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Investigation on the durability of use fly ash and eggshells powder to replace the cement in concrete productions

A Teara¹, S I Doh¹, S C Chin¹, Y J Ding¹, J Wong¹ and X X Jiang²

¹Faculty of Civil Engineering and Earth Resources, University Malaysia Pahang, Lebuhraya Tun Razak 26300 Gambang, Kuantan, Pahang.

²School of Mechanical Engineering, Ningxia University, Ningxia Hui Autonomus Region, China.

E-mail: dohsi@ump.edu.my

Abstract. Carbon emissions became one of the most significant issues that affect the environment leading to climate change and other environment problems. Concrete productions depend on cement as a main element. The manufacturing of cements produces high CO₂ emission which is approximately 5-7% of total CO₂ emission on earth. This paper will investigate the possibility of reducing the cement amount in concrete productions by replacing it partly with waste materials in the mixing design while maintaining acceptable quality of concrete strength and quality. Fly ash (FA) and eggshells powder (ESP) are the waste materials that are used for this research. The combination of FA and ESP between 35-45% has been used to replacement cement in the mix design. The replacement of cement with FA and ESP was conducted according to weight instead of volume. From the experimental, it is observed that cement replacement with 35% of fly ash and eggshells improved the compression strength and durability of the concrete as compared to the conventional concrete. In conclusion, replacing 35% in total (FA+ESP) instead of cement is an acceptable amount that can reduce the use of ordinary cement in construction applications.

1. Introduction

Since the finding of cement as a main component of the concrete manufacturing a huge amount has been used in the construction and this amount been increased from year to year. High demand of cement drained the natural resources and the carbon emissions are compounded from the cement factory as well. The most widely used construction material is concrete, commonly made by mixing Portland cement with sand, crushed rock and water. In 2017, 40.2 million metric tons of cement was produced by 8 factory of cement in Malaysia. Now days, the rate at which concrete is used is much higher than it was 50 years ago. It is estimated that the present consumption of concrete in the world is of the order of 4.1 billion metric tons in 2016 [1]. During the cement production process, huge amounts of CO₂ which is harmful to the environment are released. In fact, 900 kg of CO₂ is emitted to the atmosphere for the production of every tone of cement [2]. In order to reduce the amount of CO₂ emission, a new formulation of concrete production using waste materials should be initiated and proposed. In this research, an investigation and analysis have been conducted to enhance the performance of reclamation of waste materials by finding the optimum percentage of replacing eggshells and fly ash instate of cement. Fly ash is industrial from burning powder of coal in the power stations for electricity or any rooms of burning coal to produce energy. The fly ash exits out with exhaust gases [3]. There are six coal fired electric power stations in Malaysia nowadays. More than 2400 MW of electricity these stations can produce. Fly ash is the outcome as a waste from the electric power stations [4]. The fly ash produced in Malaysia is estimated to be reach about two million tons a year [5]. Unused fly ash is one of the main issues of most coal combustion power plants and also the bottom ash bring environmental problems which are air pollution and groundwater contamination due to the leaking of metals from the ashes specially the accumulation of the very fine elements of the fly ash. The wise consumption of fly ash by replacing partly instead of cement in concrete mixing decreases both CO₂ emitted to the environment and save energy [6]. Fly ash in Malaysia is a waste



