Influences of macro polypropylene fibre-reinforced lightweight concrete incorporating recycled crushed LECA aggregate

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Abstract. The huge amount disposal of light expanded clay aggregate (LECA) had become a serious environmental issue across the globe which represents an immediate threat to the environment. One of the potential solutions is to incorporate these wastes into construction materials, mainly concrete. These waste materials are abundant and easily available. The addition of recycled crushed LECA creates void space in the concrete which helps in decreasing the density of concrete, and reducing the dead loads needed to be sustained for buildings. In this study, different volume fraction (0, 0.15, 0.3 and 0.45%) of macro polypropylene (MPP) fibre have been used to enhance the strength properties of lightweight concrete (LWC). The combination of lightweight LECA and MPP fibre have been used to achieve compressive strength between 25 to 40 MPa with a density ranged between 1800 to 2100 kg/m³. It is found that the addition of MPP fibres at an optimum volume fraction concrete enhances the compressive strength. Hence, the findings of this research revealed that it can be used as an alternative solution for concrete industry.

1. Introduction

Concrete is the most used building material since the 20th century. With the rapid growth of urbanisation, the amount of concrete used also increasing. Concrete had been the 2nd most consumed material in the world, and its production consumed an enormous amount of natural resources such as aggregate, cement and water. With the current trends of concrete consumption, it has negative impacts toward the concrete industry. The natural resources, aggregate, are extracts from the seabed, riverbeds and other water sources. These activities cause environment problem after prolonged extractions and it is slowly depleting. Thus, a minor amount of recycled materials comes in to replace natural aggregate will result in saving natural resources, and more sustainable. This pursues researchers to use diverse recycled material in concrete in the early 2000s [1].

Among all types of lightweight aggregate concretes (LWAs), it can be divided into three (3) types, which are industrial waste lightweight aggregate, natural aggregate, and artificial lightweight aggregate. One type of industrial waste lightweight aggregate is known as recycled lightweight expanded clay aggregate. LWA are great in lightweight construction applications such as lightweight concrete wall, building facades, and architectural units. Lightweight construction means constructing the structure with minimal weight possible yet keeps the structure safe. As civil construction consumes 50–60% of
resources worldwide, it is vital to study its behavior and apply lightweight construction in building structure [2]. In this research, the LWA in the form of crushed LECA will be used to replace portions of coarse aggregate to investigate its effect on the engineering properties of the LWAC.

Structural lightweight concrete (LWC) plays a crucial role in the lightweight construction. One of the current methods to achieve this structural LWC is using the lightweight aggregate (LWA). It has been reported by Aslam et al. (2017) [3] showed that the used of blended oil palm boiler clinker (OPBC) to substitute both coarse and fine aggregate in concrete able to create a LWC with a 28 days compressive strength range from 17 MPa to 47 MPa with density in range of 1440 kg/m$^3$ to 1850 kg/m$^3$. The application of this blended LWA produced a high strength LWC which is suitable for structure design.

Ironically, the increase the concrete strength results in an increment of its brittleness [4]. These brittle properties cause concrete more susceptible to cracking. Initiation and propagation of cracks cause detriment effect on structural health and its lifetime, which will eventually affect the serviceability of the concrete structure. Instead of prevent cracking, the development of fibre-reinforced concrete (FRC) controls the cracking by restraining the cracking openings [5]. In current research, non-experimental researches have been performed by incorporating macro polypropylene fibre with the combination of crushed lightweight expanded clay aggregate (LECA) method to investigate its influences on the strength properties of the lightweight aggregate concrete (LWAC).

2. Materials and Methods

2.1. Materials

2.1.1 Ordinary Portland Cement (OPC)

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

2.1.2 Water and superplasticizer (SP)

Potable water with pH value of 6 was used for both mixing and curing. The water to cement ratio of 0.33 was used for all the mixes. The high range water reducing admixture namely superplasticizer used in this study is the MasterGlenium SKY 8808 supplied by BASF.

2.1.3 Fine and coarse aggregate

Fine aggregate utilized in this research is namely localized river sand from LABTECH Laboratory Supplies company. To ensure moisture is completely driven out of the pores, sand is oven-dried to constant weight at temperature of about (105±5) ºC for 24 hours. The sand is required to sieve through 4.75 mm sieve. The sand available having a specific gravity, fineness modulus, water absorption and maximum grain size of 2.65, 2.70, 0.96% and 4.75 mm, respectively.

