Utilisation of Eggshell Powder (ESP) as Partial Replacement of Cement Incorporating Superplasticizer

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Abstract. This research showed the results of experiments evaluating the use of eggshell powder from egg production industry as partial replacement for ordinary Portland cement. Research on the reuse of waste materials in the concrete industry has been quite intensive in the past decade. The objective of this research is to identify the performance of dried eggshell powder as a partial cement replacement in the production of concrete. Eggshell powder of various amounts, namely 5%, 10%, 15% and 20% by volume, was added as a replacement for ordinary Portland cement. The results showed that eggshell concrete greatly improved the compressive and flexural strength of concrete. The rate of water absorption of eggshell concrete was reduced as eggshell powder filled up the existing voids, making it more impermeable. However, the compressive strength of the eggshell concrete decreases gradually when the amount of eggshell powder increased. It can be concluded that the optimum percentage of dried eggshell powder as a partial cement replacement is 15%. In this direction, an experimental investigation of ultrasonic pulse velocity, rebound hammer concrete test, compressive strength, flexural strength and FTIR spectra and TGA analysis was undertaken to use eggshell powder and admixtures as partial replacement for cement in concrete.

1. Introduction
Concrete is one of the most significant natural resource products. The use of concrete in the modern era was the foundation of the nation's construction industry. The local construction industry growth requires greater concrete quantity, which indirectly increases the need for greater supply of natural resources for concrete production. A change in cement can be obtained on the market and each type is used under persuaded illness owing to its unique characteristics such as cement colour and different way of arrangement. In latest years, there has been a general trend towards reducing the use of natural resources and the reuse of waste products. This experiment is to examine the performance of chicken eggshell blended into eggshell powder as potential replacement and chicken eggshell waste used as a limestone filler in Portland cement mortar [1]. A handling technique has been created to generate big amounts of eggshells. Limestone is introduced as replacement of cement. Measurements of compressive test and flexural strength are performed. Eggshell consists several growing layer of calcium carbonates. The innermost layer-maxillary 3 layer develops on the outermost egg membrane and produces the core on which the thickest portion of the eggshell at the palisade layer. The quality of eggshell waste is strongly affected by the sunlight exposure, raw water and severe conditions. Before using with concrete or mortar, the fine-grained powder with the appropriate proportion that is sieved to the required size [2].
2. Problem statement
Eggshell is referred to as waste products or by-products from hatcheries and food sectors. Majority of the eggshell was disposed of in the landfill without any pre-treatment since it is recognized as useless traditionally. In Malaysia, water disposal and land filling are one of the severe problems. It is observed that Malaysia has very high consumption of chicken and eggs among all the Asian countries. The number of landfills and waste disposal increase significantly from years to years. If the waste disposal did not dispose in a correct way, it will lead many negative impacts in terms of environmental pollution and water pollution [3]. Compared to European nations, the use of food waste such as eggshells in Malaysia is very limited. All the landfill had waste related to aesthetic problem, contamination, landfill gas or odour problems. Almost all the waste is disposed using landfill method and majority of the sites have poor management. Discovered an alarming increase in the dumping site in Malaysia, which encouraged the Malaysian government to open up more dumping sites resulting in soil scarcity. Land scarcity has dramatically increased the price of landfill. Identify material from waste and use it in concrete production in construction industry could be a wide idea and bringing a lot of benefits as Portland cement is very costly, energy intensive and produce great amounts of carbon emission [4].

3. Literature review

3.1. Physical properties of eggshell powder
Egg Shell Powder (ESP) can be used as an industrial lime supplement on expansive clay land and it has also been reported that the mixture can be used where elevated subgrade output is not essential. Conducted the inquiry into eggshell waste. It can be used as an alternative raw material in the manufacture of wall tile goods based on the presence of CaCO₃ in eggshells. They also found that eggshells can be used as an exceptional choice for techniques of reuse of materials and waste recycling [5]. Eggshell powder concrete properties as a substitute for cement, this research discusses studies on the use of concrete poultry waste by developing concrete that incorporates eggshell powder (ESP). By exchanging 5-15% of ESP for cement, different ESP concretes were created [6]. The findings showed that ESP can be used effectively in concrete manufacturing as a partial substitute of cement. The information provided contains the growth of strength and characteristics of transportation. Regarding the outcomes, the yields were greater than the control material at 5% ESP substitute and suggest that 5% ESP is an optimal material for peak strength. Five mixes were used in this research to explore the characteristics of ESP concretes.