material by the factories of electricity which generally deposited in landfills and that caused serious environmental issues [7]. As an engineering material, coal fly ash can be used for many different purposes: it can be used for construction, catalysis, agriculture to water treatment and soil improvement. Fly ash is useful in many applications because it is a siliceous aluminosiliceous material. If it's finely ground form in the presence of water, coal fly ash will combine with lime or kiln dust to form cementitious compounds. Fly ash reduces the cost of concrete by reducing the amount of cement content. In addition to that, it is an effective factor for improving concrete workability. Also, it helps in reducing the heat of hydration, mainly in mass concreting, and in attaining required levels of strength in concrete at ages beyond 56 days [3,8]. They attempted direct electric curing in alkali activated fly ash concrete using sodium hydroxide and sodium silicate and succeeded in achieving improved early age strength. Eggshell is a waste product produced by the food industry in restaurants, poultry farms and bakery shops [9]. The production of eggs in Malaysia was 659.664 million tons in 2013 which had increased to 679.803 million tons in 2015, this high number gives huge weight of eggshells as a waste [10]. According to Nadu using eggshell will assist in reducing the alkali-silica and sulphate expansions. Eggshells have been shown to possess excellent durability and a washable finish [11]. Eggshell can resist mildew and mold on paint film. Using eggshells has its profitable benefits and has the possible to meet strict act as well as aesthetic requirements [11]. Mohamad showed that the optimal replacement ratio for eggshell powder is 10% [9]. At this ratio, both replacement and control samples stretch to the equal strength. He noted that when replacement ratio was raise up to 20%, difficulties of micro cracks, segregation and bleeding may happen. A few previous years, Kumar had gotten a comparable deduction with the optimal eggshell-cement replacement proportion of 15% [12].

2. Methodology

2.1. Materials

The materials have been involved in this research is Portland cement, fly ash class C, eggshells powder, 10mm and 20mm of natural aggregate, sand and water. That has been used to prepare 4 types of concrete. The sources of the materials are mentions below:

Portland cement: it has produced in YTL Company and it has been recommended to use for constriction concrete such as fibre concrete manufacture, building possesses and all projects for civil engineering.

The fly ash has been used in the lab is class C that supplied by Tanjung Bin Power Plant Station in Johor. Chemically, the fly ash contains: Sulphur trioxide (SO_3), alumina oxide (Al_2O_3), silica dioxide (SiO_2), titanium dioxide (TiO_2), iron oxide (Fe_2O_3), magnesium oxide (MgO), calcium oxide (CaO), and sodium oxide (Na_2O). Figure 1 show the fly ash when it comes from the power station of electricity. The chemical analysis has been done in University Malaysia Pahang centre lab the results shown in the Table 1.

Table 1. The chemical analysis for the ingredients of Fly Ash

Parameter	Percentage (%)
Silicon dioxide (SiO_2)	38.11
Calcium oxide (CaO)	2.46
Aluminum oxide (Al_2O_3)	7.51
Iron oxide (Fe_2O_3)	3.24
Sodium oxide (Na_2O)	0.22
Magnesium oxide (MgO)	0.25
Potassium oxide (K_2O)	0.54
Titanium Dioxide (TiO_2)	0.81
Phosphorus Pentoxide (P_2O_5)	0.63

Zirconium Dioxide (ZrO_2)	0.41
Sulphur Trioxide (SO_3)	0.28
Strontium Oxide (SrO)	0.24
Barium Oxide (BaO)	0.1
Yttrium(III) Oxide (Y_2O_3)	0.03



Figure 1. Raw Fly Ash

Eggshells powder: Eggshells are waste product produced by the food industry in restaurants, poultry farms and bakery shops [9]. The raw eggshells were dried by oven for 24 hours at 110°C . The dried eggshell shells then were ground to finer particle $<60\mu\text{m}$ that fulfill the requirement of ASTM C618-12 [13]. Table 2 and Figure 2 shows the ground eggshells and the chemical composition of the eggshells. The coarse aggregate used are crushed granite from a quarry in Panching, Pahang while the fine aggregate are river sand from Kuantan River.

Table 2. Chemical properties of eggshells

Composition	Eggshells
CaO	47.49%
SiO_2	0.11%
Al_2O_3	-
Fe_2O_3	Traces
MgO	-
SO_3	0.38%
K_2O	-
Na_2O	0.14%
Specific gravity	2.14



Figure 2. Ground Eggshell Powder

2.2 Mix Proportion

There are 4 different mixing types of concrete has been made in this research which includes control mix and three had 35%, 40% and 45% of fly ash and eggshells powder. After mixing each type of mix, workability of the fresh concrete was tested through slump test which following BS 12390:2 [14]. All the specimens were cast into cube size (100x100x100) mm and placed in the water for curing purpose. Compressive strength analysis was conducted by following BS 12390-3 [15]. Table 3 shows the mixing design for the 4 types of concrete.

