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Study on Cockle Shell as Partial Sand Replacement in Concrete

Tengku Juliani Tengku Mamat*, Nur Alwani binti Abdul Latif** & Haliza binti Ab Karim***

* Politeknik Port Dickson, **Politeknikk Port Kuching, ***Politeknik Melaka

Abstract

Concrete is widely used in construction industry because of its economical factor and high durability characteristic in the long run. However, the production of concrete involves the use of natural resources such as river sand, mine sand and granite. The continuous demand from the industry on these natural resources will increase in the future which can lead to its depletion. This research investigates concrete's performance using crushed cockle shell as partial sand replacement towards workability, compressive strength and density characteristics of a concrete. Cockle shell used in this experimental work were crushed to smaller size, been graded as per sand distribution particles and was partially integrated in the concrete mix as a replacement for fine aggregate. A total of six concrete mixtures were developed with varying percentages of cockle shell which replaced river sand by weight from 0%, 4%, 6%, 8%, 10% and to 12%. Control mix using Ordinary Portland Cement was designed to produce concrete with target strength of 30 N/mm^2 at 28 days using 1:2:4 mixture. Finding shows that the optimum concrete strength achieved is at 4% mixture that is 36 N/mm^2. The said testing samples manage to attain the target strength which is 30 N/mm^2. While for workability properties, the mixture is workable for reinforced beam and column casting. However, the properties can be improved by using admixtures such plasticizers. Cockle shell can be the alternative material to a more environmentally friendly concrete that uses lower content of natural resources and most importantly, develop the required strength.

Keywords: cockle; concrete; cockle shell; concrete properties; concrete partial replacement

1. Introduction

Generally, high utilization of concrete in construction industry is because of its economical factor and high durability characteristic in the long run. However, the production of concrete involves the use of natural resources such as river sand for fine aggregate, as well as granite for coarse aggregate. The continuous demand from the industry on these natural resources will increase in the future which can lead to its depletion. The imbalance scenario of demand and supply will result in increasing cost for this concrete material. Anticipating to this issue, society recognizes the need to move towards a sustainable development. One of the efforts towards encouraging sustainable construction is by practicing resource efficient alternative. The utilization of natural resources can be replaced with a recycled material that costs less and normally just been disposed in land fill.

This research investigates concrete's performance using crushed cockle shell as partial sand replacement towards workability of concrete, compressive strength of concrete, and density of concrete. The cockle shell has been used as one of the mixing ingredients in concrete. This would expand the function of this waste thus the amount of waste ending up as environmentally troubling waste as well reducing the natural sand consumption. There will be unpleasant smell and disturbing view to the surrounding when there are shells that been dumped and left untreated. It is expected the availability of cockle shell as waste would be in bigger amount as well which will lead to negative impact to the nearby area by referring the growing cockle production which retail the value of cockles alone increased by 33.53% by RM 91.60 million in 2010 from 68.60 million the previous year (Fisheries, 2010).

2 Literature Review

Concrete is a construction material that is widely used throughout the country. It's strong and workability make concrete the material of choice compared to other materials such as wood and steel. The most common form of concrete is Portland cement concrete, which consists of mineral aggregate (generally gravel and sand), Portland cement and water. Contrary to common belief, concrete does not solidify from drying after mixing and placement. Instead, the cement hydrates, gluing the other components together and eventually creating a stone-like material. During hydration and hardening, concrete needs to develop certain physical and chemical properties, among others, mechanical strength, low permeability to ingress of moisture, and chemical and volume stability.

Concrete contains numerous flaws and micro cracks. The rapid propagation of micro cracks under an applied load is considered responsible for the low tensile strength of concrete. It is reasonable to assume that the tensile strength as well as the flexural strength of concrete can be substantially increased by introducing closely spaced fibers.

