Utilization of construction and agricultural waste in Malaysia for development of Green Concrete: A Review

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Abstract: Green Concrete (GC) is defined as a concrete that utilize a waste material for at least one of its component. The production of GC has been increasing due to the drawback of conventional concrete that create many environmental problems. In Malaysia, the amount of waste generates from agricultural and construction industries were increasing every year. Hence, one of the solutions to reduce the impact of conventional concrete and limited landfill spaces due to excessive waste is by utilizing it in concrete. This paper reviews the possible use of construction waste (Recycle Concrete Aggregate) and agricultural waste (Palm Oil Fuel Ash, Rice Husk Ash and Palm Oil Fibre) as partial replacement for the basic material in a concrete to produce an innovative Green Concrete. The optimum replacement level for each type of waste was also been review. Green Concrete also has the potential to reduce environmental pollution and solve the depletion of natural sources. The result from this review shows that the addition of agricultural waste or construction waste in concrete indicate positive and satisfactory strength when compared to normal concrete. Finally, a mass production of Green Concrete can fulfil the Construction Industry Transformation Plan (CITP) 2016-2020 made by CIDB that emphasizes on a construction system which is environmentally sustainable.

1. Introduction

Recently, the government together with the Construction Industry Development Board (CIDB) has launched a Construction Industry Transformation Plan (CITP) 2016-2020 which emphasizing an environmental sustainability as it four major strategic thrust. The sub element highlighted in environmental sustainability is to reduce the carbon emission and the waste dumping generated from construction and agricultural sectors. The waste continuously increasing for each year due to the rapid development happens in Malaysia. As Malaysia is one of the largest producers of Palm Oil Fuel Ash (POFA) in the world. This is apparent when one thousand tons of POFA were produce annually by 200 numbers of palm oil mills in operation. These POFA if not utilised will be dumped into ponds as agricultural waste products [1]. It has also been documented that approximately 110 million tons of rice husk and 16-22 million tons of rice husk ash (RHA) are generated world wide [2]. Consequently, as issues on sustainable construction gains more prominence, research on utilization of using agricultural by products waste such as POFA [3]-[6] and RHA [7][8] in concrete was actively and construction demolition waste such as recyle concrete aggregate (RCA) were given serious considerable work by researchers from Malaysia and other parts of the world. Utilization of these wastes in concrete can contribute to reduction of environmental problem as the production of original material in concrete could be reduced. Hence, the objective of this paper is to review previous research regarding to utilization of
construction and agricultural waste as supplementary cementitious material, natural aggregate replacement, and addition material in concrete.

2. Waste as supplementary cementitious material (SCM)

2.1 Palm Oil Fuel Ash (POFA)

Palm oil industry is one of the major agro-industries in counties like Malaysia and Thailand, and this industry produces a large amount of waste in the forms of empty fruit branches, fibers, and kennel. [9][10]. As huge number of waste produce from this industry, the by-products then have been used as fuel to heat up boiler to generate electricity at temperature of about 800-1000°C. The ash produced from the process has been known as palm oil fuel ash (POFA). Figure 1(a) show a palm oil residue before it was burned and become palm oil fuel ash as shown in figure.1(b).

![Figure 1. Palm Oil Residue and Palm Oil Fuel Ash (POFA)](image)

Utilizing POFA in concrete has a lot of benefit in terms of concrete strength. Muthusamy [12] study on the replacement of POFA in concrete from 10% to 30% resulted in strength higher than control. However, it reaches the maximum compressive strength at the replacement of 20%. The improvement in modulus of elasticity also been observed at 20% replacement of POFA in concrete. The densification of the internal structure of concrete has improving the concrete performance. Equation below shows the pozzolanic chemical reaction of silica in pozzolan with the calcium hydroxide generates by cement hydration. The increasing in strength of concrete with POFA could be attributed by the filling effect of the fine ash and the pozzolanic reaction that improved the bond between hydrated cement matrix and aggregate [12]. Although POFA has been observed to have a slower pozzolanic reactivity as it produces a low compressive strength at 1, 3, and 7 days of curing time due to the lack of calcium silicate hydrate. But, the concrete mix with POFA will have similar or higher strength than normal concrete as the curing period started to increase from 28 days [13]. During the pozzolanic reaction as shown in equation 1, 2, and 3, calcium hydroxide (Ca(OH2)) generated from the hydration process will react with silica in POFA then produce a secondary calcium silicate hydrate gel (C-S-H) that improve the concrete strength. The secondary C-S-H gel fills up the void between cement and aggregate generated a stronger bond between the paste and aggregate.

