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Effect of green mussel (*Perna Veridis*) shell powder as partial fine aggregate replacement on the mechanical properties of concrete

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Abstract. Depletion of natural resources is one of sustainability problem which requirement to address in efficiently. Nowadays, the trend in construction industry is to use the alternative source of construction materials which can substitute the use of new materials. The aim of this attempts is to reduce environmental impact in terms of energy consumption, pollution, waste disposal and global warming. As an alternative solution to reduce waste quantity by utilizing it in construction materials. Thus, this study was carried out to identify the physical properties of the mussel shell powder as partial fine aggregate replacement and to define the optimum percentage of mussel shell powder in concrete based on its physical and mechanical properties. The percentage of mussel shells powder used in this study were 0%, 10%, 20% and 30% (C100, C10MSP, C20MSP and C30MSP). The total 48 cubes sample size, 100mm x 100mm x 100mm were used and tested on its compressive strength and capillary water absorption test for 7 and 28 curing days. The result shows that specific gravity of fine aggregate is lower than mussel shells powder which was 2.76 and 2.90. Based on compressive strength resulted, C20MSP has high strength (35.9 MPa) compare to another concrete mixes. While for the water capillary absorption resulted that C30MSP has the low average water capillary absorption (0.12cm/s). Therefore, for the mechanical properties of this research, it can be concluded that mussel shell replacement should be in average between 20% to 30% of fine aggregates. Furthermore, the high content of calcium carbonate ($CaCO_3$) in chemical composition of mussel shell powder act as a filler in concrete and promoting early hydration process.

1. Introduction

Concrete is one of the most used materials in construction sector and its properties have undergone many modifications through technological advances [1]. It is importance not to underestimate of concrete ability since it plays a prior material in the construction industries. Concrete also is a material that is regarded as the most applied construction material for various purpose of building and compare to other materials [2]. Generally, concrete is made from mixture of water, cement, coarse aggregates, and fine aggregates [3]. Predominantly in manufacturing concrete, natural aggregates were used [4]. The sand and coarse aggregate are harvested from the river and mountains. The aggregate that is used has effect on the workability, strength and durability of concrete [3]. The developing concrete production to meet the need of increasing construction project for building and infrastructure also demands for more aggregate supply. The demand for sand has risen radically because of modernization and increasing urbanization worldwide [5]. The unregulated aggregate harvesting industry has a negative impact on the environment. Sand scarcity is caused by excessive sand mining, which poses a hazard to aquatic habitat, water supply, sedimentation, marine food, and the environment [6]. In most countries, indiscriminate river sand and gravel mining causes irreversible damage to river ecology, as well as inland regions and flood plains [7]. Aside from that, quarry facilities' total manufacturing process includes extraction, crushing, grinding, and filtration, all of which consume a lot of resources and add to carbon emissions [8]. The strategy of using alternative materials as natural aggregate replacements would allow this resource to be preserved for future generations.

Furthermore, the availability of wastes generated by agricultural, aquaculture, and industrial operations enables the current work to assess the potential of these materials as aggregate substitutes in concrete. Mussel shells, for example, can be used as a partial material in concrete for fine aggregates or cement. The application of additional materials from waste in concrete had become a new approach such as mussel shell, oyster shell, etc. [9]. According to several researchers, the addition materials partially improving concrete performance and quality. Application of waste and recycled materials can produce high-strength, durable concrete, cost saving and reduce environmental pollution [10]. Thus, application of mollusc waste is convenient to be applied in concrete designing.

The mussel which known as *Perna viridis* is a type of bivalve mollusc that can be found in rivers and beaches. It was affordable and rich of protein [11]. According to Chairman of the South Johor Area Fishermen's Association, the coastline around Pasir Gudang is an industrial area as it is the largest mussel production in Malaysia [12]. Covering an area around 1 km^2, this mussel farm is developed through traditional methods and uses high technology known as smart farm [13]. Based on statistics released by the Department of Fisheries Malaysia, mussel farming in Malaysia has received a high response with increasing number of productions every year and becoming a major income to the economic growth. Table 1 shows the mussel farming statistics in Malaysia [12].

