ENGINEERING PROPERTIES OF BIO-INSPIRED CEMENT MORTAR USING SEASHELL

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Abstract: Cement mortar is a semi liquid formed by a composite of cement, sand and water. Generally, cement mortar is used as a medium forbricks laying in costruction. Nowadays, the properties of various types of waste materials are studiedas construction material in buildingssuch as blast furnace ash, fly ash and palm oil fuel ash. In this study, the seashell is used as a replacement of building material in cement mortar.Seashell consists of high amount of calcium carbonate thatprovides remarkable mechanical propertiesand suitable to be used as building material. The engineering properties of cement mortar is studied, which including the compressive strength, flexural strength, splitting tensile strength, durability, modulus of elasticity in compression, setting time, water absorption and shrinkage. Cockle (*Anadaragranosa*) and mussel (*Pernaviridis*) are selected to replace the sand in the cement mortar with a ratio of 0, 25, 50, 75, and 100 percent by total weight of sand. A total number of 2800samples are prepared and tested up to 1 year and subjected to four exposure conditions, which are water, air, natural weather and wet-dry cycle.The replacement of seashell in cement mortar islikely to increase its engineering properties especially compressive strength due to high amount of calcium carbonate.The replacement of seashell in cement mortar will reduce the construction cost, improve the engineering properties of mortar and can beapplied in various mortar applications.

Keyword:*Masonry; Mortar; Seashell; Cockle (Anadaragranosa); Mussel (Pernaviridis)*

1.0 INTRODUCTION

Seashell consists of major proportion of calcium carbonate ($CaCO_3$), more than 90% of its weight and small amount of organic compounds (Yoon and et al., 2004). The compressive strength of mortar is increased as the higher replacement levels of seashell in sand (Yang and et al., 2005). The cost of materials can be reduced as the seashells are used as cement or sand replacements in concrete production (Lertwattanaruk, P. and et al., 2012). The application of seashell still has a lot of potential to conduct research on the strength of mortar by mixing seashell in mortar. The application of seashell in mortar still has a lot of unexpected research outcome especially the strength of mortar.

Masonry is one of the building materials used for building construction. Masonry is widely used in building construction such as housing and non-housing sectors. There are a lot of industrial, commercial and educational buildings constructed by masonry. Besides that, masonry construction has a wide variety of market used for administrative and recreational sectors (Hendry, A.W. and Khalaf, F.M., 2001).

Masonry construction has excellent properties in terms of building materials. The buildings constructed by masonry have well appearance, high durability and low building cost compared with other building alternatives. The quality of masonry construction is determined by the materials used, hence the masonry must achieve certain minimum standard. The components of masonry basically are block, brick and mortar. Mortar is formed by a composite of cement, lime and sand and sometimes of other constituents (Hendry, A.W. and et al., 2004).

Generally, cement mortar is formed by mixing cement, lime and sand. A cement, lime and sand ratio of 1:2:9 is appropriate for the load bearing brickwork. The cement mortar has excellent properties in term of the workability, water retention and bonding properties when the lime is added to it. Lime can improve the water retentivity property of cement mortar which can ensure the amount of water is required for the hydration process of the cement where a considerable amount of water is absorbed by the dry bricks from the cement mortar (Hendry, A.W. and et al., 2004).

2.0 PROBLEM STATEMENT

According to FAO (2005), world oyster production including aquaculture and capture was approximately 4.7 million metric tonnes in 2003 year. There was a total amount of around 200,000 metric tonnes of oyster produced from aquaculture in the year of 2003. In 2003, there were 46 oysters producing countries in the world (FAO, 2005).The Pacific Ocean along the coasts of China, Japan, and Korea are the major production areas of oyster. Among these countries, China is the largest oysters producing country in oyster aquaculture production with 3.7 million metric tonnes of oysters which is approximately 82% of total world aquaculture production in 2003. In 2003, Japanese oyster production was 221,000 metric tonnes while the oyster production in Korea was 238,000 metric tonnes. Figure 2.1 shows the statistics of the world oyster aquaculture production trends of selected countries (FAO, 2005).

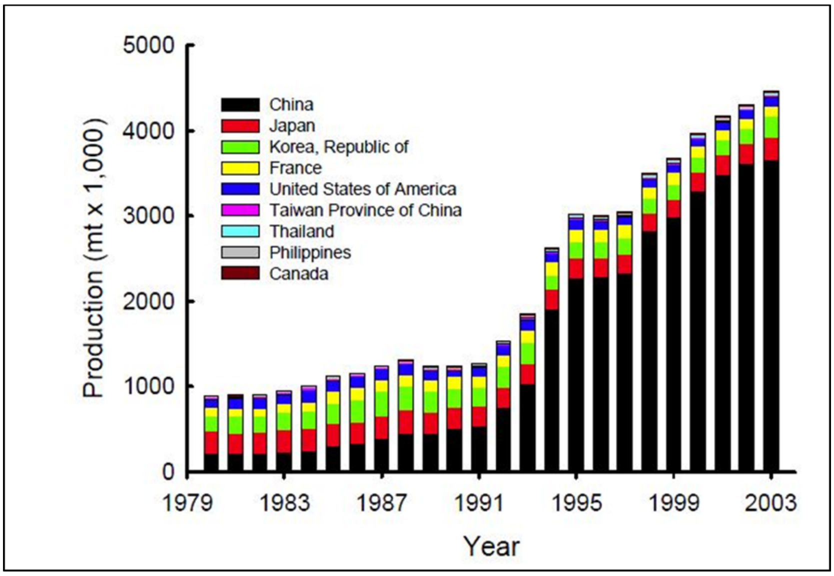

Figure 2.1: The statistics of the world oyster aquaculture production trends of selected countries (FAO, 2005).

