Potential use of foam in the production of lightweight aggregate (LWA) and its performance in foamed concrete

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Abstract. This paper discusses about the production and characteristic of lightweight bubble aggregate and foamed concrete. Lightweight aggregates (LWA) are produced by mixing an appropriate amount of foam and ordinary Portland cement and pelletized into assigned size and shape. Then, the characteristics of LWA are identified to ensure that aggregate produced can be categorized into LWA with acceptable qualities. For the foamed concrete, its performances are tested and studied by selecting five different percentages for partial substitution of LWA as coarse aggregate. Main aim of the research is to identify the characteristic of lightweight foamed concrete such as density, water absorption, aggregate impact value (AIV), compressive strength after using LWA as an alternative material for construction industry. This aim also in parallel to main idea of reducing the usage of natural coarse aggregate which is granite that is facing serious depletion. Three different percentages of concrete mixtures using LWA have been prepared that consist of 25% and 50% of LWA together with control sample that contained 100% natural coarse aggregate. These three different mixes are produced manually where the mortars, foam, granite and LWA were mixed together in mixer. The samples have undergone several testing including density test, water absorption test and compression test. Microstructure of the samples also was examined using SEM. From the results obtained, foamed concrete that were produced with 25% substitution of LWA showed the highest compressive strength of 10.74 MPa with density of 1735 kg/m³. In conclusion, LWA have shown promising potential to be used in the foamed concrete production.

1. Introduction

Lighter coarse material can contribute to lower density of concrete. It can be achieved if using lighter natural aggregate such as oil palm shell or by producing artificial aggregate using raw materials such as slag and pumice. Aggregate can be defined as a rock like material with various sizes and shapes that is used in the manufacturing of cement composite, bituminous/asphaltic concrete, filter beds, railroad ballast, sub-grade layer in highway, filler for foundation and base course for roads. Aggregate can come in forms of granular materials such as gravel, crushed stone or iron-blast-furnace slag used with cementitious media to form mortar or concrete, or alone as a road base or filler for foundation. The application of aggregate in concrete was influenced by several factors such as cost reduction and economic, reducing the heat output per unit volume of concrete and thermal stress, minimised drying shrinkage of concrete and improve the plastic property of concrete. Since it makes up approximately
75 % of the total volume for concrete, it is well known that quality of aggregate plays important roles in influencing the compressive strength of concrete. The performance of aggregate is usually depending on the properties of the parent rock, as natural aggregate such as granite is resulted from the weathering process [1]. Various types of LWA can be obtained either it comes from natural resources or manmade. Some of the examples of natural aggregate is from expanded clay and oil palm kernel [2] pumice, scoria and volcanic cinders. On the other hand, manufactured LWA can be obtained by pyro processing shale, clay, ground vermiculite and diatomite. But, most of the LWA were made from sintering process which requires a thermal treatment at higher temperature from 1000 to 2000 °C. Stephen J. Hayde who was a contractor has successfully invented a rotary kiln process of expanding shale, clay and slate at the early twentieth century [3]. However, his aggregate was manufactured in the kiln at temperature more than 1200 °C. Although his aggregate was hard and durable, the sintering process contribute to high energy consumption. Thus, this paper focusses on the development of LWA using a combination of foam and ordinary Portland cement (OPC) and examined its potential use in foamed concrete.

On the other hand, foamed concrete is one of the lightweight concrete and it’s referred to cellular material which is consisting of Portland cement, fine aggregate, water, foaming agent and compressed air. Foamed concrete is used for a variety of applications, ranging from thermal insulation and fire protection to void-filling and building elements with successively increasing density and strength requirements, such as, an insulating fill in fire walls or other precast elements, a replacement for soils and backfills, and the construction of cast-in-place pile. Currently, contractor in Malaysia have introduced low-cost housing in Malaysia using foamed concrete, but foamed concrete is generally not strong enough compared to normal concrete. Several attempts have been made from previous researcher in improvising the properties mainly compressive strength of foamed concrete. [4]–[6]. All these studies lead into one permissible result which is the quality of foamed concrete can be improved with the addition of artificial LWA.

2. Materials and methods

2.1. Preparation of samples

2.1.1. Production of LWA. For production of LWA, Ordinary Portland Cement (OPC) and foam have been used in this research. By using dilution factor of 1: 2.5 where one portion of foaming agent diluted with two and half portion of water, foam will be produced. Next, foam is mixed with OPC in the ratio of 1:2 which one portion of foam mix with two portions of OPC. It is formed by mixing between the foam and OPC according to composition which have been set. After the mixture is well blend, the mixture is formed into spherical shape before it undergoes 24 hours of oven drying process. Table 1 shows the proportion of mortars, foam and percentage of LWA used for each samples. The palletisation process of LWA is shown in Figure 1. Production of LWA is using manual method in which every single aggregate particle is made using hand with designated size of 10 mm - 20 mm and circular in shape.