Table 1. Mussel farming statistics in Malaysia [12]

Year	Production (Metric tons)
2019	1220.63
2020	1363.12
2021	1472.51

According to Mosher *et al.* [13] mussel shell is a potential material that are suitable to be applied in concrete. Its content high percentage of calcium carbonate ($CaCO_3$) which is more than 90% and similar to the calcium carbonate content in limestone powder used in manufacturing ordinary Portland Cement [14]. More interesting, the crystal structure of mussel shell will produce a large quantity of calcite and aragonite that generates strength improvement compared to limestone powder [15]. Thus, makes mussel shell a suitable material to be used as a partial fine aggregate replacement. Therefore, the aim of the study is to determine the optimum percentage of mussel shells powder and its ability in improving concrete physical and mechanical strength through capillary absorption and compressive analysis.

2. Literature Review

Malaysia, which is known as coastal countries, consumes about $1.6x10^6$ metric tonnes of seafood per year with a trade value of RM4.2 million [16-19]. Besides on high demand among consumers, it also lost monetary cost. This is due to the high growth rate and weather-independent reproductive ability

[20]. Although the mussel breeding industry has contributed to the economic development of fisheries, especially in the Southern region of Malaysia, however mussel shell waste has become a worrying environmental problem due to waste generated from this sector [21]. This is seeming in areas with high statistics of canning factories and seafood restaurants. About 1 million tons of mussel shells worldwide have becoming an environmental alarm and impending issue in term of disposal management [22]. Improper disposal methods can affect water quality thus inhibiting the growth of other aquatic life [23]. In addition, mussel shell waste that has been discarded for a long time giving unpleasant odours as a result of the decay of the mussel meat or the microbial decomposition of salts into gases such as ammonia, hydrogen sulphide and amines [24-25]. In recent years, the field of construction has become increasingly aware of the need to change towards sustainability. Therefore, using mussel shells waste have been developed in recent as a building material, using it as an aggregate or filler to incorporate into concrete or mortar [26]. Mussel is a common name used for some of the bivalve mollusk species in saltwater habitats [26]. The most common species of mussel in Malaysia is the Asian green mussel (*Perna viridis*) [18]. The green mussel is a large bivalve shell with smooth and long skin. It has a uniform bright green, but pale to brown with a green margin on the mature part [20]. This group has a general shape outline is elongated compared to other edible shells, which are often rounder or oval. The outer shell of the mussel consists of two hinged parts or "valves". The valve is joined outward by a ligament and closed, when necessary, by strong internal muscles [27]. Figure 1 shows the mussels and the muscles between them. During the period of 12-15 months, the mussels reach a size (40mm) and are ready for harvest. The method for harvesting depends on the livestock area and the breeding methods used.

Figure 1. Mussel shell

Generally, mussel shell is made up of several layers of calcium carbonate. The X-ray diffraction technique (XRD) proves that the mussel shells are made from calcite with a small amount of aragonite as shown in Figure 2 [21]. Barbachi *et al.*, are also confirming the same results showing calcium carbonate contains in the range of 94% [28]. It is extremely durable and multiply in terms of breeding that produce them over a very long period and sometimes thousands of years. They become fossils easily and large amounts that form sediment and become compressed limestone (calcium carbonate) [29,30 & 31].

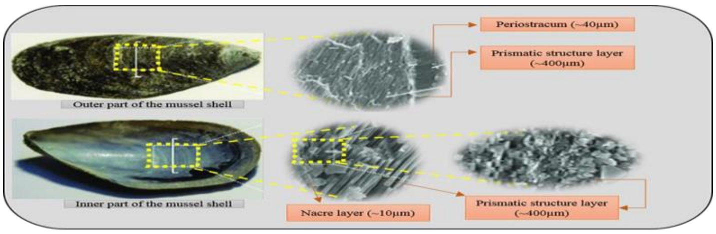

Figure 2. Description and SEM of mussel shell structure [21].

Commonly, mussel shells have no commercial and market values [32]. However, chemical and microstructural analyses revealed that mussel shell contains approximately over 90% calcium carbonate ($CaCO_3$) [33]. According to previous studies, the content of chemical composition in mussel skin is very useful for concrete designing and manufacturing. The chemical composition in mussel shell will affect the concrete strength due to calcium carbonate ($CaCO_3$) content which is higher than other oxide compositions. Thus, the utilization of mussel shell is expected enhance the strength of concrete.

