Effect of Eggshell Powder on the Mechanical and Durability Properties of Cement Mortar

X. F. Li, S. I. Doh, P. J. Ramadhansyah, M. R. Hainin, and W. I. Mohd Haziman

Abstract Concrete is a civil engineering material and widely used in various constructions. Cement, as major composition in concrete, consumes amounts of energy and generates pollution during production. Thus more research should be conducted to reduce the dependency of cement. In this paper, micro sized eggshell powder is used as a cementitious supplementary material to partially replace cement. Four cement replacement percentages are set with 2.5, 5, 7.5 and 10%. Workability, compressive strength, flexural strength, water absorption and acid attack were tested to analysis the performance of eggshell mortar. The results revealed that 0.4 micron micro size eggshell powder could improve the workability and mechanical properties of mortar while cause negative effect on durability of concrete. Replacement of 5% cement replacement with eggshell powder is the optimum percentage for both of compressive strength and flexural strength. On the basis of mechanical properties, eggshell could be a potential alternative material to replace cement.

Keywords Concrete · Eggshell · Cement · Replacement · Compressive strength

1 Introduction

Cement is an important civil engineering material for the construction industry. The use of cement can provide the strength required by all kinds of buildings and make construction more convenient and efficient, but it causes a large amount of consumption of energy and natural resources. Cement, as a binder in concrete,

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consumes high non-renewable resources but also produces a large amount of CO_2, which is the main product of greenhouse effect [16]. For a long time, researchers around the world have been trying to find alternative materials cement replacement in order to minimize the dependency on the natural resources. Industrial waste can be used as an alternative cement material to replace the binder material needed in the manufacture of concrete. These waste materials are often stacked in the open air or buried in landfills as industrial by-product, and cause waste of resources and environmental pollution. In the past, researchers have studied the effects of replacing cement with industrial waste, such as steel slag, fly ash and palm oil shells [2, 10]. These materials show a good bonding property when used as a cementitious supplementary material. These industrial wastes can provide substances needed for cement hydration, such as calcium or silicon, which could react with cement hydration products and lead to secondary hydration reactions that produce more C-S-H. This reaction could increase the performance of the concrete. Eggshell is a kind of solid waste which is largely produced in the confectionary industry. The calcium, which forms the main component of eggshell, can be utilized as renewable material for the cement production. Eggshell, which have relatively high CaO make it a potential alternative material to cement production [9, 17]. Some researchers have studied the mechanical properties and durability of concrete made from eggshell instead of cement. In the study of Jhatial et al. [14], partial replacement with cement by eggshell powder could improve the compressive strength of concrete. The optimum compressive strength was the specimen with replacement of 10% eggshell powder. Similar result was achieved by Tan et al. [18], in which the performance of concrete with the addition of eggshell powder increases in two types of curing condition. It is also indicated that eggshell concrete is suitable for strong acid and sulfate environments as its durability would decrease with the addition of eggshell powder. Overall, eggshell powder as cementitious supplementary material is feasible for improving the properties of concrete.

This research studies the effect of micro size eggshell powder as cement replacement on the mechanical and durability of mortar. The workability, mechanical property and durability of mortar were analyzed to evaluate its performance.

2 Experimental Programme

2.1 Materials

2.1.1 Cement

The cement powder used in this research is YTL Cement Orang Kuat, type one. The chemical and physical composition of cement is tabulated in Table 1.

Table 1 Chemical and physical composition of OPC

Tests	Units	Specification MS EN 197-1: 2014 CEM/B-L 32.5 N	Test results
Sulfate content (SO_3)	%	Not more than 3.5	2.1
Chloride (Cl^-)	%	Not more than 0.10	0.01
Fineness (According to Blaine)	m^2/kg	–	440
Setting time: initial	mins	Not less than 75	155
Soundness	mm	Not more than 10	0.8
Compressive strength			
7 days	MPa	Not less than 16	24.0
28 days	MPa	$32.5 \leq x \leq 52.5$	35.2

2.1.2 Eggshell

The waste eggshells were the byproduct of Eggtech Manufacturing Sdn Bhd located in Ijok District of Selangor. Only brown eggshells waste were collected from the factory. The eggshell waste was then cleansed using tap water immediately upon arrival to the laboratory to avoid rotten smell emission. The cleansed eggshells are then sun dried before crushing and grinding it into micro size powder. The particle size of eggshell powder ranges from 190.1 to 396.1 nm. The gradation of micro size eggshell powder is shown in Fig. 1. The comparison of chemical compositions for Ordinary Portland Cement and eggshell powder is tabulated in Table 2.