2.1.2. Production of foamed concrete. In the meantime, for the production of foamed concrete, it required LWA, OPC, sand, water and also foam. At first, LWA, OPC, sand and water were mixing together until the mixture become homogenous. Next, foam is added slowly to the mixture until the batch is well mixed. It is necessary to added the foam slowly because foam contain water. If excessive of foam, the batch will become too lurry. Three types of foamed concrete are produced which is the control sample (CS), 25% addition of LWA (25LWA) and 50% addition of LWA (50LWA).
Table 1. Mix proportion of raw materials for LWA production.

|        | Cement | Sand | LWA | Water | Foam |
|--------|--------|------|-----|-------|------|
| CS     | 9.00 kg| 9.00 kg | 0.00 kg | 4.50 kg | 4.23 kg |
| 25LWA  | 9.00 kg| 6.75 kg | 2.25 kg | 4.50 kg | 4.23 kg |
| 50LWA  | 9.00 kg| 4.50 kg | 4.50 kg | 4.50 kg | 4.23 kg |

Figure 1. Palletization process of LWA

2.2. Testing of materials

2.2.1. Density. In this study, loose bulk density was determined according to the standard of ASTM C29/C29M since the aggregate are below the maximum size, 37.5 mm. For the determination of loose bulk density, it is measured by mass of non-compacted aggregates required to fill the container of a unit volume after aggregates are batched based on volume. Loose bulk density is determined by shovelling method [7]. Meanwhile, for foamed concrete, density of foamed concrete is analysed to differentiate either the concrete are normal concrete or lightweight concrete. This analysis can be done after the concrete cube is immersed in the curing tank for 7 days. The sample is taken out and wipes the wet surface and the concrete cube is weighed and recorded [8].

2.2.2. Water absorption. Water absorption is the increase in mass of aggregate due to water penetration into the pores of the particles during a prescribed period of time, but not including water adhering to the outside surface of the particles. It is conducted to calculate the change in the mass of an aggregate due to water absorbed in the pore that present in the aggregate [9]. Water absorption test are conducted to analysed the amount of water absorbed by foamed concrete. This test was needed to determine the capability of concrete cubes to absorb water and is commonly expressed as a weight percent of the test specimen. The specimen is placed in the oven at 105 ± 5 °C for 72 hours. Next the specimen is taken
out and the mass is weighted. Then the specimen is immersed in the curing tank for 30 minute. Next, it was removed and the wet surface of specimen was wiped. Lastly, it was weighted [10].

2.2.3. Aggregate impact value (AIV). The aggregate impact value is a test to determine the strength of coarse aggregate that is conducted using apparatus namely aggregate impact value tester. The equipment consists of a hammer that will fall freely from height of 380 mm towards the LBA in measured container beneath the hammer, for 15 times for 15 seconds. Then, the crushed LBA are removed from the cup, then sieved using 2.36 mm IS sieve and weighted. AIV is calculated by dividing the weight of LWA passing the sieve with initial weight of LWA and multiply with one hundred to give the value in percentage. Then, the value obtained is obtained with the value tabulated in Table 2.

Table 2. Aggregate classification.

| Value | Group                        |
|-------|------------------------------|
| <10%  | Exceptionally Strong        |
| 10–20%| Strong                       |
| 20-30%| Satisfactory for road surfacing |
| >35%  | Weak for road surfacing      |

2.2.4. Compressive strength. One of the mechanical properties of concrete is compression. Compression test are conducted in order to identify the ultimate strength of concrete. It was done as part of hardened concrete testing which requires the casting of concrete. For this study, selected batch is poured into 100 mm x 100 mm x 100 mm mould. Next, the cubes were immersed in curing tank for 7, 14 and 28 days. Then according to these specific curing days, the sample is taken out from the curing tank and tested. The testing is referred to MS EN 12390-3, 2012.

2.2.5. Microscopic analysis for aggregate. Microscopic analysis of the lightweight aggregate is carried out by using Scanning Electron Microscope (SEM) model JEOL JSM-6460LA with ×100 magnification which is a high resolution scanning electron microscope as shown in Figure 2. It uses high energy beam at an acceleration voltage of 25 kV. Using this equipment, the microstructure in the aggregate can be captured and interconnected particles can be examined. Thus the porous structure, small and big void in the aggregate can be seen clearly.

