Properties of cold-bonded lightweight artificial aggregate containing bottom ash with different curing regime

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Abstract. Cold-bonded pelletizing technique is frequently used in aggregate manufacturing process as it can minimise the energy consumption. It has contributed to both economical and environmental advantages because it helps to reduce the gas emissions problems. Bottom ash collected from municipal solid waste incineration (MSWI) plant was selected as raw material in this study and was utilised as a partial replacement for cement for artificial aggregate production. Several percentage of ash replacement was selected ranged from 10 to 50%. Aggregate pellets were subjected to different types of curing condition which is room-water (RW), room-room (RR), oven-room (OR) and oven-water (OW) condition. Properties of aggregate pellets were examined to obtain its density, water absorption, aggregate impact value (AIV) and specific gravity (SG). The results indicated that the most efficient curing regime is by exposing the aggregate in RW condition. The optimum aggregate was selected at 20% where it has satisfied the required density of 739.5kg/m^3, and classified as strong aggregate with AIV 14. However, the water absorption of aggregate increased proportionately with the increment of ash content.

1 Introduction

The amount of solid waste dumped into landfill nowadays is beyond our expectation and imagination. It was estimated that currently, over 23,000 tonnes of waste is produced each day in Malaysia. However, this amount is expected to rise to 30,000 tonnes by the year 2020. This solid waste is either being dumped in sanitary landfill or disposed by means of incineration process. Volume of solid waste can be reduced up to 80 – 95 % depending on the composition and the degree of recovery materials [1]. Nevertheless, the combustion of solid waste will produce two by-product ashes, which is fly ash and bottom ash. Many research attempts have been done by previous researchers to utilise fly ash in aggregate and concrete due to its pozzolanic characteristic that can contribute to the strength of materials [2-3]. Studies have been made to explore the effect of fly ash volume to the compressive strength of concrete [4-6]. However, bottom ash from incineration process was left

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untreated and considered as trash and dumped in the landfill. Most of the time, bottom ash is used in the field of road construction and pavement [7]. Seldom efforts were taken place to reuse and recover the potential use of bottom ash especially MSWI bottom ash as mineral admixtures in concrete. Therefore, it is important to investigate the properties of bottom ash so that full potential of bottom ash can be utilised. Recent studies shows that bottom ash either with or without prior treatment can be incorporated in concrete manufacturing and gives significant improvement in the quality of concrete [3], [8–12]. Several studies have been conducted to use bottom ash in the production of artificial aggregate.

Aggregate pellets can be produced using two main techniques i.e. sintering process and cold-bonding pelletization process. It is well known that in sintering process, it involves high-energy consumption during pelletization, which will lead to increasing cost of production. Pellets were produced by a bloating process and the temperature usually can reach up to 1200 °C [12-13]. Meanwhile, more economic technique has been proposed whichis known as cold-bonding pelletization method. In this method, the agglomeration of fine materials happened at ambient temperature with the aid of wetting agent, usually water, to become bigger solid particles. The spherical and rounded shaped of cold-bonded aggregate facilitated the workability of concrete and reduce the water cement ratio.

Curing process of aggregate is as important as the curing process of concrete. It will significantly influence the strength of structural element that used these aggregate pellets. Conventional curing method is the most preferred way to cure samples whereby they were immersed in water for 28 days. However, the presence of optimum heat and moisture are also important. Method of curing are normally depending on several factors such as availability of curing materials, size, shape, age of concrete, production facilities either in place or on plant, esthetic appearance and economic. A study from Ibrahim et al. (2015) shows that aggregate that have been cured in the oven at 100 ± 5 °C possessed comparable strength to the aggregate cured in water. Therefore, in this study four (4) different types of curing regime were employed to examine the properties aggregate produced. The curing conditions were set to room-water (RW), room-room (RR), oven-room (OR) and oven-water (OW) conditions.

The main objective of this study is to study the potential use of bottom ash in lightweight aggregate production and to investigate the physical and mechanical properties of the aggregate. The effect of different curing regime towards the strength of aggregate was also determined.

2 Materials and methods

2.1 Raw materials preparation

The main materials involved in this study were prepared prior the commencement of any experiment. Type 1 ordinary Portland cement (OPC) and bottom ash from MSWI plant were used in this study. The chemical composition of the cement and bottom ash is presented in Table 1 after they were determined using X-Ray Fluorescence (XRF). The bottom ash used was collected from an incineration plant located in Cameron Highland, Malaysia. It comes in wet and black solid form with different particles size and shape. To remove excessive moisture content, it was dried in the oven at 100 ± 5 °C for at least 24 hours and sieved to obtain required size (300 μm) before it was used as partial replacement for cement. It is important to distinguish between irrelevant ash and low-grade ash that contained high carbon compound, which will affect the strength of aggregate.