These fibers would arrest the propagation of micro cracks, thus delaying the onset of tensile cracks and increasing the tensile strength of the material (Yin and Hsu., 1995). Concrete is a composite material made of water, cement, aggregates of aggregates coarse and fine aggregates. (M.L.Gambhir, 2014). The most important property of fresh concrete is its workability or flow-ability, because this determines the ease with which it can be placed. It is determined using a slump test, in which a standard truncated metal cone form is filled with fresh concrete. Workability of the concrete shall be within one of the following limits:

Table 1 Limits of workability test (PWD, 2005)

Type of Test	Limits of the test
Slump	± 25mm or ± one third of the 'designed workability', whichever is greater
Compacting Factor	Compacting Factor ± 0.03 where the 'designed workability' is 0.9 or more. ± 0.04 where the 'designed workability' is between 0.8 and 0.9. ± 0.05 where the 'designed workability' is 0.8 or less.
Vebe	± 3 seconds or ± one fifth of the 'designed workability' whichever is lesser.

Besides, the most important property of hardened concrete is its compressive strength. Since this strength continues to increase with continuing cement hydration, it is a function of age which is the time after casting. In Malaysia, the strength is determined 7 or 28 days after casting by loading standardized test cylinders up to failure.

Table 2 Compressive Strength Requirements for Prescribed Mix
(Malaysia Public Work Department, 2005)

Grades of Concrete	28-day Strength of Concrete (N/mm^2)	Cube Strength at 7 Days* (N/mm^2)	Average Cube Strength at 28 Days*(N/mm^2)
20P	20.0	14	20.0
25P	25.0	17	25.0
30P	30.0	20	30.0
40P	40.0	27	40.0

2.1 Mixed Concrete Materials

2.1.1 Cement

In concrete, the most commonly used is Portland cement. Cement is the "glue" that binds the concrete ingredients together and is instrumental for the strength of the composite. Portland cement is made up primarily of four mineral components (tricalcium slilicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite) (Meyer, 2003) each of which has its own hydration characteristics.

In Malaysia, the Standard Specification for Building Works 2005 by Public Work Department state that the cement to be used throughout the Work shall be Portland cement obtained from an approved manufacturer. The cement shall be described under the following headings:

i) Ordinary Portland Cement to comply with MS 522
ii) Rapid Hardening Portland Cement to comply with MS 522
iii) Sulphate Resisting Portland Cement to comply with MS 1037
iv) Portland Pulverized-Fuel Ash Cement to comply with MS 1227
v) Portland Slag Cement to comply with MS 1389

2.1.2 Aggregate

The aggregate accounted for 70% to 80% of the volume of concrete and with this it's a big influence on the properties of concrete. Aggregates intended as a cementing medium to produce mortar or concrete. Aggregates can be obtained from natural sources and industrial waste. Materials commonly used as aggregates is like sand, dust probes, gravel, crushed stone, slag (molten ore tailings), clinker etc. Stone aggregates shall be of a material that is hard, durable and clean. (M.S.Shetty, 2005). Most concrete aggregate are several times stronger compare to the other components in concrete when determining the strength of normal concrete.
Aggregate is classified as two different types which are fine and coarse. Fine aggregate is usually less than 5 mm while coarse aggregate is usually greater than 5 mm. (Halim, 2014)

2.1.3 Fine Aggregates

In order to get a desirable mixture, physical properties of aggregate is very important to be known before mixing concrete. Shape and texture, size gradation, moisture content, specific gravity, reactivity, soundness and bulk unit weight are the example of the properties. The strength, workability, and durability of concrete can be determined by the properties along with water or cementitious material ratio. The properties of fresh concrete easily affected by the shape and texture of aggregate compare to hardened concrete. Instead of rough angular or elongated aggregate, concrete is more workable when smooth and rounded aggregate is used.

