Exploring the Properties of Mortar Containing Incineration Fly Ash

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Abstract. Fly Ash (FA) is one of the waste materials generated from the combustion of solid waste through incinerator and contains hazardous substances. Further treatment to the ash needs to be done to avoid further environmental destruction. As an alternative solution for this problem, FA is used as a replacement material for cement in the mortar. The main objective of this study is to explore the potential use of FA as partial replacement of cement in mortar. The percentage of FA used to replace the cement in this study is 0%, 5%, 10%, 15% and 20%. Several important tests were conducted to identify main properties of the mortar such as compressive strength, water absorption, density and ultra-pulse velocity. Mortar containing 15% of fly ash has the highest of compression strength which is 35 MPa after 28 days. Besides, the mortar containing 5% of fly ash has the highest result of water absorption test and density test whereas mortar containing 20% of fly ash has the highest value for pulse velocity after 28 days. Thus, mortar containing fly ash has good physical and mechanical properties.

1. Introduction
Term of fly ash (FA) has been widely used to define the ash generated from either incineration process or combustion of coal ash for thermal power plant [1]. Utilization of FA has received lots of attention in these current years due to its promising properties which offer beneficial cost reduction in some of relevant industries. It was recorded that Malaysia has produced more than 54 million metric tons of the FA and only 23 million metric tons which is 42.6% of the total FA was used in 2013. The other 57.2% of the remaining total FA produced were disposed in the landfills. The existence of such large amounts forms a serious problem that has negative effect on the society and the environment. Hence, the optimum utilization of the FA will contribute to solving this problem [2]. This waste must be handled properly without having caused any adverse effects on the environment [3]. Additionally, the best method should be investigated in addressing and treating by-products of coal combustion which is the FA. It has been
generally used to obtain sustainability in the cement and concrete industry for many years. It can be considered as good supplementary cementitious materials for concrete. In addition, general benefits of using FA to partially replace the cement in concrete including improvement in workability, reduction of bleeding, reduction in the temperature rise in hardening concrete, reduction of drying shrinkage, reduction of reinforcement corrosion in reinforced concrete, and overall improvement in durability. In economical aspects, the use of FA can reduce the costs in concrete manufacturing and in FA final disposal [4]. Lots of researchers have tried to produce new construction materials by using recycle and reusable materials. Many construction materials such as concrete, cement, masonry block and insulating materials used today are fabricated with different types of wastes either fully or partially replacing standard raw materials in the mixture. Application of FA as a mixture to mortar and concrete whether plain cement concrete or self-compacting concrete is very common, and several studies have been carried out to determine the performance characteristics of FA for concrete and mortar. The researchers find that FA would reduce the emissions of carbon dioxide compared to standard concrete [5] due to the total amount of cement used has been reduced. Fly ash has also been used to enhance mortar cement workability [6]. The present study explores the properties of mortar containing different percentage of FA calculate using volume fraction method and its physical and mechanical properties were discussed thoroughly.

2. Materials and Methods

2.1 Material Preparation
In this study, FA was collected from local thermal power plant located in Northern Region of Peninsular Malaysia and has been ground first by using a grinder before proceeding with the process of sieving. This is to ensure that the FA is crushed into a smaller particle as the requirement for cement replacement. Then, FA is sieved using 75μm sieve size. For fine aggregate, also undergone sieving process to obtained size less than 4.75 mm.

2.2 Mix design for Mortar and Experimental Set-up
At the beginning of this study the particle density for FA and fine aggregate (sand) were determined. This research was designed with four different mix design and using cube mould for each types of samples. The percentage was set to be 5%, 10%, 15% and 20% of FA content and used to partially replace the cement in mortar mixtures into each sample respectively (excluding the control sample). The size of mould is 50 x 50 x 50 mm which is a standard size for mortar. The ratio used for mortar in this study is 1:4. The density test was carried out to determine the density of the concrete with different parameters. By weighing the cubes before and after curing, density of concrete was calculated. In determining the density of concrete, the formula which is stipulated in ASTM C138 is applied. Density was determined at 28 days of curing. Concrete can be classified as porous material as it has ability to absorb and transport water through the pores in cement. FA also has high rate of water absorption. ASTM D570-13 (2013) was used as a reference for the water absorption test. After the concrete has been cured for 28 days, the samples are taken to lab to be weighted. The specimen is weighted to get its saturated surface dry weight. After that all the sample cubes were soaked back in the water tank about an hour. Wet weight was recorded. Thus, from both dry and wet weight of the specimens, the percentage of water absorption is determined. For ultra-pulse velocity test, it is usually used to test the integrity and density of concrete samples and also can be tested for mortar samples to gauge the consistency of mortar matrix. Measurements of signal travel time through the specimen of pulses were performed between both transducers. In ultrasonic pulse velocity, the longitudinal ultrasonic velocities of the samples, V, were calculated from the distance between the two transducers (path length). Finally, for the compressive strength test Axial load applied on all the cube sample in direct contact with machine or spacing. The compression test was used to determine the material behavior under the load. The maximum stress of the mortar samples that can survive for a period of time under progressive load was determined in this study.
3. Results and Discussions

