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WATER ABSORPTION AND DRYING SHRINKAGE OF RECYCLED FOAMED AGGREGATE CONCRETE

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Abstract: Abstract: This paper presents some experimental results and discusses the used of recycled foamed aggregates as natural coarse aggregates replacement in producing concrete. The physical properties of recycled foamed aggregates concrete were investigated. The properties studied are water absorption and drying shrinkage from the concrete early ages until the periods of 56 days. The 100 mm x 100 mm cube specimen was used to study the water absorption at the age of 7, 28 and 56 days. Meanwhile, the 100 mm x 100 mm x 300 mm length prism had been casted and used for drying shrinkage test for recycled foamed aggregates concrete. The foamed aggregates was produced from crushing recycled foamed concrete blocks. It were coated with cement paste to reduce its water absorption ability during casting process. Superplasticizer was used to maintain the workability of fresh concrete with a slump vary between 50 mm to 100 mm. The physical tests were conducted on recycled foamed aggregates to determine their initial properties such as loose bulk density, sieve analysis and water absorption rate. Recycled foamed aggregate concretes were produced with varied water cement ratio. The results obtained indicated that the linear elastic relationship between water cement ratio and water absorption rate. The higher the water cement ratio of concrete specimen will obtained higher water absorption rate. Vice versa, the density is low for drying shrinkage. The water absorption decreased while drying shrinkage becomes more stabilized over curing period.

Keywords: *Recycled foamed aggregate concrete, slump, water absorption, drying shrinkage, density.*

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1.0 Introduction

Concrete is one of the major construction material for building and infrastructure around the world. It is approximately about 75% of the concrete volume is aggregate and the consumption of concrete is estimated 10 to 15 billion metric tones per year worldwide (Lee *et al.,* 2013). Due to this, an alternative ingredient materials for concrete such as aggregates need to be sourced for. In recent years, lightweight concrete posed great interest and high demand from construction industry due to its low weight properties. It is a concrete having an oven-dry density between 800 kg/m^3 to 2000 kg/m^3 produced by replacing natural aggregates partially or wholly with the lightweight aggregates compared to normal weight concrete having an oven-dry density between 2000 kg/m^3 to 2600 kg/m^3 (British Standard Institution, 2000). It can be further classified into lightweight aggregate concrete, foamed concrete and no-fines concrete (Mohammed and Hamad, 2014). When lightweight concrete had been implemented in the building element, the lighter weight of superstructure make the smaller size of foundation that reducing total reinforcement cost, provide good insulation and fire resistance, and also saving the expenses and time in transporting or handling the components which make it attractive in the market (Chandra and Berntsson, 2002).

The waste from construction and demolition(C & D) process contributes to the production of huge amount of solid waste which contributes to major environmental and economic concern around the world. Moreover, the scarcity of natural aggregate is a common situation in many urban areas (Erik and Hansen, 1985). Recently, the reuse of C&D waster as a recycled material in the manufacturing of new concrete has becoming a trend. It is a recycling method to reduce the amount of C&D waste by reusing it in the form of recycled aggregate that replace the natural coarse or fine aggregate in concrete making process. The previous research on recycled aggregate from site tested concrete cubes and demolish recycled aggregates in producing concrete were limited. The recycled materials depends on the sources of the wastes materials generated (McNeil and Kang, 2013).

In this research, the recycled foamed concrete blocks were reused as recycled lightweight aggregates in the production of foamed aggregate concrete. It is an effective method to mitigate the wastage problem and consequently preserve the available resource of natural aggregates. Foamed aggregate concrete can be classified as lightweight aggregate concrete whereby the normal weight aggregate is replaced by lightweight aggregate of low specific gravity in the concrete production process. According to the types of lightweight aggregate used in the production of concrete, the density of lightweight aggregate concrete produced may varies between 300 kg/m^3 to 1850 kg/m^3 with the strength range between 0.3 MPa to 40 MPa (Neville and Brooks, 2010).

Water absorption is a process whereby the concrete absorbs or draws water into its pores or capillaries. The previous research indicated that 24 hours water absorption of lightweight aggregate range between 5 % to 25 % by weight of dry aggregate, while normal aggregate will absorbing less than 2 % in common (American Concrete Institute, 2003). This is because the moistures are largely penetrate into particle's interior of lightweight aggregates, while for natural aggregates it is mainly surface moisture only. From previous research, it is found that the percentage of water absorption of recycled or lightweight aggregate concrete is higher than normal weight concrete.

