A review on seashells ash as partial cement replacement

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Abstract. This review paper emphasis on various sea shells ash such as cockle, clam, oyster, mollusc, periwinkle, snail, and green mussel shell ash as partial cement replacement and its objective is to create sustainable environment and reduce problems of global warming. Cement production give huge impact to environment in every stage of its production. These include air pollution in form of dust and, gases, sound and vibration during quarry crushing and milling. One of the solutions to solve this problem is by using modified cement. The modified cement is a cementitious material that meets or exceeds the Portland cement performance by combining and optimizes the recycle and wasted materials. This will indirectly reduce the use of raw materials and then, become a sustain construction materials. Therefore, the replacement of cement in concrete by various sea shell ash may create tremendous saving of energy and also leads to important environmental benefits. This study includes previous investigation done on the properties of chemical and mechanical such as specific gravity, chemical composition, compressive strength, tensile strength and flexural strength of concrete produced using partial replacement of cement by seashells ash. Results show that the optimum percentage of seashells as cement replacement is between 4 – 5%.

1. Introduction
Concrete is one of the two most used structure materials in construction [1]. Every year, the used of concrete increasing 2 tonne for each people [2]. In order to reduce reliance of raw material in concrete producing, the green concrete had been promoted. Green concrete is the concrete that had been produced using recycle or wasted natural materials [3]. One of the ways to produce green concrete is by using modified cement. Cement is the second largest volume materials used by human being after water [4]. Cement plays the role of a binder, a substance that sets and hardens and might bind alternative materials along. During production of cement and hydration process of cement, the amount of CO₂ emitted by the industry is nearly 900 kg of CO₂ for every 1000 kg of cement produced [5]. This CO₂ production causes serious environmental damages.

The sea shells are high potential materials to become partial cement replacement and filler in concrete. The calcium carbonate (CaCO₃) in the sea shells is more than 90% and is similar to the contain of calcium carbonate in the limestone dust that been used in the Portland cement production [6]. Impressively, the crystal structures of seashells are largely composed of calcite and aragonite, which have higher strengths and density than limestone powder [7]. Also, the particle size of seashells is between 36μm to 75μm and are similar to the particle size of Portland cement [8].
2. Literature Review

2.1. Specific gravity

Table 1. Specific gravity of the seashells

| Researcher          | Type of seashell/Portland cement | Value |
|---------------------|----------------------------------|-------|
| Noel D. Binag       | Portland cement                  | 3.15  |
|                     | Oyster                           | 3.09  |
|                     | Mussel                           | 3.01  |
|                     | Mollusk                          | 3.01  |
| Lertwattananruk     | Portland cement                  | 3.11  |
| Pusit et al. (2012) | Oyster                           | 2.65  |
|                     | Mussel                           | 2.86  |
|                     | Cockle                           | 2.82  |
|                     | Clam                             | 2.71  |
| Adewuyi et al.      | Periwinkle                       | 2.50  |
| (2015)              | Oyster                           | 2.33  |
|                     | Snail shell                      | 2.44  |

Specific gravity is the ratio of the density of a substance to the density of a suggest substance; equivalently, it is the ratio of the mass of a substance to the mass of a suggest substance for the same given volume. In construction industry, the specific gravity is important to determine the suitability of materials that will be used in concrete production. The specific gravity also used to estimate the weight of the concrete. From Table 1, the specific gravity of the seashells was approximately similar to the Portland cement. Although the specific gravity among the seashells was different, the value was approximately similar to specific gravity of Portland cement. [9-10] found that the specific gravity of oyster is different which is 3.09, 2.65 and 2.33. But, this value is below than the Portland cement which was 3.15[9] and 3.11[8]. Also, from the table it can be concluded that the specific gravity value of oyster shell is 2.33 and it was the most suitable to be used as cement replacement compare to other seashells.

