

Transport Properties of Lightweight Concrete Incorporated with Expanded Clay Aggregate in Marine Environment

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Abstract. Employing porous material such as expanded clay lightweight aggregate (EC LWA) as an internal curing agent in the production of mass concrete proof to mitigate early age cracks in resulting concrete. However, introducing EC LWA could increase the porosity of concrete, leading to concrete degradation due to water penetration. Thus, this research aims to investigate the suitable natural aggregate replacement rate with EC LWA in the production of concrete with acceptable mechanical and transport properties. Three replacement rates of 0, 50, and 100% were applied. The water-per-cement ratio of 0.6 was used to produce concrete. The workability of fresh concrete and the compressive strength were tested. The transport properties of concrete were assessed by monitoring the capillary water uptake of concrete. To mimic the marine environment, the concrete sample was immersed in sodium chloride and sodium sulphate for seven days. The result shows that the workability, bulk density, and compressive strength of concrete with 50% EC LWA have a similar value to the reference sample. Moreover, samples with 50% EC LWA also have a slower capillary rate in a sodium chloride environment than in fresh water.

1 Introduction

As a country located in the ring of fire and in the intersection between two major tectonic plates, Indonesia's infrastructure needs to be seismic resistant. Reducing the structure element's weight could be an effective solution to minimize structure damage due to earthquakes[1]. When concrete was used as construction material, utilizing lightweight aggregates (LWA) to replace natural aggregate could become an alternative way to reduce the structure weight [1]. Several researchers reported promising results when various porous aggregates, such as expanded clay, expanded shell, and perlite, were used as natural

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aggregate replacements [1–3]. Expanded clay was reported to deliver acceptable properties when incorporated into concrete.

In the literature, most researchers using aggregates replacement rate vary from 20% to 55% [1,2,4]. With those aggregate replacement rates, acceptable mechanical properties were achieved [1–5]. Aiming to replace as much as possible natural aggregate with LWA, in this research, expanded clay was used to partially or replace the natural coarse aggregate in the concrete mixture. However, most of the reports are mainly concentrated on investigating the physical and mechanical properties of mortar or concrete containing LWA. A limited study could be found on the transport properties of concrete containing expanded clay (EC) LWA, especially when exposed to marine environments. As the existence of LWA will increase the number of pores in concrete, the behaviour of resulting concrete to uptake liquid will be an essential aspect to be investigated to ensure concrete still has acceptable durability[6].

Furthermore, the capillary water uptake test could become one alternative test to measure concrete's ability to take liquid for the time being [7–10]. A previous study that replaced 30% of fine Aggregate with EC LWA in mortar production found that the addition of EC LWA in the mixture could decrease the capillary imbibition rate due to denser interfacial zone (ITZ) in EC LWA mortar [11]. However, most literature only reported that the capillary imbibition was only taken in normal water. Only limited studies on the transport properties of lightweight concrete in marine environments could be found.

Thus, this research aims to investigate the suitable aggregate replacement rate for lightweight concrete production with acceptable mechanical, physical and transport properties in the marine environment. This research conducted a capillary water absorption test on sodium chloride 3.5% and sodium sulphate solution 0.5 % to mimic the marine environment. To maximize the portion of EC LWA in the mixture, the aggregate replacement rate applied in this research was set to 50 and 100 %. By conducting this research, an initial recommendation is expected to be drawn on the feasibility of using lightweight concrete in marine environments.

2 Materials and Methods

2.1 Materials

Pozzolan Portland cement from *Tiga roda*, equal to 42.5N, was used as a binder. River sand with a gradation zone of 2 was used as fine aggregate. Natural gravel with a maximum diameter of 40 mm was used as coarse aggregate. The commercial expanded clay with a maximum diameter of 40 mm was used as coarse aggregate replacement. The specific density of sand, natural gravel, and expanded clay were 2.5; 2.6, and 1.14, respectively. Sodium chloride and sodium sulphate technical grade (95%) were used to mimic marine environment. The solution of sodium chloride was set to 3.5%, while sodium sulphate solution had a concentration of 0.5%.

