

DOI: <https://doi.org/10.24425/amm.2022.137501>NORLIA MOHAMAD IBRAHIM^{1,2*}, ROSHAZITA CHE AMAT^{1,2}, MUSTAQQIM ABDUL RAHIM¹,
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RECLAMATION AND REUTILIZATION OF INCINERATOR ASH IN ARTIFICIAL LIGHTWEIGHT AGGREGATE

This study focused on the reclamation of ash from incineration process and development of new artificial lightweight aggregate (LWA) that have comparable properties with existing natural coarse aggregate. The main objective 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 pelletization. Two types of incineration ash which is bottom ash (BA) and fly ash (FA) were collected from Cameron Highland Incineration Plant, Malaysia. The properties of BA and FA are studied by means of X-Ray Fluorescence (XRF) and microstructure of these ashes were inspected using Scanning Electron Microscope (SEM). The properties of BALA and FALA produced in this study is examined including loose bulk density, water absorption and aggregate impact value (AIV). From the results of both types of artificial LWA, the lowest loose bulk density of BALA is BALA50 with 564.14 kg/m³ and highest is at 831.19 kg/m³. For FALA50, lowest loose bulk density is 573.64 kg/m³ and highest is 703.35 kg/m³. Water absorption of BALA and FALA is quite similar with one another in with the value of 23.8% and 22.6%, respectively. Generally, FALA have better qualities of LWA comparing with BALA with lower bulk density and water absorption and can be categorized as strong aggregate. In summary, reclamation and reutilization of incinerator ash has generated acceptable qualities for artificial LWA. Both types of BA and FA shown a great potential to be recycled as additional materials in artificial aggregate production.

Keywords: light weight aggregate; incinerator; bottom ash; fly ash; concrete

1. Introduction

Huge amount of solid waste creates a massive waste processing industry in all over the world and not all of these industries are legally established. These factories usually select the waste that they wanted to recycle and discarded the rest of the unwanted waste in illegal and improper manner. When rains come, the rainwater will penetrate through the pile of waste and the murky water just flows into nearby river. This horrendous mass needs to be disposed in proper disposal manner in order to solve the environmental pollution. For most countries, most convenient way for the authorities to handle the solid waste is by providing a dedicated land as a landfill. However, these landfills require huge areas of land and requires more money.

Considering the massive amount of solid waste being dump at the landfill that causing environmental pollution, it is very crucial to reclaim, reuse and recycle all these wastes or its residues. For most developed nations, most proper way to dispose

the solid waste is by burning all of these waste in the incinerator. Incinerator is a facility that provides a service of burning large volume of waste especially industrial waste in huge furnace with high temperature which in most countries including Malaysia, it is well known as Municipal Solid Waste Incineration (MSWI) Plant. New approach has been implemented by upgrading the plant to Waste-To-Energy Plant. Changes in volume of solid waste after being burned will provide major helps in the management of solid waste which intended to reduce an adverse effect on human health, environment and aesthetics aspect. In Malaysia currently, there are at least four small-medium scale plants have been built and were designated at tourism place and in highland due to scarcity of land. Medium scale plant which is Pulau Langkawi Incineration Plant has the highest capacity of 100 tonnes/day followed by Cameron Highland Incineration Plant with the ability to processed 40 tonnes of solid waste per day. The small-scale plant which is Pulau Pangkor and Pulau Tioman Incineration Plant has a capacity of 20 tonnes/day and 15 tonnes/day, respectively [1].

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However, the incineration process does have its residues which is harmful to our health and our environment. The incineration of waste would generate the hazardous air pollution control (APC) residues. APC residues may represent 2-3% of the MSWI [2]. Other residues from the incineration process is basically known as fly ash (FA) and bottom ash (BA). FA is lighter particles collected at the upper chamber of the incinerator. Meanwhile, heavier particles that have not been burned completely is called BA and usually black in colour and comes in wet condition. However, properties of ash will be different depending on the types of incinerators. Mechanical bed incinerator has lower silica content compared with fluidized bed incinerator with the value 4.3% and 21.9%, respectively [3].