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\text{Cement + Water} \rightarrow \text{Calcium Silicate Hydrate (C-S-H) + Calcium Hydroxide (Ca(OH2))} \quad (1)
\]

\[
\text{Silicon + Oxygen} \rightarrow \text{Silica Oxide (Si(OH))} \quad (2)
\]

\[
\text{Silica Oxide (Si(OH)) + Calcium Hydroxide(Ca(OH2))} \rightarrow \text{Secondary Calcium Silicate Hydrate} \quad (3)
\]
Meanwhile, it has been documented that Nano POFA particle triggered the hydration of cement and acted as fillers to refine the microstructure of pastes compared to micro POFA particle [14]. The size of POFA mixes influences the concrete performance as it contributes to the filling ability and increasing in pozzolanic reaction [15]. Replacement of cement with grounded POFA up to 20% in concrete will give a better strength performance than a concrete without grounded POFA. The compressive, splitting tensile and flexural strength show better results with replacement of POFA. However, the excessive volume of POFA in concrete will produce concrete with lower workability. The decreasing in workability for the concrete was recorded because POFA has a porous area resulting an increase in water demand. Hence, the amount of POFA added in the concrete influences the workability as the suitable slump was recorded until 30% of replacement. Higher than 30% replacement will make the concrete become dry and porous [12]. Another advantage of utilizing POFA in concrete was reduction toward releasing energy in the form of heat. Excessive heat causes crack and shrinkage in the concrete [1]. Hydration of cement compound was an exothermic process where it generates heat due to the presence of calcium in OPC. By replacing partial of OPC with POFA, the amount of calcium in concrete will then reduce the production of heat.

2.1.1 Chemical composition of POFA. POFA containing high percentage of Silica that is from 47% to nearly 65%. It can be used as cement replacement as it has cementitious element that can react with the calcium hydroxide to produce a secondary C-S-H gel. However, it can be seen at Table 1 that a difference plantation will produce a difference POFA chemical composition due to the difference burning temperature of the material. A lower percentage of calcium in POFA compare to cement will prevent thermal cracking. The sum of silica, alumina and iron oxide for POFA based on previous research is from 52% up to 75%. Hence, according to ASTM C618 [16], this ash can is classified between classes C to F pozzolan. Table 1 shows the chemical composition of POFA from different researchers.

### Table 1. Chemical composition of Palm Oil Fuel Ash

| Chemical Composition (%) | OPC [13] | OPC [14] | OPC [1] | OPC [18] |
|-------------------------|---------|---------|---------|---------|
| SiO₂                   | 20.40   | 62.60   | 54.80   | 59.62   | 47.22   |
| Al₂O₃                  | 5.20    | 4.65    | 7.40    | 2.54    | 2.24    |
| Fe₂O₃                  | 4.19    | 8.12    | 4.47    | 5.02    | 2.56    |
| CaO                    | 62.39   | 5.70    | 14.00   | 4.92    | 6.48    |
| K₂O                    | 0.05    | 9.05    | -       | 7.52    | 11.86   |
| MgO                    | 1.55    | 3.52    | 4.14    | 4.52    | 5.86    |
| P₂O₅                   | 0.28    | -       | -       | 3.58    | 5.37    |
| Na₂O                   | 0.75    | -       | -       | 0.76    | 1.22    |
| SO₃                    | 2.11    | 1.16    | -       | 1.28    | 1.32    |
| SiO₂+Al₂O₃+Fe₂O₃       | -       | 75.37   | 66.67   | 67.18   | 52.02   |