Cockle is a local bivalve shellfish that live in muddy coastal area, existed in coastal regions of South East Asian especially Malaysia, Thailand and Indonesia. Malaysia had produced 45,674.58 metric tonnes of cockle for seafood industry in 2006 (Izura, S.N. and Tan, K.H., 2008). Department of Fisheries Malaysia (2009) stated that there are 64,958.51 metric tons of cockles produced in Malaysia at 2009. This figure not only indicates the cockle production but also the amount of seashell waste generated. The disposal of seashells left untreated can cause unpleasant and smelly odour. Recently, there are some studies stated the seashell can used as building materials in concrete construction and masonry (Yang, E.I. and et al., 2005; Lertwattanaruk, P. and et al., 2012).

Sand is the building material required by the masonry construction. Sand and soil mining is becoming an environmental issue as the sand demand in industry and construction increases. Sand mining activities can cause considerable environmental damage (Saviour, M.N., 2012). The habitats at the river sides are destructed and cause the living creatures at river sides to perish. Water pollution will be occurred when mining sand activities conducted at river sides. Many water sources in Malaysia have been polluted due to the sand mining activities are conducted at river sides.

3.0 OBJECTIVES

This research aims to study the engineering properties of cement mortar with the substitution of ground seashell in cement mortar. In achieving this aim, the following objectives are formulated: _

(i) To evaluate the mixture of ground seashell in cement mortar for the use of masonry structure in cement mortar to optimize the strength of mortar.
(ii) To study the effect on engineering properties of ground seashell in cement mortar.
(iii) To determine of the strength and durability of ground seashell under various exposure conditions at different periods of time.
(iv) Toanalyze the interfacial bonding of ground seashell in cement mortar using scanning electron microscopy (SEM).

4.0 SCOPE OF STUDY

This research focuses on the development of new mix proportion of cement mortar for the use of masonry structure by using ground seashell in cement mortar. The ground seashells proposed in this study are mussel (*Pernaviridis*) and cockle (*Anadaragranosa*). The scopes of this study include: _

(i) Mix samples for the trial mixes of cement mortar based on the different sizes of sand using (<1.18mm, <600µm and <300µm), the different ratios of sand to cement (1:2.25, 1:2.5, 1:2.75 and 1:3), the different water to cement ratios (0.5, 0.6, 0.7 and 0.8). The effects of the sizes of sand, sand to cement ratios and water to cement ratios are studied.
(ii) Selection of suitable mixture of ground seashell in cement mortar based on the screening results of the trial mixes according to the optimum performance of the compressive strength on duration of 28days.
(iii) Determine the engineering properties of selected cement mortar mixes under the four different exposure conditions, namely water, air, natural weather and wet-dry cycles on the duration of 3days, 7days, 28days, 3months, 6months and 1 year. The ratios of ground seashell for the sand replacement are 25%, 50%, 75% and 100%. The engineering properties including compressive strength, flexural strength, splitting tensile strength, durability, modulus of elasticity in compression, density, setting time, water absorption and shrinkage.
(iv) Analyze the interfacial bonding of the cement mortar samples of control and different types of ground seashell using scanning electron microscopy (SEM).

5.0 SIGNIFICANCEOF STUDY

Due to the increasing use of waste material in construction industry, seashell can be one of the alternative materials in cement mortar. The significant of this research study are achieved as shown as below: _

(i) The application of seashell in cement mortar is expected to improve the engineering properties of mortar.
(ii) The application of seashell in cement mortar is to identify and apply in various mortar applications such as masonry structure.
(iii) The findings of research study will contribute the knowledge to the application of seashell in construction.

6.0 LITERATURE REVIEW

According to Pollution Control Department (2010), more than 15 million tons of municipal solid waste is collected in Thailand for every year. Seashells comprise approximately 0.9% of the total solid waste (0.135 million tons) in Thailand. Although most of these wastes of seashells currently are disposed by incineration or landfilling, environmental concerns demand the development of some more effective waste utilization process for the disposal of wastes.

In South Korea, the oyster farming in the southern sea has become a major income source of the local fishermen and provides a steady supply source to meet the domestic oyster demand. At the same time, oyster farming causes some serious environmental problems involving the large quantity of oyster shell wastes is disposed. According to Ministry of Affairs and Fisheries of Korea (1999), there are approximately

0.327 million tons oyster shell waste is disposed illegally at southern sea and a portion of western sea of South Korea.

Department of Fisheries Malaysia (2009) mentioned that there are total amount of 64,958.51 metric tons of cockles produced in Malaysia at 2009. This figure shows the amount of cockle production. At the same time, the amount of cockle shell wastes disposal is indicated. The cockle shells are treated as waste and mostly left at dumpsite to naturally deteriorate. They are hard to dispose due to its strong property.

Recently, various waste materials including construction rubble, tire rubber ash, blag furnace slag, silica fume and fly ash have been tested in the preparation of dry mortars with proven advantages and its beneficial reported. Most of the new binder/aggregate admixtures improve the mechanical properties of mortar and allow the proportion of cement content in the mortar composition to be reduced. The limestone obtained from seashell waste was used as a new filler material to produce mortar. The reuse and recycling of seashell waste has become a major source of limestone (Ballester, P. and et al., 2007).