Figure 2. SEM apparatus.
3. Results and discussion

3.1. Density
After conducting the test, the evident shows that the value of loose bulk density for LWA is 812.500 kg/m$^3$ which is below the permissible value stipulated in the Standard which is 880 kg/m$^3$ [7]. The LWA is lighter due to the cellular structure of LWA and high internal porous microstructure, which resulted in this low density. Density analysis for cube was also conducted. Based on the Table 3, it represents the density for CS, 25LWA and 50LWA. According to the result, CS has the density of 1577 kg/m$^3$ while 25LWA gives density of 1735 kg/m$^3$. Meantime, 50LWA has the density of 1832 kg/m$^3$ which is the highest density compare to the other two samples. Overall, depending on the substitution of LWA, it shows the 25LWA and 50LWA will cause the increasing in density due to addition of mass of the LWA in the foamed concrete. The higher the substitution of the LWA, the higher the density of foamed concrete.

Table 3. Density of CS and LWA.

| Sample | Density (kg/m$^3$) |
|--------|-------------------|
| CS     | 1577              |
| 25LWA  | 1735              |
| 50LWA  | 1832              |

3.2. Water absorption
LWA have porous structure thus, it absorbs more water than normal aggregate. After undergoing the test for 24 hours which is according to procedure in ASTM Test Method Specific Gravity and Absorption of Coarse Aggregate [9], LWA will absorb from 5% to more than 25% by weight of dry aggregate while for normal aggregates, it generally absorb less than 2% [12]. According to the result for foamed concrete, the highest water absorption was for sample that contained 50LWA with 26.027% followed by 25LWA with 23.766%. Meanwhile, the lowest water absorption was for CS which is 18.890%. Based on the Table 4, it can be seen that water absorption was increased when the percentage LWA usage was increased. As stated, LWA typically has porous structure with a higher absorption capacity than normal-weight aggregate. Although the surface of the LWA is smooth, but the presence of tiny void on the surface of the LWA allows the water to enter the hole and infiltrating further into LWA thus make the percentage of water absorption higher for increasing percentage of LWA used.

Table 4. Water absorption of CS and LWA.

| Sample | Water Absorption (%) |
|--------|----------------------|
| CS     | 18.890               |
| 25LWA  | 23.677               |
| 50LWA  | 26.027               |

3.3. Compressive strength
Compressive strength is the important parameter that need to be measured as it one of the mechanical properties of aggregate. In the meantime, compressive strength for sample consist of 25% substitution of LWA have the highest compressive strength on day 28 with 10.74 MPa which increased more than thrice than the CS. CS only achieved 3.21 MPa compressive strength. 50LWA increase the value of compressive strength almost doubled to CS. It is important to remember that CS do not contained any coarse aggregate in the mix that can contribute to the compressive strength of concrete. It can be said that 25% substitution of LWA is practically effective. So in conclusion, the optimum percentage of
LWA that can be used to replace sand is 25LWA as the percentage increase the strength of foamed concrete effectively.

3.4. Aggregate impact value (AIV)
AIV obtained is 18.99 % which can be classified as strong aggregate. This can be achieved since during the formation of LWA, the uniform LWA paste is slightly compressed before it is formed into a circular shape. Due to compression, some of the pore will diminish or the some of it will become smaller resulting in thin dense layer at the outer surface of LWA thus, increasing in strength of LWA which make it difficult to be crushed. The impact value of LWA are considered strong when compared to other type of aggregate such as fly ash aggregate (FAA) which have the impact value 20.1 %. FAA is the aggregate that are formed by using similar technique of pelletization [13]. The production process of FAA does not require compression techniques; thus the pore is still preserved. This porous structure of FAA made the structure of the aggregate more brittle that give the aggregate impact value is 20.1 % that is higher than LWA which is 18.99 %. The higher the value of aggregate impact, the weaker the aggregate.

3.5. Microscopic analysis for aggregate
Based on Figure 3, pores in the LWA are evident to appear in variety of sizes. Although, the spherical shape of pores or also known as censosphere is dominating, they are also accompanied with small amount of irregular shaped pores in the aggregate. The pores are form during the production of the aggregate as the bubble from the foam entrapped between the cement. At the same time, sightings of cracks or fractures also can be seen which occurs resulting from the impact of a hammer as this analysis requires only a fragment of the aggregate to be enlarged using SEM.

![Figure 3. Microstructure of LWA.](image)

4. Conclusion
The best performance of foamed concrete is with the 25% substitution of LWA which it is optimum percentage of LWA to be added that increase the strength of foamed concrete effectively. Meanwhile, characteristics of LWA play a vital role in performance of foamed concrete. Since LWA have smooth and spherical in shape, it gives the foamed concrete more workable instead of rough and angular aggregate. LWA are also able to provide high absorption of water that can enhanced the hydration process during curing that lead to better development of concrete strength in 28 day.
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