Table 1. Chemical Compositions for OPC and bottom ash.

	Chemical Compositions (%)	
	OPC	Bottom Ash
Silicon dioxide (SiO_2)	13.40	31.5
Aluminium oxide (Al_2O_3)	2.60	14.4
Ferric Oxide (Fe_2O_3)	4.43	26.48
Calcium Oxide (CaO)	72.90	17.9
Magnesium Oxide (MgO)	-	0.28
Sodium Oxide (Na_2O)	-	-
Pottasium Oxide (K_2O)	1.54	2.89
Sulfur trioxide (SO_3)	3.73	1.04
Others	1.00	3.87

The lightweight artificial aggregate (LWA) in this study was produced using cold-bonded pelletization method. Lightweight property of the aggregate was obtained by introducing foam into aggregate mixture. The foam will create pores that subsequently will produce less dense material. A protein-based foaming agent was used with the dilution ratio of 1: 33 where one portion of foaming agent was mixed with 33 portion of water.

The required weight of the foam was calculated by multiplying the foam density by the foam volume to be added. It was added immediately into the dry mixture and mixing it until uniform paste was achieved. Then, pelletization process will take place where spherical shaped aggregate was produced. Five different percentage of dry mixture containing only bottom ash and OPC were prepared. The percentage of bottom ash is 10, 20, 30, 40 and 50 %. After pelletization, the aggregate was subjected to different curing regime to study its physical and mechanical properties. Four different curing regimes were set namely oven-room (OR), oven-water (OW), room-room (RR) and room-water (RW). In OR and OW curing condition, the pellets were put in the oven for 24 hours at temperature 100 ± 5 °C. Next, it will be either left for curing at ambient temperature or immersed in water for another 14 days. As for RR and RW, the pellets were left at curing room first before it was subjected to next curing regime, which is immersion in water. The pellets in RR were left in curing room for continuous 14 days. The different curing regime was proposed in order to study the effects of different curing conditions toward the strength of aggregate. The samples were examined based from their types of curing regime and percentage of ash replacement for example one sample was denoted as BAOR10 which refers to aggregate that was cured in oven-room condition with 10 % bottom ash replacement in the mixture.

2.2 Testing Procedures

2.2.1 Density and specific gravity

Physical and mechanical properties of lightweight aggregate are interrelated with one another.better conclusions cannot be made if each and every aspects of produced aggregate is not well-analysed. Therefore, the mos timportant criteria for aggregate was determined including its specific gravity, water absorption, AIV and density. The density of aggregate was determined by following standard method which was stipulated in ASTM 330 [15]. The oven dried density (ODD) of lightweight aggregate must not exceed 1040 kg/m^3. It is necessary to wash aggregate with tap water to remove impurities in lightweight aggregate.

Lightweight aggregate were wiped and dried using water absorbing towel. Then, it was weighted and the mass was recorded as B. After that, lightweight aggregate were immediately immersed in water, weighted, C, and dried in the oven for 24 hours with 110 ^{o} C ± 5 ^{o}C. The mass was recorded as A. ODD can be calculated using equation 1 as follows:

$$ODD = A / (B - C) \times 997.5 \tag{1}$$

where A = oven-dried mass of bulk aggregate

B = saturated mass of aggregate

C = surface dry mass of aggregate

On the other hand, specific gravity test was also conducted based on the saturated surface dry condition of the aggregate. Specific gravity of aggregate is defined as the ratio of the mass of solid in a given volume of sample to the mass of an equal volume of water at the same temperature. The specific gravity was determined using Electronic Densimeter Model MD-300S. The results were indicated in SG and V for volume. Fig. 2 shows the apparatus to obtain specific gravity measurement. This machine adopts Archimedes' Principal and the determination of relative density value based on the density of 4 °C : 1 g/m^3.

2.2.1 Water Absorption

The second test is to obtain water absorption of aggregate. Water absorption was generally known as increment in mass of aggregate due to penetration of water into pores of particle during a certain time but not including water adhering to the outside surface of particle ASTM C127, 2010 [16] . Water absorption of aggregate can be determined using equation 2 as follows:

$$\text{Water absorption, \%} = (M_A - M_S) / M_A \times 100\% \tag{2}$$

where M_A = mass of dry moist sample

M_S = mass of dry oven sample

2.2.3 AIV

The aggregate impact value is needed to classify the strength of aggregate produced in this study. An apparatus used in this study is as shown in Fig. 1 and the test method was strictly followed testing method as stipulated in BS 812 (1975). The value of AIV will represents the strength of aggregate produced. It should be noted that, AIV for aggregate should not exceed 25 % for heavy-duty concrete application. AIV can be determined using equation 3.

$$\text{Aggregate impact value (AIV)} = (B/A) \times 100 \tag{3}$$

where A = net weight of aggregate (g)

B = weight of crushed aggregate passing 2.36 mm sieve (g)

Fig. 1. AIV testing machine.