The change in concrete structure in terms of volume due to the loss of water through evaporation or by hydration of cement is commonly known as shrinkage of concrete (Neville and Brooks, 2010). Basically there are four types of shrinkage which are plastic shrinkage, carbonation shrinkage, autogenous shrinkage and drying shrinkage. This research focused on drying shrinkage of foamed aggregate concrete. It cause mass loss followed by reduction in volume of concrete when it is being exposed in low relative humidity environment (Andreu and Miren, 2016). From previous research, it is found that the drying shrinkage of recycled or lightweight aggregate concrete is greater than conventional type of concrete. Therefore, this study aims to examine and explored the physical properties of lightweight concrete in term of water absortion and drying shrinkage of recycled foamed aggregate concrete.

2.0 Materials and Methods

2.1 Materials Preparation

The raw materials prepared for the concrete mix are Ordinary Portland cement (OPC), recycled coarse aggregates, natural fine aggregates, water and superplasticizer. Recycled foamed concrete block was used to produce coarse aggregates with size range between 5 mm to 20 mm using sieves. Figure 1 shows the foamed aggregates of size between 10 mm to 20 mm that was coated with cement paste with water cement ratio of 1.0 before casting process. Figure 2 shows the natural quarry sand that was used as fine aggregates and was air dried before casting. The type of cement used was OPC with cement class of 42.5 as shown in Figure 3. Meanwhile superplasticizer was used to maintain the workability of fresh concrete with a slump value of 50 mm to 100 mm as shown in Figure 4.

Figure 1: Coated foamed aggregates

Figure 2: Natural quarry sand

Figure 3: Ordinary portland cement

Figure 4: Superplasticizer

2.2 *Concrete Mix Proportion*

There were four different types of series mix design were proposed with the alteration of water cement ratio and superplasticizer. Initially water cement ratio of 0.60 was proposed for M_4 concrete mix. However, it is found that the M_3 concrete mix with water cement ratio of 0.65 was dried even after the addition of superplasticizer. So it is decided to remain water cement ratio factor but with increasing percentage of superplasticizer for M_4 concrete mix. In this research, the type of curing used was air curing. All the cube and prism specimens underwent air curing process in which it was subjected under room temperature after de-mould. The mix proportions for the present study are tabulated in Table 1

Table 1: Mix design of concrete specimen

Mix Id	*Cement (kg)*	*Fine Aggregates (kg)*	*Coarse Aggregates (kg)*	*Water (kg)*	*Water Cement Ratio*	*Superplasticizer (%)*
M_1	1	1.60	1.53	0.75	0.75	-
M_2	1	1.60	1.53	0.70	0.70	-
M_3	1	1.60	1.53	0.65	0.65	1.5

M_4	1	1.60	1.53	0.65	0.65	2.5

2.3 Test Method

Preliminary test was conducted on aggregates to determine their initial physical properties. Both loose bulk density and water absorption were conducted and compared on foamed aggregates, coated foamed aggregates and natural coarse aggregates. They were conducted according to procedure stated in BS 812: Part 2:1995. Meanwhile, sieve analysis was conducted on fine aggregates or sand under BS 882:1992. Water absorption test was conducted on 100 mm cube specimen and complies with BS 1881:122:2011. It was oven-dried before being submerged under water to determine the percentage of water absorption. It was tested at 7, 28 and 56 days. Meanwhile, 100 mm x 100 mm x 300 mm prism specimen was used for drying shrinkage test. It was assembly inside the steel frame with attached dial gauge once after de-mould as shown in Figure 5. The value of shrinkage of prism specimen had been provided by dial gauge with accuracy up to 0.001 mm. It was tested in their early ages up to 56 days.

Figure 5: Drying shrinkage measurement

3.0 Data Analysis

The loose bulk density for all tested aggregates was summarised in Table 2. It can be concluded that both foamed aggregates and coated foamed aggregates can be categorized under lightweight aggregates since its loose bulk density was less than 1200 kg/m^3 as stated in BS EN 13055:2016

Table 2: Loose bulk density of raw material

Material	*Loose Bulk Density (kg/m^3)*			
	1	*2*	*3*	*Average*
Foamed Aggregates	460	477	472	470
Coated Foamed Aggregates	580	580	585	582
Natural Coarse Aggregates	1341	1358	1347	1349

The graph of cumulative percentage passing of sand over sieves of different size was showed in Figure 6. There were about 1 kg of sand was collected and oven-dried before test. The sieve size was 10 mm, 5 mm, 2.36 mm, 1.18 mm, 0.60 mm, 0.30 mm and 0.15 mm respectively. The test result indicated that all sand had passing through sieve size of 10 mm. It can be classified as medium graded sand when comparing with grading limit for sand as stated in BS 882:1992.