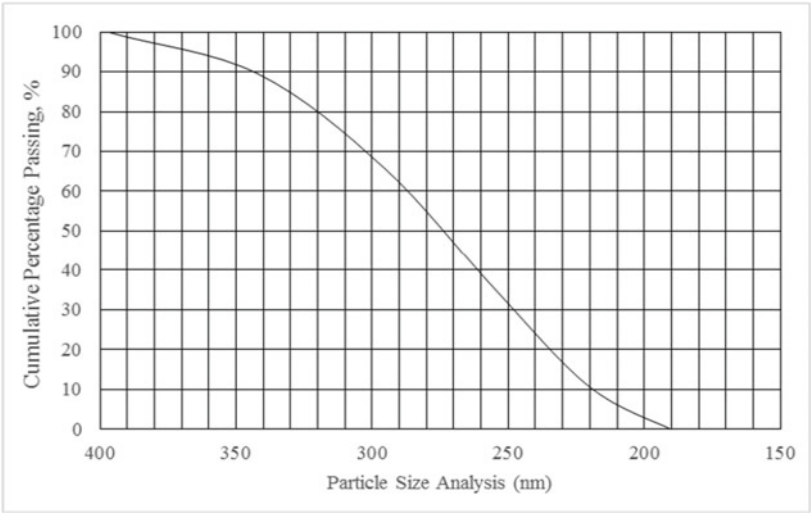

Fig. 1 Gradation of micro size eggshell powder

Table 2 The chemical compositions of ordinary Portland cement and eggshell powder

Oxide group	OPC (%)	Eggshell (%)
Calcium oxide	60.1	61.71
Silicon dioxide	21.8	0.06
Sulphur trioxide	2.5	0.82
Iron oxide	4.1	0.08
Magnesium oxide	0.5	0.34
Potassium oxide	0.25	0.05
Aluminium oxide	6.66	–

2.1.3 Water

The water used in this research is from the tap water supplied by Pengurusan Air Pahang Berhad (PAIP).

2.1.4 Fine Aggregate

Sand used throughout the research are washed river sand from Pahang River. Figure 2 shows the grading of this sand which meets the British Standard sieving test (BS812: Part103) [8].

2.2 Specimen Preparation

The specimen preparation throughout the study complied with ASTM C1329-05. The ratio between cement and sand is 1:2.75, while water/cement (w/c) ratio is 0.6. The cement was replaced by micro size eggshell powder according weight at the interval of 2.5% from 2.5 to 10%.

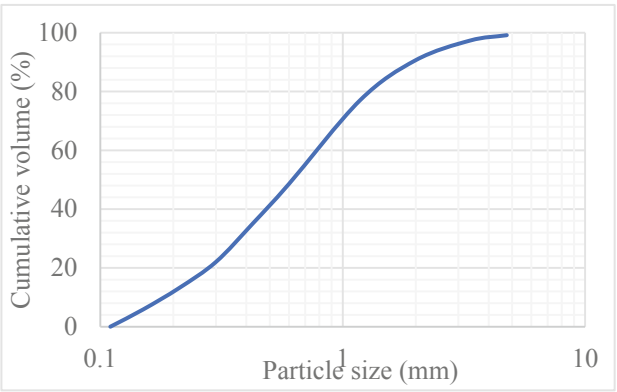

Fig. 2 Gradation of river sand

2.3 Test Method

Once the fresh mortar is prepared, the flow table test was carried out according to ASTM C1437-15 standard. For compressive strength test and flexural strength test, both were tested at the age of 1, 7, and 28 days according to BS EN 12390-3:2009 [6] and BS EN 12390-5:2009 [7] standard, respectively. The durability of mortar was tested with the same methods in the study of Tan et al. [18].

3 Result and Discussion

3.1 Workability

Workability is a parameter used to evaluate the concrete quality. Flow table test is considered as one of the standard methods to identify the characteristics of mortar which could measure the consistency of mortar. Figure 3 shows that the flow table value of mortar increases with the addition of micro size eggshell powder. This is due to the lower rate of water absorption of micro eggshell powder as compared to cement [18]. Compared with control mortar specimen with value of 105 mm, the highest flow table value could reach 120 mm with 10% replacement by eggshell powder. The result demonstrates that adding eggshell powder as supplementary cementitious material would not absorb water excessively, and it could improve the workability of mortar [18].