Therefore, riverbeds or seashores are the suitable places to get most natural sands and gravel which are smooth and rounded as there are the excellent aggregates can be found. A workable mixture can be produced by using crushed stone where it produces much more angular and elongated aggregates. Bond between aggregate and cement paste is an important factor in the strength of concrete, especially the flexural strength, but the nature of bond is not fully understood. Bond is due, in part, to the interlocking of the aggregate and the hydrated cement paste due to the roughness of the surface of the former. A rougher surface, such as that of crushed particles, results in a better bond due to mechanical interlocking; better bond is also usually obtained with softer, porous, and mineralogically heterogeneous particles. (Neville, 2011)
Fine aggregates shall comply with MS 29. In the context of MS 29, the term 'sand' is used to mean 'fine aggregate'. If it is found necessary, the fine aggregate shall be washed and screened to the approval of the S.O. (PWD, 2005) The grading of fine aggregates shall be analysed as described in MS 30 and shall be within the limits specified in Table 3.

Table 3 Grading For Fine Aggregate (Malaysia Public Work Department, 2005)

Sieve size (BS 410)	Percentage by mass passing BS 410 sieve			
	Overall limits	Additional limits for grading		
		C	*M	F
10.0mm	100	-	-	-
5.00 mm	80 to 100	-	-	-
2.36mm	60 to 100	60 to 100	65 to 100	80 to 100
1.18mm	30 to 100	30 to 90	45 to 100	70 to 100
600 μm	15 to 100	15 to 45	25 to 80	55 to 100
300 μm	5 to 70	5 to 40	5 to 48	5 to 70
150 μm	0 to 15#	-	-	-

Increase to 20% for crushed rock fines, except when they are used for heavy-duty floors.
* For prescribed mix only Grading Limit M is applicable. See also clause 2.2.3(b).
NOTE: Individual sands may comply with the requirements of more than one grading. Alternatively some sands which satisfy the overall limits but may not fall within any one of the additional limit C, M or F may also be used provided that the supplier can satisfy the S.O that such materials can produce concrete of the required quality.

2.1.4 Water

Based on standard specifications for building works 2005 by Public Work Department, water shall comply with the requirements of MS 28. It shall be clean and free from materials deleterious to concrete in the plastic and hardened state and shall be from a source approved by the Superintendent of project. Contractor should carry out chemical tests at any approved laboratory.

2.2 Alternative material

2.2.1 Cockle shell

Cockle shell is a group of mostly small, edible, saltwater clams, marine bivalve molluscs in the family Cardiidae is known as cockle (Lamarck *et. al.,* 1809). True cockles live in sandy, sheltered beaches throughout the world. The shell of a cockle is able to close completely (i.e., there is no "gape" at any point around the edge). The distinctive rounded shells of cockles are bilaterally symmetrical, and are heart-shaped when viewed from the end.

Cockle shell also one of the seashell that contributed to the plentiful waste shell. Based on annual Fisheries statistic 2010, the growing cockle production increased 33.53% from previous year. (Fisheries, 2010). This at once will be unpleasant smell and disturbing view to the surrounding when there are shells that been dumped and left untreated (Mohamed et. al., 2012). However we can solve this issue through applying the waste shell in green technology as a green concrete.

Shell has three openings inhalen, ekshalen and pedal to drain the water and to remove the leg. The difference in physical characteristic of the denser granite aggregate compared to the curved and roughly parabolic shape of the textured cockle shell is also one of the factors lowering concrete workability. (N.Sabri, 2012). However, the surface texture of cockle shell which is rougher than granite aggregate improves bonding and increases inter particle friction which is turn enhances the compressive strength of the concrete.

The influence of surface texture of coarse aggregate towards concrete workability has been discussed by Mindess, Young and Darwin (S. Mindess, 2003) who highlighted that the use of smooth particles for concrete mixing would produce more workable than the one consisting rougher particles.

So that, the crushed shells have better permeation properties than the concrete without seashells. (Monita Olivia, 2015). This is partly because the shapes and configuration in the mixture could reduce the turtoisty of pores in concrete.