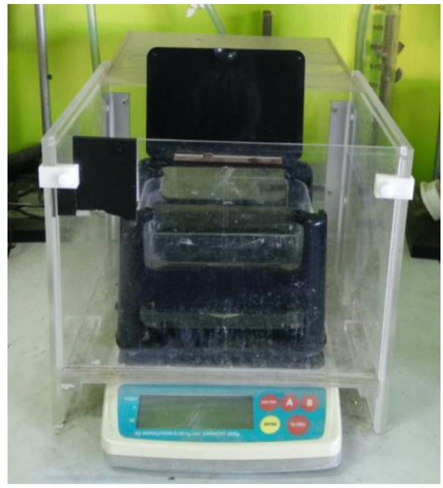

Fig. 2. An Electronic Densimeter Model MD-300S.

3 Results and discussions

3.1 Density and specific gravity

Density of lightweight aggregate will be used to classify the types of aggregate. According to BS EN 13055-1 (2002), concrete can be identified as lightweight if the density obtained was below than 2000 kg/m^3. Meanwhile, aggregate can be classified as lightweight aggregate if its unit weight was less than 880 kg/m^3 as stated in ASTM C330, [15]. It can be noted from results shown in Table 2, 90 % of aggregate produced in this study can be classified as LWA regardless their curing regime. Only BARR10 and BARW10 obtained slightly higher density from the limit stated in the standard which increased by 1.14 % and 1.59 % respectively. Light weight criteria of aggregate was contributed by the existance of pores structures inside the mixture It was found that maximum value of density was obtained from BARW10 with 894 kg/m^3 and the lowest BAOR50 and BAOW50 which is 570 kg/m^3. Greater percentage replacement of bottom ash will produce lower density of aggregate.

Specific gravity of aggregate also plays an important role in reducing the density of aggregate. From the test that has been done, 100 % of aggregate samples had less than 2 (SG) with the lowest SG are 1.28 for 50 % bottom ash replacement. Meanwhile, highest SG was identified at BARW10. Value of SG acquired in this study is interrelated with the value of density. It was due the fact that bottom ash itself has lower SG compared with OPC.

The relationship of density and SG also can be discussed based on their curing regimes. From the same table, we can see that the value of density is higher when LWA undergoes water curing compared to air curing process. For example, 20% LWA with RW condition exhibits higher density compared to RR condition, which is 740 and 725 kg/m^3. This is because LWA with air curing at ambient temperature for 14 days has lesser moisture content compared to LWA with water curing regime. However, excessive moisture content will resulted in lower compressive strength [17].

Table 2. Density, water absorption, AIV and specific gravity of LWA.

Sample	Density (kg/m^3)	Water absorption (%)	AIV (%)	Specific gravity
BARR10	890	22.1	17.2	1.72
BARW10	894	21.1	15.4	1.83
BAOR10	843	26.5	25.4	1.71
BAOW10	861	24.5	22.1	1.67
BARR20	725	23.6	16.9	1.51
BARW20	740	20.0	13.9	1.52
BAOR20	719	29.5	22.4	1.35
BAOW20	721	27.3	20.4	1.49
BARR30	684	33.7	29.7	1.37
BARW30	698	30.2	28.6	1.40
BAOR30	678	39.3	30.8	1.35
BAOW30	668	35.7	31.3	1.35
BARR40	600	37.1	36.0	1.34
BARW40	609	35.7	38.6	1.38
BAOR40	589	40.6	42.4	1.34
BAOW40	593	36.7	39.8	1.31
BARR50	574	39.8	57.9	1.28
BARW50	588	39.0	55.7	1.31
BAOR50	570	41.3	61.0	1.28
BAOW50	570	39.5	58.5	1.30

3.2 Water absorption

In all samples, water absorption in aggregate increased proportionately with the increased of bottom ash volume inside aggregate mixture. Previous research suggested that cold-bonded LWA has higher water absorption than that sintered fly ash. The moisture inside aggregate pellet was evaporated during the burning process of aggregate. Table 2 also shows result of water absorption test for 20 samples of LWA in five different percentages, which is 10, 20, 30, 40 and 50%, and at different curing regime. Water absorption test was carried to measure the amount of water absorbed by LWA. It can be seen that the value of water absorption are increasing according to the percentage of bottom ash used in LWA production. For example, it can be observed that the result of 10% until 50% of LWA with RR curing condition is increasing from 22.6, 23.6, 33.7, 37.6 and 39.8 %. Same trend was also found in OW curing condition where the water absorption increased from 24.5 to 39.5 % for 10% until 50% bottom ash replacement. Higher water absorption will adversely affect the strength of concrete produced using LWA. It can be concluded that, the higher the amount of bottom ash used in LWA production, the higher value of water absorption of LWA and reduced the strength of LWA. Bottom ash in aggregate mixture tends to absorb more water and affect the strength of aggregate. The existence of internal pores created by foams was also contributed to higher value of water absorption. The water absorption capacities are depending on the raw materials composition, curing parameters and also hydration kinetics.