3.1 Particle Density Test
Particle density test is conducted to identify the density of the cement and the FA. The density for FA is 0.38 g/cm\(^3\) and the density for cement is 1.03 g/cm\(^3\). From the result obtained, the cement is denser than fly ash about 37%. This result contributes to the final density of mortar samples.

3.2 Density OF Mortar
From the figure 1 below, the mortar containing 20% of FA has the lowest density which is only 2000 kg/m\(^3\) when compared with other percentage of mortar samples. The highest density is 2240 kg/m\(^3\) that obtained from samples containing 5% of FA. This is in accordance with the results for particle density that shows that specific gravity of cement is higher than specific gravity of FA thus contributing to higher density as in 5% FA replacement which has not shown any significant different with control sample. The trend shows that the higher percentage of the ash the lower densities of mortar samples as depicted in Figure 1.

![Figure 1. Density of mortar by the percentage of fly ash](image)

3.3 Water Absorption
Results for water absorption is shown in Figure 2 below. It can be seen that the highest water absorption can be found for sample containing the least amount of FA which is only 5%. For this sample the water absorption obtained was 10.67% which is 38.75% higher than control sample. However, the decreasing trends can be found for other samples containing 10, 15 and 20% of FA with the least water absorption is for 20% FA content. Future test on this mechanism is recommended to fully understand the behavior of FA in absorbing water either at the beginning of the hardening process or during the curing process.
Figure 2. Density of mortar by the percentage of fly ash

3.4 Ultra-Pulse Velocity
From table 1 shown below, the pulse velocity started to increase at 5% of fly ash in mortar. The highest pulse velocity of mortar is 4.72 km/s which contains 20% of FA. Velocity reduced from higher content of FA to lower content of FA. This attributes to the fact that the FA content is also function as the filler that filled up the void thus the sample becoming a very highly dense packing structure. The higher the percentage of fly ash, the higher the pulse velocity.

Table 1. Pulse velocity on the percentage of fly ash in mortar

| Percentage of Fly Ash in Mortar (%) | Pulse Velocity, V (km/s) |
|------------------------------------|--------------------------|
| 0                                  | 3.78                     |
| 5                                  | 4.21                     |
| 10                                 | 4.46                     |
| 15                                 | 4.58                     |
| 20                                 | 4.72                     |

3.5 Compressive Strength.
Figure 3 below shows the compressive strength for mortar tested after 28 days of curing period. It shows that all samples containing FA had achieved an early strength at approximately 60% from its targeted strength. FA potentially affects the early increase in strength due to the free lime that is still reacting during the healing process [7]. The highest compressive strength of mortar was obtained from sample that has 15% of FA in it with the strength of 35 MPa at 28 days. It can be evident that, the strength of mortar started to decrease when the percentage of FA replaced in mortar was above than 15%.
Figure 3. Compressive strength at 7 and 28 days of all mortar samples

4. Conclusions
In this study, the physical and mechanical properties of mortar containing FA is determined by conducting the density test, water absorption test, ultrasonic pulse velocity (UPV) test and the compressive strength test. It can be concluded that the properties of mortar that utilized FA varies and independent with each other. However, the optimum percentage in this study can be taken as 5% because it shows consistent properties. The silica, calcium, iron and aluminium content in FA contributes to the acceptable properties of mortar. Further studies on the effect of size, origin and pre-treatment of FA is recommended to better understand the mechanism of FA and its reaction in mortar and concrete.

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