#### 2.2 Rice Husk Ash (RHA)

Rusk Husk Ash (RHA) is a by-product that gains by incinerating the husks of rice paddy. During the milling of paddy, about 78% of weight is received as rice, broken rice and bran (see figure 3). The rest of 22% of the weight of paddy is received as husk. The husk contains about 75% of volatile and another 25% was converted into RHA due to the firing process. Due to the excessive amount of waste generate from the mill processing has make RHA as an environmental hazard [17]. RHA contain high amount of non-crystalline silica that can be used to partially replaced cement in concrete. The high specific surface area of RHA is accountable to its high pozzolanic activities.
The high reactivity silica content depends on the burning temperature, it is reported that 95% of silica could be produce after heating at 700 °C for 6 hours. This high content of active silica will contribute to the strength of concrete due to the production of additional C-S-H gel that makes the concrete microstructure became denser [18]. Many researchers believe that the burning temperature influences the production of amorphous reactive ash. RHA with its cellular microstructure and highly pozzolanic activity is formed by burning rice husk at temperature lower than 700 °C.

![Image](a) and (b) Rice husk ash (a) and rice husk (b)

The addition of RHA in cement increase its normal consistency and setting time. Furthermore, the incorporation of RHA in concrete results in improvement of compressive strength and flexural strength [19]. RHA also reduce density of concrete compared with conventional concrete. A research conducted by Ephraim et al [20] on the compressive strength of concrete with RHA as partial replacement of OPC resulted an increasing in water demand and also strength. The researcher replaces cement with RHA for 10%, 20% and 25% found that the optimum percentage of replacement was at 10%. The strength at 10% replacement for 28 days was higher than control but for 20% and 25% replacement, the strength shows a slight reduction. Meanwhile, Chao et al. [21] use grounded RHA to replace cement and observed that the optimum percentage of replacement was at 20%. The researcher also observes that compressive strength of concrete with up to 20% ground RHA added attain value equivalent to the control concrete after 28 days. Although ground RHA present high carbon content, its strength has high similarity to the plain concrete. Mohseni et al. [22] observe the similar result with Ephraim et al. [20] where the additions of RHA increases compressive strength of sample up to 1% from the control specimen at 28 days when cement was replaced by 10% RHA. For the replacement of 20% and 30% of cement, it decreases the compressive strength but only after 90 days. This is due to the pozzolanic activity starting to occur at a later age which improved the concrete microstructure. Meanwhile for the flexural strength, the result shows a reduction by up to 2% until 14% from its original level when cement was replaced by 10%, 20%, and 30% RHA. However, the higher strength development was observed at 90 days for all replacement level. The compact microstructure at 90 days was due to the formation of secondary C-S-H gel that delay the failure by cracking. RHA also improve the ability of concrete to resist tensile loading. It has been found that the split tensile strength of concrete mix with 10%, 15%, 20% of RHA at 7, 28, and 56 days was higher than control mix [23]. The highest tensile strength was observed at 15% replacement of RHA. Although that there was a decrease in strength for mix 20% of RHA, but the values is still higher than control mix at all ages. The compact microstructure of concrete with RHA has improved the bonding between cement matrix and improved resistance toward tensile loading.

2.2.1 Chemical composition of RHA. RHA contains very high amount of silica compared to POFA. RHA contains 89.9% to 90.21% of silica respectively. The sum of silica, alumina and iron oxide in RHA is more than 70% and according to the ASTM C618 [15] RHA can be considered as class F pozzolan due to amount of SiO₂, Al₂O₃ and Fe₂O₃ that is more than 70%. This high amount of silica was important towards the dilution process of calcium hydroxide. The pozzolanic reaction of RHA depends on the amount of calcium hydroxide release by the hydration of calcium silicate [24]. Calcium hydroxide will
be consumed by the silica to produce calcium-silicate-hydrate gels which then improve the strength of concrete. Table 2 show the chemical composition of RHA.

