Durability Analysis of Natural Lime concrete

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Abstract: Concrete is known to be durable and dependable material since it is resistance to weathering action and chemical attacks while maintaining its engineering properties. However, carbon dioxide produced by the cement industries had caused severe environmental pollution. To minimize carbon dioxide emission into the atmosphere, eggshell wastes are treated as partial cement replacement in this study. The eggshell was oven-dried at 105.5 °C for 24 h before grinding it into powder passing through sieve size 45 µm. Eggshell powder was used as partial cement replacement at 5, 10, 15 and 20%. The performance of the concrete mix was evaluated against control concrete mix. The specimens were tested on acid attack and sulphate attack. The concrete specimens were prepared in the form of cubes and then subjected to water curing for 28 days before immersed in sulphuric acid solution for 1800 h and sodium sulphate for 50 weeks respectively. From the analysis, it is observed that reduction of compressive strength of the concrete cubes for the acid attack and sulphate attack reduce gradually when the eggshell powder increase.**Keywords** acid attack, cement replacement, eggshell powder, sulphate attack, compressive strength

Introduction

Concrete is extensively used in the building and construction sector. One of the main ingredients is ordinary Portland cement. However, production of ordinary Portland cement will consume a lot of energy in the manufacturing process and generate high amount of carbon dioxide that is approximately 1 tons of cement will generate 1 tons of carbon dioxide (Pliya and Cree 2015). Social and environment issue of sustainability and energy conservation are assisting in changing the cement industry by lowering and partially replacing its cement production with supplementary cementing materials.

The physical nature of the eggshell waste and the foul rotten egg odors produced when the materials degrade, reduce the lime value and renders the waste difficult to recycle to land (Amu et al. 2005). Ideally, the eggshell waste should be dried at source transported to a site where it would be finely ground immediately and used as source of lime to agriculture and other applications. In the ever increasing efforts to convert waste to wealth, the efficacy of converting eggshells waste to beneficial use become a knowledge that worth embracing. It is scientifically known that the eggshell is mainly composed of compounds of calcium which is similar to the cement (Neville 2011).

In this investigation eggshell was selected as the source of the partial cement replacement. Eggshells are known as the agricultural waste that generated from hatcheries, bakeries, fast food restaurants which is traditionally useless and treated as landfilling (Sivakumar and Mahendran 2014). Eggshell consists of several mutually growing layers of $CaCO_3$, the innermost layer-maxillary 3 layer grows on the outermost egg membrane and creates the base on which palisade layer vertical layer covered by the organic cuticle. The primary chemical content that available in the eggshell was mainly calcium (Raji and Samuel 2015). Thus, the quality of the calcium in the eggshell is greatly influence by the extent of exposure of sunlight, raw water and harsh weather condition. In this study, various percentage of eggshell powder had been used as the partial cement replacement to produce concrete and tested the durability of it with sulphuric acid solution and sodium sulphate solution.

Method

Materials used on this investigation consisted of ordinary Portland cement, river sand, granite aggregate, eggshell powder and tap water. A single batch of ordinary Portland cement that fulfill the requirement of BS EN part 1 (2011) was used as the binder to produce all the concrete cube specimens Fine aggregate used was taken from the local river sand with the fineness modulus of 1.64. Granite aggregate was obtained from Bukit Rangin quarry. Eggshell was obtained from Eggtech Manufacturing Sdn Bhd.

Concrete cube (100 mm x 100 mm x 100 mm) were selected for this study. Initial, plain concrete of Grade 30 was prepared using Department of Environment (DOE) method. The plain concrete was act as the control specimens which produced 100% of ordinary Portland cement as cement binder. After that, eggshell concrete specimens were prepared by integrating a range of eggshell powder as partial cement replacement used from 5% to 20% with 5% interval by weight. All the concrete cubes were demolded after 24 hours before subjected to full water curing for 28 days prior to immersing them into 5% of sodium sulphuric acid solution for 1800 hours and 5% of sodium sulphate solution for 50 weeks respectively. The durability of the both plain concrete and eggshell concrete mixes were determined by measuring the mass loss and reduction of compressive strength.