3. Experimental Analysis

In this study, Ordinary Portland cement, coarse aggregates, water, fine aggregates and mussel shell powder were used. The mussel shell powder is applied as a partial replacement for fine aggregate which was replaced with mussel shell powder size of less than 50mm as shown in Fig 3. The physical properties of mussel powder and fine aggregate tested on sieve analysis (BS EN 12620:2002+A1:2008) and specific gravity (ASTM C128-01). The concrete cubes sizes used is 100mm x 100mm x 100mm. The laboratory test procedures are based on BS EN 12390-3:2019, BS EN 12390-7:2019, BS EN 197-1:2011 and RILEM CPC 11.2 Standard [34-37].

Design of Normal Concrete Mixes [42] method was applied with appropriate ratio for concrete mixes. The percentage of mussel shell powder to be used is 0% (NC), 10% (C10MSP), 20% (C20MSP), and 30% (C30MSP). The total sample number are 48. The curing period was on 7 days and 28 days and involving slump test, density test, compression test and water capillary absorption test. According to this study, water capillary absorption was analysed to determine the rates of water absorption through its capillary which been measured according to its weight specimens when contact with bottom surface of specimens only. This is because tape will be wrap on surrounding surface of specimens to prevent absorption on another surface. This test was carried out according to RILEM CPC 11.2 Standard [37].

Figure 3. Green mussel shell (*Perna Viridis*)

The green mussel (Perna viridis) types were selected, which is one of the highest productions in Johor compare to other states in Malaysia [12]. The mussel shell was cleaned to remove dirt, then dried under sunlight until the mussel shell was dried completely [38]. Then, it was crushed with Jaw Crusher Machine and sieved to obtain less 5mm particle size. The materials used such as Ordinary Portland Cement and mussel shell powder in this study follow according to BS EN 197-1:2011, ASTM C128-01 and BS EN 12620:2002+A1:2008, with the specific gravity value of 3.09 for OPC, respectively [36, 39 & 40]. For coarse aggregates, the maximum size was 20mm.

A total of 48 cube samples were prepared for compression and capillary absorption test. The sample was unmolded and left for air in dry 24 hours before undergoing the curing process for 7 and 28 days. The water used in mixing and for curing must be free of impurities such as organic matter, silt, clay, acid, alkali, salt and wastewater. Generally, the permissible pH value of the water is between 6 and 8 [41]. The sample designed into different mussel shell powder ratio. Table 2 shows the proportion of mixing on concrete mix for cube size 100mm x 100mm x 100mm.The value for mussel shell powder replacement were measured in weight. All the materials used in this study were measured in kilograms (kg) units.

Table 2. Mix proportion of concrete (all in unit kg)

Sample	Cement	Water	Fine Aggregate	Coarse Aggregate	Mussel Shell Powder
NC	0.376	0.188	0.544	0.692	0.000
C10MSP	0.376	0.188	0.490	0.692	0.054
C20MSP	0.376	0.188	0.435	0.692	0.109
C30MSP	0.376	0.188	0.381	0.692	0.163

4. Result and Discussion

The result and discussion stated include the analysis of the experiments that have been conducted. The data obtained are based on the result of specific gravity tests, sieve analysis tests, compressive strength tests and water capillary absorption tests.

4.1. Sieve analysis

The results of the sieve analysis test show value of fineness modulus of fine aggregate and mussel shell powder are 3.08 and 2.82. As per the results of the sieve analysis, mussel shell powder complies with the overall limits specified in the BS EN 12620:2013 [40]. Therefore, the mussel shell powder is suitable for concrete production as partial fine aggregate replacement. This indicates that mussel shell powder is finer than fine aggregates. Figure 4 shows the graph for the fine aggregate grading.

Figure 4. Sieve analysis graph of fine aggregate and mussel shell powder.

4.2 Specific gravity

The specific gravity of fine aggregate is 2.76 while mussel shell powder is 2.90. Overall, the specific gravity of mussel shell powder and fine aggregate are slightly different.

