The effectiveness of oil palm shell (OPS) as major aggregate replacement in concrete

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Abstract. Malaysia known as one of global leaders in production and export of palm oil. This huge production of palm oil has produced high waste product which might cause to environmental pollution. The aim of this study is to determine the effectiveness of oil palm shell (OPS) as aggregate replacement in concrete and at the same time help to reduce the environmental pollution. The workability, density, and strength performances of concrete incorporated with 80% of OPS as coarse aggregate replacement were being investigated. Through the experimental test has shown that the OPS have high potential to be used as aggregate replacement in concrete. Furthermore, the experimental test results exhibited the advantage of OPS in reducing the density of concrete within 1800kg/m³ to 2000 kg/m³. However, the compressive strength of concrete containing OPS was decreased up to 35% from normal concrete strength. Thus, by introducing steel fibres into the OPS concrete has help in improving the concrete strength. Hence the additional of steel fibre into concrete has shown good potential in improving the lightweight concrete since it shows lower in density and 35% higher than minimum lightweight concrete strength as stated by ASTM C330-89.

1. Introduction
Construction industry development is the deliberate and managed process to optimise the contribution of the construction industry in meeting national construction demand. This situation has cause to high demand of construction material that lead to the issue of the shortage of material supply and raise of material cost. As a solution there are lot of research work has been done to get the alternative material that have high potential to replace the conventional material used in construction especially for concrete material. One of the alternatives is by incorporating an artificial or natural lightweight aggregate in concrete production. Low density of lightweight aggregate contributing in producing concrete that significantly lighter weight than conventional concrete [1]. Conventional concrete generally has bulk density of 2400 kg/m³, while lightweight concrete (LWC) has a bulk density that is not higher than 2000 kg/m³. In past decades, the research on LWC has sparked a lot of interest from researchers. This is primarily due to the advantages of LWC, which include; savings on reinforcement, formwork and scaffolding, foundation expenditure as well as cost reduction for transportation and fabrication of the structures [2]. LWC has been introduced as one of the sustainable technologies in industry which has been highlighted in Brundtland Commission Report as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ [3].
Numerous of natural or artificial lightweight aggregates has been used to replace conventional granite aggregates in producing LWC such as recycled concrete waste, steel slag, brick waste and etc. Oil Palm Shell (OPS) is one of the potentials aggregate replacement material, which is one of the agricultural waste originating from the palm oil industry. The oil palm industry is one of the most significant industries in Malaysian economy. Whereby, Malaysia is one of the global-leaders in the production and export of palm oil as it yields more than half of the world’s palm oil productions [4]. Over 4.56 million tonnes of waste OPS have been produced annually [4] and about 4506 kilotons in 2007 had been thrown or burned away [5].

On the other hand, thorough study on steel fibres additional material in concrete as reinforcing material shows a positive influence on concrete performances. It is also a waste product from automobile industry or waste steel which had been recycle and remanufacturing as steel fibre with high strength capacity. Previous research has shown that the application of hooked end steel fibres (SteFib) helps in improving the strength of OPS concrete at 28 days [5]. Incorporation of SteFib concrete also helps in distributing the stress evenly within the hardened concrete [6]. At the same time, it helps to provide durable concrete surface with high resistance concrete [6]. Moreover, it helps to improve the toughness, ductility, post cracking performance, shrinkage, crack resistance, impact strength, torsional strength except modulus elasticity when the SteFib being incorporated into the mix design of concrete [5].

However, application of OPS in concrete as coarse aggregate replacement material is still scarce and previous researches were limited to lower to partially aggregate replacement which is less than 50% [4,5,7]. Hence, this study explored the performances of concrete containing 80% of OPS as aggregate replacement. Additional of SteFib in OPC were also studied in order to evaluate the interaction between these two components in enhancing concrete properties. The combination of these two materials might facilitate in overcome some of the concrete properties and at the same time producing sustainability of concrete structure. Hence the utilization of waste material helps in providing a proper management in reducing the risk of environmental pollution. The properties investigated are workability, compressive strength and flexural strength of the concrete. Details on materials preparation and experimental works were discuss from section 2 onwards.

2. Experimental work

2.1. Raw materials

The main materials used in this study is Ordinary Portland cement (OPC), coarse granite aggregate, sand and water. However, the SteFib were added as additional reinforcement in concrete to help in increasing the strength of concrete and to increase the sustainability of concrete. OPS was used as aggregate replacement and SteFib as reinforcing material in concrete. The oil palm shell (OPS) was supplied from Jugra Palm Oil Mill Sdn Bhd and the hooked end steel fibre (SteFib) from Oriental Housetop. The hooked end steel fibre with 60 mm length and 0.75 mm in diameter was used based on optimum performance in previous study had shown that this fibre is good in bonding and bridging the crack in concrete [8]. The OPS were wet and oily when received from factory. The OPS then were washed with water to remove the oil and oven dried at 110 °C for 24 hours to remove excess moisture [9].