Results and Discussion

Acid attack

The durability of the concrete towards acid attack decrease as the percentage of the eggshell powder increase. Mass loss and compressive strength loss can be observed in the Fig. 1 and 2. Plain concrete cube specimen exhibit the lowest total mass loss and compressive strength reduction compared to other eggshell concrete mixes. The specimens experienced gradual mass loss and strength as the eggshell powder increases. However, when the eggshell powder increases up to 20%, the concrete significant drop in mass and compressive strength up to 0.76% and 31.1% respectively.

Mass loss that occurs as a result of leaching out of the calcium chloride from the concrete due to the reaction between calcium hydroxide in concrete with sulphuric acid (Goyal et al. 2009). This is because acid attacks mainly calcium hydroxide and then the hydration products in the cement matrix which leads to hydrolytic decomposition of hydration cement products followed by degradation of the mechanical properties of the cement based material (Hussin et al. 2008). It was found that the decomposition of larger amount of hydration product of cement matrix in eggshell concrete specimen loss of adhesion between the aggregate particles on the concrete surface to be higher thus resulting in more corner and edges losses as shown in Fig. 3.

As the immersion become longer, the sulphuric acid solution attack progresses from the concrete surface to the internal part, thus resulting in larger percentage of strength loss. Eggshell concrete (Water-cured Oven-dried, WO 20%) had the severe condition among all the concrete specimens. The percentage of calcium hydroxide is much greater than the other specimens which it is more vulnerable to the acid attack (Khairunisa et al. 2015). Evidently, strength reduction and severity of physical damages is higher for the specimens using eggshell powder as partial cement more than 20%. This deterioration process observed on the specimen is in line with the findings by Zivica and Bajza (2001) who highlighted that the reduction of the compressive strength and degradation process of concrete when it exposed to acid attack. Principally, from the study of Zivica and Bajza the gradual reduction of the compressive strength due to increase in the amount of the lateric aggregate integrated in the mix also diminished the concrete durability. Generally, the gradual reduction in the concrete compressive strength is due to the addition of the eggshell powder which had increase the amount calcium hydroxide that vulnerable to acid attack.

Care need to be taken, not to use the eggshell powder as partial cement replacement more than 20% due to adverse effect to the resistance of concrete to acid attack. When the amount of the eggshell powder increase, the amount of the ordinary Portland cement in the mixer is lower which is directly less silicon dioxide to react with calcium hydroxide to form secondary C-S-H gel during the pozzolanic reaction and hydration process. As the result, there is left unreacted eggshell powder left in the concrete which is readily react with the acid solution (Karthik and Gandhimathi 2015).

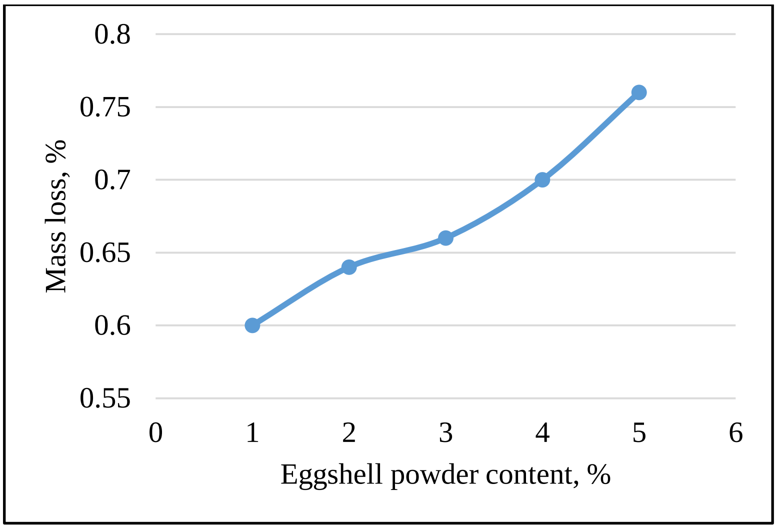

Fig 1 Total mass loss of concrete consisting various percentage of eggshell powder after submerged in sulphuric acid solution

