The strength of lightweight aggregate in concrete – A Review

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Abstract. Concrete elements are the heaviest weight in structure, and it is the main component of the dead load in structure. Lightweight concrete is used to minimize overall dead load in structures, and also has a remarkable fire resistance quality more than normal weight aggregate concrete. Lightweight concrete can be characterized as a concrete consists of normal and artificial lightweight aggregate such as lightweight expanded clay aggregate (LECA). LECA produced in a rotary kiln which is approximately 50% lighter than normal aggregate, which is a new method in minimizing concrete self-weight. The main purpose of concrete in structure is to resist the compression stresses, the tests need to prove the effectiveness of using LECA in concrete to produce acceptable compression strength. For this reason, many attempts has been made to discuss and review the strength of structural element using LECA. This paper reviews several tests for the strength of LECA concrete by determining the mechanical properties such as flexural strength and compressive strength. The LECA concrete compressive strength is found to be slightly lower than normal weight aggregate concrete. It can be seen from researches results that LECA concrete produced medium strengths, both in compressive and flexural.

1. Introduction
Lightweight aggregate concrete has been used in buildings structure as prefabricated wall panels, precast concrete units, and masonry blocks. Lightweight concrete used in structures to minimize its overall dead load. Furthermore, it has low heat transmission and high fire resistance compared to normal weight concrete. It can prevent steel reinforcement from corrosion and salt water. Lightweight concrete can be characterized as a concrete that consists of normal and artificial lightweight aggregate such as oil palm shell and lightweight expanded clay aggregate (LECA) [1]. This paper aims to review researches that demonstrate the possibility of producing light weight concrete which has strength that applicable for structural application.

2. Literature review
This section gives a review of previous studies that have been investigated by researcher that expert in the field of structural engineering. Several studies were evaluated to understand the method used in lightweight aggregate to produce lightweight concrete. Many researches concentrated on the lightweight aggregate and its significance in concrete and the researches covered particularly on the physical and mechanical properties of various types of lightweight aggregate.
2.1. Mechanical properties of lightweight concrete in previous studies

2.1.1 Compressive and Flexural Strength.

Many researchers had reported on the mechanical properties of lightweight concrete with various type of lightweight aggregates. Work done on the use of oil palm shell (OPS) aggregate as a coarse aggregate, which evaluated strength and performance of the light weight concrete [2]. The study identified that the potential usage of oil palm shell as light weight aggregate particularly at high level of replacement. Furthermore, the strength of concretes produced were about medium to high strength (between 34 MPa to 55 MPa), which had potential for structural usage. The flexural strength of concretes were between 5 - 6 MPa. Figure 1 shows the concrete properties relation between flexural to compressive strength, where the ratio are about 11.6 – 13.5%.

![Figure 1](image-url)  

Figure 1. Relation of 28-day compressive and flexural strength of OPS concrete (Shafigh et al., 2012)

A study investigated on the use of lightweight expanded clay aggregate (LECA) and scoria with silica fume in producing light weight concrete [3]. The finding identified that the use of both aggregates, LECA and scoria, gave a significant reduction in the weight of concrete compared to normal weight aggregate and concrete with scoria had a heavier weight of concrete compared to those with LECA. On the strength aspect, the use of scoria and the presence of 10% silica fume improved the concrete’s strength. The results also determined that concrete containing lightweight aggregates was more vulnerable to external damage compared to normal concrete.

A study carried out by [4] on the properties of lightweight concrete contains expanded glass, which evaluated the mechanical and flexural strengths of the concrete. The result indicated that both strengths, compressive and flexural strengths, were greater with the incorporation of expanded glass granules. The compressive strength gained was about 4.0 - 5.8 MPa and flexural strength was in the range of 1.5-1.7 MPa. In previous studies, flexural strength was within the range of 2.13 – 4.93 MPa. The flexural strength of 28-day was with an average of 13.7 %. While the compressive strength of 28-day varied from 12.9% to 14.8%. It has been also stated that flexural strength of high and medium strength lightweight aggregate concrete is normally within the range between 9 - 11%. This particular investigation revealed that although the strength obtained by the concretes was about the same range, the concrete consist of ops gave 23% increment in weight compared to concrete produced by lightweight aggregate expanded clay (LECA).
2.1.2. Elastic modules.
Ardakani and Yazdani [5] studied on the relationship between particle density and static elastic moduli of LECA. The micromechanics method with some simplifications has been used in this study to determine the modulus of elasticity for different size of LECA. Based on the results, it was found that the elastic modulus of LECA ranged between 0.6 to 6.3 GPa and have a linear relationship with density. Figure 2 shows the elastic modulus of LECA decreases as particle size increases.

![Figure 2. Particle size VS elastic modulus](image)

Another research conducted by [6] compared elastic properties between conventional concrete and lightweight structural concrete designs with LECA. The study controlled both, the volume of total aggregate and water-cement ratio, at constant rate to investigate a significant change in elastic properties with remarkable different in density. Furthermore, study has also been conducted on the relation between dynamic elastic modulus and particle density [5]. Both studies found that in term of particle density, the standard method was not applicable on LECA particles due to its small particle size. For that the elastic modulus, concrete with LECA were not be determined through a direct test. The results showed that the relationship between particle density and elastic modulus is the best performed by a linear regression line with a coefficient of determination of 0.96.

2.2. Physical Properties of Lightweight Concrete in previous studies
2.2.1. Density &Porosity.
Ardakani & Yazdani, [5] tested different sizes of LECA and generally found that smaller LECA resulted higher density, where the density was within the ranged between 480 to 1100 kg/m³. The density was depended on the size of aggregate, which between 4 to 14 mm. Furthermore, the study found that there was a linear relationship between LECA density and modulus elasticity and LECA dry density increased with increasing of the modulus of elasticity (see Figure 3).
2.2.2. Water Absorption in Lightweight Concrete.

A research has been investigated by [7] stated that water absorption coefficient of concrete increased with higher perlite level. The high volume of expanded perlite used, the more reduction in weight of concrete was obtained and this resulted in high water absorption. The study stated that the water absorption increased with constant rate for density of concrete about of 1000 kg/m³. The perlite behaves as air voids, which minimize the capillary suction and it is found that the pores increases the water absorption. Furthermore, the results showed that the thermal conductivity was virtually improved with the use of perlite.

Another study determined that the water absorption in recycled lightweight clay aggregate (RLCA) was more compared to the original lightweight clay aggregate [4]. Thus, it can be explained that the higher amount of broken particles in RLCA may lead to reduction of crushing strength. It is well understood that water absorption is high for concrete contains honeycombing and this will affect the performance of concrete, which lead to a lower strength of concrete.

3. Conclusion

Many researches have been reviewed on using various type of lightweight aggregate with different objectives to produce lightweight concrete that have similar physical and mechanical properties to normal concrete. In the case of LECA, it is found that LECA is suitable to be used in structural elements due to its properties, which is lightweight and acceptable strength compared to other type of lightweight aggregate. It reduces the density of concrete, which is beneficial for lightweight structural. It is known that lightweight aggregate concrete is not as strong as normal concrete, however, flexural strength of LECA concrete is clearly strong compared to concrete produced of normal weight concrete elements.
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