Yew et al. [6] reported that crushed oil palm shell (OPS) aggregate significantly increased the compressive strength compared to original OPS aggregate. Therefore, crushed LECA aggregate was used as the coarse aggregate in this study. These LECAs are obtained from Weng Thye Horticulture Sdn. Bhd. located at Kota Damansara, Selangor. Furthermore, all these coarse aggregates must have size able to retain on 4.75 mm sieve. In this study, crushed LECA was utilized, as shown in Figure 1 (a).

Figure. 1 (a) Crushed lightweight expanded clay aggregate and (b) Macro polypropylene fibre
2.1.4 Fibres
A photograph of the macro polypropylene (MPP) fibre is shown in Figure 1 (b)

2.2. 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 1.

| Specimen          | SPP (%) | Cement (kg/m³) | Sand (kg/m³) | Water (kg/m³) | Granite (kg/m³) | LECA (kg/m³) | SP (kg/m³) | SPP (kg/m³) |
|-------------------|---------|----------------|--------------|---------------|----------------|--------------|------------|-------------|
| LLWAC-50-MPP-0%   | 0.00    | 420            | 875          | 138.6         | 232.5          | 240          | 7.175      | 0.000       |
| LLWAC-50-MPP-0.15%| 0.15    | 420            | 875          | 138.6         | 232.5          | 240          | 7.175      | 1.365       |
| LLWAC-50-MPP-0.30%| 0.30    | 420            | 875          | 138.6         | 232.5          | 240          | 7.175      | 2.730       |
| LLWAC-50-MPP-0.45%| 0.45    | 420            | 875          | 138.6         | 232.5          | 240          | 7.175      | 4.095       |

Note: LLAC-50-PP-0% = LLWAC-50 with 0% of macro polypropylene fibre inclusion

2.3. Testing methods
The procedure adopted for mixing the crushed LECA lightweight aggregate fibre-reinforced concrete (LLWAFRC) with different volume fraction involves the following steps. Firstly, the sand and aggregate were poured into a concrete mixer and dry mixed for 60 seconds. Secondly, the cement was spread and dry mixed for 60 seconds, after which the specified amount of fibres is distributed and mixed for 180 seconds in the mix. This is followed by the addition of water and superplasticizer with a mixing time of 300 seconds. The concrete specimens were cast in 100-mm cube steel oiled moulds, and a poker vibrator was used to eliminate air bubbles in the mixture. The specimens were demoulded approximately 24 +/- 1 hours after casting and were cured in water at 25 ± 2 °C until age of testing.

3. Results and discussion
3.1. Properties of fresh concrete (Workability)
The workability of concrete determines the ease and homogeneity, with which it can be mixed, placed, consolidated, and finished. It is a way to understand the behaviour of concrete and to recognize the requirements of workability on site. In this study, the slump tests were carried out to determine the consistency of fresh concrete. The workability of LLWAC-50 with different volume percentage of polypropylene fibre is represented by the normal slump value as indicated in Figure 2.

![Figure 2](image-url) Relationship of fresh density, hardened density and slump with various % of polypropylene fibre

The use of fibres is well known to affect the workability and flowability of plain concrete intrinsically [7]. In this study, the quantity of water and SP were kept constant for all mixes in order to access the effects of different content of SPP fibre on the workability of LLWAC. From Figure 3, it could be seen that the workability of fresh LLWAC decreases due to an increase of SPP fibre content. The addition of MPP fibre in LLWAC-70 has a negative effect on the workability. Slump value reduces remarkably with the increase of MPP fibre percent. The slump is declined gradually by 4.55%, 13.64% and 27.27% at 0.15%, 0.30% and 0.45% with the inclusion of SPP fibre respectively.

Addition of fibre decreases the workability of concrete in a way which bridge and hold the cement matrix, forming a network structure in concrete. This structure hence promotes cohesion and adhesion
among the matrices. It can be ascertained that the fibres will absorb more of the cement paste in order to ‘wrap around’ due to the high content and large surface area of the fibres, and the increase in viscosity of the mixture promotes a decrease in workability [6]. It can be concluded that the inclusion of SSP fibre up to 0.45% $V_f$ had significantly reduced the workability of LLWAC. Furthermore, the geometry of PP fibres through the surface area had an impact on workability. It has been reported that the fibrillated fibres produced higher slumps as compared to multi-filament fibres is mainly due to the fibre geometry [8]. However, LLWAC-70 inclusion of MPP fibre from 0%-0.45% had achieved the high workability with the slump value between 160- 220 mm.

