Using Palm Oil By-Products to Reduce Environmental Impacts From Concrete: A Case Study

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Abstract. The increasing need for sustainable development especially in the construction industry has led to utilization of palm oil by-products (POBPs) in concrete. Many studies on the structural properties of POBP concrete can be found in the literature. However, there are not many studies on their environmental impact. This paper aims to systematically determine the environmental impact of concrete made using POBPs using a public school building was as a case study. Two mixes were studied: (1) a conventional concrete mix with 420 kg/m³ of cement and compressive strength of 47.4 MPa; and (2) a concrete mix incorporating OPBC as a replacement for coarse natural aggregate with the similar cement content and compressive strength. Life cycle assessment (LCA) was used to calculate the environmental impacts. Results show that replacement of natural aggregates with OPBC would reduce damage to resources by 11.5%, ecosystem quality by 8% and human health by 2.3% and financial cost by 22.7%. Feasibility analysis showed that POBPs can potentially replace approximately 12.7% of natural aggregate consumed by the Malaysian construction industry.

1. Introduction
Malaysia is a global leader in palm oil production and the leading contributor for technical palm oil studies [1-2]. The production of palm oil of this magnitude creates a proportionally large quantity of palm oil by-products (POBPs). This creates an opportunity for Malaysia to be a leader in the use of POBPs in the construction industry. Academic and industry professionals are turning towards agricultural waste such as POBPs to improve the sustainability of concrete. The manufacture of concrete produces approximately 6% of all man-made carbon dioxide [3]. Therefore, any efforts to reduce concrete’s environmental impact will help drive the construction industry towards sustainability.

In the past 25 years, palm oil has been reported in the literature not only as an agricultural product, but also as a construction material. Hansen et al. [1] found that published research related to palm oil increased from 355 to 1796 between 2004 and 2013. They found that most of these papers studied the technical aspects of palm oil and its by-products, but few address sustainability issues. The general consensus is that the use of agricultural by-products in construction is positive and leads to sustainable development [4]. However, a systematic evaluation of these ‘green’ materials and their environmental impact can provide a basis for comparison to other construction materials. This can be achieved by using life cycle assessment (LCA) which calculates the total environmental impacts of a material or finished product throughout its life cycle. Various studies in the literature have successfully used LCA to show the environmental benefits of ‘green concrete’ over conventional concrete [5-7]. To our knowledge, we have found no existing environmental impact studies of concrete containing POBPs using the LCA methodology.
2. Literature Review

2.1. Life cycle assessment (LCA)

The manufacture of a product, such as concrete, occurs in several stages. At each stage in the manufacturing chain, different amounts of resources and energy are consumed. In other words, various inputs and outputs are involved in a product’s life cycle. The calculation of these inputs and outputs is a critical part of LCA and represents a systematic method to determine a product’s environmental impacts. The undertaking of an LCA will require two important reference documents. ISO 14040 [8] describes the general framework of an LCA as shown in Figure 1 while ISO 14044 [9] describes its requirements and guidelines. The first stage involved in an LCA is known as goal and scope definition. Here, several initial parameters are defined including the objective of the LCA, its boundaries and functional unit. Next, inventory analysis is the stage where any data that is deemed relevant is identified and quantified. Impact assessment is the third stage of an LCA and is where the inventory is converted into environmental impact values. The final stage of the LCA is the interpretation phase and is where all information gathered from previous stages are analysed and interpreted.

The literature relating to LCA in the construction industry is generally fragmented due to the variety of case studies, functional units, system boundaries, materials and geographic locations [10]. However, LCA studies in construction can generally be divided into two categories: (1) A comprehensive building LCA (also known as whole building LCA) which evaluates the environmental impact of a building over its life span; and (2) A comparative LCA which compares the embodied environmental impacts between different construction materials [11].

![Figure 1. Framework of a life cycle assessment [8]](image)

2.2. Palm oil by-products in concrete

The by-products of palm oil are detailed in Figure 2. Few of these by-products are discarded and most are re-used by the palm oil plantations such as oil palm boiler clinker (OPBC) for filling road potholes, empty fruit bunches (EFB) for mulching, and excess oil palm mesocarp fibre (OPMF), oil palm shell (OPS) and oil palm kernel (OPK) is sold as biomass fuel [12]. OPS and OPMF are typically used as boiler fuel at the palm oil mill itself and the remains of this combustion process are called boiler ash or OPBC. The use of POBPs as a construction material has been studied extensively in the literature. Research into the use of POBPs in concrete started as early as the late 2000s [13]. Beginning in the 2010s, research in this field diversified with the investigation of using OPS in concrete mixes particularly in lightweight concrete [14-17] and the use of OPBC and OPS in concrete beams [18-21].
3. Methodology