Many attempts have been made by previous researchers to investigate the potential of these ashes to be utilized in the construction industry including manufacturing a concrete or brick, as coarse aggregate in concrete [4-6], incorporated them in the blended cement [7] and as materials in amended pavement [8]. The cementitious properties of incineration ash made it fit to be used in many due to sufficient constituents of SiO_2 and Al_2O_3 in ash provides supplementary cementitious materials and contributed to its mechanical properties [9]. Although cement-based granulation process has not been studied equally deeply, the feasibility of using cement and ash for the manufacturing of aggregate is undoubtedly worth of consideration. Therefore, in this study, an extensive work on the recycling of BA and FA and the agglomeration process between ash and cement by means of cold bonding pelletizing process was presented. The cement-based aggregate was developed and studied so that it can be used to replace coarse aggregate in the concrete.

2. Materials and methodology

Collection of ashes

The BA and FA is collected from MSWI plant located in Cameron Highland, Pahang, Malaysia. It was located approximately one kilometer from Blue Valley Plantation area and is managed by Department of National Solid Waste Management, Malaysia. This small-scale plant uses autogenous combustion technology (ACT) which is a combination of rotary kiln and air injection technology to ensure continuous combustion which was designed and constructed by a private company.

Characterization of raw materials

Characteristics of main raw materials involved in this study were examined including its elemental compositions and microstructure property. FA and BA were collected in bulk and oven-dried at temperature of $100 \pm 5^\circ\text{C}$. Next, it was grinded and sieved to the size of $300 \mu\text{m}$ and its elemental compositions were determined using X-Ray Fluorescence (XRF) PANalytical MiniPal 4 Machine. X-ray fluorescence analysis is a method to

identify the composition of material and can be used for small size or fine particles of rocks, mineral or sediments. Firstly, the sample must be dried in oven at least a day to remove the excess water content within it. Next, the sample is sieved through a sieve of $63 \mu\text{m}$ size to remove the contamination in the sample and with at least 5 grams of the sample weight was collected and tested through the XRF test. Then, the sample was mixed with a diluted solution and was put into the track of the X-ray spectrometer under a high speed of rotation. Oxide amount of element can also be determined using this test. Morphologies and microstructures of BA and FA were identified using high resolution Scanning Electron Microscope (SEM) model JEOL JSM-6460LA and taken at 10 kV. This property was compared with cement for its chemical constituents and mineral composition. Fig. 1 is the example of BA and FA collected from the site and used in this study.



(a) Bottom ash

(b) Fly ash

Fig. 1. Bottom Ash and Fly Ash Collected from Cameron Highland MSWI Plant

Artificial lightweight aggregate (LWA) production

LWA was produced with addition of foam that created pores inside the aggregate paste which contributed to the lighter density of aggregate. Manufacturing process was done manually and employing cold-bonded pelletization technique. The three main raw materials used in this study were incineration ash, foam and cement as shown in Fig. 2. Ordinary Portland cement was partially replaced by ash in LWA mixture and was set to replace 10%, 20%, 30%, 40% and 50% by volume fraction method. Important physical and mechanical properties of LWA produce during this stage is determined including loose bulk density, water absorption and aggregate impact value (AIV).

The aim for this study is to reclaim and reuse the residue from incineration process and produce artificial aggregate which is lightweight and has acceptable quality and performance when compared with normal coarse aggregate. The mixtures proportions are shown in Table 1 and have been designed for every 2 kg mass of paste. Size of each aggregate were maintained in between 10 mm – 20 mm to obtain more similar data as in construction industry. For all LWA produced in this study, the samples were denoted as BALA which is Bottom Ash Lightweight Aggregate and FALA for Fly Ash Lightweight Aggregate.

