Strength properties of green concrete mix with added palm oil fibre and its application as a load-bearing hollow block

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Abstract. As issues on sustainable construction material gains prominence in Malaysia, experimental work to investigate the combination of agricultural and construction waste material into a single concrete mixture was conducted. These waste materials will partially replace cement and aggregate content with added Palm Oil Fibre (POF) involving twenty-four cube specimen and six stretcher units of Green Concrete Hollow (GCH) block samples. The optimum replacement percentage of the green concrete material is 10% Palm Oil Fuel Ash (POFA), 15% Rice Husk Ash (RHA), 20% Recycled Concrete Aggregate (RCA) and 0.25% Palm Oil Fibre (POF) resulting a cube compressive strength of 40.4 MPa at 28 days and an average compressive strength for GCH stretcher block unit at 16.31 MPa. From the results obtained, the innovative green concrete mix with added POF and the GCH stretcher block units show its potential as a building material with the ability to be sustainable, eco-friendly and a possibility to meet the reduction in carbon emissions and low carbon footprints.

1. Introduction

The Malaysian construction industry was urged to change from the traditional construction system to the industrialised building system (IBS) to attain better construction quality and productivity. The usage of IBS has been made compulsory in the construction of public buildings and the government fully supported the adoptions of this alternative construction system through programmes, incentives and encouragement policies stipulated under the IBS Roadmap 2011-2015 [1]. For the past recent years, the Malaysian construction industry has seen the growth of reinforced concrete frame structure and brick masonry as its primary construction system. These conventional construction systems have met with various problems such as its low quality and its dependency on unskilled workers [2-3]. Furthermore, the excessive usage of ordinary Portland cement (OPC) during the construction project has significantly contributed to the expansion of the global warming effect. As been reported by He et al. [4], 5 – 7% of global CO2 emission comes from the cement manufacturing process.

As the issue on sustainable green building material gains prominence in the 11th Malaysia Plan (2016-2020), the Government of Malaysia through the Construction Industry Development Board (CIDB) has been emphasising on an alternative material for a prefabricated system in IBS [5]. As such, this study utilises the agricultural and construction waste towards partially replacing the cement and aggregate content. This new concrete mix design is called green concrete (GC). From here, initial works on substituting green concrete material from normal concrete has been conducted through the design of
a green concrete stretcher hollow block unit (or GCH block). This is to investigate the capability of the prefabricated system as an alternative IBS classification.

2. Literature review

2.1. Green concrete material
As issues on sustainable construction gain more prominence, research on green concrete using agricultural by-products waste such as POFA [6-9] and RHA [10-11] and construction waste (such as recycled concrete) were given serious considerable work by researchers from Malaysia and other parts of the world. The outcome of the research shows that the addition of agricultural waste or construction waste for green concrete shows positive and satisfactory strength when compared to normal concrete. However, researchers observe that the construction industry in Malaysia has yet to accept green concrete with a combination of both POFA and RHA due to lack of investigation and reliable data. Research has also shown that using natural Palm Oil Fibre (PoF) [12-15] by percentage weight of cement increases the strength of concrete by more than 40% from normal concrete. Commonly, a percentage of fibre at 0.1% - 0.25% by weight of cement was used by most research. However, past results have yielded that palm oil fibre tends to create an uneven distribution causing a balling-like effect to occur in the concrete.

Consumption of natural aggregate as a concrete component has raised concerns about the preservation of natural resources. Researchers studied the cause and effect of this issue and recommended ways to balance the shortfall of future natural resources. Recycling the demolished concrete to produce new structural concrete elements was seen as a solution to this problem. Studies have shown that recycled aggregate (RA) was a viable option for construction’s material in term of its mechanical properties and structural behaviour [16-20]. Hence, it is seen that the successful use of agricultural and construction waste contributes to energy saving, conservation of natural resources and reduces construction cost. It also solves the disposal of waste and protects the environment. The consumption of agricultural and construction waste in green concrete reduces the dependency of earth natural resources, will reduce waste, improves the environment and quality of life. However, literature has shown a lack of research evidence on green concrete encompassing the hybrid combination of agricultural and construction waste in green concrete. The researchers are not aware of any further investigation related to this area around the world and thus causing a deficiency in the material and mechanical properties of the proposed green concrete. It is expected that the high composition of agricultural and construction waste in green concrete generates a severe non-homogeneous and anisotropic material. Therefore, an effect on its strength and mechanical properties of the green concrete is to be expected. Therefore, Tambichik et al. [21] has conducted an experimental investigation on combining the agricultural and construction waste into a single concrete mix. The study concluded that the optimum cement replacement in a green concrete mix was 10% POFA, 15% RHA and 20% RA.