4.3 Slump test

According to concrete workability summarized in Table 3, the slump value of each C10MSP, C20MSP and C30MSP mussel shell powder specimens were 29 mm, 28 mm and 15 mm respectively. The result shows that concretes slump value decreases with the increment percentage mussel shell powder. C30MSP indicates the lowest slump value. The total value obtained from this analysis is in the range that have been determine in the concrete mix design which is 10-30 mm indicated of true slump and low workability. The results show that the value of slump for control sample is 30mm, while the slump value with mussel shell powder, increasing with the percentage of mussel powder in concrete. MSP concrete resulting a lower collapse value compared to control concrete. This is because MSP concrete has less water compared to control concrete. Moreover, hydration time can influence this experiment where it is closely related to the workability of concrete. The addition of water tends to isolate cement and aggregates which can affect the quality. Thus, it can be concluded that, if the percentage of this mussel shell powder increases, the slump value of concrete decrease. It completely proved that, $CaCO_3$ were able act as a filler and increasing concrete workability.

Table 3. Slump test result of concrete mixes

Concrete mix	Slump value (mm)
NC	30
C10MSP	29
C20MSP	28
C30MSP	15

4.4 Density test

Density of concrete mixtures were indicated in Table 4. Overall density of concrete mixes was increase at 28 days curing compared to 7 days. Density of control concrete, C100 at the age of 28 days was 2261.4 kg/m^3 while the higher density of concrete containing admixture, C30MSP was is 2354.9 kg/m^3. This demonstrate that the more content of mussel shell powder gives higher density.

Table 4. Result of density test

Days	Density (kg/m³)			
	C100	C10MSP	C20MSP	C30MSP
7	2256.2	2339.4	2260.5	2320.1
28	2261.4	2345.7	2280.8	2354.9

4.5 Compressive strength test

The strength percentages are depending on numerous factor such type of cements, type of mixes, admixture uses, etc. [43,44]. Thus, the effect of MSP in concrete were study in this paper. Generally, there are two type of specimens that will be used in this analysis either cube or cylinder specimens. The compressive strength was analyzed according to each percentage of mussel shell powder and curing duration. The procedure of these analysis according to BS EN 12390-3:2019 [45].

Table 5 indicates that the result for concrete compressive strength on 7 days and 28 days. Based on the data, concrete achieved maximum strength during curing process of the hydration reaction between the mixtures. Figure 5 shows the graph of concrete compressive strength against curing period for 7 days and 28 days. C20MSP concrete mix indicates almost similar strength value to control sample at 7 days and 28 days which was 34.6 MPa and 35.85 MPa. However, C30MSP shows the lowest strength readings at 7 days and 28 days at 28.6 MPa and 32.50 MPa. There is increase in strength with the increase in MSP percentages; however, the rate of strength decreases with the increase in MSP content. This trend is more obvious between C20MSP and C30MSP replacement level. This increase in strength due to the replacement of fine aggregate with MSP is attributed to the pozzolanic action of MSP. Concrete with MSP shows higher strength because inclusion of MSP as partial replacement of sand starts pozzolanic action and densification of the concrete matrix.

Table 5. Result of compressive test

Sample Curing	Compressive strength (MPa)	
	7 days	28 days
NC	33.9	40.2
C10MSP	32.7	33.2
C20MSP	34.6	35.9
C30MSP	28.6	32.5

