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Effects of Recycled Crushed Light Expanded Clay Aggregate on High Strength Lightweight Concrete

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Abstract: Many researchers are carrying out environmentally-friendly action in the construction field, such as using recycled aggregate for sustainable development. Disposal of light expanded clay aggregate (LECA) waste into the land causes a severe impact on the environment. LECA is one of the construction materials that are broadly used for various applications. LECA has some excellent properties in its due to technical features, eco-friendly and entirely natural product with a low cost, lightweight, hardness and highly resistant to biological, chemical, and physical degradation forces. Recently, lightweight structural concrete by incorporating lightweight aggregate (LWA) is used to compensate heavy loads by reducing the overall self-weight of structure and minimize the size of the foundation simultaneously. In this study, partially replacement of high content light expanded clay aggregate (LECA) (50, 60, 70, 80, and 90%) have been used to achieve the mechanical properties of high strength LWA concrete. In this study, crushed LECA has been used to achieve compressive strength between 20 to 40 MPa with a density ranged between 1700 to 2000 kg/m^3. It is found that the inclusion of crushed LECA at 70% of replacement had shown the most optimal results in terms of density, workability, compressive strength, splitting tensile strength, and flexural strength. Hence, the findings of this research proved that it could be used as an alternative solution for advanced and sustainable infrastructure applications.

Keywords: lightweight concrete; recycled aggregate; mechanical properties; density; compressive strength.

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1. Introduction

The advancements of technology and effectiveness in the construction industry have dramatically contributed to rapid growth for concrete materials. The development and construction of these buildings and infrastructures demand a huge amount of materials. Concrete is undoubtedly the most essential and economical construction material, and it is virtually irreplaceable [1]. Among all types of concrete, lightweight concrete poses huge market value, especially in tackling the optimum design as the cost, time and quality are always the main concern in construction. The demand for lightweight concrete has been seen increasing progressively due to its unique emerging characteristic. Application of lightweight concrete as the structural members such as beam, column,

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and slab as the framework of a building structure can tremendously reduce dead loads. Hence the overall cost of a project can be minimized. Lightweight concrete plays a significant role in lightweight construction. Lightweight construction can be classified into three categories which are (1) design of lightweight structures, (2) lightweight construction materials, and (3) lightweight structural systems, respectively. It seeks minimal load conditions and hence reduces the exploitation of natural resources and enhance the recyclability of building structures [2]. The lightweight aggregate can be categorized as natural and artificial aggregates such as pumice, scoria, and those of volcanic origin, expanded blast-furnace slag, vermiculite, and clinker aggregates [3]. Lightweight expanded clay aggregate (LECA) is a special type of lightweight aggregate which produced from naturally available clay through a series of processes. In the production process, the clay is fired and pelletized at a very high temperature around 1150 °C in a rotary kiln. There are a lot of advantages by introducing LECA in LWC due to its physical properties, which include higher strength, lower density, better thermal and sound insulation, saving in construction cost and etc. Many studies have been reported that over the last two decades, the high compressive strength of lightweight concrete is within 17-35 MPa, and there is a reduction in density of 20-25% compared to normal weight concrete [4-8]. It has been reported that a structural lightweight aggregate concrete produced by replacing coarse aggregate with LECA is able to achieve 35 MPa to 47 MPa of cube compressive strength with a density range from 1760 kg/m^3 to 1900 kg/m^3) [9]. In the current research, non-experimental researches have been performed by incorporating recycled crushed artificial aggregate known as the LECA method to investigate its influences on the mechanical properties of the high strength lightweight aggregate concrete (LWAC).

2. Materials and Methods

The cement used in the mixing was Ordinary Portland Cement (OPC) Type 1, which meets the Malaysian Standard MS 522: Part 1: 2003 certified by MS ISO 14001, MS ISO 50001, and OHSAS 18001. It is a product from one of the largest manufactures in Malaysia, YTL Cement Sdn. Bhd. The density and fineness of ORANG KUAT OPC are 3150 kg/m^3 and 3170 cm^2/g, respectively. The cement content was kept constant at 410 kg/m^3.

Potable water with pH value of 6 was used for both mixing and curing. The water to cement ratio of 0.32 was used for all the mixes. The high range water reducing admixture, namely superplasticizer used in this study, is the MasterGlenium SKY 8808 polycarboxylic ether (PCE) supplied by BASF. The SP was added in all the mixes at a constant amount of 1.75% of the cement weight in order to facilitate workability.