Table 2. Chemical Composition of Rice Husk Ash

| Chemical Composition (%) | OPC     | RHA     | RHA     | RHA     |
|--------------------------|---------|---------|---------|---------|
|                          | [24]    | [20]    | [19]    | [21]    |
| SiO$_3$                  | 20.40   | 89.91   | 92.40   | 91      |
| Al$_2$O$_3$              | 5.20    | 0.13    | 0.26    | 0.35    |
| Fe$_2$O$_3$              | 4.19    | 0.95    | 0.30    | 0.41    |
| CaO                      | 62.39   | 0.76    | 1.63    | -       |
| K$_2$O                   | 0.005   | 2.75    | -       | 3.21    |
| MgO                      | 1.55    | 0.30    | 0.38    | 0.81    |
| P$_2$O$_5$               | 0.28    | -       | -       | 0.98    |
| Na$_2$O                  | 0.75    | 0.01    | 1.24    | 0.08    |
| SO$_3$                   | 2.11    | 0.83    | -       | 1.21    |
| SiO$_3$ + Al$_2$O$_3$ +  | 82.99   | 92.96   | 91.76   | 91.76   |
| Fe$_2$O$_3$              | -       | -       | -       | -       |

3. Waste as natural aggregate replacement in concrete

3.1 Recycle Concrete Aggregate (RCA)

Recycle concrete aggregate (RCA) is a new approached in reducing the number of waste generate from the demolition of old building. The increasing of construction and demolition waste (CDW) has led governments to find an alternative means to utilizing back the waste. RCA is inhomogeneous with respect to its dynamic properties unlike properties of natural coarse aggregate [25]. Natural coarse aggregate is derived from a rock meanwhile RCA is from the CDW which makes it contain a deleterious material. The fresh and hardened properties of concrete made with RCA depends upon the amount of mortar content at the aggregate. The size of recycle aggregate influence the amount of mortar attached as the finer the aggregate, more mortar will attached to it. On the other hand, the quality of concrete made with recycle aggregate also depends entirely on the quality of the recycle aggregates and its percentage of replacement in concrete.

Figure 3. Recycle Concrete Aggregate (a) and Natural Coarse Aggregate (b)
The properties of concrete with natural aggregate improved by recycle aggregate addition [26]. It has been found that the compressive strength increases with an effective water cement ratio used for the mix. The compressive strength of concrete containing 100% of RCA was observed to be higher than the reference concrete (with 100% of NA). The result was difference with a study conducted by Exeberria et al. [27] where replacement of NA with 25%, 50% and 100% of RCA and found that optimum replacement level was at 25%. The strength for 25% replacement was similar with the control specimen. The strength was increase because of the rough texture and absorption capacity of the adhered mortar in RCA then providing a better bonding between cement pastes and recycle aggregate. This means that condition of RCA also affects the performance of concrete. A research on the rheological and mechanical behaviour of concrete made with saturated and dried RCA found that concrete that mix with a dried RCA will produce a higher compressive strength than concrete with saturated RCA [28]. It also tends to reduce the flexural strength of a concrete due to present of excessive water content. The best way to maintaining the strength of concrete and reduce the water absorption by RCA is by wetted the RCA by using sprinkler system the day before they were used and maintain their high humidity by covered it with plastic sheet [28].

Soares et al. [29] study on the replacement level of RCA from precast concrete reject at 10%, 20%, 30%, 40%, 50% and 100% found that at 28days, the highest compressive strength was recorded at 30% of replacement. For 10% and 20% replacement, the strength was slightly below reference concrete. The researcher also tries to mixes 25% of RCA with addition of 1% superplasticizer and the result was higher than 30% of replacement RCA without SP. Meanwhile, according to Zhang & Zhao [30] only one type of Interfacial Transition Zone (ITZ) exists in natural concrete (NC) that is lying between the Natural Aggregate (NA) and the new cement mortar. By replacing the NA with several percentage of RCA, there will be three types of ITZ as follow: the ITZ between the NA and the new mortar, the ITZ inside the RCA between the old virgin aggregate and the surrounding old mortar, and the ITZ between the old mortar and the new mortar. RCA was usually obtained by crushing and grinding through which the old cement mortar may be partially or completely removed from the RCA particle and some old ITZ that attached to the RCA have also been damage. Therefore, when this RCA embedded with the NA in the new concrete mix, a new ITZ will be formed between the exposed ITZ of RA and the new cement mortar. The diverse types of ITZ in RCA and the porous old mortar adhering to RA are potential weak point in RCA. This will result in reduction of strength for the new concrete.