2.2. Mix design and testing

2.2.1. Mix proportions. Concrete was designed based on Department of Environment (DOE) mix design as shown in Table 1. There are four different types of concrete has been prepared in this study; normal weight concrete (NWC), steel fibre reinforced concrete (SFRC), Oil Palm Shell concrete (OPS) and combination steel fibre and Oil Palm Shell concrete (SteFib OPC). Concrete grade 30 with target slump of 10 – 30 mm was designed with normal concrete density 2400kg/m³ as this study is aiming to focus on the effect of OPS as a replacement of coarse aggregate and steel fibre as additional material to improve the strength of concrete. The steel fibre dosage was set as 1% of normal weight concrete density which is equivalent to 25 kg/m³ as had been used by Abdul Rahman et al. [10]. Moreover, the oil palm shell (OPS) dosage was adopt from Waqbitu [11] for 80% of coarse aggregate replacement. The mixing procedure used is similar as normal weight concrete mixing procedure. The process followed by adding
small amount of steel fibre at a time continuously into the mixer to avoid the steel fibre to clump and become fibre ball. The mixer was run constantly until everything well mixed. In total twelve concrete cubes were cast using 150 mm x 150 mm x 150 mm steel mould. Beside that nine concrete prisms were prepared for each type of concrete with size 150 mm x 150 mm x 750 mm. The samples were allowed to set in room temperature for 24 hours before it had been demoulded and cured into water tank for 7, 14, and 28 days curing process.

Table 1. Mix proportion of concrete (in kg/m$^3$).

| Mixes     | Replacement material | Fine Aggregates | Coarse Aggregates | Water |
|-----------|----------------------|-----------------|-------------------|-------|
| NWC       | 432                  | -               | 750               | 410   | 208   |
| SFRC      | 432                  | 25              | 750               | 410   | 208   |
| OPS       | 432                  | -               | 330               | 750   | 80    | 208   |
| SteFib OPS| 432                  | 25              | 330               | 750   | 80    | 208   |

2.3. Testing

2.3.1. Slump test. As normal procedure on concrete material study, the slump test was conducted to test the workability of concrete. Based on BS EN 12390 – 2 [12], only true slump is permissible where the concrete is intact and having a spherical shape with 0.5 water cement ratio.

2.3.2. Compressive cube test. The compressive strength test was conducted to determine the compressive strength of hardened concrete and was set based on BS EN 12390 – 3 [13]. The cubes were removed from curing tank and weighted before placed at compressive test machine. The specimens were then loaded to failure in a compression testing machine. The load was set with constant rate of loading to prevent sudden failure and in order to obtain the maximum concrete compressive load. The maximum load sustained was recorded and compressive strength of the concrete was been determined.

2.3.3. Flexural strength test. Flexural test is also known as tensile strength test which the load was applied as to the concrete beam after 28 days curing. This test was done to test the ability of concrete to withstand failure in bending. According BS EN 12390 – 5 [14], the size of specimen was cast for 150 x 150 x 750mm dimension and was test under two-point loading arrangement as specified. The test machine should be cleaned, and the specimen should be aligned with the machine. The loading and roller support should be in even contact with the specimen. The load was applied continuously at constant rate and without shock then the data was recorded. The flexural strength test was carried out and discussed.

3. Results and discussions

The slump, compression and flexural test results for steel fibre oil palm shell (SteFib OPS) concrete, oil palm shell (OPS) concrete, steel fibre reinforced concrete (SFRC) concrete and normal weight concrete (NWC) were compared and discussed in further section.

3.1. Density

According to BS EN 12390 – 7 [15], the density of concrete can be determined by using the Equation 1.

$$\rho = \frac{m}{V}$$
Where $\rho$ is the mass of a unit volume in $kg/m^3$, $m$ is the mass of specimen in air measured in $kg$ and $V$ is the volume of the specimen in $m^3$. The details of mass and density of concrete are shown in Table 2.

|                | NWC  | SFRC | OPS  | SteFib OPS |
|----------------|------|------|------|------------|
| Mass (kg)      | 8.05 | 8.02 | 6.83 | 6.65       |
| Density (kg/m$^3$) | 2385.8 | 2376.3 | 2022.8 | 1970.4     |