Fine aggregate utilized in this research is namely localized quartz type river sand. To ensure moisture is completely driven out of the pores, sand is oven-dried to constant weight at a temperature of about (105±5) °C for 24 hours. The sand is required to sieve through 4.75 mm sieve. The sand available from Hanson Quarry Selangor was used as the fine aggregate, having a specific gravity, fineness modulus, water absorption, and maximum grain size of 2.67, 2.71, 0.97%, and 4.75 mm, respectively. Sieve analysis is performed according to ASTM C 136-01 in order to obtain the grading of fine aggregate used in this study. The average distribution of sand is obtained by performing two sieve analyses using a similar source, as shown in Table 1. The fine aggregate was dried in an open-air before use and was kept constant at 870 kg/m^3 for all mixes.

Table 1. Average Results of Sieve Analysis

Sieve Size	Weight of Mass Retained (g)	Cumulative Mass Retained (g)	Cumulative percent Retained (%)	Cumulative Percent Passing (%)
2.36 mm	21.50	21.50	4.30	95.70
1.18 mm	95.25	116.75	23.33	76.67
600 µm	193.75	310.50	62.05	37.95
300 µm	73.75	384.25	76.77	23.23
150 µm	68.50	452.75	90.46	9.54
63 µm	36.75	489.50	97.80	2.20
Receiving pan	11.00	500.50	100	0.00

Yew et al. [10] reported that crushed oil palm shell (OPS) aggregate significantly increased the compressive strength compared to the original OPS aggregate. Therefore, crushed LECA aggregate was used as the coarse aggregate in this study. These recycled LECAs are obtained from Therapeutic Garden Sanctuary Company located at Petaling Jaya, Selangor. LECAs are spherical in shape with a smooth surface and contain numerous voids. For the purpose of this study, all of these coarse aggregates must have sizeable to retain on 4.75 mm sieve. In this study, both crushed LECA and granite were utilized, as shown in Figure 1. The crushed

LECA and granite content in all the mixes were kept within the range of 246 kg/m^3 and 233 kg/m^3, respectively. Water absorption of crushed LECA was performed as tabulated in Table 2.

Figure 1. Crushed LECA (left) and granite (right)

Table 2. Water absorption of crushed and uncrushed LECA.

	Crushed LECA
Existing Mass (g)	150.00
Saturated Surface Dry Mass (g)	212.80
Oven-Dried Mass (g)	149.30
Water Absorption (%)	42.53
Current Absorption (%)	0.47

2.1. Mix proportions.

A total of four (4) mixes were prepared. The mix proportions of all the LECA lightweight aggregate concrete (LLWAC) mixes used in this study are presented in Table 3.

2.2. Testing methods.

The procedure adopted for mixing the crushed LECA lightweight aggregate concrete (LLWAC) with different content of LECA involves the following steps. Firstly, the sand and LECA aggregate were poured into a concrete mixer and dry mixed for 3 min. Secondly, the cement was spread and dry mixed for 1 min. This is followed by the addition of water and superplasticizer with a mixing time of 5 min. The concrete specimens were cast in 100-mm cube steel oiled molds, and a poker vibrator was used to eliminate air bubbles in the mixture. The specimens were demoulded approximately 24 hours after casting and were cured in water at 25 ± 2 °C until the age of testing. The compression testing machine used was an ELE (Engineering Laboratory Equipment) with a load capacity of 3000 kN running at a pacing rate of 3.0 kN/s, in accordance with BS EN 12390-4:2000. To determine the mechanical properties for each mixture, 18 cubes (100 × 100 × 100 mm) are used to determine the compressive strength at 7 and 28 days. In addition, three cylinders (diameter: 100 mm, height: 200 mm) and three prisms (length: 500 mm, width: 100 mm, depth: 100 mm), are used to determine the behavior of splitting tensile and flexural strengths on the 28th day.

Table 3. Mix proportions of LLWAC.