The chemical composition of shells is more than 90% calcium carbonate (CaCO3) by weight (Falade,1995; Yoon et al., 2004; Yang et al., 2005; Ballester et al., 2007; Mosher et al., 2010), this composition is similar to limestone powder or dust-like stone powder from grinding limestone to produce Portland cement. Ground seashells also are used as an ingredient of cement or sand replacements in concrete production to save costs. Interestingly, the crystal structures of green mussel and cockle shells are largely composed of aragonite and calcite, which have higher strengths and densities than limestone powder (Mosher et al., 2010).

The disposal of seashell waste will cause environmental damage and pollution due to the leakage of water as well as difficulty of landfill maintenance and control of landfill. In addition, seashell waste is considered as undesirable material due to a serious odor and pollution and it causes a negative impact on the local health and living environment. The cost of building materials increase becomes a great concern in the construction industry. The used of sand in large quantity for construction has brought about a serious situation. In addition, environmentally friendly methods of aggregate extraction and material selection are in demand, because the over-extraction of natural aggregate generally leads to the destruction of the environment. Research on utilization of crushed seashell as substitution materials for fine aggregate mixed in concrete can contribute to disposal of seashell and development of new concrete materials (Yang, E.I. and et al., 2005).

6.1 Nacre

Nacre, also known as mother-of-pearl, is a hard biological composite found in the inside layer of many seashells such as oyster, cockle and mussel. Nacre is the iridescent material which forms the inner layer of seashells from gastropods and bivalves. It is mostly made of microscopic ceramic tablets densely packed and bonded together by a thin layer of biopolymer (Barthelat, F. and et al., 2007).

The basic structural motif in nacre is the assembly of oriented plate-like aragonite crystals with a 'brick' ($CaCO_3$ crystals) and 'mortar' (macromolecular component) organization. As in most structural natural materials, nacre exhibits a hierarchical structure. The longitudinal cross section of nacre-containing shells, such as the abalone shell, exhibits two layers with distinct microstructures: an outer prismatic calcite layer and an inner nacreous aragonite layer (Luz, G.M. and Mano, J.F., 2009). The calcite layer is hard and suitable to prevent penetration of the shell, but it is prone to brittle failure. The nacreous layer is softer, can withstand larger inelastic deformations, and can dissipate significant mechanical energy. It is much tougher than the calcite layer, so even if the brittle outside layer cracks the nacreous layer can retard catastrophic failure and preserve the integrity of the shell (Sarikaya, M. and Aksay, I. A., 1995).

Nacre is the material that composes the inner layer of many species of gastropods and bivalves, made of 95% of aragonite (a form of $CaCO_3$, close to calcite). Nacre is composed of microscopic polygonal tablets of aragonite, bonded together by a small fraction (5%) of organic materials (proteins, chitin) (Barthelat, F. and Espinosa, H.D., 2007). The high composition of $CaCO_3$ in seashell is suitable to replace the role of sand as filler in mortar. Seashell is defined as nacre which contains same composition of chemical content with seashell. The previous study has proved that the hierarchical structure of nacre is able to provide superior mechanical strength and toughness to the seashell (Luz, G.M. and Mano, J.F., 2009). Seashell becomes the replacement of sand in mortar, the cost of material can be reduced because seashell is a type of waste material. Table 6.1 shows the chemical properties of clam, mussel, oyster and cockle while Table 6.2 shows the physical properties of clam, mussel, oyster and cockle are tabulated in Table 2.1.

Table 6.1: The chemical properties of the different types of seashell (Lertwattanaruk, P. and et al., 2012)

Chemical compositions (%)	Materials			
	Clam	Mussel	Oyster	Cockle
SiO_2	0.84	0.73	1.01	0.98
Al_2O_3	0.14	0.13	0.14	0.17
Fe_2O_3	0.06	0.05	0.07	0.06
CaO	53.99	53.38	53.59	54.24
MgO	0.08	0.03	0.46	0.02
K_2O	0.03	0.02	0.02	0.03
Na_2O	0.39	0.44	0.23	0.37
SO_3	0.16	0.34	0.75	0.13
Cl	0.02	0.02	0.01	0.01
SO_4	0.06	0.11	0.43	0.07
Free CaO	-	-	-	-
$CaCO_3$	96.8	95.6	96.8	97.13

Table 6.2: The physical properties of the different types of seashell (Lertwattanaruk, P. and et al., 2012)

Physical properties	Materials			
	Clam	Mussel	Oyster	Cockle
Loss in ignition (LOI) (%)	42.73	42.22	42.83	42.87
Moisture content (%)	0.26	0.47	0.36	0.15
Specific gravity	2.71	2.86	2.65	2.82
Water requirement (%)	100	101	101	99
Blain-specific surface area (cm^2/g)	8279	6186	14,280	8299
Fineness (Accumulated passing) (%)				
≥75 mm	4.73	10.62	2.89	1.9
75 mm	7.44	7.38	3.89	4.22
45 mm	7.31	6.54	4.22	4.87
≤36 mm	80.52	75.46	89.01	89.02
Strength index (%)				
at 7 days	31.16	66.38	86.34	63.68
at 28 days	25.08	59.14	73.82	58.83

Nacre is a typical example of such hard biological materials. It exhibits appealing hierarchical structural organizations and remarkable mechanical properties dissipation not achievable in current man-made ceramic composites (Barthelat, F. and et al., 2006). The hierarchical microstructure of this biological material is the result of millions of years of evolution, and it is so well organized that its strength and toughness are far superior to the ceramic it is made of (Barthelat, F. and et al., 2007).Some structural materials found in nature show remarkable mechanical properties. Mostly using components with modest mechanical performances, they can achieve surprisingly high modulus, strength or toughness as a result of their very well constructed microstructures organized over several length scales (Sarikaya, M. and Aksay, I. A., 1995).