2.2. Chemical composition

Calcium carbonate has the common properties of other carbonate. It reacts with acids, releasing carbon dioxide.

\[
\text{CaCO}_3 + 2\text{H} \rightarrow \text{Ca} + \text{CO}_2 + \text{H}_2\text{O} \tag{1}
\]

It also produces carbon dioxide when heating above 840 °C to form calcium oxide, commonly called burnt lime or quicklime. Through thermal decomposition process known as calcination, CaCO₃ can be converted into calcium oxide (CaO) [22].

\[
\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \tag{2}
\]

Calcium carbonate also will react with water that is saturated with carbon dioxide to form the soluble calcium bicarbonate.

\[
\text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{Ca(HCO}_3)_2 \tag{3}
\]

According to the Table 2, the highest content of CaO was found in the clam shell [19]. The quantity of CaO in the seashells is sufficient to form silicates and aluminates of calcium. The deficiency in CaO will reduce the strength of cement. Also, the deficiency in CaO causes cement to set quickly.
Table 2. Chemical composition of seashells and Portland cement

| Chemical composition (%) | Type of seashells/Portland cement | Portland Cement | Clam<sup>a</sup> | Mussel<sup>b</sup> | Oyster<sup>b</sup> | Periwinkle<sup>c</sup> | Snail<sup>f</sup> | Cockle<sup>d</sup> | Clam<sup>e</sup> |
|-------------------------|----------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|----------------|----------------|----------------|
| SiO<sub>2</sub>         | 21.20                            | 0.84            | 0.73            | 1.01            | 26.26           | 10.20           | 1.6            | 0.39           |
| Al<sub>2</sub>O<sub>3</sub> | 5.47                            | 0.14            | 0.13            | 0.14            | 8.79            | 4.81            | 0.92           | 0.28           |
| Fe<sub>2</sub>O<sub>3</sub> | 3.31                            | 0.06            | 0.05            | 0.07            | 4.82            | 3.15            | -              | 0.02           |
| CaO                    | 65.52                            | 53.99           | 53.38           | 53.59           | 55.53           | 61.95           | 51.56          | 67.70          |
| MgO                    | 1.97                             | 0.08            | 0.03            | 0.46            | 0.40            | 0.18            | 1.43           | -              |
| K<sub>2</sub>O          | 1.71                             | 0.03            | 0.02            | 0.02            | 0.20            | 0.05            | 0.06           | -              |
| Na<sub>2</sub>O         | 0.46                             | 0.39            | 0.44            | 0.23            | 0.25            | 0.04            | 0.08           | -              |
| SO<sub>3</sub>         | 1.90                             | 0.16            | 0.34            | 0.75            | 0.18            | 0.03            | -              | -              |
| Cl                     | -                                | 0.02            | 0.02            | 0.01            | -               | -               | -              | -              |
| SO<sub>4</sub>         | -                                | 0.06            | 0.11            | 0.43            | -               | -               | -              | -              |
| CaCO<sub>3</sub>       | -                                | 96.8            | 95.6            | 96.8            | -               | -               | -              | -              |

Source: <sup>a</sup>[16], <sup>b</sup>[8], <sup>c</sup>[17], <sup>d</sup>[18],<sup>e</sup>[19]

2.3. Compressive strength

Table 3. Compressive strength of the seashells

| Type of seashell | Type of replacement | Grade | Control sample strength (MPa) | Optimum percentage of replacement (%) | Compressive strength (MPa) |
|-----------------|---------------------|-------|-----------------------------|--------------------------------------|-------------------------|
|                 |                     |       | 7 days curing               | 28 days curing                       | 7 days curing | 28 days curing |
| Periwinkle<sup>e</sup> | concrete            | -     | -                           | 17.5                                 | 10           | -             | 19            |
| snail<sup>f</sup>     |                     | -     | -                           | 17.5                                 | 20           | -             | 18            |
| oyster<sup>e</sup>   |                     | -     | -                           | 17.5                                 | 15           | -             | 16.5          |
| cockle<sup>d</sup>   |                     | 35    | 38                          | 45                                   | 5            | 34           | 36            |
| cockle<sup>c</sup>   |                     |       | 32                          | 36.5                                 | 4            | 31.5         | 36            |
| clam<sup>e</sup>     |                     |       | 33.8                        | 37                                   | 4            | 34           | 39.8          |
| oyster<sup>f</sup>   |                     |       | 31.6                        | 43.04                                | 5            | 28.59        | 37.59         |
| mussel<sup>e</sup>   |                     |       | 31.6                        | 43.04                                | 5            | 28.34        | 38.33         |
| mollusk<sup>e</sup>  | Masonry cement mortar| -    | 31.6                        | 43.04                                | 5            | 28.73        | 39.54         |
| clam<sup>f</sup>     |                     |       | 10.2                        | 14.9                                 | 5            | 9.9          | 12.6          |
| oyster<sup>f</sup>   |                     |       | 10.2                        | 14.9                                 | 5            | 9            | 13            |
| cockle<sup>f</sup>   |                     |       | 10.2                        | 14.9                                 | 5            | 8.5          | 12.6          |
| mussel<sup>f</sup>   |                     |       | 10.2                        | 14.9                                 | 5            | 9            | 10.5          |

