Eggshell as the partial replacement of Portland cement in the production of concrete

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Abstract. The population rate in Malaysia is increasing thus contributing to more undesirable wastes pollute the environment and the development in Malaysia flourishes rapidly. Consequently, the requirement of concrete is escalating thus maximizing the production of Portland cement. Such production liberates more carbon dioxide and causes air pollution. This study investigates the use of poultry waste in concrete production by replacing eggshell powder with Portland cement. Eggshell is identified rich in calcium similar to what cement has as it mainly contains 93.70% calcium carbonate (CaCO$_3$). Chicken eggshells are collected, cleaned, dried, grinded and sieved until the desired 90 µm size. 4 different batches are prepared by substituting 10-30% of eggshell powder with Portland cement in order to determine the suitability of eggshell powder as the partial replacement by investigating both workability and mechanical properties of eggshell blended batches via slump test and 3 destructive tests respectively. Consequently, the workability experiences reduction in the range of 30-70% whereas the results of all 3 destructive tests decrease in the range of 13-48% as the amount of eggshell powder increases. To conclude, eggshell powder is unsuitable for projects that require high strength concrete but may be suitable for projects that require less strength concrete.

1. Introduction

Nowadays, the development in Malaysia is growing rapidly as a result of the increasing population. As a result, swift infrastructure growth occurred that definitely need a huge amount of concrete to accommodate such growth [1]. Consequently, both residential and industrial sectors are also growing thus leading to the increasing discharge of various types of unused waste to the environment that vary from by-product from manufacturing industries, unwanted wastes released by restaurants and residential areas and many more. Such waste has been occupying many landfills until maximum capacity [2]. One of the identified wastes is eggshell. Eggshell is an outer hard covering of an egg that is produced from poultry farms and widely used for cooking and eating. It is mostly removed for its egg and unused thus making it an undesirable waste. Approximately 36.5 million eggs are produced daily and anticipated to rise up to 3-5% in Malaysia [3]. Majority of eggshells are left in landfills as they are basically useless and damaging the environment [4]. Eggshell waste in landfills attract parasitic worms and insect that could contribute to problems relating to human health and odour [5].

On the other hand, rapid development in Malaysia has generated more construction projects thus demanding more concrete and subsequently more cement. Interestingly, the manufacturing of 1 ton of cement discharges an equal amount of carbon dioxide thus a vast amount of carbon dioxide discharged undeniably brings harm to the environment [6]. This study focuses on the incorporation of poultry waste particularly eggshell waste into the production of concrete as the partial replacement of cement to determine the suitability of eggshell as the partial replacement for cement by investigating the
workability and mechanical properties of eggshell blended concrete. Eggshell is mainly composed of compounds of calcium similar to cement. It is composed of 93.70% calcium carbonate, 4.20% organic matter, 1.30% magnesium carbonate and 0.8% calcium phosphate [7].

2. Methodology
Chicken eggshells are collected from several sources ranging from bakery shops, burger stands, restaurants and stalls in the night market. Collected eggshells are gathered in large buckets and cleaned using tap water to remove unwanted dirt around the eggshell before being left to dry at room temperature for 24 hours. After 24 hours of air dry, the eggshells are oven-dried at temperature 110°C for at least 24 hours in order to achieve zero moisture. Portland cement, fine and coarse aggregate as well as water are prepared. On top of that, the size of Portland cement used is 90 µm as stated in [14]. The eggshells are then grinded and sieved through at least 90 µm sieve to ensure the fineness of the eggshell powder is similar to the fineness of Portland cement used. Four different batches are prepared including one without eggshell powder as shown in Table 1.