3.3 AIV

The AIV test is carried out to determine the strength of aggregate and it was tested by using compaction technique. Based on Table 2, it can be observed that aggregate impact value increasing proportionally with the increase of percentage bottom ash used in LWA production. For example, we can see that the result of 10% until 50% LWA is increasing from 17.2 % for BARR10 until 58.5% for BAOW50. Padhi, 2014 [18] in his study stated that, any aggregate that has AIV greater than 20 % cannot be used in concrete production and, if higher than 30 %, it can be considered as very weak aggregate. This finding also tallied with the requirement stated in BS 812 (1975) that is, AIV for aggregate should not exceed 25 % for heavy-duty concrete application. The results obtained in this study shows that, the higher the percentage of bottom ash used in LWA production resulted in lower AIV. The AIV also can be discussed based on their respective curing condition. All BARW10, BARW20, BARW30, BARW40, BARW50, BAOW10, BAOW20, BAOW30, BAOW40 and BAOW50 that undergoes at least once water-curing regime tend to have lower aggregate impact value compared to air curing but will increase if the volume of bottom ash increased.

4 Conclusions

As a conclusion, sample denoted with BARW20 can be selected as the optimum LWA among the entire samples because it has the lowest AIV which 13.9 %. According to the result, the AIV obtained can be classified as strong aggregate. In addition, it also met another criteria based on water absorption test which is the water absorption value is in the range of 5 until 25 % referring to ASTM C127 [16] and lowest among all samples with 20% water absorption value. Lastly, it was also categorised as LWA because it has density 740 kg/m^3.

References

1. C. Hwang, L. A. Bui, K. Lin, and C. Lo, Cem. Concr. Compos. **34**(10) 1159–1166 (2012)
2. F. Colangelo, F. Messina, and R. Cioffi, J. Hazard. Mater. **299**, 181–191 (2015)

3. J. R. Pan, C. Huang, J. Kuo, and S. Lin, “Recycling MSWI bottom and fly ash as raw materials for Portland cement,” **28**, 1113–1118 (2008)
4. S. Mengxiao, W. Qiang, and Z. Zhikai, Constr. Build. Mater. **98**, 649–655 (2015)
5. E. P. Kearsley and P. J. Wainwright, Cem. Concr. Res. **31**, 105–112 (2001)
6. H. K. Kim, J. H. Jeon, and H. K. Lee, Constr. Build. Mater. **29**, 193–200 (2012)
7. J. G. Roessler, T. G. Townsend, and C. C. Ferraro, J. Hazard. Mater. **300**, 830–837 (2015)
8. U. Müller and K. Rübner, Cement and Concrete Research **36**(8), 1434–1443 (2006)
9. R. Cioffi, F. Colangelo, F. Montagnaro, and L. Santoro, Waste Manag. **31**(2), 281–288 (2011)
10. G. Pecqueur, C. Crignon, and B. Que, Waste Manag. **21**(3), 229–233 (2001)
11. J. M. Chimenos, M. Segarra, M. A. Fernandez, and F. Espiell, J. Hazard. Mater. **64**(3), 211-212 (1999)
12. M. Han, D. Han, and J. Shin, Constr. Build. Mater. **99**, 192–199 (2015)
13. C. R. Cheeseman, A. Makinde, and S. Bethanis, Resources, Conservation and Recycling **43**(2), 147–162 (2005)
14. N. M. Ibrahim, L. Q. Wen, M. A. Rahim, K. N. Ismail, R. C. Amat, S. Salehuddin, and N. L. Rahim, Applied Mechanics and Materials **755**, 348–353 (2015)
15. S. Specification, *Standard Specification for Lightweight Aggregates for Structural Concrete 1*, 1–4 (2015)
16. C. Ag-, B. Statements, and C. Aggregate, *Standard Test Method for Density , Relative Density (Specific Gravity), and Absorption*, 1–6 (2013)
17. C. Hwang and V. Tran, Constr. Build. Mater., **87**, 78–85 (2015)
18. Padhi, *Aggregate Impact Test-10+ Important Notes To Remember*, *http://civilblog.org/2014/07/16/aggregate-impact-value-test-important-note-to-remember/*, 2014