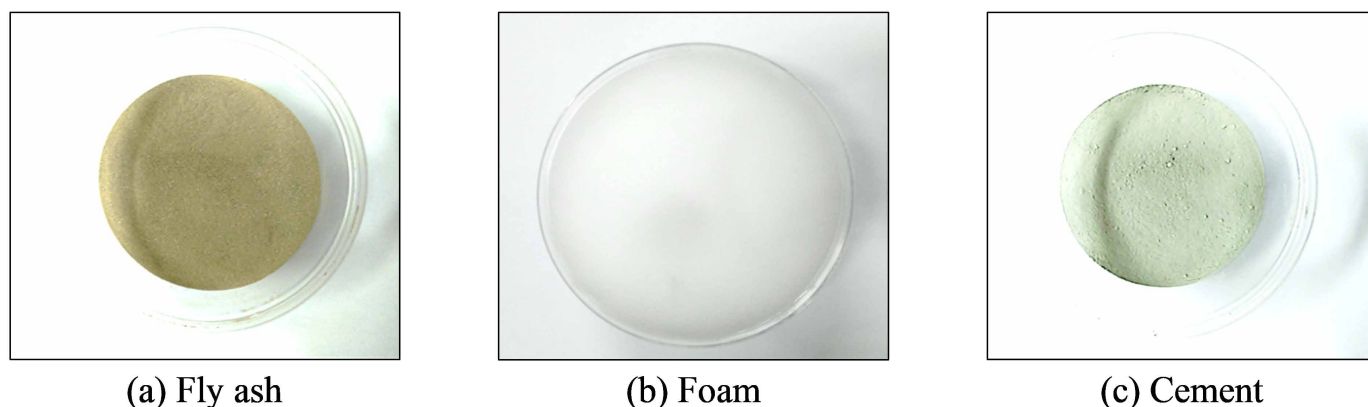


Fig. 2. Raw Materials in Production of Artificial LWA

 TABLE 1
 Proportion Ash and Cement in the Mixture

| | Mix proportion in LWA (gm) | | | | |
|--------|----------------------------|------|------|------|------|
| | 10% | 20% | 30% | 40% | 50% |
| Ash | 200 | 400 | 600 | 800 | 1000 |
| Cement | 1800 | 1600 | 1400 | 1200 | 1000 |

Loose bulk density, water absorption and aggregate impact value testing method

The determination of loose bulk density for aggregate was in accordance with ASTM C29/C29M (2009) [10]. The amount of water penetrating the concrete differs with the prevailing transport mechanism, saturation degree and exposure time of the material. Water absorption of aggregate is important because it can determine the porosity of the aggregate. Since the materials of aggregate usually contains more or less pores inside it, partially all dry particles are capable of absorbing water. In this study, the test for water absorption is strictly followed BS 812-122 (1990) [11]. Meanwhile, aggregate impact value test was done in order to classified the aggregate strength. It will give a relative measure of the resistance of an aggregate to sudden shock or impact. It is actually percentage loss of weight particles passing 2.36 mm sieve by the application of load by means of 15 blows of standard hammer and drop. This test was done in accordance with BS 812-122 (1990) in dry condition [12].

3. Results and discussions

Compositions of ashes and cement

Referring to the results obtained for elemental analysis of compositions shown in Table 2, the major compound contained in the BA collected from Cameron Highland Incineration Plant are Silica (Si) and Iron (Fe), followed by Aluminium (Al) and Calcium (Ca). On the other hand, Potassium (K), Sulphur (S), Magnesium (Mg) and Titanium (Ti) were detected as minor compositions in the BA. The high content of Si that was de-

tected at 31.5% indicates that high content of SiO_2 present in the combustion residues of municipal waste. SiO_2 was produced when the heating is involved, hence it can be easily found in the incinerator ash. SiO_2 is one of major cementitious materials that contributed to engineering properties of LWA which is the strength of the aggregate especially for BALA. However, for the case of amount of Ca, the amount is quite low compared with cement where in cement it shows tremendous amount of Ca with 35.3%. Si was detected at the highest value in the BA samples which were sourced from the inert waste such as rock, construction waste, dirt or debris that was mixed into the solid waste after the quenching process. This is in parallel with the fact that BA was generated from incombustible solid waste from the incineration process. In addition, the Si content was derived from the domestic waste and glass bottles, meanwhile Ca content was originated from paper, alimentary and industrial wastes and the Fe content depend on the presence of a metal separation process in the incinerator [13]. These three main element compositions were normally identified in cement that majorly contributed to strength and durability of concrete.