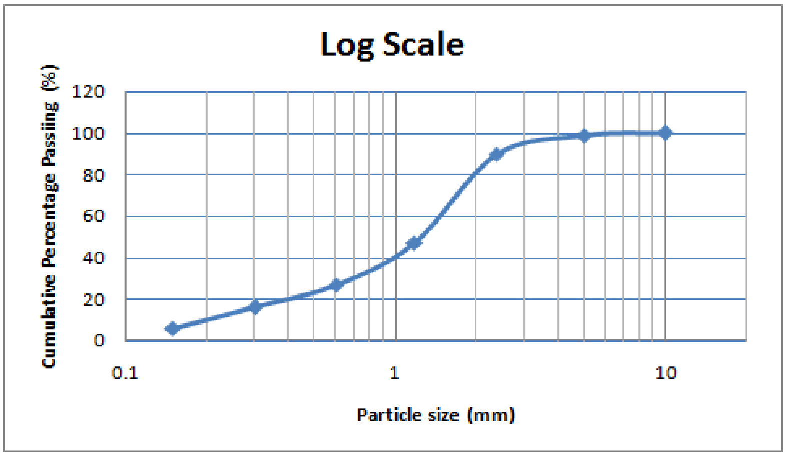

Figure 6: Graph of cumulative percentage passing of sand

The percentage of water absorption for all tested aggregates was showed in Table 3. Natural coarse aggregates absorb least water with only 6.12 % while foamed aggregates absorb highest water with 29.79 %. It can be concluded that the absorption capability of foamed aggregates can be reduced after coating it with cement paste.

Table 3: Water absorption (% of dry mass) of raw material

Material	*Water Absorption (%)*
Foamed Aggregates	29.79
Coated Foamed Aggregates	23.81
Natural Coarse Aggregates	6.12

The development of dry density of cube specimens with different water cement ratio was depicted in Figure 7. It showed that the lower the water cement ratio, the higher the dry density of concrete produced. M_1 concrete mix obtained lowest dry density since it has highest water cement ratio. This is because adding more water to a fixed amount of cement will create a more dilute paste that is weaker. M_4 concrete mix with same water cement ratio but higher percentage of superplasticizer than M_3 concrete mix has slightly lower density than M_3 concrete mix. This could be due to compaction problem during casting process that creates more void within the concrete.

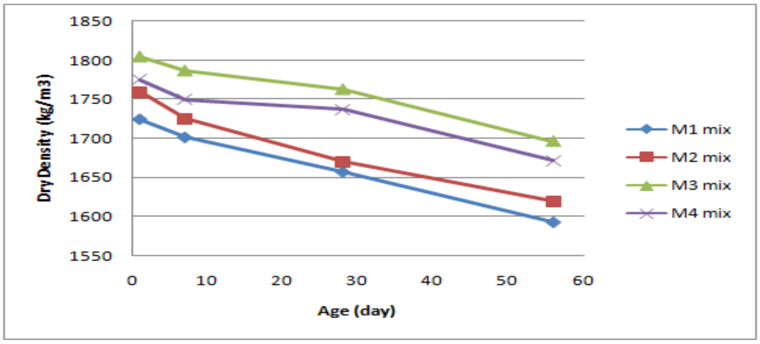

Figure 7: Dry density of cube specimen over age

The relationship between water absorptions of cube specimens of different water cement ratio over 4 hours total at certain days were indicated in Figure 8, Figure 9 and Figure 10. The oven-dried specimen was immersed under water with increasing time interval which is 10, 20, 30, 60 and 120 minutes until it reach a total time of 4 hours. Based on results obtained, it proves that the lower water cement ratio of concrete mix, the lower the percentage of water absorption it get since porosity which is the spacing between particles of concrete specimen is lower. M_4 concrete mix with same water cement ratio but higher percentage of superplasticizer than M_3 concrete mix possesses higher percentage of water absorption. It may be due to compaction problem during casting process that caused it containing more voids within concrete and thus have higher tendency to absorb water. Meanwhile, the highest water absorption of each concrete mix over age was showed in Figure 11. It was recorded after total time of 4 hours. It shows that the water absorption of each concrete mix decreased over the curing period.