2.2 Methods

Physical and mechanical properties of aggregate, such as water absorption and aggregate impact value test, were conducted. The water absorption test followed ASTM C127, while the aggregate impact value (AIV) test was conducted by following the guidelines from BS 812-112:1990.

A water/cement ratio of 0.6 was applied to produce concrete specimens. Three coarse aggregate replacement rates of 0,50 and 100% were used. The replacement of coarse

aggregate was calculated by its volume. The mix design of 1 m³ concrete is displayed in table 1

Table 1. Mix Design of 1 m³ Concrete.

Materials	LWA replacing rate		
	0%	50%	100%
Cement (kg)	350	350	350
Water (kg)	210	210	210
Sand (kg)	644	644	644
Coarse aggregate (kg)	1196	607.36	-
EC LWA (kg)	-	266.30	532.60

The cylinder mold with a diameter of 100 mm and height of 200 mm was employed to cast the sample. The concrete was produced following SNI 03-4810-1998 standard. To avoid EC LWA taking up water in the mixture, EC LWA was treated to saturated surface condition (SSD) before being added to the concrete mixture. The workability of fresh concrete was measured in line with SNI 03-1972-1990 norm. Twenty-four hours after casting, the sample was demolded and subjected to water immersion curing until the testing date.

The compressive strength of hardened concrete was measured at the age of 28 and 56 days following SNI 1974:2011 standard. For the capillary water uptake test, samples were cut into three slices that had a height of 50 mm. The illustration of the cutting mold of the sample is displayed in Figure 1.

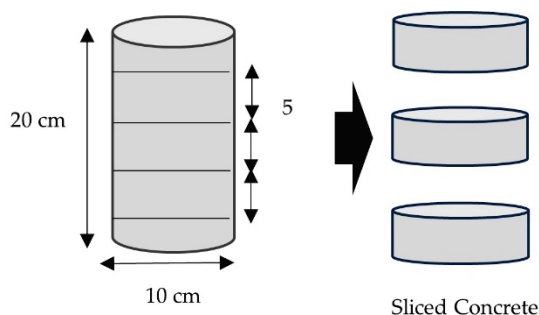


Fig. 1. Sample preparation for capillary water uptakes test.

The capillary water uptake test was conducted in three environmental conditions: water, sodium chloride, and sodium sulfate (Figure 2). The capillary test was conducted on 56-day-old specimens. The first step to do the capillary test is by drying concrete slices in the oven until they reach constant weight. After the samples gained constant weight, the side part of the samples was covered with aluminum tape to make sure that water reached the top of the sample vertically. Finally, the sample was put in a container filled with the desired solution. The height of water contact with the sample was kept at 3-5 mm. The measurement was taken at 0, 0.5, 1, 2, 3, 4, 5, 6, 24, 48 and 72 hours after the sample had contact with the solution. The water uptake rates were calculated by dividing the amount of water the sample took by the measurement time. We used the final observation time to calculate the water uptake rate in this case.

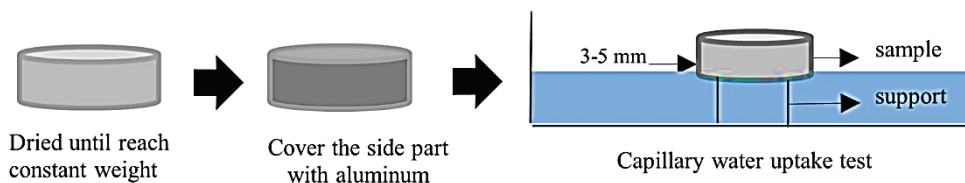


Fig 2. Illustration of capillary water uptakes test

3 Result and Discussion

3.1 Properties of Aggregate

The water absorption, specific density, and aggregate impact value (AIV) of natural coarse Aggregate and EC LWA are presented in Table 2. It could be seen that the AIV of EC LWA is very low in comparison with natural aggregate and was categorized as low-quality aggregate that could not be used for pavement. The sintering process during the production of EC LWA caused the formation of pores in the LWA. However, from the water absorption result, the water absorption of EC LWA is comparable with in-house LWA generated with the sintering process [12–15]. The sintering process allows EC LWA to build up close pores that water cannot penetrate. The specific density of EC LWA is also lower compared to natural aggregate due to the existence of pores in the LWA system.