On the other hand, for FA sample, the highest element composition of ash that can be found is Si, Fe, Ca, Al and K. Si content from FA was 11.45%. Si content in cement is lower compared with FA and consist only about 9.02%. The lowest Al content is obtained from cement with only 5.7%. Also, for Ca content, cement dominates most portion as it contains approximately 36% of Ca content from total element composition. Higher Si and Ca content contributed to the higher strength of specimen and increase durability of specimens. Nowadays, the trends of incorporating FA has been increased and were used as partial replacement for cement in order to save overall production cost and support the vision for more sustainable environment. However, incineration FA could not replace the cement entirely because it did not have the self-bonding ability which was owned by cement and required additional of chemical activator like quicklime, cement and sodium silicate as a binder. As a result, it only can be used as partial replacement in cement or admixture to achieve higher the strength of concrete and the concrete's finish surface. Classification of incineration ash cannot be made since the existing Standard Method did not specify the method

to classify the ash based on its own unique properties but classification of ash can be assumed based on specification of coal ash and can be used as referring properties.

TABLE 2

Element Composition in BA, FA and Cement

| Element | BA | FA | Cement |
|---------------|--------|-----------|-----------|
| Magnesium, Mg | 2.000 | — | 0.00 |
| Aluminium, Al | 14.400 | 8.400% | 5.7% |
| Silicon, Si | 31.500 | 11.45% | 12.67% |
| Sulphur, S | 1.040 | 0.5038% | 0.2707% |
| Potassium, K | 2.890 | 2.020% | 0.980% |
| Calcium, Ca | 1.900 | 22.436% | 35.343% |
| Titanium, Ti | 1.690 | 0.608% | 0.0606% |
| Vanadium, V | 0.062 | 144 ppm | 25.7 ppm |
| Chromium, Cr | 0.0419 | 369 ppm | [2] ppm |
| Rubidium, Rb | 0.057 | 70.8 ppm | 18.6 ppm |
| Manganese, Mn | 0.279 | 385 ppm | 211 ppm |
| Strontium, Sr | 0.428 | 171.5 ppm | 106.0 ppm |
| Iron, Fe | 26.480 | 1.3491% | 0.7838% |
| Zirconium, Zr | 0.120 | 0.110 | 0.023 |
| Nickel, Ni | 0.0429 | 156.6 ppm | 0.00 |
| Copper, Cu | 0.109 | 551 ppm | 130.1 ppm |
| Zinc, Zn | 0.070 | 2032 ppm | 94.3 |
| Barium, Ba | 0.580 | 0.0404% | 0.0111% |
| Lead, Pb | 0.120 | 0.00 | 0.00 |

Microstructure of ash

Scanning Electron Microscope (SEM) test was carried out to examine the microstructure of BA and FA in order to see the particles shape and size. Fig. 3 shows the SEM images of raw BA and FA taken at 10 kV with two magnifications which is at 5000 \times and 10000 \times . It can be noted from this Fig. 3, that raw FA has quite low sphericity and has needle-shaped formation. On the other hand, BA which consists of coarser materials shows an irregular various shaped of particle. BA in raw form has various shape, size and in dark grey-black colour because of the existence of un burnt carbon. The same formation and particle shape is similar in the case of Tang et al., (2017) [14]. When the samples of FA are zoomed in to 10000 \times , it can be seen that the particles appear to be as plate-like particle which forming a series of thin layer structures as shown in Fig. 3(c). The interior structure for BA was consisted with more spherical microstructure and have higher formation of agglomerates particles.

The sizes of particles these ashes can be as low as 11.3 μm for BA and 27.9 μm for FA. However, these sizes are not limited to those aforementioned especially for BA since the size could be much longer and larger depending on the samples tested. It can be noted that the size among ash is not uniform and can be various due to the crushing and sieving process. Nevertheless, these sizes proved that the samples is below 70 μm as per submitted for testing.