2.3 Lightweight Concrete

In Malaysia, the usage of lightweight concrete is low because there is a lot of coarse aggregate available on the market. The use of lightweight concrete not widely used probably because it involves higher costs, lack of knowledge, experience, expertise and material to produce lightweight concrete is not enough in market. (Fathi, 2008). Foreign countries such as German supplies to Malaysia lightweight aggregates such as clay, shale or slate such as vermiculite and rock slag as an alternative material. These alternative materials are produced from raw materials developed 2 times compared to the original volume. (Zaniewski, 2006). This material has been developed further to become less dense and will help generate concrete lighter. The cost of lightweight aggregates is expensive compared to the aggregate / natural rock because of the difficulty in producing and supplying the aggregates. This situation encourages the construction industry players to use natural stone in their construction projects. Therefore, decreasing of natural resources has increasing an awareness in people to protect the environment. The use of waste as construction material is the best alternative for addressing this issue, without risking the security forces and that the core of the project. Production of lightweight concrete will facilitate the handling of the concrete at the construction site and reduce the number of workers on construction sites. (Fathi, 2008)

3 Methodology

Materials

The cement used in this study was Ordinary Portland Cement (OPC) complies with the Type 1 Portland Cement as in ASTM C150. Coarse aggregates used was a granite coarse aggregate of 20mm maximum size while for fine aggregate, river sand was used for optimum result. Cockle shell was partially integrated in the concrete mix as a replacement for fine aggregate/ sand. The cockle shells in Figure 1 were collected from the local seafood stall. The shells were cleaned, dried, crushed and grounded until it turns into small-grained particles, similar to the sizes of sand. The grounded shells in Figure 2 were then sieved using a sieve size of passing 0.06mm and retained at 2.36mm in Table 4. The gradation using Sieve Analysis Method in of the particles Figure 4 showed that the sample can be considered as sand.

Figure 1 Cockle Shell

Figure 2 Crushed Cockle Shell

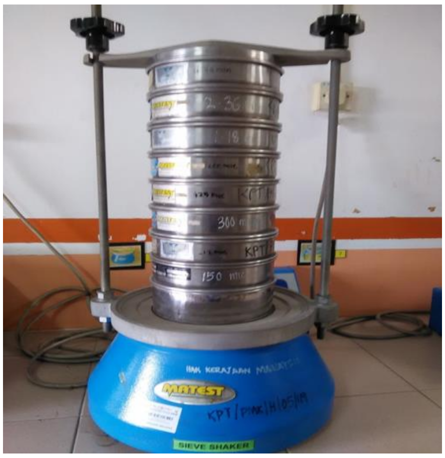

Figure 3 Sieve Analysis Equipment

Table 4 Sieve Analysis Data

No.	Sieve Size (mm)	Mass Of Retained Soil (g)	Mass Of Passing Soil (g)	Percentage Passing (%)
1	4.75	0.3	99.7	99.7
2	**2.36**	0	99.7	**99.7**
3	1.18	72.4	27.3	27.3
4	0.425	6.5	20.8	20.8
5	0.212	2.2	18.6	18.6
6	**0.06**	12.5	6.1	**6.1**
7	0.015	1.6	4.5	4.5
8	PAN	4.5	0	0
		100		