Table 2. Properties of aggregates.

Test	EC LWA	Natural Aggregate
water absorption (%)	20.65	12.40
specific density	1.14	2.6
AIV (%)	52	19.9

3.2 Properties of Aggregate

The aggregate replacement rate is inversely proportional to the compressive strength of the resulting concrete (Figure 3). Replaced natural coarse aggregate with EC LWA leads to a significant strength decrease of hardened concrete tested in 28 and 56 days. However, by replacing 50% of natural Aggregate with EC LWA, the compressive strength of the resulting concrete (EC 50) is comparable to the control sample. An increase of concrete's strength at a later age was observed. This mechanism is expected, as continued hydration could still occur due to using PPC cement that contains pozzolan, which might need more time to react with water.

Compared to results reported in the literature, the compressive strength of the concrete containing EC LWA is comparable. With a water/ cement ratio of 0.52, 50% of natural aggregate was replaced with sintered LWA, and the compressive strength obtained was 33 MPa [5]. In this research, with a similar replacing rate and lower w/c ratio, the compressive strength reached 25 MPa. The acceptance of mechanical properties of concrete containing 50% EC LWA might be achieved due to internal curing provided by EC LWA [16–18]. With the internal curing mechanism, water entrapped inside the aggregate pores was slowly released and reacted with unreacted cement in the matrix, causing extra hydration product at

the interfacial zone between aggregate and paste that contributed to the improvement in concrete's mechanical properties[11,16].

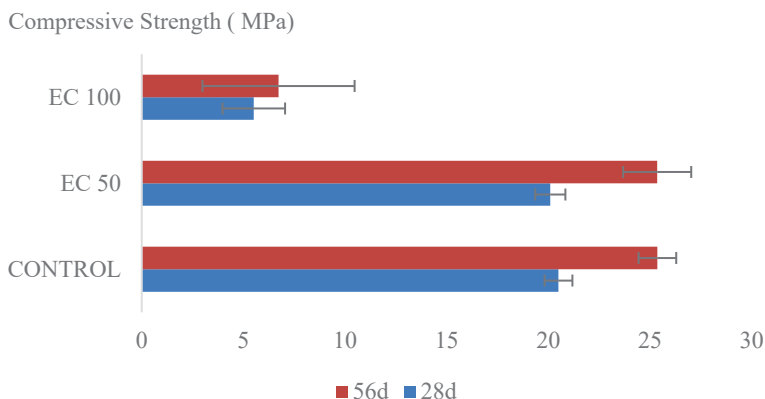


Fig. 3. The Compressive Strength of Concrete Tested at 28 and 56 days. The error bar represents standard deviation (n=5).

3.3 Bulk Density of The Resulting Concrete

The bulk density of the resulting concrete has a good correlation with its compressive strength. Increasing the amount of EC LWA in the mixture tends to decrease the bulk density of the resulting concrete. However, the bulk density of concrete with 50% aggregate replacement was almost similar to the reference sample, while a significant decrease in the density was observed when all the natural aggregate was replaced with EC LWA. Based on the guidelines from ACI 213R, only EC 100 specimens could be categorized as lightweight concrete, as it has a bulk density of less than 1920 kg/m³. Compared to the bulk density of concrete incorporated with similarly expanded clay with 50% replacement rate in the literature, the bulk density achieved in this research is slightly high[19]. The high river sand density and natural aggregate could contribute to this difference.