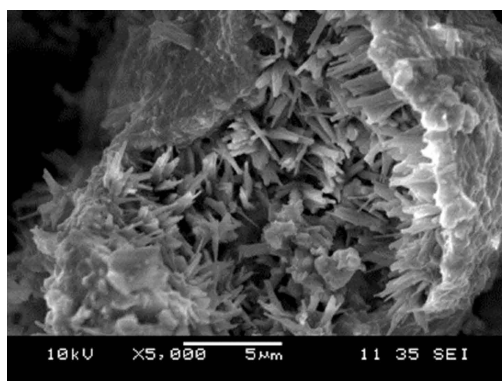
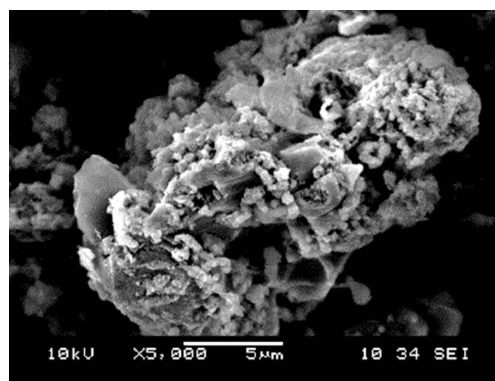
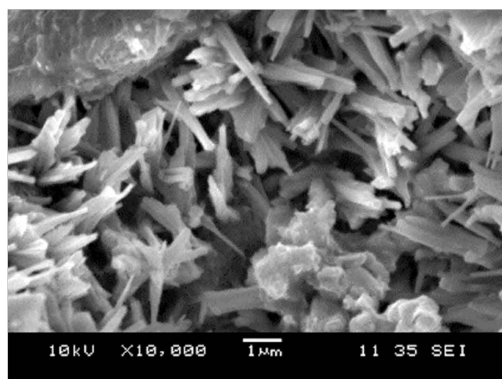
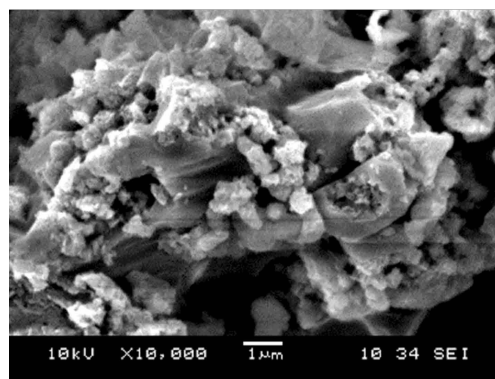
(a) FA at 5000 \times magnification(b) BA at 5000 \times magnification(a) FA at 10000 \times magnification(d) BA at 10000 \times magnification

Fig. 3. SEM images of FA and BA at different magnifications

4. Properties of Lightweight Aggregate

Loose bulk density

Fig. 4 illustrates the loose bulk density results of LWA in five different percentages which is based on 10%, 20%, 30%, 40% and 50% of partially replaced cement. Comparing the two figures i.e Fig. 4(a) and Fig. 4(b), it can be observed that the lowest bulk density obtained from sample BALA50 with value 564.14 kg/m³ and 573.64 kg/m³ was obtained for FALA50. Meanwhile, the highest loose bulk density can be evident from samples BALA10 with the density of 831.19 kg/m³. 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. The difference between the highest density to the lowest is approximately 32% for BALA samples.

Meanwhile, for FALA samples the percentage different between the highest value and the lowest value is 18.4%. The differences in loose bulk density can also be discussed into its types and percentage of ash used. This can be explained by the specific gravity value for the ash which FA has the lowest specific gravity amongst two ashes. It can be seen from Fig. 4(b), the

bulk density of LWA varies from as low as 573.64 kg/m³ to as high as 703.35 kg/m³. Obviously, the highest percentage of FA is used in the mixes, the lowest the density of FALA. From the results for both type of LWA it can be clearly seen that all LWA batches can be classified as LWA since the maximum density is only 831.19 kg/m³. Typically, commercially available LWA for civil engineering application exhibits higher density in range between 1100-1500 kg/m³ [15]. Even more, the natural aggregate which is in this case granite have higher density between 2400-2800 kg/m³. BALA produced in this study has much lower density if compares with aggregate manufactured using MSWI BA from Southern Italy Incineration Plant, which is in range of 1170 and 1330 kg/m³, as stated in study done by Cioffi et al., (2011)[16]. However, for LWA manufactured using FA, which in this case FALA, the results of density are in similar range of 700-800 kg/m³ with a research done by Ugur & Ozturan, (2011) [17].

