A Framework for Green Concrete Noise Barrier Materials using Palm Oil Clinker

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Abstract. Noise pollution from traffic is an increasing environmental problem worldwide. The most popular mitigation measure is the control of path by means of construction of noise barriers. Current concrete barrier incorporated with perforated surface infilled with non-mineral fibre sound absorbing material on the highway side are the commonly found. The disadvantage of this type is it’s easily damaged and the non-mineral fibre is so dreadful to human health. On the other hand, palm oil clinker (POC) is a by-product waste material produced in palm oil mills, are currently dump in open land or landfill sites, which leads to environmental problems. POC is internally porous and if it replaces the aggregate in porous concrete it may absorb sound better than standard porous concrete which is the most important characteristic for noise barrier development. This paper discusses how the palm oil clinker substitution will make concrete noise barrier material to be labelled as green and sustainable. A framework for developing green noise barrier made of palm oil clinker concrete will also be presented and discussed.

1. Introduction
Cities in developing countries faces severe noise pollution problem from traffic. Data collected, by the World Health Organization (WHO) researchers, alongside densely travelled roads were found to have equivalent sound pressure levels for 24 hours of 75–80 dBA [1]. Due to increase in number of vehicles and rapid urbanization of cities, noise level exceeds the permissible value. For many years noise barriers have been erected along major arterials to screen residential areas from high levels of traffic noise. Noise barriers for reduction of noise levels could be warranted for certain portion of road network. Noise barriers can have a substantial effect on the visual environment of a highway and its surrounding environment [2]. They are long continuous structures, and can significantly change the view of the road by blocking view of the roadside and creating a monolithic uniformity of walls instead changing urban scenery. Nonetheless, noise barrier may be highly sought after by neighbourhoods as a means to reduce roads noise level [3].

In Malaysia, the applications of noise barrier become significant after the establishment of its first guideline of Guideline on Noise in 2004 [4]. The most popular mitigation measure in Malaysia is the control of path by means of construction of noise barriers. The requirements for the noise barrier’s design and method for installation on highways are documented in Lembaga Lebuhraya Malaysia (LLM) guideline [5]. An obvious benefit from this LLM guideline is the provision of the comfort for residents lining the highway if the traffic noise exceeds the permissible limit given by the DOE 2004 guidelines. Concrete masonry barrier is the most sought after with requirement for sound absorption as much as 60% is suggested to have good acoustic performance. The ability of such absorption can be
obtained by providing the porous surfaces or perforated surfaces and in filled consisting of fiberglass or rockwool in hollow concrete masonry. For example, the installation of a 4 metre hollow block concrete masonry noise barrier at Bukit Setiawangsa is to protect the residents from the intense traffic noise coming from the Duta Ulu Kelang Expressway (DUKE) highway [5]. The construction of the DUKE highway has raise the noise level to about 15 or 19 dBA during day and night, and 9 dBA and 7 dBA during day and night. The construction of barriers of sufficient height and length, although relatively expensive (RM 800 to 1000 per square meter) however it could give comfort to residents.

On the other hand, porous concrete made of palm oil clinker has been extensively research for building construction [6-7]. It is well known that POC reduces the compressive strength of concrete in comparison with normal porous concrete due to existing of internal pores in POC aggregate that lead to high porosity. Some researchers coat the POC aggregate [8] to maintain the strength comparable with natural aggregate and some research suggested the high strength cement binder for structural usage. The bad pores in POC can be a good sound absorption enhancer in porous concrete. To the authors’ knowledge, none of research so far has focused on POC concrete acoustic performance and its possible application for noise barrier development. Hence, this paper discusses how the palm oil clinker substitution will make concrete noise barrier material to be labelled as green and sustainable. A framework for propose green noise barrier made of palm oil clinker concrete are presented and discussed.

2. Guideline and previous research on the development on noise barrier

Concrete noise barrier can be constructed from concrete panel or masonry block. According to the Malaysian guideline of highway (LLM), basically properties for masonry concrete noise barrier shall be with compressive strength of minimum 7 N/mm², transmission loss of 20 to 25 dB and the absorptive surface with sound absorption coefficient of 0.6 [5]. According to FHWA, concrete noise barrier can be precast concrete in the form of concrete panel, can in place barrier and masonry. Structurally, since mostly it will be built lining the road or free standing noise wall, noise barrier are designed to carry self-weight and wind load.

According to [9], one of the most common materials used for concrete noise barrier applications is a combination of two-layer material components consist of sound proof hard backing and porous medium consist of porous concrete for absorbing sound from the source (Figure 1). [9] reported that the standard concrete for hard backing and porous concrete for noise barrier employed in commercial product in Europe is shown in Table 1. It can be seen that porous concrete is developed by eliminating the sand volume in the matrix and aggregate size greater than 3 mm and less than 9 mm with target porosity of 26%.