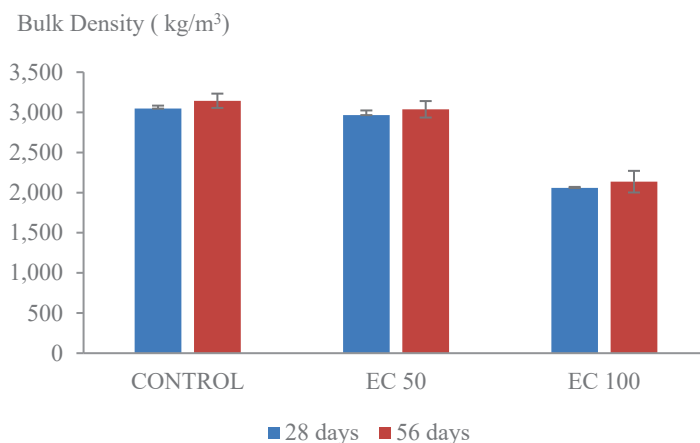


Fig 4. The Bulk Density of Concrete Tested at 28 and 56 days. The error bar represents standard deviation (n=5)

3.4 Bulk Density of The Resulting Concrete

The transport properties of the resulting concrete were assessed through a capillary water uptake test. In all cases, the water uptake rate tended to decrease slightly when samples were subjected to salt solution (Figure 5). In the control sample, the lowest water uptake rate was achieved when samples were immersed in a sodium sulfate solution. When EC LWA was incorporated into concrete, the lowest water uptake rate occurred when samples were immersed in sodium chloride solution. The slower water uptake in the salt environment was also reported in a previous study by De Brabandere et al, revealed that mortar with w/c of 0.4 has slower water uptake when immersed in sodium sulfate solution [7]. The pore-blocking effect due to the formation of Friedel's salt could contribute to the slower water uptake of concrete in marine or salt environments [20].

In line with the compressive strength result, the acceptable water uptake of concrete containing EC LWA is owned with a 50% replacement rate (EC 50). This sample has less than a 10% increase in water uptake rate compared to the control sample in salt or normal environments. Replacing all natural coarse aggregates with EC LWA resulted in a faster water uptake rate in all environments. This result is in accordance with the prediction; as concrete's porosity increases by replacing coarse aggregate with EC LWA, a significant increase in the water uptake rate is expected.

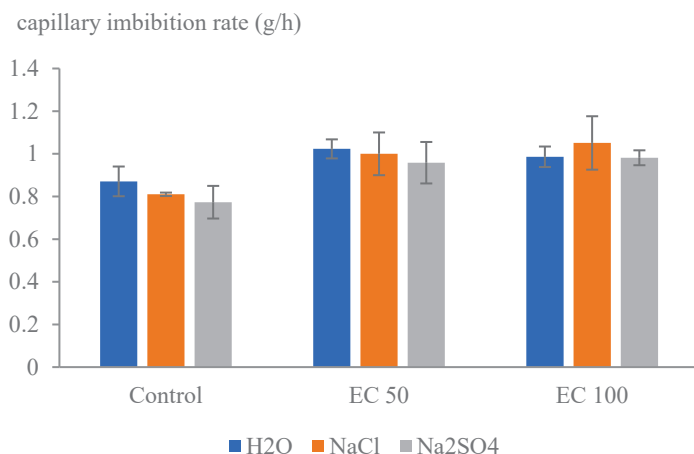


Fig 5. The water uptake rate of resulting concrete. The error bar represents standard deviation (n=3)

4 Conclusions

In general, it can be concluded that the expanded clay used in this research has high water absorption, low specific density, and low strength compared to natural coarse aggregates. Replacing natural coarse Aggregate with EC LWA has significantly affected the fresh and hardened properties of the resulting concrete. The higher the aggregate replacing rate, the lower the slump value, bulk density, and strength achieved. Regarding the capillary imbibition rate, the higher the replacement rate, the faster the capillary imbibition rate occurs. It is also worth mentioning that the capillary imbibition rate of concrete in salt or marine environments is slower than in normal water. The pore-blocking mechanism due to the formation of Friedel salt could be the reason behind this mechanism. Based on the results of investigating the mechanical, physical, and transport properties of concrete containing EC

LWA, the optimum aggregate replacing rate could be recommended to be 50 %. With this replacing rate, the resulting concrete has comparable properties to the reference sample.

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