Fire resistance of lightweight foam concrete by incorporating lightweight bio-based aggregate

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Abstract. Concrete is widely used in the industry due to its effectiveness in terms of cost and strength. In this study, the introduction of bio-based aggregate as coarse aggregate in lightweight foam concrete will be investigated to find a better solution for fire incidents that are commonly happened. As such, lightweight foam concrete (LWFC) has been applied in many buildings especially in non-load bearing wall to enhance thermal conductivity, sound insulation and fire resistance. The aim of this research is to investigate the effect of incorporating bio-based aggregate namely oil palm shell (OPS) into lightweight form concrete in terms of strength properties and fire resistance. Three different concrete mix was designed containing different percentage of OPS aggregate replacement (0, 5, 10 and 15%). From the result, the compressive strength of the LWFC-CTR mixture had achieved the highest compressive strength at 28-day, which is recorded at 3.82 MPa. The fire resistance of LWFC-OPS 15% had showed a positive outcome with improvement by almost 23.5% compared to control mix at 15 minutes. Therefore, the major finding of this research is the incorporation of eco-friendly OPS aggregate has improved the fire resistance of lightweight foam concrete, which can be used as an alternative solution for non-load bearing walls.

1. Introduction
The rapid growth of urbanization had led to a rise in the economic development worldwide, simultaneously stimulated the expansion of infrastructure development. According to the world research, about 20 billion metric tonnes of concrete were consumed per annum, leading it to one of the most manmade material ever used globally. Conventional concrete as a composite substance is chemically bound of aggregate, water and binder as the fundamental constituent material. It is relatively economical and widely available around the globe due to its unique advantages compared to other material. A significant problem that is currently facing
in the industry is the fire resistance that needed in a building structure. Concrete is indeed a fire resistive construction material by its nature; however, fire wall panel and door have heavy loading. Therefore, studies on fire resistance of lightweight concrete have done showing that lightweight concrete is better in resisting fire due to the voids or hollow section that made insulation and fire resistance more efficient. Therefore, it is desirable to replace the structural elements at the designed fire-rating with lightweight concrete. Lightweight concrete is convenient, fast, and easy to be shifted to its designated position. Lightweight concrete offers low dead weight for construction due to its low density that can be used to cut down the cost as it eases the shipping and save transportation cost of pre-cast product. The main concerned is the fire resistance and soundproof due to lightweight concrete porosity. Malaysia as one of the world’s largest palm oil producer is expected to maintain its dominant position over the next decade, with the supply of approximately 18 million tonnes in the year of 2020. According to Basiron and Simeh [1], Malaysia and Indonesia have a total land share of 6.2 million hectares. However, the extraction of palm oil generated various solid waste including the palm oil fibre, husk, kernel, empty fruit bunches and shell which has been a highly controversial topic. The oil palm shell species are commonly cultivated in most areas in Malaysia categorize as dura and tenera [2-4]. Due to increasing in sustainability concern, many researchers are constantly looking out for an alternative material such as oil palm shell (OPS) as coarse aggregate in producing of structural and non-structural lightweight concrete as building materials [5-8]. The main focus in this research paper is to investigate the performance of LWFC in terms of fire resistance and strength properties by incorporating different percentage (0, 5, 10 and 15%) of oil palm shell lightweight aggregate.

2. Materials and Specimens

Type I Ordinary Portland Cement (OPC) namely Orang Kuat was used in this study which meets the ASTM: C150/C150M-12. The specify gravity and Blaine’s specific surface area for this cement were 3.14 g/cm³ and 3510 cm²/g, respectively. Local crushed sand having a specific gravity in SSD state, fineness modulus, water absorption and maximum nominal grain size of 2.68, 2.78, 0.98% and 600 μm, respectively. Furthermore, crushed hybrid oil palm shell species (dura and tenera) was used as the coarse aggregate with specific gravity of 1.22. Nonetheless, in order to achieve homogeneous mix, OPS aggregates were sieved to eliminate particle size larger than 4.75 mm, as presented in Figure 1. Foaming agent used in this research is the synthetic foaming agent, Sika® AER 50/50 manufactured from Sika Kimia Sdn. Bhd. Dilution ratio of 1:20 by volume is applied to dilute the foaming agent with water and the optimum w/c ratio at 0.60 was used. Formation of foam could be achieved through the process of feeding diluted foaming agent mixture into pressurized foaming generator under 500 kPa condition. Apart from that, fire resistance test was carried out for all specimens, Bunsen burner was used that could release 1400°C of hot flame and be placed at 15 cm away from specimen such that the flame tip is still connecting while not generating high temperature that may melt the thermometer sensor. The specimen used was a 300 mm x 300 mm x 50 mm cuboid where the centre had been marked as a reference point. The thermometer sensor was placed directly behind to heating point such that more accurate data was obtained. It was connected to the cuboid through a thermal sensor attached with masking tape. Moreover, stopwatch has been utilized in this test for time recording. The whole testing environment has been covered up with steel plates such that the effect of wind and rain could be minimized. Data was collected at an interval of 1 minute along the 1-hour test.
3. Mix proportions