Nacre is amongst the strongest of the materials found in seashells, and it has a remarkable toughness despite being mostly made of a brittle ceramic.Nacre is stiff (E=60-80 GPa) while maintaining a relatively high toughness (JIC=1.5 kJ/m^2). Nacre is about 1,000 times higher than the toughness of aragonite (Barthelat, F. and Espinosa, H.D., 2007). Seashells are highly mineralized tissues (at least 95% mineral content) and as a direct result have high stiffness and hardness. Their most impressive property however is their toughness (their ability to resist the propagation of cracks), which is two to three orders of magnitude higher than the minerals they are made of. No manmade composite material can boast such amplification in toughness (Barthelat, F., 2010).

Compared with man-made ceramics, nacre is also less sensitive to internal defects and flaws, and is relatively strong in tension. Nacre has the highest tensile strength amongst all the materials used by seashells (Barthelat, F. and Espinosa, H.D., 2007). Simple shear tests and shear compression tests also demonstrated the large inelastic deformations and strain hardening of nacre under hydrated conditions. Dry specimens possess higher strength but are more brittle. Normal compressive stresses across the interfaces have a limited effect on the shearing resistance of hydrated nacre, but they significantly increase the shear strength of dry nacre.As the stress was increased, the layers of aragonite tablets sled on one another, creating a staircase like deformation (Wang et al., 2001) and generating large deformations (Barthelat, F. and et al., 2007).Table 6.3 shows the mechanical properties of nacre retrieved from some different researchers.

Table 6.3: The mechanical properties of nacre retrieved from some different researchers.

Mechanical Properties	Unit	Barthelat, F. (2010)	Barthelat, F. and et al. (2007)	Barthelat, F. and Espinosa, H.D. (2007)	Luz, G.M. and Mano, J.F. (2009
Compressive Strength	MPa	-	400	350	-
Tensile strength	MPa	40-100	70-135	70	130-170
Toughness	kJ/m^2	0.2-2	-	1.5	0.35-0.45
Modulus of elasticity	GPa	40-70	70-90	60-80	60-70

6.2 Mechanical properties of seashell on mortar

The waste seashells were investigated experimentally to develop a cement product for masonry and plastering.Increasing the percentage replacement of ground seashells tended to reduce the compressive strength of the mortars, because the less reactive material of ground seashell mixed with the Portland cement. However, because the particle sizes of ground seashells were a little smaller than those of Portland cement, the small particles of ground seashells acted as a filler material, inserting themselves into the void of the Portland cement. Therefore, the compressive strengths of the seashell-containing mortars were a little lower than that of the control mortar (Lertwattanaruk, P. and et al., 2012).

The oyster shell powder was utilized to substitute fine aggregate to determine the effects of different oyster shell addition amounts on mortar for construction industries use. Compressive strength at an early age demonstrates an increasing tendency as substitution rate of oyster shell increases (Yang, E.I. and et al., 2005). In the case of substituting higher oyster shell amounts, the strength decreases at old ages is due to stress concentration occurring with the relative lower strength of oyster shell presents in concrete (Yang, E.I. and et al., 2010). Oyster shells mixed were fully dehydrated for pulverization. Oyster shells absorb surrounding free water and, as a result, the relative water to cement ratio decreases (Yang, E.I. and et al., 2005).

The strength characteristics of the mixed mortar specimens depend on various factors, such as the oyster shell mixture, the self-hardening properties of the cement paste, the solid matrix composition (oyster shell particles and cement paste) and the contact interface between the oyster shell particles. However, the difference in the rate of decrease of the compressive strength can be interpreted as being the result of the difference in particle size. An increase in the relative density of the oyster shell particles within the mixed concrete moulds results in an increase in the contact strength of the structure, which eventually increases the compressive strength (Yoon, H. and et al., 2004).

The mechanical and structural properties of mortar by replacing quarry limestone aggregate with limestone obtained from waste of the mussel cannery industry were investigated. The strength values increased with curing time. At an early stage of curing (up to day 7) the mortars reached around 50% of their maximum strength. Such strength resulted from hydration of the cementitious phases in mortar to form hydrated calcium silicates (commonly CSH phases), as major compounds. At short curing times (up to 7 days), mortar strength decreased as the seashell content increased. At longer curing times, the compressive and flexural strength increased with increasing seashell content. The chemical composition of seashell showed that no pozzolanic activity was to be expected from its components. Therefore, increased strength at long curing times must have arisen from differences in internal microstructure and the kinetics of the setting process (Ballester, P. and et al., 2007).

With increasing the addition amount of 5% oyster shell powder, the compressive and flexural strength of test samples in different curing ages increased. After that, with continuous increase of the addition amount of oyster shell powder, compressive and flexural strength of the test pieces in different curing ages reduced gradually (Zhong, B.Y. and et al., 2012).The XRD patterns of oyster shell powder mortar showed that $CaCO_3$ phase of oyster shell exists stably in the cement mortar samples, which means its addition does not cause the change of crystalline phase of cement mortar, revealing that the oyster shell powder has no chemical reaction in the cement mortar system, just existing independently with only filling effect (Zhong, B.Y. and et al., 2012).