Source: <sup>e</sup>[20], <sup>f</sup>[7], <sup>c</sup>[18], <sup>d</sup>[19], <sup>f</sup>[9], <sup>f</sup>[8]

For the compressive strength, there are two type of material that had been studied which were concrete and masonry cement mortar. Adekunle [20] stated that the concrete which contained periwinkle shell as partial cement replacement gained the most compressive strength compare to snail and oyster shell recorded at 19 MPa after 28 days curing which was higher than the control sample reading at 17.5 MPa. For the cockle, the concrete of grade 35 MPa had been made [7,18]. Although the material was the same, the optimum percentage of replacement was different which is 5% [7] and 4% [18]. According to Nor Hazurina et al. [7], the compressive strength of control sample for the 7 days curing is 38 MPa and it was higher than cockle shells concrete (34 MPa). While for the 28 days curing, the compressive strength of control sample was 45 MPa and the compressive strength for the concrete that use cockle shells as cement replacement was lower which is 36 MPa. But for the 4% of optimum...
percentage of replacement, the result was different. Olivia et al. [18] found that the compressive strength for the 7 and 28 days curing cockle shell concrete are 31.5 and 36 MPa respectively, while for the control sample, it was 32 and 36.5 MPa. From both result, it can be seen that the compressive strength of the cockle shell was lower than the control sample. But, its value is still exceeding the minimum strength of grade 35 MPa concrete. For the grade 35 MPa concrete using the clam shells, the result is different. According to Olivia et al. [19], the compressive strength of clam shell concrete was higher than the control sample which is 34 MPa (7 days curing) and 39.8 MPa (28 days curing) while for the control sample, the value was 33.8 MPa (7 days curing) and 37 MPa (28 days curing). Also, based on the Table 3, the clam shell was the only seashell that gains higher compressive strength than control sample. It can be concluded that the clam shell is the most suitable material to be used as cement replacement in concrete and the optimum percentage of replacement is 4%.

There are also a few research had been done on the use of seashells as cement replacement in cement mortar for masonry. Noel D. Binag [9] had been used oyster, mussel and mollusk shell in cement mortar while Lertwattanarak Puwit et al. [8] used clam, oyster, mussel and cockle shell as cement replacement materials. Both of the studies used 5% as an optimum percentage of cement replacement. Both studies also found that the compressive strength of 7 and 28 days curing cement mortar result is lower than the control sample. But the cement mortar result is still acceptable and can be used in construction industry.

2.4. Tensile strength

| Type of seashells | Researcher | Year   | Control sample tensile strength (MPa) | Optimum percentage of replacement (%) | Tensile strength (MPa) |
|-------------------|------------|--------|--------------------------------------|--------------------------------------|------------------------|
|                   |            |        | 7 days curing | 28 days curing | 90 days curing | 7 days curing | 28 days curing | 90 days curing |
| Cockle (Anadara Granosa) | Nor Hazurina et al. [7] | 2013   | 6.1 | 7.2 | 9.8 | 5 | 7.1 | 6.9 | 10.2 |
| Cockle (Anadara granosa) | Monita Olivia et al. [18] | 2015   | 4.5 | 5.5 | 6.1 | 4 | 4.6 | 6.1 | 6.7 |
| Clam (Polymesoda expansa) | Monita Olivia et al. [19] | 2017   | 2.7 | 3.3 | 3.6 | 4 | 2.5 | 3.15 | 3.25 |