Water absorption

The results for water absorption as a function of percentage in weight differences for the LWA is depicted in Fig. 5. Fig. 5(a) shows water absorption for BALA after curing period of 28 days.

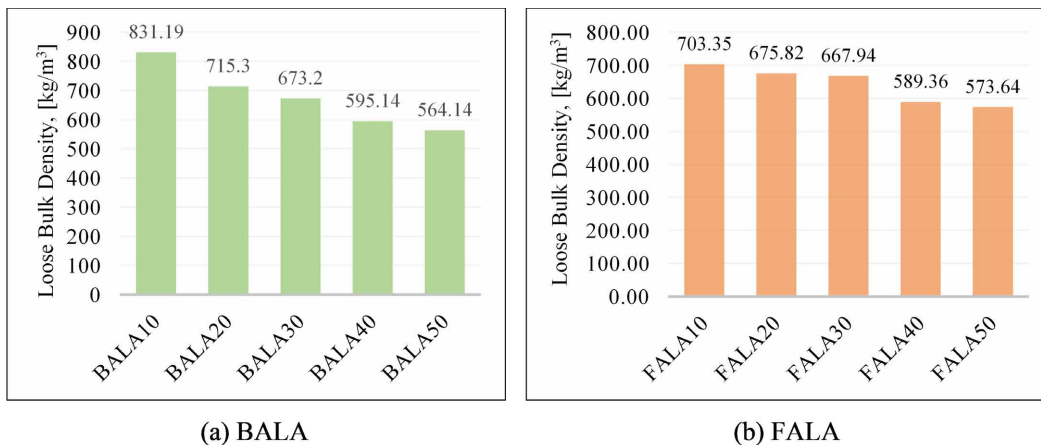


Fig. 4. Loose Bulk Density for All LWA Samples

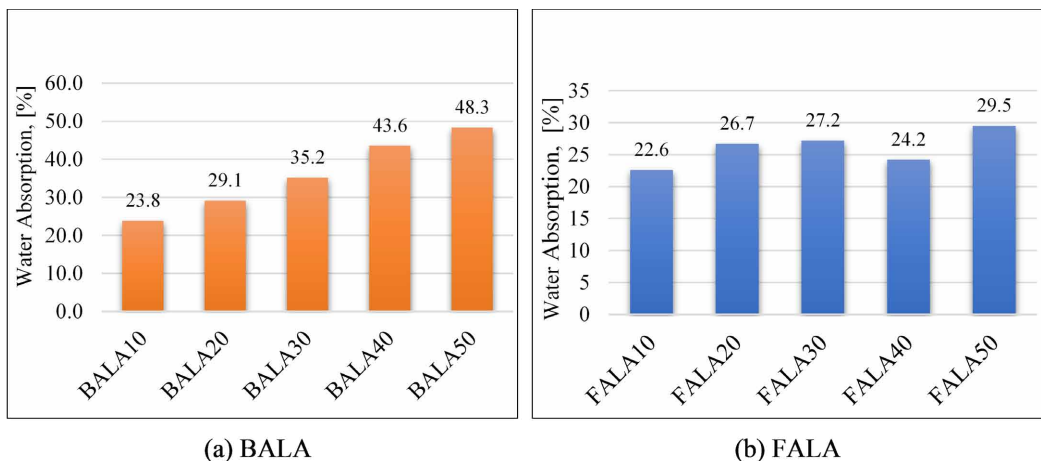


Fig. 5. Water Absorption for All LWA Samples

As can be seen, the lowest water absorption can be found for sample BALA10 with 23.8% water absorption and the highest water absorption can be found in sample BALA50 with the value of water absorption is 48.3%. The effect of ash content on the water absorption capacity for FALA is obvious. With the increased amount of FA, water absorption also increased. Generally, BALA and FALA retained higher percentages of pores due to the broken bubbles thus, their density is lower. Ratio of surface area to water absorption will become higher when density is lower. Because of the nature of cold-bonded aggregate in this study which is denser on the outer area, the tendency to absorb water is less whereas an aggregate with connected or open pores have more tendency to absorbed water [18]. However, since both BALA and FALA is made from addition of foam, the ability to absorb water is still quite high regardless the lacking of open pores at the outer surface.

Aggregate impact value (AIV)

AIV is a value that measures the resistance of aggregates to sudden impact or shock and usually represented by unit percentage. Higher value percentage denotes low performance of aggregate in concrete and can determine the suitable application in