A total of 4 mixes were arranged with a constant water/cement (W/C) ratio of 0.60 was cast, inclusive of a control mix, different percentage of fibres (5, 10 and 15%). Table 1 presents the mix proportion of LWFC-CTR, LWFC-OPS5, LWFC-10 and LWFC-OPS15.

| Mix code     | Materials (kg/m³) | Cement | Fine sand | Water | OPS |
|--------------|-------------------|--------|-----------|-------|-----|
| LWFC-CTR     |                   | 600    | 600       | 360   | -   |
| LWFC-OPS5    |                   | 600    | 570       | 360   | 5   |
| LWFC-OPS10   |                   | 600    | 540       | 360   | 10  |
| LWFC-OPS15   |                   | 600    | 510       | 360   | 15  |

*Note:
LWFC-CTR = lightweight foamed concrete control with 0 % oil palm shell aggregates as partial replacement
LWFC-OPS5 = lightweight foamed concrete with 5 % oil palm shell aggregates as partial replacement

4. Results and discussion

4.1 Inverted Slump Test

Inverted Slump Test were carried out with the fresh mix in order to study the effect of OPS aggregates on the flowability of lightweight foamed concrete. The slump value was recorded and tabulated in Table 2.

| Mix code     | Slump Value (mm) |
|--------------|------------------|
| LWFC-CTR     | 788              |
| LWFC-OPS5    | 733              |
| LWFC-OPS10   | 685              |
| LWFC-OPS15   | 643              |

Based on the result as shown in Table 2, the most significant finding is the inverted slump value for LWFC incorporating 5%, 10% and 15% of oil palm shell aggregates has reduced 7%, 13% and 18% respectively compared to LWFC-CTR. The LWFC-CTR had an inverted slump value of 788 mm while LWFC-OPS15 was only 643 mm. The result had proved that mixing water was absorbed by the OPS aggregates during the mix, thus result in lower workability. As such, it is predicted that further increase in OPS content would cause even lower workability. Despite the difference, all inverted slump values were more than 500 mm, which is the optimum slump value for self-compacting concrete. This might cause by the high w/c ratio.
adopted in this research. From the previous researchers, self-compacting concrete can be achieved with the concrete mixing method by incorporating silica fume and ceramic dust powder with the high w/c ratio [9,10].

4.2 Density

Fresh and hardened density of the mix was determined and tabulated as shown in Table 3. The density of foamed concrete is highly variable according to the volume of foam added and the mix proportion.

| Mix code     | Fresh Density (kg/m³) | Dry Density (kg/m³) | Demoulded | Air dry (28 days) |
|--------------|-----------------------|---------------------|-----------|-------------------|
| LWFC-CTR     | 1121.0                | 1070.6              | 1014.6    |                   |
| LWFC-OPS5    | 1094.6                | 1031.5              | 982.3     |                   |
| LWFC-OPS10   | 1053.7                | 1006.1              | 957.8     |                   |
| LWFC-OPS15   | 1033.5                | 995.4               | 945.2     |                   |

According to the result, it can be observed that fresh and dry density in LWFC-CTR had the highest density and the lowest density is found in the LWFC-OPS15. The reason behind is the OPS has lower specific gravity as compared to sand, which result in reducing of overall density with the increment of partial replacement of OPS from 5 to 15% in the specimen. As such, the density will be lower compared to the control mix where no OPS aggregates were incorporated.