Table 3. Mix design for 1m³

Mix design	NC 0%	30% FA 5% ESP	30% FA 10% ESP	30%FA 15%ESP
Water (kg)	136	136	136	136
Cement(kg)	400	260	240	220
Fly ash (kg)	-	120	120	120
Eggshells(kg)	-	20	40	60
Sand (kg)	600	600	600	600
Aggregate(kg)	1200	1200	1200	1200

2.3 Testing

2.3.1. Compressive strength test

Compressive strength test is conducted to determine the concrete compressive strength. The specimen of compressive strength test is prepared and tested according to BS EN12390-3 [16]. The specimens were casted for M30 grade concrete by blended of cement with egg shell powder and fly ash (35 to 45 %). In this study, 48 units of concrete cubes were produced with size of 100mm x100mm x 100mm and underwent curing process in water tank. The compressive strength test was conducted after the specimen was removed from water tank. The weight of specimen was measured to determine the wet density of concrete. All specimens were tested on 3, 7, 14 and 28 days. During the testing, concrete specimen was subjected to increasing compression load in order to determine the maximum load that can be sustained by the concrete specimen. The maximum concrete strength was recorded based on the data shown in machine or can be calculated using equation,

$$Sc = \frac{P}{Width \times Thickness}$$

Whereby,

Sc, the compressive strength, N/mm₂ whereas P, Maximum load carried by specimen, N.

2.3.2. Water absorption test

Water absorption test is to determine the rate of moisture absorption by concrete. It is done by measuring the increase in mass of specimen after the specimen exposed to water. The concrete cubes of size 100 mm x 100mm x 100mm were prepared and used for this research. The cubes were dried in the oven for 24 hours at temperature 110°C. The initial weights of concrete cubes (W1) were recorded before the cubes were immersed in the water. After 24, 48, 72 hours, the cubes were weighed repeatedly and recorded as W2, W3 and W4. The cubes were dried by wiping off the water on the surface with dry cloth. The test was conducted according to modified BS 1881: Part 122 [16].

2.3.3. Water penetration test

Water Penetration test is to determine the rate movement of water through the porous material under capillary action. It is done by measuring the increase in mass of specimen after the specimen exposed to water. The concrete cubes of size 100 mm were prepared and used for this research. The cubes were dried in the oven for three days at 50°C. Vinyl electrician's tape was used to seal the sides to ensure one directional flow of water. The bottom surface of the cubes were immersed in distilled water for 24 hours after the initial weight of concrete cubes (W_1) were recorded. Only 2-4 mm of the height of the cubes were immersed. The rate of water penetration was determined by observing and measuring the colored water mark on the cut cubes. The test was conducted according to BS EN-12390-8 [17].

3. Results and discussion

Table 4 shows the results of compressive strength test for the cubes after 3, 7, 14, 28 days. Four type of mixing has been tested, the first mix was a control mix which had 0% of fly ash (FA) and eggshells powder (ESP), the second mix had 35% FA with ESP then third mixing with 40% of FA with ESP and the fourth mix with 45% of FA and ESP. The second mix had better results than control mix in all days test. The third and fourth mix gave less result than control mix.

Table 4. Compressive Strength Test

Sample	Compressive Strength, N/mm ²			
	3 Day	7 Day	14 Day	28 Day
0% FA+ESP	28.8	36.54	44.05	52.43
35% FA+ESP	31.7	48.63	55.21	61.25
40% FA+ESP	26.1	34.77	42.56	49.33
45% FA+ESP	22.5	31.23	39.78	44.65

Figure 3 shows the rate of water absorption for the 4 type of concretes. It is clear that the mix with 35% of cement replacement had closest results to the control mix (0%). Figure 4 shows the Depth of Water Penetration for the 4 type of concretes. It is clear that the mix 45% had the same results to the control mix (0%). The 35% had lower results than control but it is not a big different just 1mm.