The materials proportion and the partial replacement of saturated surface dry sand with dry oyster shell were evaluated in term of practical application of crushed oyster shell as construction materials. The elastic modulus with the substitution of oyster shell decreased inversely proportionally to substitution rate. In the case of substituting 20% oyster shell, the elastic modulus decreased approximately 10-15% due to the elastic modulus of oyster shell is lower than that of fine aggregates (Yang, E.I. and et al., 2010).The elastic modulus is increased with increasing filler proportion. The higher the porosity and water to cement ratio, the more flexible the mortar is, the lower elastic modulus is. Filler additions of calcite up to 15% sand induce greater elastic modulus by 15% (Benachour, Y. and et al., 2008).

6.3 Physical properties of seashell on mortar

An experimental study was carried out to investigate the recycling possibilities for fine aggregate of oyster shells on concrete. Oyster shell is primarily composed of calcium carbonate (91.18%), with a small quantity of mineral and organic materials. Therefore, when oyster shell is substituted as fine aggregate it is necessary to evaluate whether or not calcium carbonate ingredients of oyster shell react with cement. The disadvantageous reactions at the interface between cement and oyster shell or formation of new materials were not found, and cement hydrate and oyster shell is independently detected. That is, it is noted that, even though oyster shell is mixed with cement paste, oyster shell does not affect the cement hydrate and only performs a role as filler in concrete matrix (Yang, E.I. and et al., 2005).

The mortars containing seashell as aggregate were more workable. The water to mortar ratio, initially fixed at 0.16 in all samples, must be increased in seashell mortar in order to obtain similar consistency values (Chen, H.L. and et al., 2004). Thus, the smaller average particle size in the limestone aggregate must facilitate water adsorption (Uchikawa, H. and et al., 1996) and detract from mortar workability. Also, the mortars made from seashell exhibited higher adhesion strength by virtue of their improved cementation properties (Ballester, P. and et al., 2007).

The phenomenon of reduction in workability with increase in the proportion of periwinkle shell to granite in the mixes may be due to the lower unit weight of periwinkle shell compared with that of the granite that they replace. Since batching is by weight, greater quantity of periwinkle shell is required to replace a given weight of granite, thus increasing the specific surface area of the aggregates to be wetted under a constant water to cement ratio. The possibility of part of the mixing water escaping into the cavities of the shells cannot be ruled out, thereby reducing the effective mixing water (Falade, F., 1995).

When the proportion of ground shells replacing Portland cement increased, there was an increase in the flow value of the cement mortar. The replacement of cement with ground seashells decreased the amount of cementitious material and increased the free water content in the mix. This process was increasingly seen as the percentage replacement of seashells was increased (Lertwattanaruk, P. and et al., 2012).

When the ratio of replacement of ground seashells in Portland cement increased, there was an increase in the initial setting times of formation. The high volume replacement with ground seashell disturbs the hydration reaction, due to a decreasing content of Portland cement in the mortar mix. In other words, mortar containing ground seashell has a longer initial setting time than the control mortar. When the replacement ratios of the ground seashells were increased, the final setting times of the seashell-containing mortars were higher than those of the control mortars (Lertwattanaruk, P. and et al., 2012).

One source of drying shrinkage in mortar is the loss of the water held in the capillary pores of the hydrated cement paste to the environment (de Sensale, G.R., 2006). A higher volume of ground seashells can cause low shrinkage, owing to the greater fineness of these ground seashells compared to cement. Therefore, the ground shell particles can insert themselves in the void between the cement particles (Chatveera, B. and Lertwattanaruk, P., 2011). The incorporation of these ground seashells causes the segmentation of large pores, leading to refinement of the pore structure. It also increases the number of nucleation sites for the precipitation of pozzolanic reaction products in cement paste (Rukzon et al., 2009). This process causes a denser internal structure, decreased internal void, and decreased shrinkage (Lertwattanaruk, P. and et al., 2012).Table 6.4 summaries the observation and findings of previous researches of waste materials on mortar application while Table 6.5 summaries the observation and findings of previous researches of seashell waste on application of mortar.

Table 6.4: Observation and findings of previous researches of waste materials on mortar application

Author	Topic	Scope of Study	Observation and Findings
Bilim, C. and Atis, C.D. (2012)	Alkali activation of mortars containing slag	1. Investigate some properties of alkali-activated mortars containing slag at different replacement levels.	1. Compressive and flexural strength values increased with the increase in activator concentration and slag replacement level. 2. Carbonation depth values of the mortars decreased withthe increase of activator dosage.
Sajedi, F.	Mechanical activation	1. Study the effect of fineness of	1. It is clear that increase in replacement slag