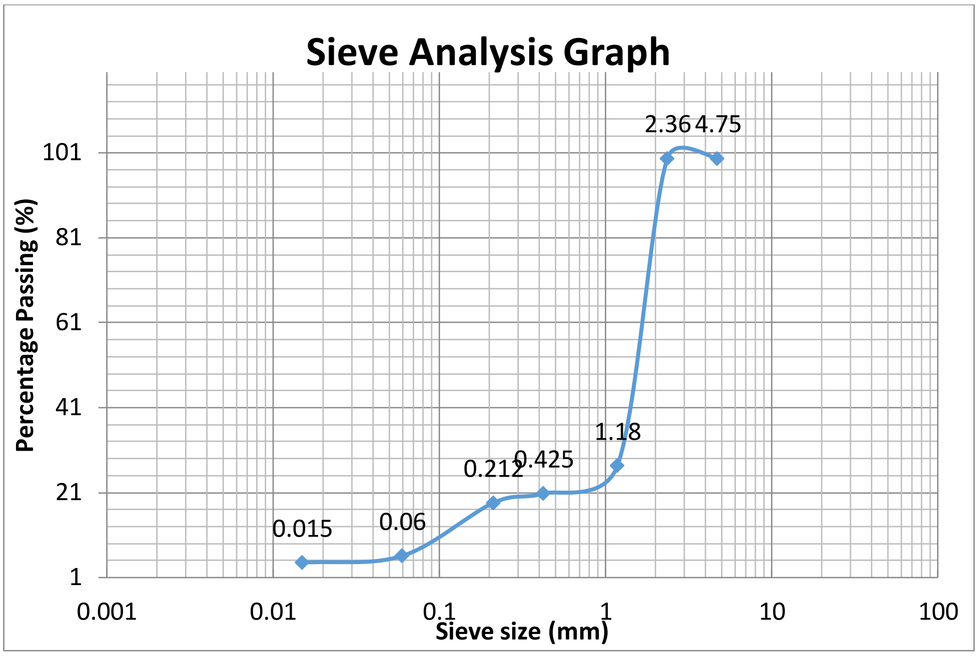

Figure 4 Sieve Analysis Graph to a crushed cockle shell as sand replacement

3.2 Mix Proportion

As a guideline for data analysis, control samples were developed. The OPC control mix was designed to produce concrete with target strength of 30N/mm^2 at 28 days using 1:2:4 mixture ratio as per Table 5. Control sample was produced by using 100% of river sand in the concrete mixture. While for testing samples, 5 mixture proportions of Cockle Shell Samples (CS) were made to observe the performance of cockle shell particle. Cockle shell gradually replaced river sand by weight from the range of 4% to 12%. Meanwhile CS 0% was considered has no cockle shell content because it was created as a control concrete in this study. Table 6 shows the designed cockle shell mixture proportions. Throughout the experiments, water to cementitious material ratio (w/b) used was 0.55.

Table 5 Concrete Mixture Ratio (Jabatan Kerja Raya, 2014)

Mixture Ratio	Usage
1:5:10	Sites walls in the trenches for hard underground work
1:3:6	Concrete slab, walls and etc
1:2:4	**Reinforcement concrete for column and beam**
1:1.5:3	Pre-stress concrete, tank and etc

Table 6 Cockle Shell Mixture Ratio

Ratio	Material
1	Cement
2	Sand/Cockle Shells(CS) CS 0% CS 4% CS 6% CS 8% CS 10% CS 12%
4	Aggregate

For each percentage concrete mixture, three (3) samples were cast in 150mm x 150mm cubes and after 24 hours of moulding, the cubes were demoulded. Then, cubes were placed in water curing tank until age of testing.

Figure 5 Concrete Cube Test

3.3 Testing Method

3.3.1 Compressive Strength

Figure 6 Compressive Strength Test

The compressive strength test was carried out based on BS 1881-116:1983. At each testing age, the samples were removed from the curing tank and weighed. The samples were centrally placed in compression testing equipment and a load was applied. The load at the failure divided by the area of the specimen was taken as the compressive strength of the concrete. The strength properties were then determined by conducting compressive strength test. The reported data were collected from the average of three (3) compressive strength test results.

3.3.2 Slump Test

Figure 7 Slump Test

Generally, slump test measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete, and therefore the ease with which concrete flows. It can also be used as an indicator of an improperly mixed batch. The test is popular due to the simplicity of apparatus used and simple procedure. The slump test is used to ensure uniformity for different loads of concrete under field conditions. The slump mould was placed on a horizontal and rigid surface. The mold was then filled on four layers with freshly mixed concrete, each approximately up to one-fourth of the height of the mould. Each layer was tamped 25 times by the rounded end of the tamping rode. The mould was removed from the concrete immediately by raising it slowly in the vertical direction. The difference in level between the height of the mould and that of the highest point of the subsided concrete was measured.

3.3.3 Density Test

The density of concrete is measured of its unit weight. Concrete weight is mixture of cement, sand, coarse aggregates, water, and air content. Density is simply a mass of concrete to volume of concrete ratio. Density of lightweight concrete is less than 2000kg/m^3. Procedure of measure the density of concrete is by placing concrete cube in weighting scale after 24 hours out from curing tank. Weight of each cube were taken for 7 days and 28 days. Average weight were recorded and devide by the volume of cube.