3.1 Mix Design
The LCA in this study was carried out according to ISO 14040 [8] and ISO 14044 [9]. The LCA compared the environmental impacts of two different concrete mixes. After an extensive literature review, these mixes were selected based on similar binder content and compressive strength. Table 1 shows the details of the mixes studied. N-420 indicates a conventional concrete mix with 420 kg/m$^3$ of cement while C-420 indicates a concrete mix incorporating OPBC as a replacement for coarse natural aggregate.
Table 1. Mix design

| Mix  | Cement | Water | w/c | Sand | Gravel | OPBC | Compressive strength (MPa)\(^a\) | Slump (mm) | Reference |
|------|--------|-------|-----|------|--------|------|-------------------------------|-----------|-----------|
| N-420| 420    | 223   | 0.53| 760  | 1007   | -    | 47.4                         | 90        | [21]      |
| C-420| 420    | 231   | 0.55| 621  | -      | 729  | 41.6                         | 105       | [12]      |

Units in kg/m\(^3\) unless otherwise stated
\(^a\)28-day cube

3.2 System Boundary
The LCA boundary begins from the production of concrete’s constituent materials, in this case (1) mining and processing of sand and gravel from quarries; (2) production of cement; and (3) production of OPBC at palm oil mills. These constituent materials of concrete were transported to a concrete mixing plant and combined to produce the desired mix design. The mixing process of concrete was not included since the emissions from this phase were assumed to be constant regardless of mix design. Also, the construction, use and end-of-life phases of the building were excluded from the LCA under the same assumptions. Therefore, the system boundary represented a cradle-to-gate study. This theoretical system boundary is reflected in the process diagram shown in Figure 3.

![Figure 3. Boundary definition for the LCA](image)

3.3 Software and Database
To accurately estimate a product’s environmental impact, a life cycle inventory (LCI) must be created. The LCI is a record of all resources going in and emissions going out of a product life cycle. LCI data for cement, admixtures, gravel, sand and water were obtained from a combination of Ecoinvent database [24], public databases and the literature. For the POBPs, information from several references on LCA of palm oil in Malaysia was used to construct the LCI for this study [12].

The production process of concrete involves a transport stage of constituent materials from place of origin to a concrete mixing plant. Using geographic information system (GIS) mapping software, real-world approximations of these transport distances were estimated and shown in Table 2.

Table 2. Approximated transport distances

| Material         | Distance (km) |
|------------------|---------------|
| Cement           | 35            |
| Sand and Gravel  | 25            |
| OPS and OPBC     | 55            |
3.4 Impact Assessment
Impact assessment can be accomplished using two methods. First is the problem-oriented approach or midpoint approach which are considered to have more certainty, but less relevance for decision support. They are useful to identify emission targets and areas of specific environmental concern. The other approach is known as the damage-oriented approach or endpoints approach. Endpoints are considered to have less certainly, but they are more relevant to decision support. They are easier for a non-technical audience to understand. This study uses the endpoints approach and impact categories were calculated using the Eco-Indicator 99 method [25].

3.5 Building Information Modelling
A digital model of a school building in Malaysia was constructed in Autodesk® Revit® building information modelling (BIM) software. The digital model of the school, seen in Figure 4, only comprises structural elements (columns, beams, slabs, shear walls and stairs) and does not include architectural, mechanical or electrical elements. The BIM software revealed the total volume of concrete as 2558 m$^3$.

Figure 4. Digital BIM model of a 3-storey school block

4. Results and Discussions
4.1. Environmental savings
A comparative LCA on the concrete of the school building was conducted using two different types of concrete: N-420 and C-420. Results in Figure 5 show that if the school was built using C-420 concrete instead of N-420, it would reduce damage to resources by 11.5%, ecosystem quality by 8% and human health by 2.3%. Since the binder content of both mixes are the same, it is inferred that substituting natural aggregate with OPBC had reduced the environmental impact. Other studies on replacement of coarse natural aggregate in concrete were found to reduce the environmental impact. Marinkovic, Radonjanin, Malesev and Ignjatovic [26] and Kurda, Silvestre and de Brito [6] found that use of recycled aggregates over natural aggregates had decreased the environmental impacts of the resulting concrete. The highest reduction in environmental impacts is for damage to resources. This is due to reduced extraction of natural aggregates from the natural system (i.e. Earth). On the other hand, reduction in damage to human health was the smallest due to the similar cement content of both mixes. The
production of cement represents the largest source of carbon dioxide emissions from concrete as opposed to the production of aggregates [26].