(2012)	of cement slag mortars	slag and OPC particles on the strength improvement of OSMs.	causes reduction in early strength, since the slag has a lower initial hydration heat compared to OPC. 2. The main finding of this study is by using both the ground slag and OPC the highest compressive strength for OPC slag mortars could be achieved. 3.Based on scanning electron microscopy images and X-ray dispersive analyses, it seems that strength loss at later ages is due to phase separation. 4.The results showed that ground slag has a greater effect on strength improvement at both the early and later ages when compared to ground OPC particles.
Aydın, S. and Baradan, B. (2012)	Mechanical properties of alkali activated slag mortars	1. Investigate effects of steam and autoclave curing on the mechanical properties and microstructure of alkali activated slag mortars.	1. Compressive strength of AAS mortars increased significantly with the increasing values of silicate modulus and Na_2O. 2. Increase in flexural strength values of sodium silicate activated GGBFS mortars with the increment of silicate modulus and Na_2O is not significant. 3. Steam curing and autoclave curing methods were significantly effective in terms of reducing drying shrinkage of AAS mortars. 4. High strength mortars can be produced with very low alkali content under autoclave curing as a result of better pore size distribution.
Pereira, D.A. and et al. (2000)	Mechanical behaviour of salt slags on mortars	1. Study the effect of waste additions on mechanical properties of cement mortars, involving partial replacements of either sand or cement.	1. The compressive strength of the mortars increase more significant with the addition of small amount fine grain slag compare to coarse grain slag. 2.The increase of small amount fine grain slag mortar flexural strength is more significant than using small amount coarse grain slag fractions. 3.The typical microstructures (SEM) of fracture surfaces of mortars show the changes are less visible, but slag samples seem to be more compact.
Lanas, J. and et al. (2006)	Mechanical behavior of masonry repair lime mortars	1. Study the mechanical behavior and durability of aerial and hydraulic lime-based mortars subjected to different environments.	1. Flexural strength has been strongly influenced by the relative humidity (RH) and the amount of free water into the mortar. 2. Increasing the amount of free water, these environments enhances the CSH formation as well as the carbonation reaction, improving the compressive strength. 3. Hydraulic mortars with higher strength show higher durability due to the porosity of the mortars. 4. The higher porosity of aerial specimens is related to their lower strength compared to hydraulic specimens. 5. In SO2 chamber, sulfation appears as a surface phenomenon, giving gypsum in aerial specimens and gypsum and syngenite in hydraulic specimens, as SEM/EDAX confirms.
Miranda, L.F.R. and Selmo, S.M.S. (2006)	Effect of construction and demolition waste on mortar	1. Analyses of the influence of the recycled aggregate composition on the properties of mortars and renderings performance.	1.Higher compressive strength and flexural strength of mortars were obtained required a lower effective water to cement ratio. 2. The modulus of elasticity varied inversely with the effective water to cement ratio. 3.The distribution of the pore sizes generated by the presence of fines in the mixtures had a greater effect on drying shrinkage than that water to cement ratio.
Benachour, Y. and et al. (2008)	Effect of a high calcite filler on mortar	1. Identify the maximum filler amount which may be added to cementitious materials without	1. Total porosity increases for high filler amounts while bigger pore populations diminish.

		performance loss.	2. The Young's modulus is increased with increasing filler proportion. 3. The compressive and flexural strengths remain remarkably high whatever the filler proportion. 4. Drying shrinkage and mass loss are not impacted dramatically either.
Akhras, N.M.A. and Alfoul, B.A.A. (2002)	Effect of wheat straw ash on autoclaved mortar	1. Investigates the effect of wheat straw ash (WSA) on the mechanical strength of autoclaved mortar.	1. Flow table values decreased with increasing WSA replacement. 2. As the percentage of WSA replacement increases, the initial setting time increases. 3. Mechanical properties (compressive, tensile, and flexural strength) of mortar specimens increased steadily with WSA replacement levels. 4. The micrograph for the control paste specimen examined after autoclaving shows more packed formation because of more calcium silicate hydrate compared to that examined before autoclaving.
Elkhadiri, I. and et al. (2002)	Mechanical behaviour of fly ash and limestone in cement	1. Study the effect of waste additions on mechanical properties of cement mortars, involving partial replacements of either sand or cement.	1. The addition of fly ash in mortar has a low effect on water content for standard consistency, but the setting time is generally prolonged with increased fly ash content. 2.The replacement of clinker by limestone gives better mechanical strengths than the mixtures containing fly ash at early days; after 28 days, the cements prepared by incorporation of fly ash gain an important strength.
Panesar, D.K. and Shindman, B. (2012)	Mechanical, transport and thermal properties of waste cork on mortar	1. Examines the impact of cork used as sand or stone replacement on the plastic, mechanical, transport, microstructural and thermal properties of mortar and concrete.	1.The density of the specimen decreased with increasing percentage of cork.The porosity of mortar increases with increasing cork sizes. 2.The mortar cube strength decreased when the cork size increased. 3.Finer cork sizes were most beneficial to achieve optimum mechanical, and transport properties however high permeability. 4.Greater percentages of cork as sand or stone replacement had the greatest impact on thermal resistance.

Table 6.5: Observation and findings of previous researches of seashell waste on application of mortar.