2.2. Green concrete hollow block (GCH block) system
The increasing energy consumptions and carbon emissions have seriously enhanced the greenhouse effects. As been reported by Ding et al. [22], global climate change is a result of human activities, and 40% of the energy used was contributed from the global construction industry. Thus, causes the government together with Construction Industry Development Board (CIDB) on emphasising a construction system which is environmentally sustainable, in-line with the requirements of green construction and the reduction of carbon dioxide gas emission [5]. Previous research on the development of mortarless masonry hollow block system uses concrete as the main material of their production [23-25]. As such, a study conducted by [26] has proposed the initial work to develop an innovative green concrete hollow block (GCH block) system to be a part of the IBS classification system in Malaysia. The stretcher block unit was cast using green concrete material, and an axial compression load was applied to determine the compressive strength value.
3. Methodology

3.1. Green concrete mixture proportion
The green concrete mix proportion used for this study is obtained from experimental work conducted by Tambichik et al. [21] and tabulated as in table 1. A targeted compressive strength of 30 MPa for the green concrete mix was designed at 28 days with a fixed water-cement ratio of 0.57 and slump value between 50 – 100 mm. The optimum replacement of agricultural and construction waste has also been concluded by Tambichik et al. [21] with POFA and RHA as cement replacement content by 10% and 15% respectively, while 20% of RA replaces the coarse aggregate content. However, literature has shown that having additional palm oil fibre (POF) as binders with the green concrete mix was never conducted before. As such, this study will incorporate in the green concrete mix, an additional percentage of POF (by weight of cement) at 0.25%, 0.50% and 0.75% for GC 1, GC 2 and GC 3 respectively, as shown in table 2 below.

| Ordinary Portland cement (kg/m³) | Coarse aggregate (kg/m³) | Fine aggregate (kg/m³) | Water (kg/m³) |
|----------------------------------|--------------------------|------------------------|---------------|
| 400                              | 756                      | 931                    | 228           |

3.2. Compressive strength test of green concrete
The compressive strength of the green concrete mix with different percentage of Palm Oil Fibre (POF), was investigated on 7 and 28 days of curing through 24 cube samples see figure 1. The compressive strength test was conducted according to BS EN 12390-3:2019, and the total number of samples according to their specified concrete mixture is shown as in table 2 below. The results obtained will finalise the optimum green concrete mix with added percentage of POF.

| Curing age (days) | POF (%) | Total samples |
|-------------------|---------|---------------|
| Control – 0%      | GC 1 – 0.25% | 3            |
| 7                 | GC 2 – 0.50% | 3            |
| 28                | GC 3 – 0.75% | 3            |

Note: GC – Green Concrete

Figure 1. Cube compressive strength test.
3.3. Compressive strength test of green concrete hollow stretcher block unit

Upon obtaining the optimum percentage of green concrete mix with added POF was cast in a custom-designed wood mould to form the interlocking load bearing hollow block or GCH stretcher block units. A total number of six GCH stretcher block units were cast including three units using normal concrete (control specimen) and another three units using green concrete mix with added POF. The blocks were tested after 28 days of curing. Before testing under compressive load, the top surface of the GCH stretcher block units was levelled to ensure even distribution of the load to the specimen. The custom-designed wood mould and compressive strength test of the GCH stretcher block units are shown in figure 2(a) and 2(b) below.

![Wood mould sample](image1)

(a) Wood mould sample

![Compressive strength test](image2)

(b) Compressive strength test

**Figure 2.** GCH stretcher block unit compressive strength test.

4. Result and discussion

4.1. Slump test of green concrete mix

Slump test was conducted to determine the workability of the green concrete mixture. Figure 3 shows the slump value measured for each type of sample according to the different percentage of palm oil fibre (POF). It can be observed that the workability of the GC mixes decreases with an increasing percentage of POF. All the green concrete mix (GC 1, GC 2 and GC 3) was in a workable state as the degree of workability was measured between 50-100 mm slump values as specified by ASTM International [27]. The lowest slump value of 50 mm was recorded by GC 3, with added 0.75% POF followed by GC 2 at 58 mm with 0.5% of POF. Meanwhile, for mix GC 1, the highest workability was measured at 65 mm compared to other GC mixes due to a lower percentage of added POF at 0.25%. Hence, reducing the stiffness of the green concrete mix. By having a higher content of POF in concrete together with POFA and RHA as cement and aggregate replacement, this causes a reduction in the workability of the green concrete. This phenomenon arises from the incremental porosity of the cross-sectional structure of POF, which eventually contributes to the reduction in its workability as the moisture content of the mixture decrease.
4.2. Cube compressive strength

Cube compressive strength test is important to determine the strength of a material to resist compressive stress. The result of cube compressive strength test is illustrated as in figure 4.