3.2 Mechanical Properties Test

3.2.1 Compressive Strength Test

For strength performance, all the specimens were cured in the water tank. Specimens are tested on 1, 7, and 28 days respectively to study strength of concrete with the age of concrete. Figure 4 shows the result of compressive strength of different mix designs with different age of concrete. From the result, the 1-day and 7-day compressive strength of eggshell with replacement of 7.5% and eggshell 10% are lower than that of others. Water curing promotes the formation of C-S-H gel during the hydration process which produces higher compressive strength [12]. For 28 days specimens, the compressive strength shows an increasing trend for eggshell powder replacement up to 5%. The improvement on strength is attributed from filler effect of micro size eggshell powder [18]. In some studies, the optimum for replacement has been observed to range from 7.5 to 15% [1, 5]. Furthermore, eggshell powder has similar chemical composition with limestone, forms calcium mono-carboaluminate hydrate phase through the reaction with alumina paste in the

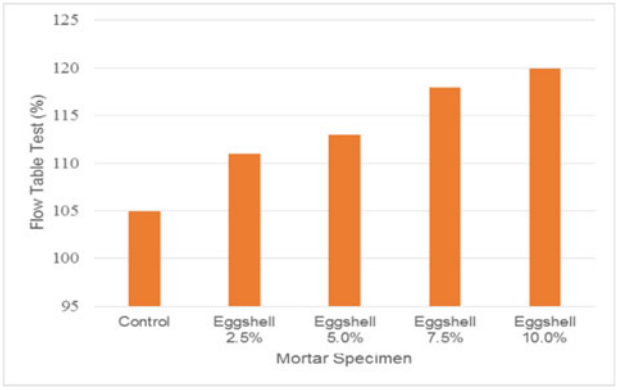

Fig. 3 Flow table result of different percentage of micro size eggshell replacement

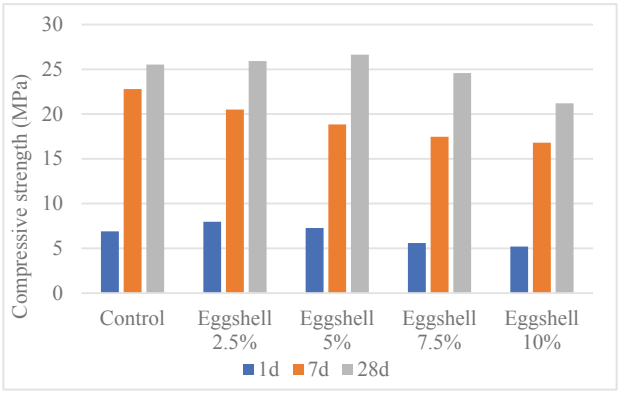

Fig. 4 The compressive strength of micro size eggshell mortar

cement [19]. As the eggshell power replacement exceeding 5%, the compressive strength of the mortar decreases, since excessive eggshell powder would weakened the bonding of the cement and aggregate [19].

3.2.2 Flexural Strength Test

Similar with the compressive strength test, the specimens for flexural strength test were also tested on 1, 7 and 28 days. Figure 5 shows the flexural behavior of specimens with different eggshell replacement. By referring to Fig. 5, 5% of cement replacement with eggshell powder has the highest strength compared to the other mix. The highest 28-day flexural strength could reach 6.17 MPa. However, the higher replacement percentage of eggshell makes the flexural strength of the

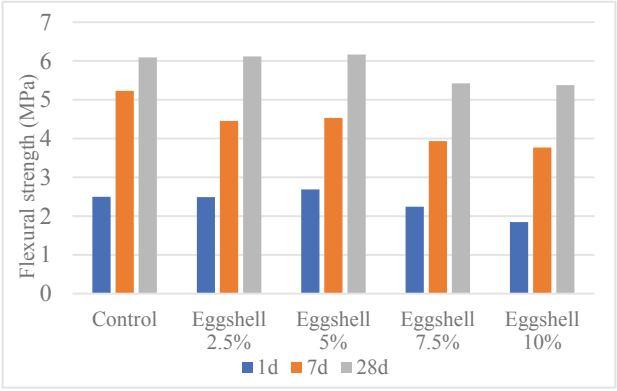

Fig. 5 The flexural strength of micro size eggshell mortar

eggshell mortar specimen decrease. It is because that excessive of eggshell powder may lead to reduction of the bonding properties between cement and aggregate. As the result, the optimum mix for the flexural strength is at 5% of cement replacement.

3.3 Durability Properties Test

3.3.1 Water Absorption Test

Figure 6 shows the result of water absorption for all the specimens. The addition of eggshell powder reduces the percentage of water absorption. According to Ing [13],

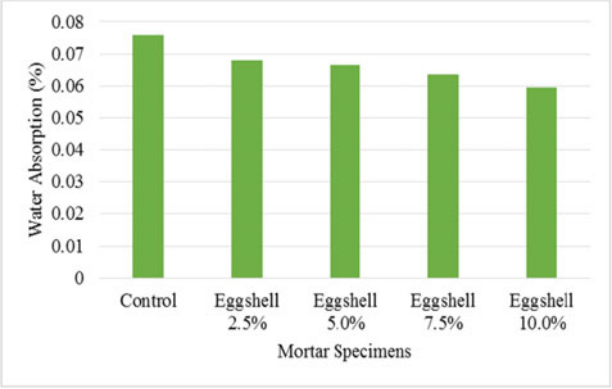

Fig. 6 Water absorption of micro size eggshell mortar

the eggshell acts as good filler to the internal voids thus producing denser cement matrix. A similar finding has been confirmed by Matschei et al. [15], revealed that micro size eggshell enhances the space filling properties of the paste.