3.2. Chemical properties of eggshell powder
Experimentally examined the eggshell as a temporary substitute for concrete cement. This document records the outcomes of studies assessing the use of eggshell powder from the egg sector as a partial substitute in cement mortar for ordinary Portland cement. It was determined the chemical composition of the eggshell powder and the concrete mix compressive strength. Mixed concrete ratio 1:2:4, in which cement is partially replaced with eggshell powder as 5%, 10%, 15%, 20%, 25% by cement weight. The compressive strength was determined at 28 days of curing age. Compressive strength dropped sharply beyond 5 percent eggshell-powder replacement. Saw dust ash, fly ash and micro silica are used as admixtures in order to increase the power of the concrete mixture with 5% eggshell powder as a partial substitute for cement. In this path, an experimental study was carried out on compressive strength [7], divided tensile strength and flexural strength to use eggshell powder and admixtures as a temporary substituted for concrete cement.

3.3. Use of eggshell powder on construction materials
Several scientists have tried to use waste products to enhance concrete's mechanical characteristics and decrease waste disposal issues. The major waste products used to date are fly ash, silica fumes, quartz sand, eggshell powder [3]. Eggshell disposal is said to add to environmental pollution, producing
undesirable odors that cause discomfort and effect on human well-being. Calcium carbonate (CaCO₃) is the primary component in eggshells. The shell itself is said to consist of 95% CaCO₃ while the remaining components consist of magnesium, aluminum, phosphorous, salt, sulfur, mercury, iron, salt, ionic acid and silica acid. Eggshells can function as a healthy bio-sorbent because they have a cellulosic framework with amino acids [2]. Using eggshell will help reduce alkali-silica and sulphate expansions. It has been shown that eggshells have great durability and a washable surface. On paint movie, Eggshell can withstand mould and mildew. The use of eggshells has economic advantages and the ability to satisfy both rigorous efficiency and aesthetic requirements [8].

4. Result and discussion

4.1. Compressive strength test

Based on Figure 1, show that the compressive strength started to increase at 5% of eggshell powder replacement compared to the control mixed design. The compressive strength is increase after added into the eggshell powder and the highest value is 26.6 MPa at 28th days of curing and the lowest value is 22 MPa at 7th days curing. At the 14th days of curing, the compressive strength is higher than 7th days of curing. The reason is because as the curing process is longer, it will increase the workability and durability of concrete. Observed that the strength increased with the curing age and the percentage of eggshell replacement. The strength is stronger than the control mix design because the eggshell powder is added into the cement. It is interesting to note that eggshell concrete exhibits high early compressive strength compared with the control specimen at the early stage of curing. Partial replacement of cement with eggshell powder improved the reaction between silica from the cement and calcium oxide from the eggshell powder, a by-product of the cement hydration process in the continuous presence of moisture. In addition, the eggshell powder also acted as a filler by filling up the existing voids, which made the internal structure of the concrete more packed and led to the development of higher compressive strength. However, further increase of ESP will decrease compressive strength at all curing ages.

![Figure 1. Compressive strength test](image)