4. Waste as additive material for strengthening the concrete

4.1 Palm Oil Fiber (POF)

Palm Oil Fiber (POF) is a natural fiber that comes from the palm oil industry. It is most grown in South-east Asia countries such as Malaysia and Indonesia. The fiber was produce from the crushed palm oil husks and fruits after the oil extraction has completed. After the oil extraction has been done, normally the palm oil fiber will be used for fuel combustion for generation of steam boiler for oil production process. Many research on utilizing palm oil fibre for strengthening the concrete has been study for over the past year as to reduce the amount of waste in landfill due to the excessive volume of POF. It has been indicated as a porous cellular cross-sectional structure. The characteristics of POF waste have 20 - 100 mm in length, 0.2 – 0.8 mm in diameter and 1450 kg/m³ in density [31]. It has similar mechanical properties to coconut coir fiber because of the cell wall fiber is thick and this make it less susceptible to chemical reaction.
By using POF as an additive material in concrete, it can improve concrete cracking resistance. A high tensile strength and high content of lignin make POF is suitable as reinforcement in concrete. It enhances the mechanical properties such as fatigue and tensile stress as well as cracking also. The mechanism involved is by transferring stress from matrix to the fiber through interfacial shear. The percentage of POF that suitable to be used in concrete is from 0.2% until 0.6%, beyond this fraction will reduce the compressive and flexural strength. This is because of excessive amount of POF in concrete will attribute to the air void and disintegration [32]. Raut & Gomez [33] study on incorporating 0.5%, 1% and 1.5% of POF in concrete containing POFA and found that there is loss in compressive strength compare to reference concrete. However, better result was recorded after 90days curing period where the compressive strength starts to increase due to pozzolanic reaction of POFA. Meanwhile, improvement in flexural strength was observed as the fiber proportion increased. The addition of fiber from 0.5% until 1.5% showed an increasing in flexural strength due to the absorbing mechanism that delays micro crack formation. Besides that, the workability of concrete containing POF will be decrease as the percentage of POF added increase due to the increase of surface area [34]. The porous cross-sectional structure of POF also contribute to the reduction in workability as moisture content of the mixture was decrease. Addition of POF in concrete also tends to reduce the thermal conductivity of specimen. The reduction in heat transfer is due to the formation of air voids through porous fibre body that possesses heat transfer which resulting a lowered thermal conductivity [33]. A lower thermal conductivity of concrete will cause a higher pore occurs and this will reduce the mechanical strength of the concrete. Previous studies found that the compressive strength and thermal conductivity are directly proportional to each other. Hence, an optimum percentage of POF must be added to the concrete mix without sacrifice both of the mechanical and thermal properties of concrete.

5. Conclusion
The contribution of waste from agricultural and construction to improved concrete performance has been review in this paper. The waste can be used as a supplementary cemenitious material (SCM), a replacement for natural aggregate, and also as an addition in concrete to improve crack resistance. Improvement in mechanical properties of a concrete can be observed until it reached the optimum percentage. Based on the previous research conducted toward POFA, RHA, RCA and POF, the waste can be used as a partial replacement for cement and natural aggregate in concrete. Previous researcher focusing on utilizing of waste from single sources only. The main idea is to producing a GC that eco-friendly and harmless to the environment can be accomplished by combining all the waste in a concrete. By combining difference type of waste, it can maximize the utilization of waste from difference sources. Hence, an extensive research need to be done to determine the optimum mix design in comprise with all waste in a concrete. Problem related to environment such as carbon dioxide emission and natural aggregate degradation can be reduced with production of GC in line with CITP 2016-2020 objectives that is to reduce waste and carbon dioxide emission also can be achieved.
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