various field. Amongst two types of ash, the strongest aggregate can be obtained from sample FALA10 with AIV value 17.4%, followed by BALA10 with AIV 22.7% and 13.9% as shown in Fig. 6. From these samples, it can be noted that the strength of aggregate is depending on water for hydration process to take place. Out of 10 samples, 50% of samples can be accepted as strong aggregate with AIV less than 30%, which is for FALA10, FALA20, FALA30, BALA10 and BALA20.

On the opposite, it can be noted that the weakest aggregates for both types of ash is from samples BALA50 with AIV 45.3% and similar results obtained from sample FALA50 with AIV 46.2%. It can be seen that both of the weakest samples have highest ash content. The acceptable strength of LWA was also contributed by the thin layer of compressed surface existed after manual pelletization process was conducted. Fig. 7 shows overall size of LWA and the thin layer at outer part of LWA after it was cut in two halves.

5. Conclusion

The utilization of incineration ash in production of LWA can be presumably as successful and have comparable qualities and characteristics. The cold-bonding process is proved to be a good

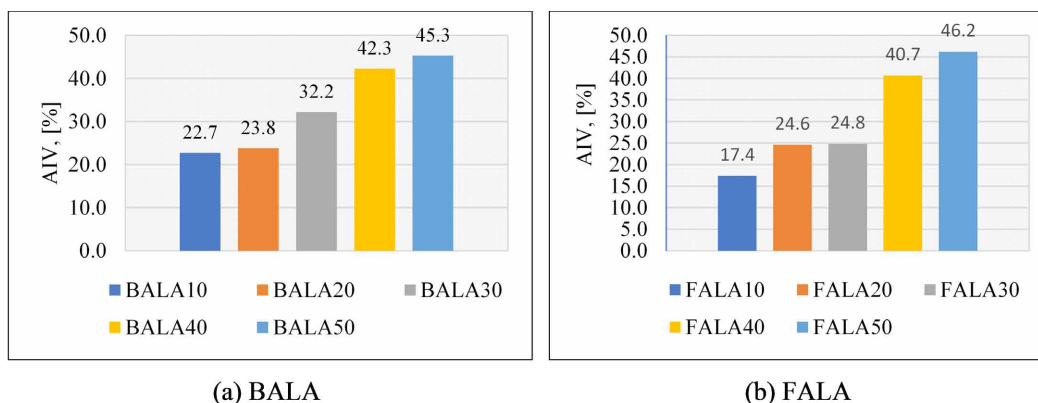


Fig. 6. Aggregate Impact Value (AIV) for All LWA Samples



Fig. 7. Image of an artificial LWA

method to produce LWA which requires no extensive heat treatment. Addition of foam inside the aggregate paste proved 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. More extensive testing of LWA can be done to further enhance the properties of LWA in order to promote the reclamation of incineration ash for a better future. This study is focus on the idea of utilizing waste materials from solid waste incineration process namely bottom ash and fly ash on the development of LWA. However, more details studies can be done to enhance the properties of LWA and examining the possibilities of using these manufactured LWA into the production of concrete or use as road-base materials.

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