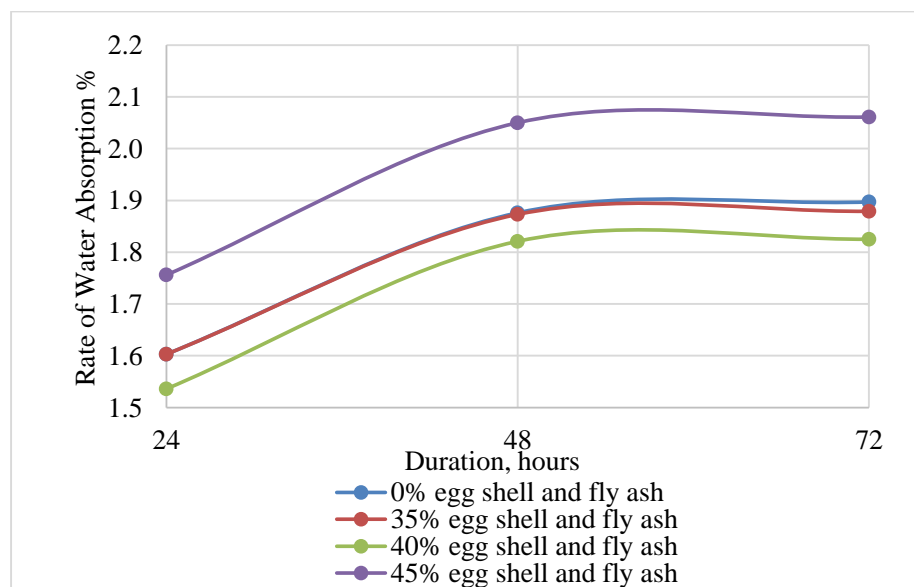


Figure 3. Rate of Water Absorption

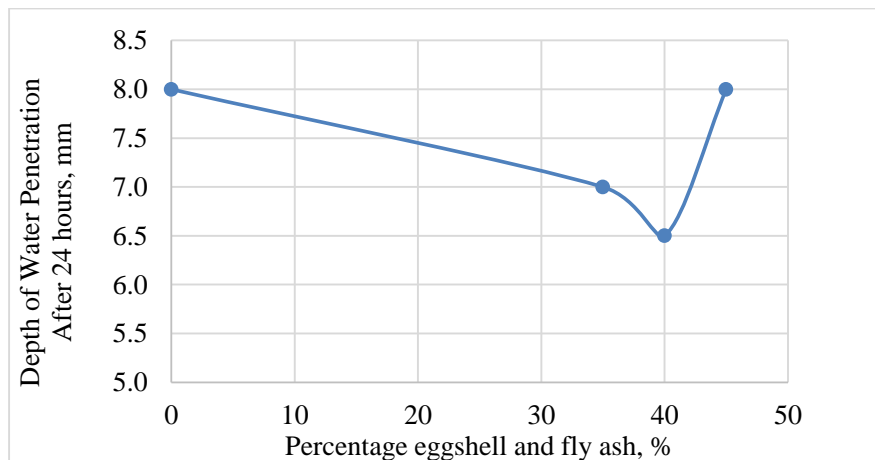


Figure 4. Depth of Water Penetration

4. Conclusions

The study reveals that eggshells powder and fly ash are effective supplementary elements to improve the properties of the concrete factory. However, without cement, ESP and fly ash together, or ESP alone gave weak concrete and unsatisfying compressive strength test, while fly ash alone yielded broken concrete before testing. It was recommended that these materials should be mixed with cement as supplementary elements for improving the concrete properties. This result agreed with previous research that increasing the replacement of fly ash in concrete declined the strength as well. Also, fly ash is more useful than eggshells powder if its amount does not go higher than 30% with the eggshells powder not more than 5%.

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