Besides, we can also deduce the density will reduce with time as there are about 5.0% decrement in the dry density between demoulded and air-dry at 28 days curing. Furthermore, dry density had shown a constantly reduction of overall density from demoulded to 28 days air-dry curing, as presented in Figure 2. The LWFC samples has met the requirements for non-structural applications with densities fall within the range of 945 -1070 kg/m³.

![Figure 2](image.png)

**Figure 2.** Density results for LWFC specimens

4.3 Compressive Strength

According to the result received in Figure 3, it was observed that the compressive strength is directly proportional to the dry density of concrete. The denser concrete will certainly provide more strength to resist
the applied pressure. In other words, LWFC-CTR could resist better compressive force compared to LWFC containing 5, 10 and 15% of OPS due to the denser properties. As predicted, the compressive strength was reduced by approximately 3.4%, 4.9% and 7.8% respectively when 5, 10 and 15% of OPS in incorporated into the cement mix. This is due to the smooth surface of OPS aggregates results in the weaker bond between aggregates and cement matrix. This may also lead to a higher porosity occur in the concrete which depleted the strength of concrete. As such, it is predicted the compressive strength is inversely proportional to the amount of OPS aggregates replacement. However, all the specimens had achieved more than 3.5 MPa at 28 days which is suitable to be used for concrete wall panels.

The test result also indicated that the 28 days strength is severely higher than the 7 days strength because of continuous hydration process taken place. According to the result, 7 days strength is projected at 67.8%, 70.7% and 70.5% and 70.4% of 28 days strength in LWFC-CTR, LWFC-OPS5, LWFC-OPS10 and LWFC-OPS15 respectively. This has identified that the compressive strength will develop at a higher rate at early stages reduced at the later stage. As such, it was believed that the compressive strength will be constantly increasing along the curing duration until all the bond is formed. It has been reported that the similar trend with the study from [11,12].

### 4.4 Fire Resistance Test

As for comparison, time versus concrete temperature graph has been plotted for all four (4) specimens with the time interval of 1 minute, as shown in Figure 4. In graph analysis, the pattern was quite similar where the temperature of concrete had increased exponentially after the first 8 minutes of continuous burning. There has been a significant difference among the four (4) samples where LWFC-CTR is increasing with a higher rate while LWFC-OPS (5, 10 and 15%) increased the least. As can be seen, the changes of temperature of LWFC-OPS5, LWFC-OPS10 and LWFC-OPS15 has reduced 19.1, 22.1 and 23.5%
compared to LWFC-CTR in 15 minutes mark. The reason behind the slower increase in temperature in LWFC-OPS5, LWFC-OPS10 and LWFC-OPS15 is due to the higher porosity of concrete after incorporating OPS aggregates in LWFC which cause the temperature having difficulties in transferring heat. Moreover, it had proven that the OPS aggregates attributed the most to the fire resistance as it has greater thermal insulation properties compared to the conventional fine aggregate, which is fine sand in this case. The effect is enhanced with the use of increment of OPS which resulted in absorbing more heat. However, the temperature for all four (4) samples had only a fine increment which can be observed at roughly 80°C to 87°C after 30 minutes of continuous heating. The initial temperature, midway temperature and final temperature is plotted in Figure 4 which able to observe that the LWFC-CTR has the highest temperature reading at all points of stage. The LWFC-OPS15 had showed the lowest reading which indicated the best fire resisting ability.

![Figure 4](image_url)  
Figure 4. Fire Resistance Test of LWFC

5. Conclusion
Following conclusion could be drawn from the analysis result, the principal role of inclusion OPS has constantly reduced the overall density of LWFC. Furthermore, all the specimens have achieved a minimum strength of 3.50 MPa at 28-days. The inclusion of OPS is used to provide better fire resistance of LWFC compared to plain LWFC. Hence, the findings of this study had showed the promising outcome performance of OPSLWFC can be used for non-load bearing wall panels.

Acknowledgement
The authors wish to extend their greatest gratitude to Universiti Tunku Abdul Rahman for providing the financial support for this work under the Universiti Tunku Abdul Rahman Research Fund (UTARRF), Grant No.: IPSR/RMC/UTARRF/2020-C2/Y02.

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