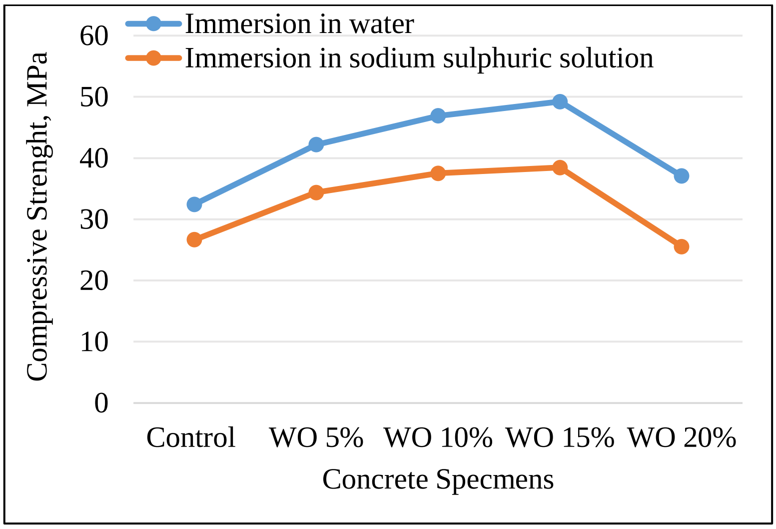

Fig 2 Compressive strength of concrete consisting various percentage of eggshell powder after submerged in tap water and sodium sulphuric acid solution

Fig 3 Eggshell concrete after submerged in sulphuric acid

Resistance to sulphate attack

The concrete cube specimens were submerged in the 5% of sodium sulphate solution to analysis the sulphate resistance of the specimens. At the end of 50 weeks of immersion period, the specimens were tested for the compression strength test. This is to determine the residual compressive strength after the subjected to sulphate environment. The result of the compressive strength was illustrated at Fig. 4 and 5. The reduction of the compressive strength increase when the eggshell powder increase. The WO 20 show significant reduction of compressive strength at 32% different from 37 MPa to 25 MPa. Generally, the reduction of the strength of the concrete was related to the weight loss. Since the concrete matrix was disturbed during the immersion period, the bonding between the ingredients inside was affected. This situation happened was due to the disintegration of the specimens owing the formation of the ettringite and gypsum (Alam et al. 2012). Thus, the loss of compressive strength of the concrete specimens during the sulphate attack is due to the loss of cohesion in the hydrated cement paste and of adhesion between it and the aggregate particles (Sumer 2012).

Since sodium sulphate is known as the salt with strong base with relatively high pH of 7.7. The formation of the gypsum from the portlandite under the attack of Na_2SO_4 is an exchange that present in the Eq. (1). As the result the formation of the calcium sulfate which precipitates and crystallizes in the cement paste microstructure had contributing to expansion process. As the immersion continue, the sulphate ion concentration in the solution increases, it will close to gypsum and monosulphate the precipitation of ettringite and expansion that showed in the Eq. (2) and (3). Thus the ultimate disintegration of the C-S-H phase had delayed. As the result, numerous of micro-cracking occur which follow by the expansion that illustrated in the Fig. 6.

The compressive strength of the eggshell concrete drop gradually when immersed in the sodium sulphate solution. This is because eggshell powder had provided extra calcium hydroxide and left less silicon dioxide in the ordinary Portland cement to react during the hydration process and pozzolanic activity (Ho 2003). As the result, there is abundantly available of free calcium hydroxide in the concrete allows the sulphate ion to react and transform into ettringite especially when the replacement up to 20%.

$$Ca(OH)_2 + Na_2SO_4.H_2O \rightarrow CaSO_4.H_2O + 2NaOH \quad (1)$$

$$C_3A.Ca(OH)_2.12H_2O + 3Na_2SO_4 + 2Ca(OH)_2 + 20H_2O \rightarrow C_3A.3CaSO_4.32H_2O + 6NaOH \quad (2)$$

$$C_3A.CaSO_4.12H_2O + 2NaSO_4 + 2Ca(OH)_2 + 20H_2O \rightarrow C_3A.3CaSO_4.32H_2O + 4NaOH \quad (3)$$