4.2. Ultrasonic pulse velocity (UPV)

The results UPV test of high performance concrete made from based on the Figure 2 above, at 7th days of curing, the highest value of ultrasonic pulse velocity is showed at 15% of eggshell powder replacement which is stated as 45.4 m/s-1. At 14th days, the value is increase compared to 7th days of curing, and figure above was observed that 15% replacement of eggshell powder and at 14th which given data for direct test is 43.4 m/s-1. 14 days of curing has higher value than 7th days of curing but lower than 28th days of curing. At the age of 28th days curing, 15% replacement of eggshell powder is achieving the highest ultrasonic pulse velocity value which is 45.9 m/s-1 if compared to other percentage replacement of eggshell powder on 28th days. There is a huge change of value from 0% to 15% of increase and a value drop at 20% of eggshell powder replacement.
4.3. Flexural strength test
Based on the Figure 3, the value is started to increase after the eggshell powder is added into the concrete. At the age of 7 days curing, the highest value of flexural strength is 2.7 MPa. It can see that the flexural strength is started to increase compared to control mix design. At the age of 14th days of curing, the value is flexural strength is increase as the curing process is longer. The lowest value of flexural strength is 2.2 MPa and the highest value is 2.9 MPa. At the age of 28 d, 15% exhibits the highest flexural strength, which is higher than that of control mixed design. Thus, the eggshell powder seems to have greatly improved the flexural strength of concrete with a partial cement replacement of up to 15%. However, the value will drop at 20% of eggshell powder replacement but still has higher value compared to control mix design. In addition, calcium hydroxide contributes slightly to the strength and impermeability of the concrete because it reduces the total pore volume by converting some of the liquid water into solid.

4.4. Rebound hammer concrete test
The Figure 4, show at the age of 7th day of curing, 15% replacement of eggshell powder is achieving the highest compressive strength at bottom and top which is 25 MPa compared to other percentages replacement of eggshell powder on 7th day. At 14th day and 28th day, the data showed that the 7th day have higher and better results due to longer curing and figure above was observed that compressive strength showed 15% replacement of eggshell powder at 28thth have the best results which given data for top and bottom is 26 MPa compared to controlled mix that without add in any eggshell powder.
Figure 4. Rebound hammer test

4.5. Microstructures of eggshell
The apparent morphologies of the eggshell examined by SEM are shown in Figure 5. The control mix concrete comprises irregular shape of particles and finely modulated, which was showed in Figure 5(a). Meanwhile, Figure 5(b) showed the microstructure of eggshell. After mix with concrete, the structure of eggshell has been changed from irregular shape to interconnected like skeleton structure. Besides that, the catalyst resulted in strong increase in active sites, which supported by SEM images [9].

![Figure 5(a). SEM images of control mix](image1)

![Figure 5(b). SEM images of Eggshell](image2)

4.6. FTIR spectra and TGA analysis
IR spectra of both eggshell were determined by fourier transform infrared (FTIR) spectrometry. Based on the results from Figure 6(a), IR spectra for eggshell showed wide stretching peaks at 1395.7 cm⁻¹ attributing to C-H bonding. Sharp and intense peak observed at 871 cm⁻¹represent C-O stretching and bending modes of CaCO₃. Meanwhile, the sharp band at 710 cm⁻¹ represent Ca-O bonds. Figure 6(b) shows the TGA curved of eggshell. Result from TGA showed that there were two stages of weight losses. For the first stage, minor weight loss occurred at temperature below 300 °C - 500°C attributed to an adsorption of water molecules to the surface of the material and loss of organic compound. [10]
Figure 6(a). FTIR spectra for eggshell

Figure 6(b). TGA analysis for eggshell

5. Conclusion and recommendation

The overall objective of the work was to investigate the feasibility of utilisation of eggshell powder as an additive material to concrete mix. This study included the preparation of concrete mixes containing and the evaluation of eggshell powder concrete properties in fresh and hardened states. The studying properties involved mix workability, compressive strength and density. According to experimental results, the usage of eggshell powder in concrete mixes as an alternative of disposal for eggshell powder is possible. The current type of eggshell powder accumulated in dumping sites and the expected future type were used in making concrete mixes. The influence of both types on concrete properties was studied. In all cases there was an optimum quantity of eggshell powder which can be used without introducing any change in mix preparation and acceptable properties were still be produced. The study showed that the eggshell powder can be used in interlock brick production without changing the normal industrial process. Recommendation for further research The following recommendations are proposed for further research and study in order to from a complete picture of using eggshell powder in concrete mixes:

1)  Further investigation is needed on the different superplasticizer used together with eggshell powder in the concrete mix design.
2) Further study is required for eggshell powder mix with other by-products in the concrete mix design.
3) Further investigation of the higher percentage of replacement of the cement by the eggshell powder in concrete mix design.
4) Longer curing time is required in order to understand the behaviour of the concrete, and it might give the different result for eggshell powder concrete.

6. Reference
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