4 Results and Findings

4.1. Compressive Strength

The results of the compressive strength for various mixes are shown as in Figure 6. It shows that the compressive strength of CS concrete, reduced as the replacement of clock shell increases. Nevertheless, strength of concrete with replacement of clock shell by 4% manages to attain the target strength with strength value of 36 N/mm^2.

Table 7 Cockle Shell Concrete Compressive Strength Data

Sample of Concrete	Compressive Strength (N/mm^2)	
Concrete Age /	7 days	28 days
0 %	22	31
4 %	25	36
6 %	26	31
8 %	28	29
10 %	20	21
12 %	11	20

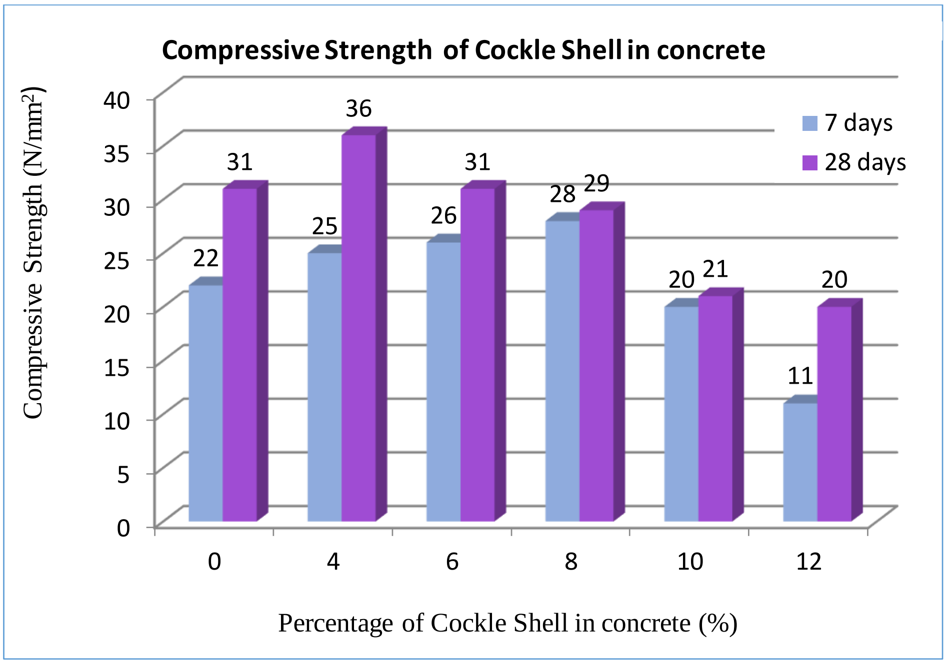

Figure 6 Cockle Shell Concrete Compressive Strength Data

4.2 Slump Test

The results of the slump test for control sample and CS specimens are shown in Figure 7. It shows that with the higher replacement of clock shell, there is tendency that the concrete mixes become stiffer. The most workable concrete was obtained by the CS4% with 27.5mm slump value which is workable for reinforced beam and column casting. However, the workability properties can be improved by using admixtures.

