at 28 days [41]

Table 5. Tensile Strength Results [44]

Sample no	% Replacement of fly ash and seashell	Split tensile strength N/mm ² (7days)	Split tensile strength N/mm ² (28days)
1	0	2.6	2.8
2	10	2.8	2.9
3	20	2.9	2.95
4	30	2.5	2.5

Modulus of Elasticity

The modulus of elasticity of concrete refers to the material's ability to bend under weight and then restore to its original proportions when the force is removed. Hazurina [55] found that a combination of 5% CSA and more than 10% as a cement alternative yielded a low modulus of elasticity (55). Olivia [49] found that the modulus of elasticity of cockle shell concrete was lower than the OPC (refer Figure 13). However, the elasticity of seashell concrete increased above OPC standards. Cement paste interfaces have a large impact on the modulus of concrete. improved friction qualities, such as the modulus of elasticity of seashell concrete As seashell concrete aged, the modulus of elasticity rose. Concrete including ground shell had substantially superior voltage characteristics, but poorer compressive strength and modulus of elasticity [49]. Conversely, modulus of elasticity for sand replacement and coarse replacement have not been studied yet.

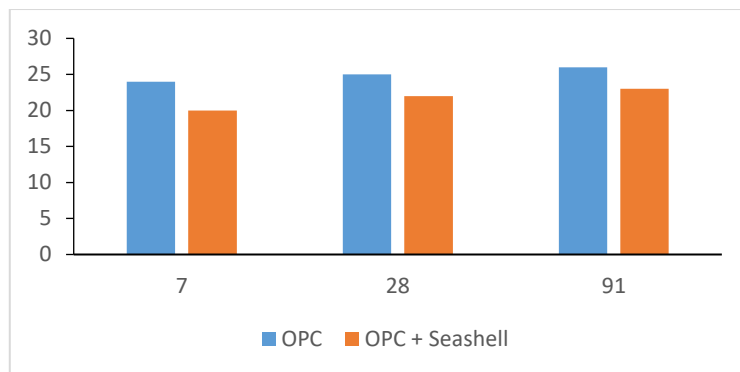


Figure 13. Modulus of Elasticity of OPC and seashell concrete at 7, 28, and 91 days [49]

CONCLUSION

This article discusses the qualities of cockle shell and the mechanical characteristics of cockle shell-containing concrete. The world's burgeoning population need an ever-increasing quantity of concrete. However, concrete manufacture has a severe impact on the environment, resulting in the depletion of these resources. Additionally, such

reuse of waste materials may have economic advantages. Cockle shell is one of these plentiful waste items, whose disposal is a significant difficulty in and of itself. By substituting cockle shell up to a specified percentage as a mixing material in concrete, the strength of the concrete is increased. Utilizing plentiful locally sourced waste materials as a substitute for non-renewable ingredients in concrete manufacturing would benefit both the environment and the economy. Additionally, it contributes to the reduction of excessive quarrying activity for raw material extraction.

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