Based on the result, SteFib OPS and OPS concrete have 16% lighter weight than NWC and SFRC. The results also show a reduction in concrete density for a concrete containing OPS as aggregate replacement (OPS and SteFib OPS). Moreover, SteFib OPS and OPS shows 17% and 15% lesser density compared to NWC. Thus it shows that the OPS have potential to reduce the weight of concrete structure by 16% compared to conventional concrete structure. This condition may help to reduce the usage of steel reinforcement in reinforced concrete structure due to lightweight structure was used OPS as coarse aggregate. Based on these results has shown that the OPS concrete can be classified as lightweight concrete which tends to have low weight and density compared to NWC. The combination of OPS and SteFib show a great potential to be used as coarse aggregate replacement and help to reduce the dead load of structure. It may help to reduce the usage of reinforcement in reinforced concrete structure and at the same time may help to reduce the size of foundation.

3.2. Slump test
The slump test was performed to determine the workability of fresh concrete. The aim of this test is to study the effect of OPS and SteFib to workability of concrete. The slump test for SteFib OPS concrete, OPS concrete and SFRC were compared to NWC. The detail results for slump test are shown in Table 3.

|                | NWC | SFRC | OPS | SteFib OPS |
|----------------|-----|------|-----|------------|
| Slump (mm)     | 28.0| 27.0 | 26.0| 24.5       |
| Type of Slump  | TRUE| TRUE | TRUE| TRUE       |
| Workability    | Low | Low  | Low | Low        |

The results had shown that the workability of concretes were increase as the oil palm shell and steel fibres were added into the concrete. The SFRC has 4% lower slump compared to NWC. On the other hand, the present of OPS as aggregate replacement has shown the effect on the water absorption in concrete. The OPS has 7% lower slump value compare to control sample NWC. Whereas, the SteFib OPS concrete has 12.5% higher slump value compare to control sample NWC. From the result, it can be summarized that the workability is adversely affected by the incorporation of oil palm shell and steel fibre in concrete. This condition may cause due to high absorption behavior by OPS compared to natural aggregate. However, the slumps value still fall in the range of the designated slump value.

3.3. Compression test
The compressive strength of concrete cubes was performed to study on the effect of OPS and SteFib on concrete strength. It is to validate whether the OPS lightweight concrete have good bonding reaction with SteFib and concrete. The details results have been illustrated in Figure 1.
The compressive strength test results have shown that the addition of SteFib into OPS concrete does not meet the design strength of the concrete (30 MPa). Incorporation of OPS in concrete does not help to improve the compressive strength of concrete. There are several possible reasons for the unsatisfied results. One of it might be due to the oily surface of OPS particles. The strength of OPS material might be affected due to the pre-treatment process. Previous research done by Waqbitu [11], the OPS did not undergo any pre-treatment process, OPC were only dried under the sun before it been used in concrete. Whereby in this study the OPS were undergoes pre-treatment process, it was soaked and washed with water before dried in the oven for 24 hours. The dried OPS will absorb more moisture than saturated OPS due to mechanical properties of OPS is high in fibre and pores [9].

The reduction of 55% of strength for SteFib OPS compared to control sample NWC might be due to the surface of OPS which is smoother compared to granite coarse aggregate may affect the bonding strength between materials. The crack pattern on OPS concrete was found to be similar to Teo et al. [5], which highlighted that the compressive failure was due to the bonding failure between the cement particle with OPS aggregates.

3.4. Flexural strength test
Concrete in nature is good in compression but weak in tensile strength. The flexural strength test result of SteFib OPS concrete beam, SFRC beam and NWC beam are illustrated in Figure 2.

The flexural strength of SFRC and SteFib OPS shows 3.8 % and 9.6 % higher than control sample NWC. Thus, it shows that SteFib has good bonding with OPS. It is also shows that the combination of
SteFib and OPS has good potential in producing a durable and sustainable materials [7,9]. Besides, on the feasibility of the beam during testing, SteFib OPS were able to sustain the load without broken into two pieces as has been observed on SFRC beam and NWC beam. The characteristic of SteFib with hook at both ends had help to anchor the aggregate and bridging the crack maybe the main reason to make the concrete to sustain longer.

4. Conclusion
Based on the study, it is shows that OPS have high potential to be use as aggregate replacement. The workability of SteFib OPS concrete is consider low compared to normal weight concrete but it still within the theoretical workability. The OPS aggregate is significantly lighter than granite aggregate. Thus, the replacement of coarse aggregate by 80% of OPS has make the reduction of mass and density of concrete for about 15-17% compared to control sample. However, the compressive strength was reduced when the OPS were added into the concrete but was good under flexural strength.

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