3.2. Density

Three types of density, namely, fresh density (FD), demoulded density (DD) and oven-dry density (ODD) were measured for all mixes. Structural lightweight concrete (SLWC) is typically defined as concrete with ODD of not greater than 2000 kg/m³. It can be observed that all LLWAFRC density having an ODD and DD within the range of 1905 – 1982 kg/m³ and 1963 – 1993 kg/m³ which fulfilled the requirement of structural LWC for all mixes.

From Table 2, all densities are observed to have a slight increment as the inclusion of polypropylene fibre increased, except for the oven-dry density of LLWAC-50-SP0.15%. This might be caused by the non-uniform of the dispersion of PP fibre in each specimen, thereby affected the average density obtained consequently. Besides, the fresh, hardened and oven-dry density of LLWAC-50-SP0.45% are noticed to be escalated sharply. In general, density increases as the inclusion of fibre increase.

Even though the incorporation of SPP fibre with relatively low unit weight might displace certain amount of cement, however, the effect of fibre in stiffening the mixture capable to overcome the former, thus result in the increment of density. Similar outcome is evidenced by Bagherzadeh et al. [9]. This can be further explained by the packing density theory, where SPP fibre holds the cement matrix close to one another, causing a packing effect. As a result, increase the material occupied within a unit volume, thus increase overall density.

Table 2. Fresh and hardened properties of LLWAC-50 with various volume fraction of polypropylene fibre

| Specimen         | Density (kg/m³) | Stability | Consistency |
|------------------|----------------|-----------|-------------|
|                  | Target | Fresh  | Hardened | Oven-Dry |    |          |
| LLWAC-50-MPP0%   | 1896.9 | 1971.8 | 1962.8   | 1906.1  | 1.005 | 1.039   |
| LLWAC-50-MPP0.15%| 1898.2 | 1980.2 | 1981.2   | 1904.6  | 1.000 | 1.043   |
| LLWAC-50-MPP0.30%| 1899.6 | 1988.3 | 1982.2   | 1906.4  | 1.003 | 1.047   |
| LLWAC-50-MPP0.45%| 1901.0 | 2048.0 | 1993.4   | 1982.7  | 0.983 | 1.077   |

3.3. Compressive strength

3.3.1. Continuous moist curing

The results of the compressive strength test for all concrete mixes subject to moist curing up to 28 days are presented. Figure 3 shows the compressive strength development for LLWAC containing SPP fibre with different percentage of $V_f$. As can be seen, there is significant difference between LLWAC-50-SP0% and LLWAC-50-PP0.45%. It can be found that a positive development of compressive strength can be noticed with the increase of PP fibre percentage at both curing age. As the curing period increase, the compressive strength increased by 11.75%, 6.71%, 14.89% and 13.55% respectively from 0% to 0.45% inclusion of fibre. The highest early strength and later strength are given by LLWAC-50-SP0.45% with strength of 32.32 MPa and 36.70 MPa respectively. In comparison among various
percentage of fibre, LLWAC-50-PP0.15% possessed a slight escalation of strength. Furthermore, LLWAC-50-PP0.45% highlighted a dramatic development of compressive strength about 28.30% at 7 days and 30.37% at 28 days respectively.

![Figure. 3 Compressive strength of LLWAC-70 with different percent of SPP Fibre at curing age of 7 days and 28 days](image)

This positive trend in the development of compressive strength have subverted the statements reported that addition of SPP fibre at different quantities has no effect on the compressive strength. This incremental of strength is mainly influenced by the fibre’s stiffness and energy absorption induced by fibre. The improvement came principally from the fibres interacting with the advancing cracks and showed the higher values of compressive strength compared to LLWAC-50-SPP0% concrete. Therefore, improve the capability of concrete to capture larger loadings, resulting in the extension of failure mode that prone to ductile mode, hence give rise to higher compressive strength. This process is attributed to the ability of the fibres to arrest cracks or bridging effect in concrete.

4. Conclusion
Based on the experimental results of this study, the following conclusions can be drawn:

1. The presence of synthetic polypropylene (SPP) fibre has a minor effect on density. There is slight increment in density as the SPP fibre percentage increased. Density is increased from 1906.1 kg/m$^3$ to 1982.7 kg/m$^3$ with addition of 0.45% SPP fibre.
2. The presence of SPP fibre in LLWAC had significantly reduced the workability, where the rate of slump drop accelerated as the fibre content increased. The inclusion of 0.45% of SPP fibre has reduced the workability from 220 mm to 160 mm.
3. Compressive strength increased as the volume percentage of SPP fibre in LLWAC increased. The compressive strength at 7 days and 28 days has increased by 28.30% and 30.37% respectively for 0.45% volume fraction of SPP fibre.

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