In general, the result shows increasing value when the curing days increases. The increasing strength of the mixture is due to the pozzolanic reaction of palm oil fuel ash (POFA) and rice husk ash (RHA) in the green concrete mixture that contributes actively to the concrete after the hydration process. However, the value in compressive strength decreases when palm oil fibre (POF) increases. Based on figure 4 above, the highest compressive strength value was recorded by GC 1 with compressive strength of 40.4 MPa. The compressive strength was 19.5% higher than the control specimen. All the GC mixture achieved its targeted strength of 30 MPa at 28 days.
4.3. Influence of POF and variation in strength of green concrete mix

Increasing of POF in mix GC 2 and GC 3 led to the reduction of compressive strength from 8.6% up to 25% compared to mix GC 1 at 28 days. Due to the excessive percentage of POF in the concrete has created voids and causes retardation to the hydration process. Also, with the addition of Palm Oil Fibre (POF) reduces the ability of POFA and RHA as filler to the concrete. This statement is in line with the result from the study of Raut and Gomez [28] where they observed that the loss of strength in fibre reinforced concrete could be due to the incorporation of higher porous fibre in the cement matrix. In conclusion, mix GC 1 with 0.25% of POF was ideally selected to achieve the optimum requirement of the green concrete mix.

![Figure 5. Variation in strength development](image)

Based on the variation in strength development between 7 days to 180 days, figure 5 shows the trend for the green concrete mix with added POF shows stable incremental behaviour. Although GC 3 was initially below the control result at 7 days, the increase in strength for the GC 3 was moving towards a positive variation at a later stage of its strength. By 180 days, the variation on strength between GC 3 with control was approximately 5.4% comparing to an early age of about -17.3%. Meanwhile, for GC 1 and GC 2, both mixes have good incremental strength behaviour starting from 28 days until 180 days.

4.4. Green concrete hollow stretcher block unit compressive strength

After the optimum green concrete mix with added percentage of POF (at 0.25%) was finalised, three GCH stretcher block units were cast and tested for its compressive strength. Another three similar GCH stretcher block units using normal concrete, as control specimens, were also cast. The result of the compressive strength test was tabulated and illustrated in table 3 below.

| Material                        | Sample number | Compressive strength (MPa) | Average compressive strength (MPa) |
|---------------------------------|---------------|----------------------------|-----------------------------------|
| Control (Normal Concrete)       | 1             | 18.02                      |                                   |
|                                 | 2             | 18.10                      | 18.0                              |
|                                 | 3             | 17.88                      |                                   |
| Green concrete mix with 0.25% POF | 4             | 16.12                      |                                   |
|                                 | 5             | 16.70                      | 16.31                             |
|                                 | 6             | 16.10                      |                                   |

From table 3 above, it is evident that the control specimen, which has no replacement or addition of waste material has resulted in higher compressive strength value than the green concrete mix. The calculation of the compressive strength is based on the net area of the GCH stretcher block unit cross-section. The average compressive strength for the GCH stretcher block unit is 9% lower than the control.
sample. However, according to ASTM C90, the minimum requirement for net area compressive strength is 13.8 MPa which is far below than the average result for both concrete samples. During the testing process, the GCH stretcher block unit started to crack in between the connection of the shell and web. As specified by Jaafar et al. [29], masonry individual block unit tend to fail either by crushing of a part of the block and/or the splitting between the web and shells of the block.

5. Conclusions

An earlier study conducted by the authors have identified the optimum green concrete mix incorporating 10% Palm Oil Fuel Ash and 15% Rice Husk Ash as a cement replacement, and 20% recycled concrete aggregate as aggregate replacement. With the same optimum green concrete mix, an attempt to obtain the highest percentage of palm oil fibre (from 0.25%, 0.5 % and 0.75% of POF by weight of cement) was added to the mix without compromising its strength was conducted. Compressive strength test results from twenty-four cube samples revealed that by using the optimum green concrete mix with 0.25% of POF recorded an improve strength of 40.4 MPa or 19.5% increment from the control specimen. Upon finalising the green concrete mix with added POF, the proposed GCH stretcher block design was cast and tested for its compressive strength. Results obtained shows an impressive compressive strength of 16.31 MPa was achieved with a slight reduction of 9% from the control specimen.

6. References

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