Author	**Topic**	**Scope of Study**	**Observation and Findings**
Lertwattanaruk, P. and et al. (2012)	Effect of ground waste seashells on cement mortars	1. Investigate seashell experimentally to develop a cement product for masonry and plastering.	1. The results indicate that ground seashells can be applied as a cement replacement in mortar mixes and may improve the workability of rendering and plastering mortar. 2. The main chemical composition of ground seashells was calcium carbonate, in the range of 96%-97%. 3.For overall performance, the mortars containing high volume of ground short-necked clam yield the optimum properties compared to the other ground seashells such as a relatively low mixing water requirement, increased setting time, good compressive strength, lower drying shrinkage, and decrease in thermal conductivity.
Ballester, P. and et al. (2007)	Effect of mussel cannery industry waste on mortars	1. Investigate the mechanical and structural properties of mortar by replacing quarry limestone aggregate with limestone obtained from waste of the mussel cannery industry.	1. At longer curing times, the compressive and flexural strength increased with increasing seashell content. 2. Mortars with a high content in mussel shell limestone exhibited a more packed microstructure, which facilitates setting of cement and results in improved mortar strength. 3. The mortars containing seashell as aggregate were more workable. Seashell mortar exhibited

			higher adhesion strength by virtue of their improved cementation properties.
Yoon, H. and et al. (2004)	Oyster shell as substitute for aggregate in mortar	1. Investigate the mechanical characteristics of pulverized oyster shell as a substitute for the aggregates used in mortar.	1.The mineral CaCO3, which is present in the form of calcite, is the predominant component of oyster shells. 2. The failure planes of the specimen containing large oyster shell (LOS) particles were more affected by the nature of the oyster shell particle formation, compared with small oyster shell (SOS) particles. 3.For the LOS-mixed mortar specimens, the compressive strengths showed low values compared with those of the sand or SOS mixed mortars.
Yang, E.I. and et al. (2010)	Effect of oyster shell on concrete	1. Evaluate the materials proportion and the partial replacement of saturated surface dry (SSD) sand with dry oyster shell.	1. In the case of substituting higher OS amounts, the strength decrease at old ages. 2. The elastic modulus with the substitution of OS decreased inversely proportionally to SR. 3. The absolute value of drying shrinkage and the shrinkage rate increased with increasing SR. 4. The difference of SR on creep decreased with increasing age and a clear effect of SR on creep is not apparent. 5. OS yields improved performance on the freezing and thawing resistance of concrete. 6. The permeability resistance is greatly improved with the increasing SR of OS.
Yang, E.I. and et al. (2005)	Effect of oyster shell substituted for fine aggregate on concrete	1. Investigate the recycling possibilities for fine aggregate of oyster shells (OS) on concrete.	1. OS is primarily composed of calcium carbonate (91.18%), with a small quantity of mineral and organic materials. 2. There was no disadvantageous reactivity between OS and cement hydrate. 3. The slump value is proportionally decreased with SR increase. 4. Compressive strength at an early age demonstrates an increasing tendency as SR of OS increases. 5. Concrete elastic modulus decreases with SR of OS increase since elastic modulus of the OS is smaller than the elastic modulus of fine aggregate.
Falade, F. (1995)	Investigation of periwinkle shells as coarse aggregate in concrete	1. Investigate the mechanical properties of periwinkle shells (PWS) partially or wholly in concrete.	1.Workability decrease with the increase of the proportion of PWS to granite in the mixes. 2. The compressive and flexural strengths decreased with increase in proportion of PWS to granite in the standard mixes. 3. The unit weight of PWS was found to be 694.44 kg/m3 and this indicates that PWS is a lightweight aggregate
Agbede, O.I. and Manasseh, J. (2009)	Suitability of periwinkle shell as gravel in concrete	1. Investigate if periwinkle shells can be used as a replacement of river gravel in concrete.	1.The reduction in workability with increasing periwinkle content could be attributed to the texture and shape of the shells. 2.The low bulk density of periwinkle shells suggests that lighter concrete can be produced from them. 3.The ACV values suggest that periwinkle shells are not suitable for normal dense concrete. 4.The periwinkle-granite concrete would be stronger than periwinkle-gravel concrete.
Zhong, B.Y. and et al. (2011)	Structure and property of oyster shell cementing material	1. Determine the effects of different oyster shell addition amounts on the cement stability and cementing sand strength.	1.The compressive strength and flexural strength of test samples increased with 5% addition amount of oyster shell powder. 2. The compressive and flexural strengths of the samples added with oyster shell powder obtained with wet method ball grinding were

			better than those with dry method ball grinding. 3.The oyster shell powder obtained with wet ball grinding was much finer and more homogeneous than dry grinding. 4.Oyster shell powder mainly has the inert filling effect in the cement mortar, and would not affect the cement stability.

7.0 METHODOLOGY

This section will describe the preparation of materials and the methods of experiment testing in this research study in order to achieve the objectives in this study. The major testing will focus on the compressive strength, flexural strength and splitting tensile strength test. Besides that, the other significant testing on engineering properties in this study is flow value, direct tensile strength, modulus of elasticity in compression, density, setting time, water absorption and shrinkage.

The materials used in this research study for mixing mortar samples are ordinary Portland cement, sand, seashell and water. The raw materials, seashell used in mortar are mussel (*Pernaviridis*) and cockle (*Anadaragranosa*). The samples of cockle show in Figure 7.1 while the samples of mussel show in Figure 7.2. The performance of mortar is determined by the properties of material. The properties of a selected material must satisfy the criteria selected from the trial mix design before mortar samples are mixed with the raw materials. The production and proportion for mixing mortar sample, the preparation and testing procedure for the testing specimen samples and the standards used for the tests are discussed in detail.

Figure 7.1: Sample of seashell**,** cockle (*Anadaragranosa*)

Figure 7.2: Sample of seashell, mussel (*Pernaviridis*)

The purpose of this study is to determine the properties of ground seashell in cement mortar cubes, prisms, cylinders, plates and prism bars. All types of tests are conducted to achieve the objective of this study to replace with the seashell in cement mortar. In this study, the overall program is to determine the engineering properties of seashell in cement mortar. Cement mortar specimens are applied to different exposure conditions such as air (indoor),water, natural weather (outdoor) and wet-dry cycle. In this research, the laboratory tests are conducted according to the procedures show in Table 7.1.