Table 8 Cockle Shell Concrete Slump Test Data

Cockle Shell in Concrete (%)	Slump Test (mm)
0	28
4	28
6	27
8	27
10	26
12	25

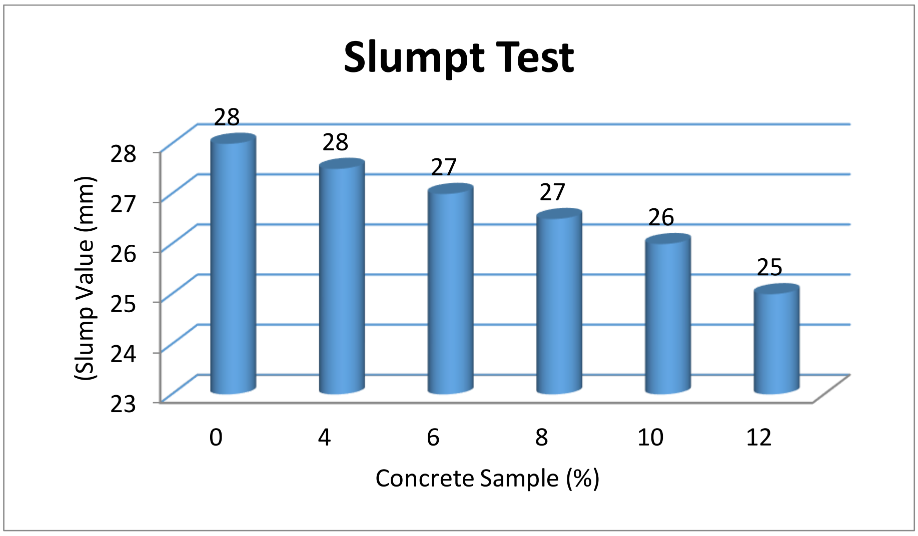

Figure 7 Cockle Shell Concrete Slump Test Data

4.3 Density

In order to produce lightweight concrete, density of concrete is an important factor other than concrete strength. Based on the data analysis above, density for sample cockle shell fluctuated when percentage of cockle shell is added more. An average value of concrete density that produced at 7 days 2181 kg/m^3 therefore for control specimen produced average value in Table 9 of density 2259 kg/m^3. Average value of concrete density produced at 28 days 2242 kg/m3 therefore for control specimen produced average value of density 2259 kg/m^3. Refered on criteria for lightweight concrete density below 2000kg/m^3 is categorized as lightweight concrete. So the study did not meet the requirements for lightweight concrete density.

Table 9 Cockle Shell Concrete Density Data

Cockle Shell in Conrete	**0%**	**4%**	**6%**	**8%**	**10%**	**12%**	**Average Density 4%-12%**
7^{th} Day Average Density (kg/m^3)	2259	2121	2241	2244	2197	2100	2181
28^{th}Day Average Density (kg/m^3)	2259	2282	2242	2212	2211	2261	2241

4.4 Cost of Concrete

The underlying fact in every production of concrete is savings in cost of material, so that there is no hindrance on its adoption on a large scale or mass production. Only when the products are cost effective they will reach the common man. Cost rate of each material calculated below based on market price in Melaka such as 1 bag of cement (50kg) is RM16.50, sand (68.61kg) is RM15 and coarse aggregate (147.02kg) is RM30. Total cost of concrete per ratio using cockle shell has reduced from 1.1% to 3.3% compare to control sample concrete 0%.

Table 10 Cockle Shell Concrete comparison cost

Cockle Shell %	**Cement (kg)**	**Sand (kg)/**	**Cockle Shell (kg)**	**Agreggate (kg)**	**Cost (RM)**	**Reduce Cost (%)**
Ratio	1		2	4		
CS 0%	0.33	0.44	0	0.82	1.58	0
CS 4%	0.33	0.42	0.02	0.82	1.57	1.1
CS 6%	0.33	0.41	0.03	0.82	1.56	1.7
CS 8%	0.33	0.40	0.03	0.82	1.55	2.2
CS 10%	0.33	0.39	0.04	0.82	1.54	2.8
CS 12%	0.33	0.38	0.05	0.82	1.53	3.3

5 Conclusion

The study shows that cockle shell can used as partial replacement of fine sand, and it is possible to obtain cockle shell concrete that complied with the standard used and achieved target strength. Data obtained suggest that crushed cockle shell should be used at 4% sand replacement. Slump test result shows the concrete are low in workability due to the rough shape of cockle shape itself. Anyway, workable of concrete but can be improved by using admixtures such as water-reducing or superplasticizer agent. Other than that, usage of cockle shell in concrete mixture can reduce the cost of concrete materials up to 3.3%. Producing of crushing cockle shell as a sand replacement will open to a wide business opportunity in the construction industry. This research is to propose waste material as an environmentally friendly concrete with lower content of sand as natural resources and most importantly, better strength compare to normal concrete.

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