From Table 4, Nor Hazurina et al. [7] found that the tensile strength of cockle shell concrete was higher than the control samples for 7 and 90 days curing. The strength of the concrete increases with the time when it is cured for longer duration [21]. The period of curing the concrete is important as it is very essential for keeping the hydration process of cement with water until the concrete attains the optimum strength. The longer curing duration also important to make sure the concrete strength was developed from the pozzolanic reaction [21]. Olivia Monita et al. [18,19] found that the tensile strength of the cockle and clam shells concrete are higher than the tensile strength of the control samples in 7, 28 and 90 days curing. It was reported that with an addition of 5% cockle ash, the tensile strength increased significantly [7]. Those highly tensile strength was likely due to the improved bonding at the interface of the cement paste and aggregates. The addition of the ground seashell could increase the density of the concrete, thus could change the interfacial transition zone phase between the aggregate and cement paste.
2.5. *Flexural Strength*

![Flexural strength graph](image)

**Figure 1.** Flexural strength of OPC and cockle shell concrete at 7, 28 and 91 days by using 5% of cockle shell as cement replacement [18]

The average flexural strength of seashell concrete and ordinary Portland cement (OPC) was shown in Figure 1. Entirely, the values varied in the range of 4.5-6.75 MPa. It shown that the flexural strength of seashell concrete will rise at 28 and 91 days. After 28 days, a considerable strength was gained probably due to calcium content in the cement that produced a better bonding between aggregates and paste. The tension properties was encourage by the bonding. This additional increase in tension properties is worthwhile to improve composite action between concrete and steel reinforcement bars.

3. **Type of seashells and it’s usage in concrete**

Table 5 shows a few types of seashell and how it was used in concrete mixture. [11,12,14] and [15] used different types of seashell to replace the coarse or fine aggregate in the concrete in range of 5% to 50% and found out that the compressive strength increased significantly. [13] had used oyster shells ashes to replace lime in production of cement based brick. It is showed that, at 15% replacement, the increment of the compressive strength was also significant.

| Researcher | Type of seashells | Application | Result |
|------------|------------------|-------------|--------|
| Martinez-Garcia *et al.* (2017) | Mussel shells | Replace coarse aggregate in concrete | Tensile strength increase at 5% replacement |
| Muthusamy *et al.* (2012) | Cockle shells | Replace coarse aggregate in concrete | Compressive strength increase at 20% replacement |
| Gengying Li *et al.* (2015) | Oyster shells | Produce cement based-brick using oyster shell ash | Compressive strength increase at 15% replacement |
| Sugiyama (2004) | Scallop shells | Replace coarse aggregate in concrete | Compressive strength decrease at 50% replacement |
|----------------|----------------|------------------------------------|------------------------------------------------|
| Yusof (2011)   | Clam shells    | Replace fine aggregate in concrete  | Compressive strength increase at 30% replacement |

4. Conclusion

From this review, we can say that the development of sea shell ash as partial cement replacement could be produce as a cement-like material where the particle size will be the same or finer than cement. Concrete with seashells as cement replacement will produce better concrete in term of chemical composition, specific gravity, compressive strength, flexural strength and tensile strength. It could be investigated by using difference types of sea shells to reduce environmental issues. Implicitly, this effort will create better benefit in future economic value to the local community and industries and also, provide better solution in concrete technology. Good values on developing the future of concrete industry should be expend through quality research among industry players and higher learning institutions to involve all parties into sustainable situation. Besides that, collaboration with local authorities through regulations and laws will create better opportunity to stake holders to come up with programs on waste minimization and utilization. Therefore, utilizing of waste materials such as sea shell in developing green concrete should be explored, expended and supported through focus researches. Development of green concrete should be proved through performance on hardened state and fresh state to understand the behaviour of each material either in long or short term effect.