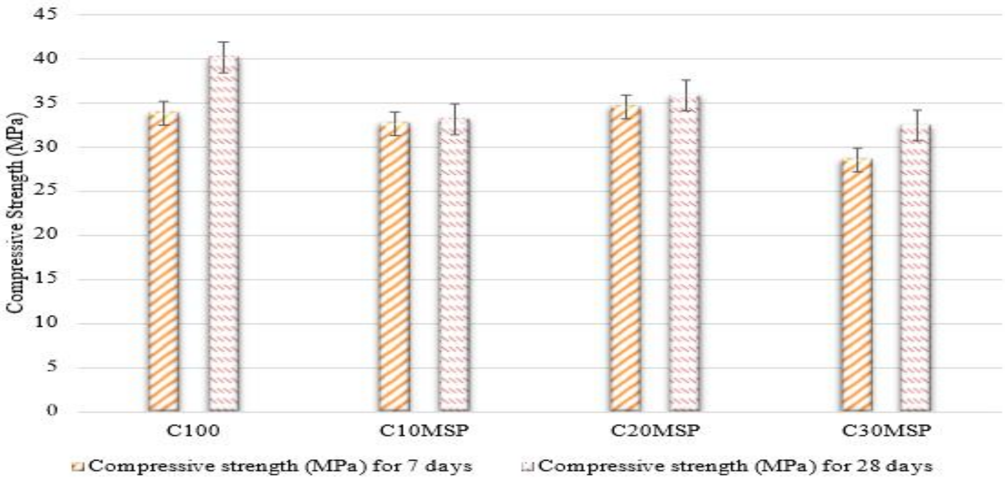

Figure 5. Compressive strength for concrete that curing for 7 days and 28 days

4.6 Capillary water absorption test

High capillary water absorption is cause by the high porosity in concrete. The rates of pressure absorption are depending on its diameter of porous concrete structure [46]. Table 6 shows the average values of water capillaries on 7 days and 28 days. Theoretically, low capillary absorption resulting better concrete in terms of durability. Figure 6 shows a graph of capillary water absorption against curing period of 7 days and 28 days. The reduction in capillary absorption can be explained with the pore blocking effect, where mussel powder tends to fill pores, leading to reduced connectivity of capillary pores [8]. Furthermore, mussel powder may reduce internal micro-cracking due to shrinkage in the matrix and hence improve resistance transport water [47].

Table 6. The value of capillary water absorption test

Sample Mix	Capillary water absorption (cm/s)	
Curing	7 days	28 days
NC	0.52	0.18
C10MSP	0.53	0.36
C20MSP	0.54	0.38
C30MSP	0.53	0.12

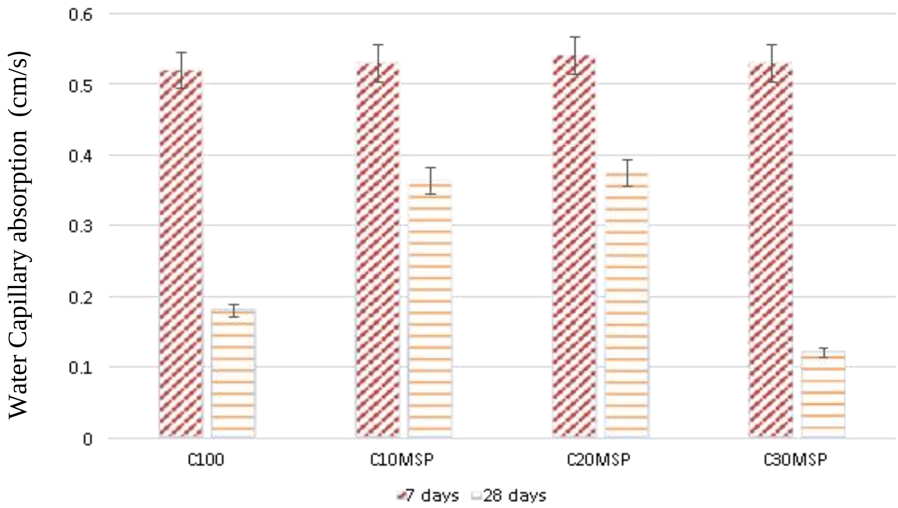

Figure 6. Graph of capillary water absorption against curing period

5. Conclusion

The composition of mussel shell with higher $CaCO_3$ were leads to an increase in the water demand, thus, resulting in a decrease in the slump value. The flaky shape also affects the bonding because of internal bleeding water trapped below shell particles increasing porosity and decreasing concrete mechanical properties (compressive strength and water capillary absorption).

Therefore, for the mechanical properties of this research, it can be concluded that mussel shell replacement should be in average between 20% to 30% of fine aggregates. Furthermore, the high content of $CaCO_3$ in chemical composition of mussel shell powder act as a filler in concrete and promoting early hydration process.

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