Workability test is conducted on the fresh concrete in accordance to [8] prior to casting on a total of 12 moulds and left to harden for 24 hours. The hardened concrete is de-mould and weighed for dry density, labelled, divided into another 2 batches with 4 cubes, 1 cylinder and 1 beam for 7 days and 28 days each shown in Figure 1 and cured inside the water tank for the next 7 and 28 days. After curing, the batch is weighed for wet density to calculate the water absorption prior to conducting rebound hammer test and ultrasonic pulse velocity test on the batch in accordance to [9] and [10] respectively. Once the non-destructive tests have been completed, 3 destructive tests namely cube compression test, cylinder splitting test and beam flexural test are conducted on the batch in accordance to [11], [12] and [13] respectively. Every data is then recorded and analysed before coming up with a conclusion.

| Batch | Portland cement (%) | Eggshell powder (%) |
|-------|----------------------|---------------------|
| 1     | 100                  | 0                   |
| 2     | 90                   | 10                  |
| 3     | 80                   | 20                  |
| 4     | 70                   | 30                  |

3. Results and discussions
The data obtained is recorded and assembled in table form. Necessary bar charts are used when analyzing the data. Only the overall results are stated along with a brief justification.
3.1 Workability
The workability of the fresh concrete is illustrated in Figure 2 below. It experiences reduction as the amount of eggshell powder increases. The height of slump for batch 1 is 50 mm and it decreases as the amount of eggshell powder increases at 35 mm, 33 mm and 15 mm for 10%, 20% and 30% of eggshell powder added respectively. This is due to the tendency of eggshell powder in absorbing moisture during the hydration process of cement. As mentioned in [15], an eggshell consists of as much as 17,000 tiny pores and is made almost entirely of calcium carbonate (CaCO$_3$) crystals. It is a semipermeable membrane, which indicates that air and moisture can pass through its pores.

![Bar chart of height of slump against ESP content](image)

**Figure 2.** Bar chart of height of slump against ESP content

3.2 Dry density
Based on Figure 3, the dry density of every specimen including cube, cylinder and beam decreases as the amount of eggshell powder increases. The dry density of cube, cylinder and beam for both 7 and 28 days reduce in the range of 0.52-1.85%, 0.59-1.35% and 0.35-2.69% respectively when the eggshell powder increases. Lack of effectiveness of the hydration process causes less C-S-H gel formed. On top of that, eggshell powder mostly acts as the filler as it is found that there is no chemical reaction between the eggshell powder and the water. Hence, its lower density than the C-S-H gel may contribute to lower dry density of concrete.

![Bar chart of dry density against ESP content for 7 days](image)

![Bar chart of dry density against ESP content for 28 days](image)

**Figure 3.** Bar chart of dry density against ESP content for 7 and 28 days

3.3 Wet density
Based on Figure 4, the wet density of every specimen including cube, cylinder and beam decreases as the amount of eggshell powder increases. The wet density of cube, cylinder and beam for both 7 and 28
days reduce in the range of 0.52-1.27%, 0.42-0.92% and 0.17-2.15% respectively when the eggshell powder increases. Less cement content may cause more permeable voids that allow excessive water particles that move freely within the concrete particles as a result of less hydration process of cement and water. Consequently, the moisture content increases thus the wet density increases.

3.4 Water absorption
Based on Figure 5, more eggshell powder content increases the tendency of the concrete to absorb more water during concrete curing thus the water absorption by the concrete increases. More permeable voids are visible among the concrete particles as well as the permeability of eggshell stated in [15] enhances the permeability of the concrete. The water absorption for cube, cylinder and beam for both 7 and 28 days increases as eggshell powder increases in the range of 0.62-46.0%, 0.51-52.05% and 8.18-83.2% respectively.
3.5 Colour change on hardened concrete

Based on the results, for hardened concrete after de-mould, 7 days and 28 days respectively, there are changes on the appearance of concrete particularly its colour. Initially, the colour for hardened concrete with zero ESP is dark grey. As the amount of eggshell increases, the brightness of the colour increases from dark grey to brighter grey. Due to eggshell powder for being very bright brown and when it mixes with cement, it increases the brightness of the hardened concrete as the amount of dark grey Portland cement decreases. On the other hand, the brightness for all batches increase after curing for 7 and 28 days when compared to the batches after de-mould. All 4 batches after 28 days of curing are identified brighter than after 7 days. Hydration process of cement and water during curing may influence the brightness of the hardened concrete as the higher the days of curing, the brighter the colour of hardened concrete. As a result, brighter appearance of concrete may be used for aesthetic purposes besides possibly eliminating the need of applying a brighter paint on its surface.