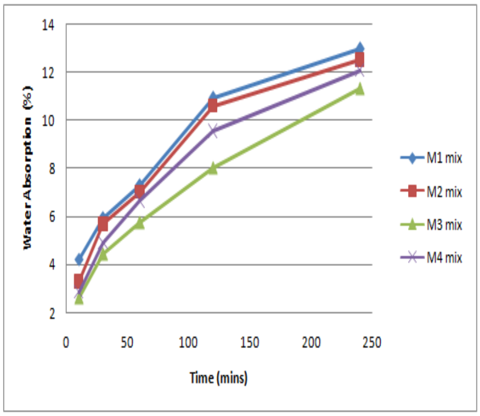

Figure 8: Water absorption at 7 days

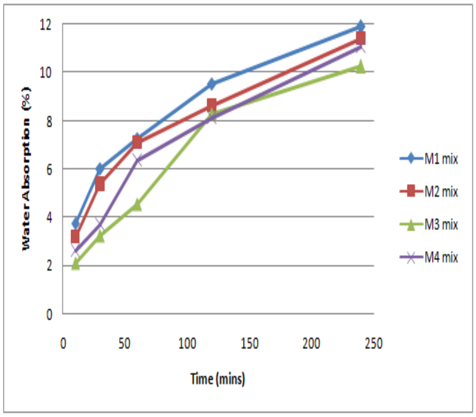

Figure 9: Water absorption at 28 days

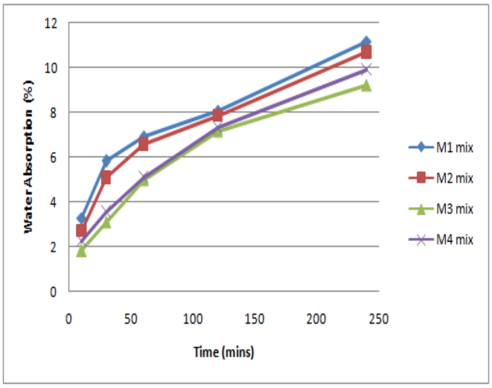

Figure 10: Water absorption at 56 days

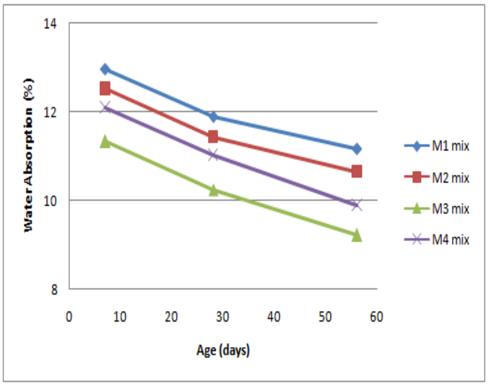

Figure 11: Water absorption of concrete over Age

The behavior of drying shrinkages of prism specimens with different water cement ratio at their early ages until 56 day were depicted in Figure 12, Figure 13, Figure 14 and Figure 15. There were two samples for each type of concrete mix. Based on the results obtained, the drying shrinkage of all the prism specimens occurred very rapidly at their early ages until reached about 20 days. After that, it gradually shrank until the end of test date. Meanwhile, the drying shrinkage comparison between each concrete mix over age was showed in Figure 16. After 56 days, M_1 concrete mix shows highest drying shrinkage with the value of 971 micro strain. While M_3 concrete mix achieved the lowest drying shrinkage with the value of 742 micro strain. It proves that the lower the water cement ratio used to produce the concrete mix, the lower the rate of absorption and drying shrinkage as well. This is because lower porosity absorbs less water and thus less water will be evaporated due to shrinkage.