Figure 5. LCA results for case study

4.2. Financial savings
It was assumed that the volume required for both concretes were the same and the total volume of concrete for the school was 2558 m$^3$. Thus, the total cost of concrete for the school building was calculated as shown in Table 3. Since OPBC is a waste product, it can be considered to have no monetary value. However, for comparison to natural aggregate, a monetary value must be assigned to OPBC. Thus, the price for OPBC was allocated in proportion to mass based on CPO. In other words, Subramaniam, Ma, Choo and Nik Meriam [12] estimated that the production of 1 metric ton of CPO produces 0.02 metric tons of OPBC (i.e. 2%). Therefore, the price of OPBC was assumed to be 2% of the price of CPO. The use of C-420 compared to N-420 resulted in approximately 23% savings in material cost. The financial analysis shows that using C-380 is economically advantageous to using N-380.

Table 3. Cost of concrete for construction of a school building

| Mix   | Cement | Natural Aggregate | OPBC | Total Cost per m$^3$ | Total cost (RM) |
|-------|--------|-------------------|------|---------------------|-----------------|
|       |        | Fine   | Coarse | Coarse     |                 |                 |
| N-420 | 147.00 | 34.20  | 45.32  | -          | 226.52          | 579,438.16      |
| C-420 | 147.00 | 27.95  | -      | 0.66       | 175.61          | 449,210.38      |

All prices are in RM per m$^3$

4.3. Feasibility of using POBP as aggregate in construction
The total production of CPO in 2018 was approximately 19 million metric tons. Subramaniam, Ma, Choo and Nik Meriam [12] estimated that 0.2 metric tons of OPS and 0.02 metric tons of OPBC are produced for every 1 metric ton of CPO. Therefore, the total production of OPBC and OPS in Malaysia was estimated as approximately 3.9 million metric tons of OPS and 390,000 metric tons of OPBC as shown in Table 4. The average consumption of sand and gravel in the Malaysian construction industry was approximately 34 million metric tons per year [27]. Assuming all excess OPS and OPBC is channelled into the construction industry, an estimated 12.47% of all sand and gravel can be replaced. However, most OPS is used for the on-site boilers. Thus, when considering only OPBC, a replacement percentage of 1.13% is possible. This means a reduced reliance on natural aggregates and the negative environmental emissions associated with its extraction, processing and transport.

Table 4. Replacement capability of OPBC and OPS for concrete aggregates in Malaysia

| CPO production [2] | Estimated OPS Production [12] | Estimated OPBC Production [12] | Consumption of sand and gravel [27] | Total replacement capability |
|---------------------|--------------------------------|---------------------------------|-------------------------------------|-----------------------------|
| 19,516,141          | 3,903,228                      | 390,323                         | 34,420,000                         | 12.47%                      |

All units in metric tons per year unless otherwise stated
While it may be possible to increase the yield of palm oil, thereby increasing production of OPS and OPBC, the use of added fertilizer to achieve this purpose can possibly increase the negative environmental impact of the green concrete mixes considered in this study. Various sources of literature have found results relating to the significance of fertilizers in affecting environmental impact of palm oil production [28]. In particular, Zulkifli, Halimah, Chan, Choo and Mohd Basri [29] find the use of N-fertilizer highly contributes to climate change, acidification potential, human toxicity and eutrophication in palm oil production. Therefore, due care is required to expand the palm oil industry in a sustainable manner so as not to create a more environmentally inferior alternative to current construction materials.

5. Conclusions
From the results of the LCA and subsequent analyses, several conclusions can be made. Environmental impact and financial cost were reduced when natural aggregate was replaced with OPBC. The results of this study show that it is possible to create an environmentally friendly alternative to conventional concrete with similar mechanical properties using POBPs.

OPS and OPBC have the potential to replace approximately 10% of the total natural aggregate consumption in Malaysia. Increasing use of POBPs in construction would lead to a boost in the local agricultural industry and potentially open a new market for POBPs [30].

A limitation of this study is that it focused on OPBC and did not investigate concrete mixes incorporating OPS. Additionally, the use of OPBC in this study was limited to an aggregate replacement. Replacement of cement could yield greater reductions as compared to replacement of aggregate. This is because cement is the main contributor to the environmental impacts of concrete. Thus, future studies could investigate the environmental impact when OPBC is used as a binder replacement.

6. References

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