3.3.2 Acid Attack

3.3.2.1 Residual Mass

Figure 7 show the mass loss of micro size eggshell mortar. It is observed that highest mass loss is not more than 1% of its original mass for all specimens. According to Zivica and Bajza [20], the gradually decrease of the weight which is one of the signs of the acid attack. The control and eggshell mortar specimens have lost some of the weight, as the calcium hydroxide is the first chemical compounds that attack by the sulphuric acid [11]. This chemical reaction forms calcium salts which are then leached away. The leaching cement compounds loosen the aggregate binding in mortar and consequently reduce the weight of mortar. Eggshell mortars which generally have higher calcium hydroxide as compared to control specimen show higher mass loss due to the reaction with the acidic environment. Thus, it indicates that eggshell mortar is not suitable for harsh acidic environment.

3.3.2.2 Compressive Strength Loss

Figure 8 shows the compressive strength loss for micro size eggshell powder immersed in the sulphuric acid solution for 28 days. It indicates that the compressive strength loss increases with the increase of cement replacement with eggshell powder. The control specimens show the lowest total compressive strength reduction compared to all the eggshell mortar. The mortar specimens experienced a gradual decrease in the compressive strength when the content of micro size eggshell powder increase. From the eggshell oxide content shown in Table 2, it indicates that eggshell has higher calcium oxide content and less silicon dioxide content compared with cement. During the hydration process, the silicon oxide reacts with

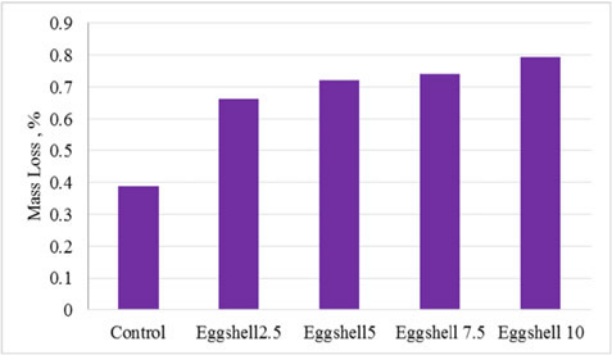

Fig. 7 Mass loss of micro size eggshell mortar

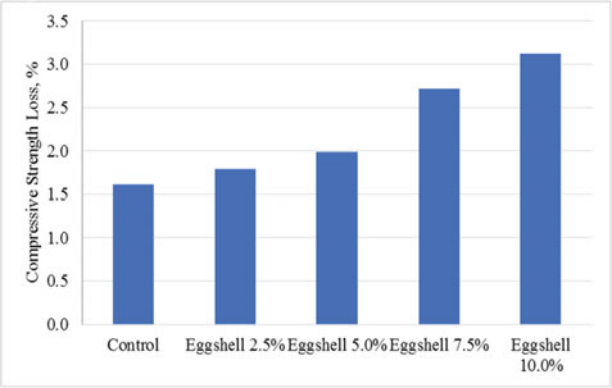

Fig. 8 Compressive strength loss of micro size eggshell mortar

the calcium hydroxide. However, for eggshell mortar, the content on silicon oxide is relatively low and generates lower amount of C-S-H gel. The excessive calcium hydroxide reacts with the aggressive solution thus reducing the compressive strength of the specimen. Therefore, the amount of the micro size eggshell used as partial replacement of cement should be consider carefully due to the low resistance of the mortar toward the acid attack.

4 Conclusion

Micro size eggshell powder was used as cementitious supplementary material for making mortar. Workability, mechanical properties and durability were discussed to evaluate the performance of micro size eggshell powder mortar. Based on the study, several conclusions could be drawn as follow:

1. The addition of eggshell powder could improve the workability of mortar which has a higher flow compared to control mix. The workability increases with the increase of eggshell replacement.
2. The 28-day compressive strength shows that a positive effect would occur when replacement percentage of eggshell powder is less than 5%, which was attributed to the filler function of micro size eggshell powder in mortar. However, when the replacement is exceeding 5%, the compressive strength reduces below the control specimen. This is due to the reduction of binding properties of the internal structure in mortar. The same phenomenon occurs for flexural strength of mortar. Therefore, optimum replacement percentage of cement by micro size eggshell powder should be 5%.

3. Water absorption and acid attack test were conducted to evaluate micro size eggshell powder mortar. The addition of eggshell powder in mortar reduces its water absorption. In acid environment, mortar was more vulnerable as the calcium oxide could react with acid solution, which resulted in mass loss and reduction of compressive strength of mortar.

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