3.6 Rebound hammer test

Based on Figure 9, the rebound number decreases as eggshell powder increases. Decrease in C-S-H gel due to the reduction of cement content influences the rebound number obtained. Hence, the estimated compressive strength decreases as the estimated compressive strength is directly proportional to the rebound number. The reduction in rebound number for cube, cylinder and beam as eggshell powder for both 7 days and 28 days increases are in the range of 10.38-40.52%, 0.45-35.87% and 11.76-44.44% respectively.

![Bar chart of rebound number against ESP content for 7 and 28 days](image)

**Figure 9.** Bar chart of rebound number against ESP content for 7 and 28 days

3.7 Longitudinal pulse velocity

Based on Figure 10, the distance travelled by the wave when conducting ultrasonic pulse velocity test increases as the eggshell powder increases. Although all concrete specimens are categorized as good concrete, they vary according to their respective quality due to the difference in the velocity. The velocity decreases when the eggshell powder increases thus reducing the quality of concrete. The velocity travelled for cube, cylinder and beam for both 7 and 28 days increases and are in the range of 1.74-10.38%, 0.14-3.88% and 3.47-19.71% respectively.
3.8 Mechanical properties test

Based on Figure 11, the compressive strength decreases as the amount of eggshell powder increases. The compressive strength of control concrete at 30.62 N/mm² and 38.38 N/mm² for 7 and 28 days respectively exceed the design strength of 22.5 N/mm² which is approximately 75% of design strength of 28 days and 30 N/mm² for 7 and 28 days respectively. However, the compressive strength experiences reduction when eggshell powder is added at 10%, 20% and 30% and are lower than the design strength for both 7 and 28 days. The percentage of reduction for compressive strength for 7 days are in the range of 41.4 - 48.1% while for 28 days are in the range of 38.2 – 48.1%. Based on Figure 11, the tensile strength decreases as the amount of eggshell powder increases. The tensile strength obtained for all 4 batches have exceeded the design strength of 3.00 N/mm² which is equally 10% of design strength 30 N/mm². The percentage of reduction for tensile strength for 7 days are in the range of 12.7 – 38.1% while for 28 days are in the range of 13.0 – 30.0%. Based on Figure 11, the flexural strength decreases as the amount of eggshell powder increases. The percentage of reduction for flexural strength for 7 days are in the range of 12.6 – 32.5% while for 28 days are in the range of 14.9 – 27.6% respectively. Low cement content, higher concrete porosity due to high water absorption are factors that reduce the mechanical properties of the hardened concrete.

4. Conclusion

Once all data have been collected and analysed, the objectives stated can be concluded in this chapter.

4.1 Workability of eggshell blended concrete

Based on the data obtained, the workability of eggshell blended concrete decreases as the amount of eggshell powder increases in the range of 30–70%. Eggshell powder tends to absorb water during the hydration process of cement thus lowering the workability of concrete.
4.2 Mechanical properties of eggshell blended concrete
The mechanical properties of eggshell blended concrete are inversely proportional to the amount of eggshell powder added. They decrease in the range of 13-48% for both 7 and 28 days for compressive strength, split tensile strength and flexural strength. Lower workability due to the permeability of eggshell stated in [15] causes less effectiveness of the hydration process of cement. Consequently, less C-S-H gel is formed which increases the inner voids among concrete particles that allow moisture content to fill in. As a result, the density decreases, the water absorption increases thus reducing the compressive strength, split tensile strength and flexural strength of concrete.

4.3 Suitability of eggshell blended concrete
The incorporation of eggshell is definitely not ideal for most projects that require high strength concrete. However, projects such as surface drainage system, road barrier and monuments as examples that are not meant to resist higher load and mainly for aesthetic purposes may be suitable for eggshell powder to be used as the partial replacement for Portland cement.

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