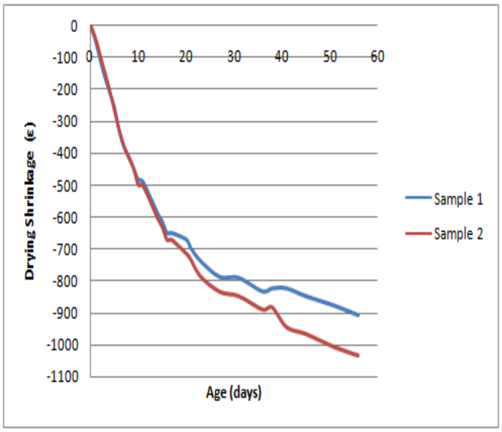

Figure 12: Dying shrinkage of M_1 over age

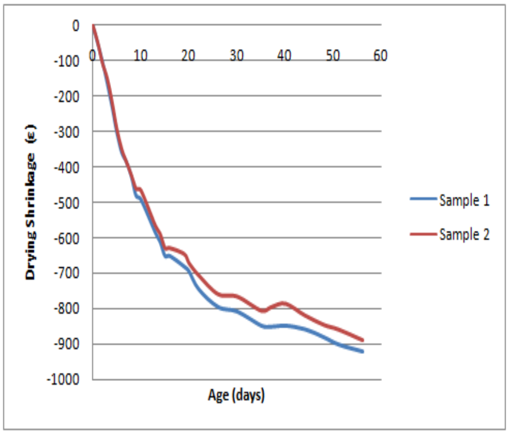

Figure 13: Drying shrinkage of M_2 over age

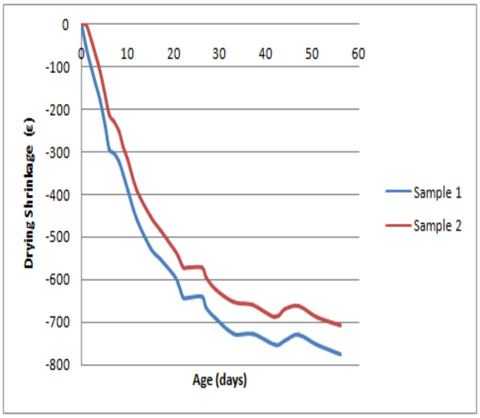

Figure 14: Drying shrinkage of M_3 over age

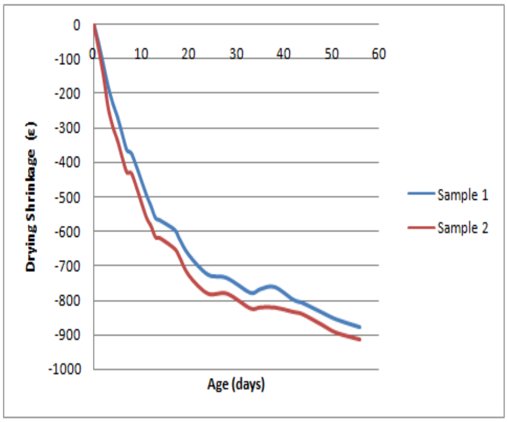

Figure 15: Drying shrinkage of M_4 over age

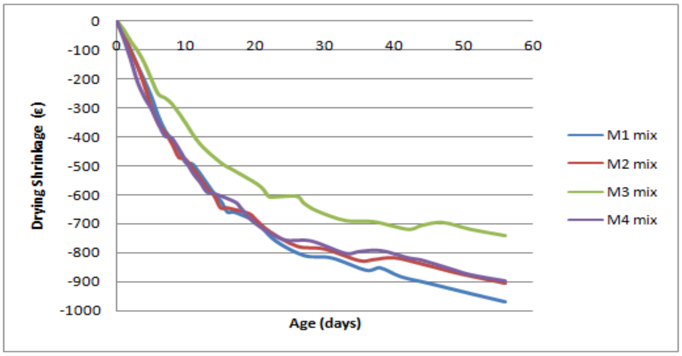

Figure 16: Drying shrinkage of concrete over age

4.0 Conclusions

The study on the use of recycled foamed aggregate which was produced from recycled foamed concrete blocks were successfully incorporated in the production of foamed aggregate concrete, a type of lightweight concrete. The result showed that the lower the water cement ratio of concrete mix, the higher the dry density obtained. The overall density of the concrete specimen produced from the range between 1500 kg/m^3 to 1800 kg/m^3. It was satisfied the density requirement of lightweight aggregate concrete that range between 300 kg/m^3 to 1850 kg/m^3. Besides, the lower the water cement ratio of concrete mix, the lower the rate of water absorption. The rate of water absorption also decreased over age.

Meanwhile, the lower the water cement ratio of concrete mix, the lower the value of drying shrinkage. The drying shrinkage of all concrete mix occurred very rapidly at the early age until it reached about 20 days. It was then gradually shrinking until the end of test date. It can be concluded that the higher rate of water absorption of a concrete specimen, the higher its value of drying shrinkage. This is because the concrete specimen with higher absorption rate normally contains more pores within the concrete. Thus, more water evaporated from it. The series of M_3 and M_4 concrete mix with same water cement ratio but different percentage of added superplasticizer had different density as well as their water absorption rate and drying shrinkage. It is largely due to the problem of compaction during casting process that segregation in series M_4 concrete mix.

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