Table 7.1: The type of laboratory tests and the testing standards required

Laboratory test	Testing standard
Sieve analysis	ASTM C 778 (ASTM, 2013)
Flow value	ASTM C 1437 (ASTM, 2001)
Setting time	ASTM C 191 (ASTM, 2008)
Density	BS 6319: Part 5 method A (BSI, 1984)
Compressive strength	ASTM C 109 (ASTM, 2012)
Flexural strength	ASTM C 348 (ASTM, 2008)
Splitting tensile strength	ASTM C 780 (ASTM, 2012)
	ASTM C 1006 (ASTM, 2001)
Direct tensile strength	ASTM D 638 (ASTM, 2010)
Modulus of elasticity in compression	BS EN 13412 (BSI, 2006)
Water absorption	ASTM D 570 (ASTM, 2010)
Shrinkage	ASTM C 596 (ASTM, 2009)
Interfacial bonding	Scanning electron microscope

The proportion of mortar mix is selected from the trial mixes of mortars based on the compressive strength value and flow value. The cement mortar mix should have consistent flow value which is determined by flow table test. For the trial mixes, cement mortar cubes are produced to conduct the test for cement mortar cube compressive strength. From the result of compressive strength test of trial mixes, the optimum cement to sand ratio and water to cement ratio are selected based on the optimal value of compressive strength test. The proportions of ground seashell used to replace the sand in the range of 25%, 50%, 75% and 100% are selected for the further tests include the engineering properties of seashell.Figure 7.3 shows the flow of the research study for the experimental set up.

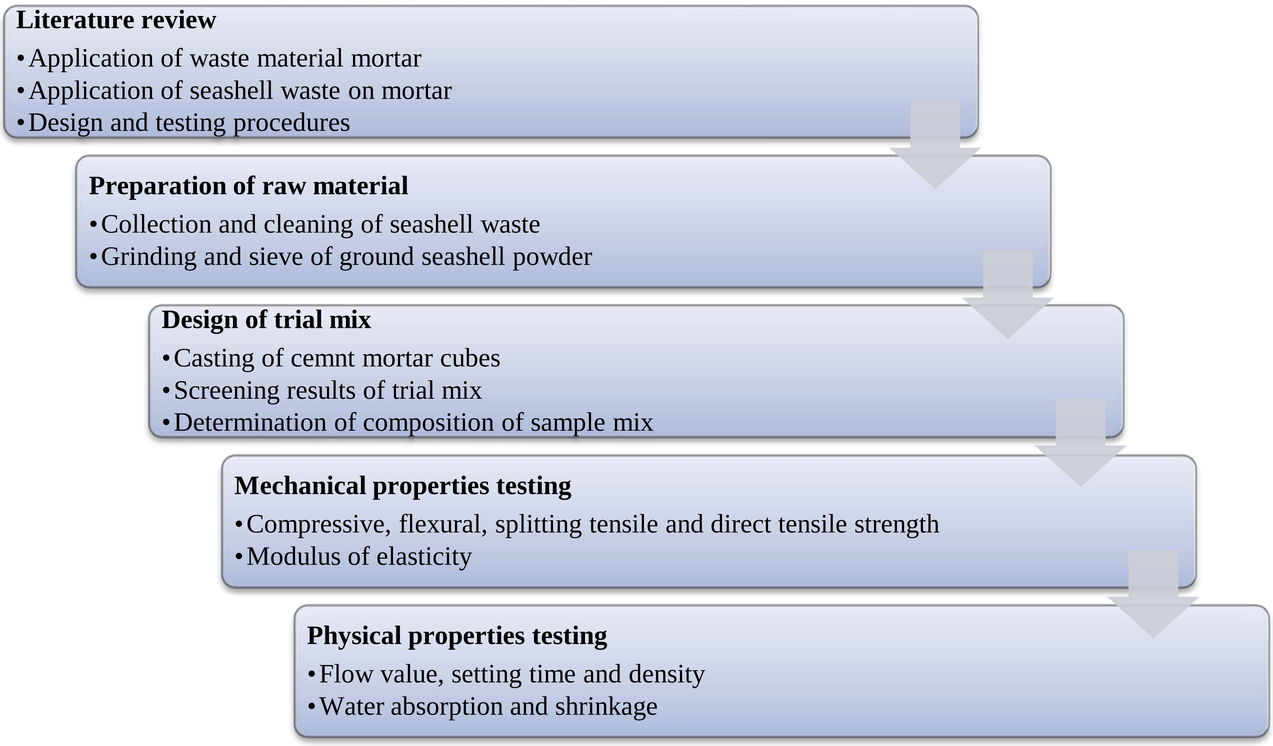

Figure 7.3: Flow chart of research study

8.0 CONCLUSION

This research will contribute advantages to mortar application with the use of seashell. Seashell consists of more than 90% of calcium carbonate. Seashell can provide high compressive strength and toughness due to the hierarchical structure of seashell. Seashell has the same chemical composition of sand (calcium carbonate) and suitable to replace sand in cement mortar. The application of seashell in cement mortar is expected to increase strength of cement mortar compare to the use of sand.

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