Specimen	LECA replacement (%)	Material (kg/m^3) Cement	Sand	Water	Granite	LECA	SP[1]
LLWAC-50[2]	50	410	870	131.2	387.5	175	7.175
LLWAC-60	60	410	870	131.2	310.0	211	7.175
LLWAC-70	70	410	870	131.2	232.5	246	7.175
LLWAC-80	80	410	870	131.2	155.0	281	7.175
LLWAC-90	90	410	870	131.2	77.5	316	7.175

Note:
[1]SP = Superplasticizer
[2]LLWAC-50 = LECA lightweight aggregate concrete with 50% LECA replacement

3. Results and Discussion

3.1. Properties of fresh concrete.

Table 4 summarizes the fresh properties of LLWACs. The desired densities for calculation of consistency are based on their respective target density.

Referring to Table 4, densities in terms of fresh, hardened, and oven-dry density of the LLWAC decreased as the percent of LECA replacement increased. As the granite is partially replaced by expanded clay, the amount of lightweight component increases yet the normal weight aggregates reduce simultaneously. Consequently, the increment of void content due to the incorporation of LECA result in the decline of density. It is also noticed that all the densities fall within the range between 1600 kg/m^3 and 2000 kg/m^3 in term of oven-dry density. However, the fresh and hardened densities of LLWAC-50 and LLWAC-60 are slightly higher than those prescribed. In terms of consistency and stability, all specimens exhibit values nearly to unity corresponding to the increment of LECA replacement.

Table 4. Fresh properties of LLWAC.

Specimen	Density (kg/m^3)				Stability	Consistency
	Target	Fresh	Hardened	Oven-Dry		
LLWAC-50	1980.9	2085.8	2052.0	1983.4	1.016	1.053
LLWAC-60	1939.4	2063.0	2030.6	1967.8	1.016	1.064
LLWAC-70	1896.9	1930.0	1919.9	1877.0	1.005	1.017
LLWAC-80	1854.4	1869.0	1898.5	1832.7	0.984	1.008
LLWAC-90	1811.9	1722.2	1799.7	1736.6	0.957	0.951

Referring to Table 4.5, densities in terms of fresh, hardened, and oven-dry density of the LLWAC decreased as the percent of LECA replacement increased. As the granite is partially replaced by expanded clay, the amount of lightweight component increases yet the normal weight aggregates reduce simultaneously. Consequently, the increment of void content due to the incorporation of LECA result in the decline of density. It is also noticed that all the densities fall within the range between 1600 kg/m³ and 2000 kg/m³ in terms of oven-dry density. However, the fresh and hardened densities of LLWAC-50 and LLWAC-60 are slightly higher than those prescribed. In terms of consistency and stability, all specimens exhibit values nearly to unity corresponding to the increment of LECA replacement.

In this study, the fresh property is referred to the workability in which is represented by slump value. Figure 2 indicates the relationship between fresh density, hardened density, and slump with different LECA replacement percent.

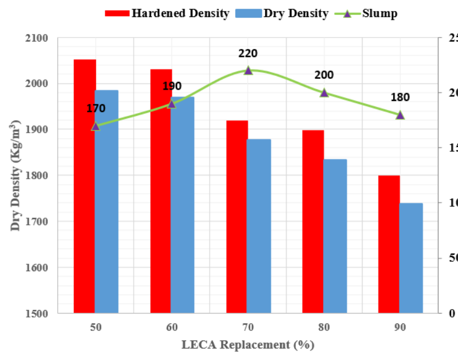

Figure 2. Relationship between fresh density, hardened density, and slump with different LECA replacement for LLWAC

Based on Figure 2, it is noticeable that the slump value of LLWACs are completely higher than that of NWC-CTR (Normal weight concrete - control), which means the concrete is more workable in the presence of LECA. In spite of the higher water absorption of LECA compared to normal weight aggregate such as granite, which has a negative effect on workability, round and smooth surface of LECA offset these undesired effects by minimizing the inter-particle friction and thus improved the overall workability ultimately. This is evidenced by the increment of slump value by 141.67%, 158.33%, 183.33%, 166.67% and 150.00% at 50%, 60%, 70%, 80% and 90% LECA replacement respectively.

A bell-shaped curve is achieved from the slump of LLWACs. As the percent replacement of LECA increase from 50% to 70%, the slump of LLWAC increase gradually from 170 mm to 220 mm. Further increase of LECA replacement from 70% to 90% reduces the slump to 180 mm. Since LLWAC-70 gives the highest slump value in comparison with others, it means that LLWAC is most workable at 70% LECA replacement. The variations of workability among LLWAC can be further explained by the rheological behavior. The decrease in slump value after the optimum value was due to the porosity and water absorption in the aggregate, which decreases the inter-particle lubrication [11].

