Recycling Fly Ash from MSWI for Artificial Aggregate Production for Concrete

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Abstract. This study focusses on the development of new lightweight aggregate (LWA) that eventually will have comparable properties with existing natural aggregate which is granite. The main objectives of this study is to examine potential use of recycled municipal solid waste incineration (MSWI) ash as raw material in LWA production with a method of cold-bonded palletization process. The ashes are collected from Cameron Highland Incineration Plant, Malaysia that can be divided into bottom ash (BA) and fly ash (FA). This study uses FA as partial raw material to substitute the Ordinary Portland Cement (OPC). The properties FA are studied by means of X-Ray Fluorescence (XRF). The LWA is fly ash lightweight aggregate (FALA). The production of LWA is based on cold-bonded palletization technique. FALA have experienced two different curing process for 28 days namely room-room (RR) and room-water (RW) curing conditions. The percentage of FA used in this study is 10%, 20%, 30%, 40% and 50% of cement replacement and the size is fixed between 10 mm to 20 mm with circular shape. The properties of FALA produced in this study is examined including loose bulk density, and aggregate impact value (AIV). Other physical properties including colour and texture are also being investigated. From the results of LWA it is clearly seen that 20% FA were the best percentage of ash used to produce good quality LWA. Loose bulk density of FALA selected is 716.72 kg/m³ and AIV 13.80%.

1. Introduction

Incineration process was found to be an efficient way of controlling the volume of solid waste as it helps to change the physical properties of waste into smaller particles such as bottom ash (BA) and fly ash (FA), gas and heat. It is advantageous as the energy can be harvested and the ash can be reuse to form new materials. These ashes are about 5% and 30% of the total solid waste being burned during the incineration process [1]. The recovery of the ashes from the incineration process and converting it into other usage have been started as early as 1996. However, FA needs to be treated well before properly disposed, most probably due to the lower density of the ash and was afraid of the possibility of it being transferred to other area by air-borne. This implies high disposal cost and subsequently compromise the efficiency of incineration process. Studies by numerous researchers shows that ash from the incineration process is proven to be valid and possible to use with several treatment [1–8].
However, most of these studies only focused on the usage of the ashes in their original forms without any modification or alteration. The significant results from their studies indicates that FA promised good potential for future usage especially in civil engineering field including manufacturing of aggregate and concrete.

2. Materials and Methods
Proper and detail characterizations of all raw materials involved in this study were examined. FA was collected and its chemical composition is determined using XRF. Its physical and mechanical properties were also studied including density and particle size analysis. Morphology of ash is determined using SEM. These properties will be compared with ordinary Portland cement for its pozzolanic constituents. Next, LWA is produced with addition of foam that will create pores inside the aggregate paste. The percentage of ash replacement was set to 10%, 20%, 30%, 40% and 50%. Then it was cured into two different curing condition which is room and water curing condition. Important physical and mechanical properties of LWA produce during this production stage is determined.

The FA is collected from MSWI plant located in Cameron Highland, Pahang, Malaysia. This facility was designed with a capacity of processing and burning total of 40 tonnes solid waste per day and was built in 2008 with RM38 million cost. It was located about one kilometre from Blue Valley Plantation area and is managed by Department of National Solid Waste Management, Government of Malaysia. This small-scale plant uses autogenous combustion technology (ACT) a combination of rotary kiln and air injection to ensure continuous combustion which was designed and constructed by a private company. The main purpose of this plant is situated in that place is to divert solid waste from the landfill to land scarcity in the highland area. Figure 1 shows the incineration facility and ash residues from Cameron Highland, Malaysia. This is where the source of FA is collected and used in this study. FA is collected from flue gases that extracted from electrostatic precipitator and usually in dry form. After that, FA were sieved using laboratory sieving machine to pre-determined size which is 300 µm to separate their natural contents and homogenize the size to tally with cement size [9].

In the making of LWA paste, dry ingredients which is ordinary Portland cement and ash were poured into a laboratory mixer and mixed for 2 minutes. Then, foam was added into the dry materials and mixed again thoroughly for another 2 minutes. Before foam can be added into the mixer, density of foam is determined so that total amount of foam that have been added into the mixture can be identified. To ensure firm and sticky paste is produce the mixer was kept moving for 3 minutes at ambient temperature. Later, aggregate paste was taken out from the mixer and proceed with palletization process to produce circular shaped aggregate balls. Aggregate samples are left at room temperature for at least 24 hours after it continues with designated curing condition. For aggregate cured in air curing, the samples were left in room temperature continuously until 28 days. Meanwhile, for water curing aggregate, it was transferred from room condition and soaked in the water. These two types of curing regime will have significant different between one another and need to be monitored closely.

![Figure 1. Incineration facility at Cameron Highland, Malaysia.](image-url)
3. Results and Discussions
This section discussed the overall properties for raw materials and LWA produced in this study.