Source: Piasta et al, 2014

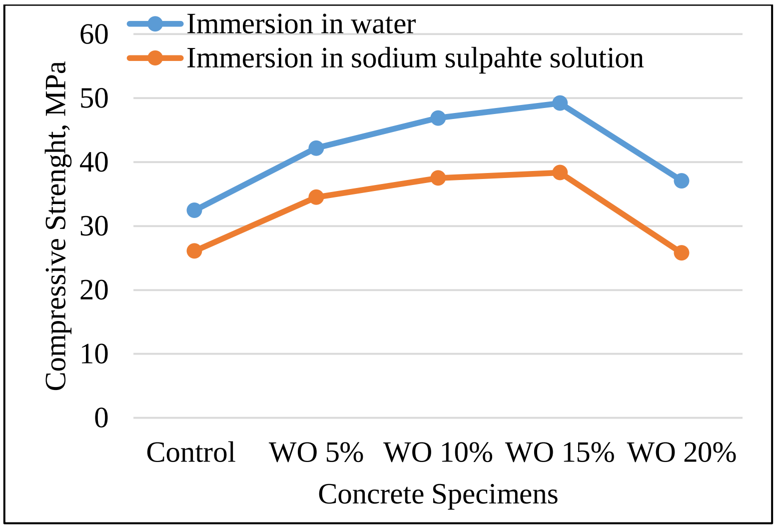

Fig 4 Compressive strength of concrete consisting various percentage of eggshell powder after submerged in tap water and sodium sulphate solution

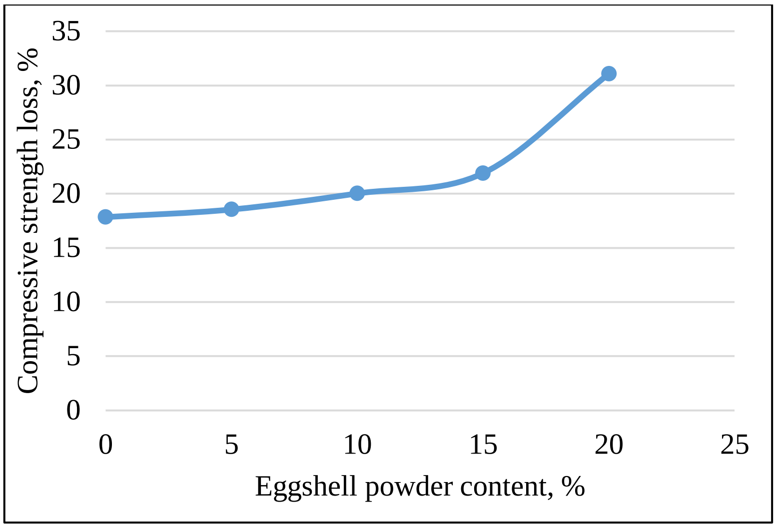

Fig 5 Changes of compressive strength of concrete specimens with different percentage of eggshell

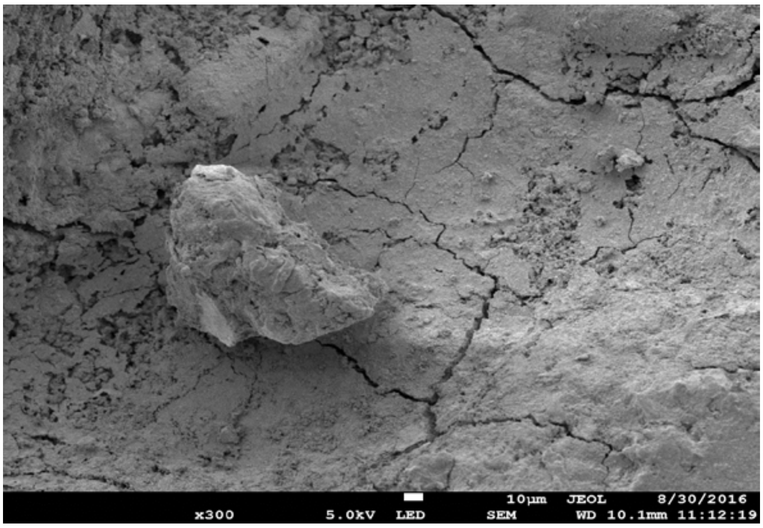

Fig 6 Micro-cracking occur in the concrete cube after submerged in sodium sulphate solution

Conclusion

The small difference in total weight loss and compressive strength for the eggshell concrete in the sulphuric acid solution and sodium sulphate solution when the eggshell powder replaces up to 15% which is comparable to normal plain concrete. However, when the eggshell powder replaces up to 20% of the partial cement replacement, it shows a significant drop of mass and compressive strength after immersed in the sulphuric acid solution. Thus, WO 20% showed a multiple of micro-cracks that available in the concrete specimens after immersed in the sodium sulphate solution for 50 weeks. As the result, eggshell powder was recommended to be used as partial cement replacement up to 15%. More research needs to be conducted to investigate the potential of using eggshell powder as the partial cement replacement.

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