3.2. Mechanical properties of LLWAC.

3.2.1. Compressive strength.

Figure 3 illustrates the compressive strengths of LLWAC with different LECA replacement at 7 days and 28 days curing ages.

Based on Figure 3, the compressive strengths at 28 days curing age are apparently higher than the 7 days. In comparison with 50% LLWAC, the 7 days compressive strength reduced by 11.11%, 18.80%, 19.31% and 27.12% while the 28 days compressive strength reduced by 13.07%, 14.68%, 23.65% and 25.46% at 60%, 70%, 80% and 90% LECA replacement respectively.

There are several factors responsible for the declination of compressive strength for LLWAC. As mentioned that the incorporation of LECA cause decline of density of concrete, therefore, the compressive strength also decreases respectively. It obeys the theory that the higher the concrete density, the greater the compressive strength of concrete. Relationship of density and compressive strength as shown in Figure 4.

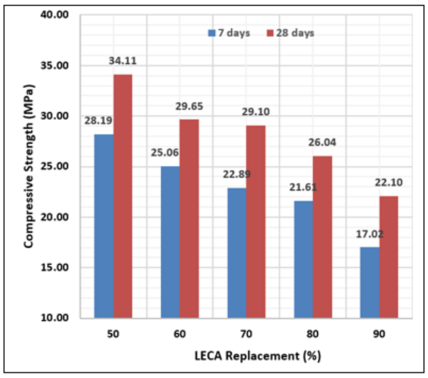

Figure 3. Compressive strengths of LLWAC with 50%, 60%, 70%, 80% and 90% LECA replacement at 7 days and 28 days curing ages.

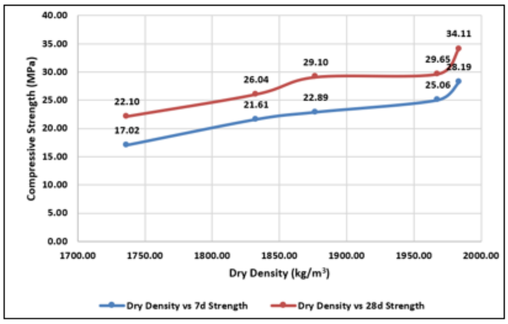

Figure 4. Relationship between density and compressive strength at 7 days and 28 days curing ages.

Another factor is governed by the physical properties of LECA itself. In comparison with normal weight aggregate such as granite, LECA owns a relatively high void content, lower particle strength and crushing strength, ultimately reduce the strength of LLWAC. The spherical shape of LECA due to the rotary effect cause weaker mechanical interlocking with ambient cement matrix in contrast with angular granite. As a result, fracture tends to initiate at LECA aggregate due to its porous properties.

3.2.1. Performance index (PI).

Variations in the densities cause difficulties in comparing the compressive strength of LLWAC. Hence, the performance index is introduced to measure the performance of LLWAC based on its respective compressive strength whilst unified the density with respect to 1000 kg/m³. Performance index serves as a parameter to determine the optimal LECA replacement, and the highest value is preferred. Figure 5 compares the performance index of LLWACs at 7 days and 28 days of curing age.

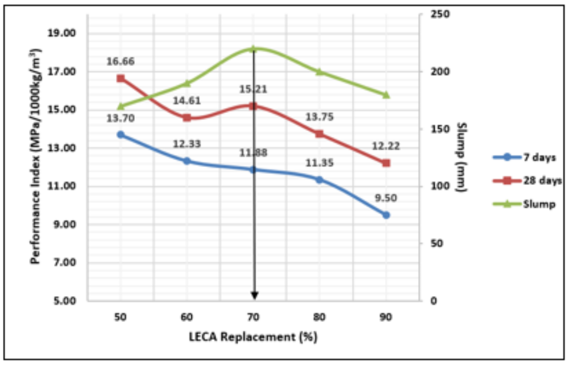

Figure 5. Comparison of slump and performance index for LLWACs at 7 days and 28 days curing ages.