3.1. X-ray fluorescent (XRF)
Attributing to the results obtained for elemental analysis of compositions shown in table 1, for FA sample, the highest element composition of ash that can be found is silica (Si), Iron (Fe), Calcium (Ca), Aluminium (Al) and Potassium (K). Highest silica content from FA is 28.4%. However, silica content in OPC is very low with only about 9.02%. The Si content derived most probably from the domestic waste and glass bottles, Ca content was from paper, alimentary and industrial wastes while the Fe content depend on the presence of a metal separation process in the incinerator. The lowest aluminium content is obtained from OPC with only 2.3%. Also, for calcium content, OPC dominates most portion as it contains approximately 78% of calcium content from total element composition. The percentage of calcium content for FA is quite high as it occupies almost 22% of total element content. Another main element composition inside all of the raw materials is the iron. It is noted that for FA the amount of iron was significantly higher when compares with OPC. The iron content in FA is 26%. Meanwhile, for other traces the compositions are very low that most of them exist for less than 1%.

| Element (%) | FA     | OPC    |
|-------------|--------|--------|
| Magnesium, Mg | -      | 1.4    |
| Aluminium, Al | 14.300 | 2.3    |
| Silicon, Si   | 28.400 | 9.2    |
| Sulphur, S    | 2.140  | 2.850  |
| Potassium, K  | 2.960  | -      |
| Calcium, Ca   | 21.600 | 78.470 |
| Titanium, Ti  | 1.900  | 0.240  |
| Vanadium, V   | 0.072  | 0.057  |
| Chromium, Cr  | 0.039  | 0.041  |
| Rubidium, Rb  | 0.047  | 0.063  |
| Manganese, Mn | 0.220  | 0.100  |
| Strontium, Sr | 0.521  | 0.054  |
| Iron, Fe      | 25.980 | 4.490  |
| Zirconium, Zr | 0.110  | 0.023  |
| Nickel, Ni    | 0.041  | -      |
| Ruthenium, Ru | -      | 0.250  |
| Copper, Cu    | 0.094  | 0.043  |
| Zinc, Zn      | 0.086  | -      |
| Barium, Ba    | 0.900  | -      |
| Rhenium, Re   | 0.082  | 0.026  |
| Lead, Pb      | 0.110  | -      |

3.2. Loose bulk density
Figure 2 illustrates the loose bulk density results for 10 samples of LWA in five different percentages which is 10%, 20%, 30%, 40% and 50% and its relationship with different curing condition. Based from the table, it can be observed that the lowest density obtained from sample is 656.17 kg/m³ for FALA50. Meanwhile, the highest loose bulk density can be evident from samples FALA10 with the density of 841.80 kg/m³ cured in RW curing condition. The existence of pores inside the mixture
eventually resulted in lighter density. The pores are induced by the air entraining agent or foam that has been used in this study. More voids in the structure system contributes to its lighter mass and density.

**Figure 2.** Graph of loose bulk density for all FALA samples at various percentage in relation with curing conditions.

In addition, for FALA samples the percentage different between the highest value and the lowest value is 28%. It can be seen from figure 2, the density of LWA varies from as low as 656.17 kg/m$^3$ to as high as 841.80 kg/m$^3$. Obviously, the highest percentage of FA is used in the mixes, the lowest the density of FALA. From the results of LWA, it can be clearly seen that all 10 samples can be classified as LWA since the maximum density is only 841.80 kg/m$^3$. Typically, commercially available LWA for civil engineering application exhibits higher density in range between 1100 – 1500 kg/m$^3$ [4]. Even more, the natural aggregate which is in this case granite have higher density between 2400 – 2800 kg/m$^3$. However, for LWA manufactured using FA, which in this case FALA, the results of density are in similar range of 700-800 kg/m$^3$ with a research done by Ugur & Ozturan, (2011).

**3.3. Aggregate Impact Value (AIV)**

From figure 3, it can be found that the strongest aggregate can be obtained from sample FALA10 with AIV value 9.8%, followed by FALA20 with AIV value 13.8. From these samples, it can be noted that the strength of aggregate is depending on water for hydration process to take place. All of the highest samples are cured in water curing. Out of 10 samples, 1 sample can be accepted as exceptionally strong with AIV less than 10%, which is FALA10 cured in RW. In addition, 2 more samples which AIV in between 10% to 20% falls into strong category aggregate.

Similar results obtained from sample FALA50 with 50.1% which also being cured in RR curing condition. It can be seen that both of the weakest samples have been cured in air curing. The lacking of water in the system can affected the strength of aggregates produced as the hydration process which contributes to the strength of aggregates does not happened adequately. The low-humidity in RR curing condition resulted in the reduction of hydration speed of cement thus generates more unconsolidated structures and reduces the strength of cement composites such as in LWA [10].
Figure 3. Aggregate impact value for FALA samples with different curing condition.

4. Conclusions
The conclusions were drawn as a result of this study on the potential use of FA from MSWI in the development of LWA. The production of LWA can be presumably as successful and have comparable qualities and characteristics when compared with NWA. The cold-bonding process is proved to be a good method to produce LWA which requires no extensive heat treatment. Addition of foam inside the aggregate paste proof to be a contributor to the density reduction of the LWA. The density of all LWA decreased when the amount of ash used is increased however increased the specific gravity and water absorption. FA has the promising potential to be used as raw materials in the making of LWA but up to until certain percentage only. In this study, the optimum percentage of these ashes that can be utilised is 20%. For FALA, optimum properties are 716.72 kg/m$^3$ for loose bulk density and 13.80 of AIV.

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