5. References

[1] Neville A M 1996 *Properties of concrete 4th and final ed.* (Addison Wesley Logman) 43-44
[2] Harrison A W John 2003 New cements based on the addition of reactive magnesia to Portland cement with or without added pozzolan *CIA Conference: concrete in the third Millenium* CIA (Brisbane, Australia)
[3] Meyer Christian 2009 The greening of the concrete industry *Cement and concrete composites* 31 8 601-605
[4] Patel A J, Patel V M and Patel M A 2015 Review on Partial Replacement of Cement in Concrete *UKIERI Concrete Congress – Concrete Research Driving Profit and Sustainability* 17 831-837
[5] Mahasenan Natesan; Steve Smith; Kenneth Humphreys; Kaya Y 2003 The Cement Industry and Global Climate Change: Current and Potential Future Cement Industry CO2 Emissions *Greenhouse Gas Control Technologies – 6th International Conference* 2 995-1000
[6] Mosher Shad, Gregory W Cope, Frank X Weber, Damian Shea, and Thomas J. Kwak 2012 Effects of lead on Na+, K+-ATPase and hemolymph ion concentrations in the freshwater mussel Elliptio complanata *Environmental toxicology* 27 5 268-276
[7] Nor Hazurina Othman, Badorul Hisham Abu Bakar, Mashitah Mat Don and Megat Azmi Megat Johari 2013 Cockle Shell Ash Replacement for Cement and Filler in Concrete *Malaysian Journal of Civil Engineering* 25(2) 201–211.
[8] Lertwattanaruk Pusit, Makul N and Siripattarapravat C 2012 Utilization of ground waste seashells in cement mortars for masonry and plastering *Journal of Environmental Management* 111 133–141
[9] Noel D. Binag 2016 Powdered Shell Wastes as Partial Substitute for Masonry Cement Mortar in Binder, Tiles and Bricks Production *International Journal of Engineering Research & Technology* 5 7 70-77
[10] Arroyo G Maria Antonia, Macias P Katrina Anna, Tayzon M Karlo Emir, Lorenzo D Maria Abigail 2005 The Feasibility of a Mollusk Shell – Based Adhesive as a Substitute for Mortar Bato balani, Sophomore 24(2) 2004-2005

[11] Martínez-García Carolina, Belén González-Fonteboa, Fernando Martínez-Abella, and Diego Carro-López 2017 Performance of mussel shell as aggregate in plain concrete Construction and Building Materials 139 570-583

[12] Muthusamy K and Sabri N A 2012 Cockle shell: a potential partial coarse aggregate replacement in concrete International Journal of Science, Environment and Technology 14 260-267

[13] Gengying Li, Xiaoyang Xu, Chen E Jie Fan and Guangjing Xiong 2015 Properties of cement-based bricks with oyster-shells ash Journal of Cleaner Production 91 279-287.

[14] Sugiyama M. 2004 The Compressive Strength of Concrete Containing Tile Chips, Crushed Scallop Shells & Crushed Roofing Tiles, edited by Limbachiya M C & Roberts J J in Sustainable Waste Management & Recycling: Construction Demolition Waste, London, Thomas Telford Publishing 165-172

[15] Yusof M, Ujai S J J, Sahari F, Taib S N L & Noor Mohamed N H 2011 Application of Clam (Lokan) Shell as Beach Retaining Wall Proceeding of EnCon 2011: 4th Engineering Conference (Kuching, Sarawak)

[16] Limbachiya M C 2009 Bulk engineering and durability properties of washed glass sand concrete. Construction and building materials 23 1078-1083

[17] Etuk B R, Etuk I F and Asuquo L O 2012 Feasibility of using seashells ash as admixtures for concrete. Journal of environmental science and engineering 1 121-127

[18] Olivia, M., Mifshella, A.A. and Darmayanti, L., 2015 Mechanical properties of seashell concrete. Procedia Engineering, 125 760-764

[19] Olivia, M. and Oktaviani, R., 2017 Properties of Concrete Containing Ground Waste Cockle and Clam Seashells. Procedia Engineering, 171 658-663

[20] Adewuyi, A.P., Franklin, S.O. and Ibrahim, K.A. 2015 Utilization of Mollusc Shells for Concrete Production for Sustainable Environment. International Journal of Scientific & Engineering Research, 69 201-208

[21] Mehta P K and Monteiro J M 1993 Concrete: Structure, Properties and Methods, Second Edition (New Jersey: Prentice-Hall International (UK) Limited) 207-208

[22] Nor Hazurina Othman, Badourul Hisham Abu Bakar, Mashitah Mat Don and Megat Azmi Megat Johari 2013 Potential Use of Cockle (Anadara Granosa) Shell Ash as Partial Cement Replacement in Concrete Caspian Journal of Applied Sciences Research 2 369-376

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