3.2.2. Splitting tensile strength.

Figure 6 illustrates the splitting tensile strength of LLWAC with different percentages of LECA replacement at the curing age of 7 days and 28 days. From Figure 6, the trend of splitting tensile strength development can be observed a decrease of strength throughout the rising of LECA replacement percentage. The splitting tensile strength dropped with the increment of LECA content from 50%-90% at 7 days and 28 days curing age. The splitting tensile strength reduces slower than compressive strength throughout the curing period. The percentage improvements from 7 days to 28 days are 5.69%, 5.29%, 5.68%, 5.45% and 4.57% with LECA percentage of 50%, 60%, 70%, 80% and 90% respectively.

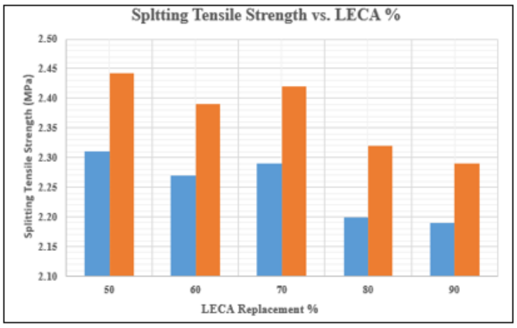

Figure 6. Splitting tensile strength of LLWAC with a different percent of LECA replacement at curing age of 7 days and 28 days.

3.2.3. Flexural strength.

According to the study, all specimens are loaded at two points until rupture. Figure 7 records the flexural strength results of llwac with various percentage of leca at 7 days and 28 days curing age. Based on figure 7, it can be declared that the flexural strength decreases proportionally to the increment of leca percentage replacement. The flexural strength ranged from a minimum of 2.11 mpa to a maximum of 2.53 mpa at 7 days and 2.24 mpa to 2.70 mpa at 28 days. the flexural strength developments of 70% leca replacement had showed the increment at about 7.35% from 7 days to 28 days. therefore, it can be deduced that the optimum replacement of leca at 70% had achieved the highest flexural strength similar in the case of splitting tensile strength.

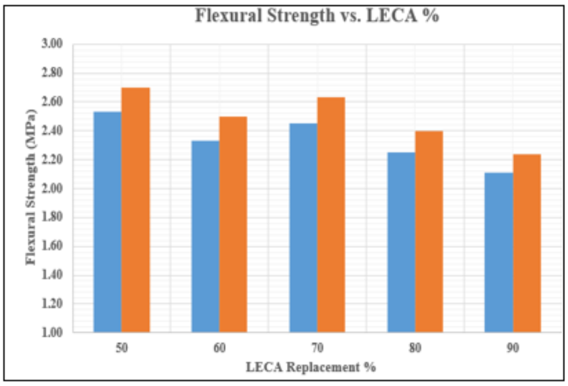

Figure 7. Flexural strength of LLWAC with a different percent of LECA replacement at curing age of 7 days and 28 days.

4. Conclusions

The main purpose of this research was to develop high strength recycled crushed Lightweight Expanded Clay Aggregate Lightweight Concrete (LWC-LECA) with desired fresh and hardened properties. Based on the experimental results of this study, the principal role of Lightweight Expanded Clay Aggregate in Lightweight Concrete played an important role in reducing the concrete density. By introducing LECA partially replaced in the mixture, the concrete mixture is able to achieve the desired range of compressive strength as well as fulfilling the concrete density. Therefore, the following conclusions can be drawn:

(1) Based on the results, it can be concluded that as the amount of LECA replaced increased, the fresh density of concrete will be decreased simultaneously. All the mixtures with LECA replacement had achieved the fresh density within the range of 1700-2000 kg/m^3. From the results, LLWAC-70 was chosen to be the optimum mixture in terms of stability and consistency.

(2) The workability of fresh concrete was indicated by using the slump test. From the results, LLWAC-70 had achieved the highest slump value at 220 mm as compared to others.

(3) Compressive strength decreased as the amount percentage of LLWAC increased. However, the compressive strength had obtained within the range of 22.10 MPa to 34.11 MPa at 28d. Thus, the high compressive strength of lightweight aggregate concrete has been fulfilled.

(4) By comparing the results among all the mixtures of LECA replacement, LLWAC-70 had achieved the highest increment splitting tensile strength from 7d to 28d at 5.68%

(5) LLWAC-70 had shown the most optimal result increment from 7d to 28 d at about 7.35% as compared to other mixes.

Hence, it can be concluded that the findings of LECA lightweight, high strength concrete had showed high potential applications in producing sustainable building materials for the concrete industry.

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Conflicts of Interest

The authors declare no conflict of interest.

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