![Figure 1. Hard backing and porous concrete materials for noise barrier](image-url)
Table 1. Mixture (wt %) proportion of employed in commercial product noise barrier [10].

|                          | Porous concrete (PC) | Hard backing mixture |
|--------------------------|----------------------|----------------------|
|                          |                      | Standard concrete    |
|                          |                      | (SC)                 |
| PC II (%)                | 20                   | 20                   |
| Coarse aggregate         | 80                   | 30                   |
| Fine aggregate           | –                    | 50                   |
| Particle size (mm)       | $3 < d_p < 9$        | $d_p < 1.25$         |
| Water/solid ratio (wt%)  | 9.0                  | 12.5                 |
| Targeted Open void ratio | 26.0                 | 7.3                  |

Few researches have been conducted to substitute the natural aggregate with the waste material especially for noise barrier. [12] studied aggregate replacement with bottom ash from plant into noise barrier with three layer consist of hard backing and two layer porous media called SOL.BA1 and SOL.BA1. Both consist of hard backing (size of aggregate bottom ash<1.25mm) and two layer of medium porous (size particle between 1.25mm and 5 mm and followed by coarser porous medium (size particle of greater than 5mm). The mix proportion is shown in Table 2. Both have the same thickness but SOL.BA1 has greater thickness of coarser porous medium. In comparison with standard porous concrete, it can be seen that three-layer sound barrier SOL.BA1 can absorb higher sound energy given by noise spectrum below 1500Hz (Figure 2).

Table 2. Mix proportion (% of weight) [12]

| Type of material              | %BA | Cement | Size aggregate (Dp) mm |
|------------------------------|-----|--------|------------------------|
| Bottom ash-coarse (BA-C)     | 80  | 20     | Dp>5                   |
| Bottom ash-medium (BA-M)     | 80  | 20     | 5>Dp>1.25              |
| Bottom ash-fine (BA-FC)      | 80  | 20     | Dp <1.25               |

Figure 2. Noise absorption spectrum of noise barrier [12]
Further, investigation of the ceramic waste for replacement of both hard backing and porous medium [13]. Again, the recycled porous concrete present better acoustic and mechanical properties than the porous concrete traditionally used to manufacture highway noise barriers. According to [14], the porous medium’s compressive strength is acceptable if the minimum compressive strength is 2-3 N/mm² with sound absorption coefficient is 0.6. Good sound absorption is described by sound absorption coefficient and also noise rating criteria (NRC). NRC is determined by calculating the arithmetic mean of the absorption coefficients at 250, 500, 1000 and 2000 Hz, in order to have single numeric data of the sound absorption coefficient to clearly identify the effect of the aggregate size of the waste material and the thickness of the specimens.

One of the key important factors for absorbing sound is the porosity of concrete. According to [15] and [16], the size and percentage of pores are important parameter for sound absorption. Interconnected pores are the characterized of good sound absorbing which are typically indicated by void content/porosity typically in the range of 15 to 35% by volume. Investigated the effect of concrete specimen with single size aggregate of various porosity but with the same pore size of 3mm diameter and 2.7mm length [16] (Figure 3). It can be seen that porosity of 15% specimen reached peak absorption at lower frequency compared with those 35% porosity.

![Figure 3. Relationship between Sound absorption and porosity [16]](image)

Thickness also influences the sound absorbing coefficient. The porous concrete with single aggregate size of with similar porosity of 24% it was found that the specimens with different heights reached peak absorption coefficient at a wider frequency range of 300–1,250 [17]. There was no clear relation of the peak absorption coefficient with specimen height, but the 80-mm high specimens had a maximum absorption coefficient of approximately 0.75 (Figure 4).

![Figure 4. Effect of thickness of sample porous concrete with maximum size of aggregate 9.5mm [17]](image)
3. Potential POC substitution in noise barrier porous medium

3.1 Aggregate replacement

POC is waste derived by combustion of the combustion of palm oil fibre and palm oil shell [18]. Typically, POC is obtained in a large chunk between 20 and 150 mm and it is porous in nature with sharp and rough broken edges, and often flaky with an irregular shape as shown in Figure 5 [19-20]. POC can be grind to required size to serves as possible aggregates in the production of concrete especially for the noise barrier production.

Further, noise barrier material consisting of the entire range of POC particle sizes that offer sound absorptive surface naturally without providing perforated surface infilled with mineral fibres that finally can be utilised in the field of noise barriers. This will overcome the production of standard noise barrier by using ordinary Portland cement, mineral wool and natural aggregate that would emit high CO2 equivalent production. As matter of fact, high amount of natural aggregates, accounting for 70% - 80% of total concrete volume are consumed. Therefore, POC can be used as substitutes to produce an environmentally friendly concrete, thus makes concrete industry to be sustainable, and construction material can be labelled as “green”.

Figure 5. Internal pore in POC aggregate [20]

Noise barrier by using POC will also utilized as an alternative material to the current concrete barrier incorporated with perforated surface infilled with absorbing material such as fiberglass/ rockwool on the highway side are the commonly found in Johor Baharu area. The disadvantages of this type are easily damaged and provide unpleasant view (Figure 6). The usage of the non-mineral fiber as infill for sound absorption enhancer also is so dreadful to human health [21]. Many would not know that the fiberglass can cause lung infection, irritation to skin and eyes and the worst case would be cancer [22].

Figure 6. Concrete currently incorporated with absorptive face with perforated surface and absorbing material are easily damaged
3.2 Mechanical Strength

According to [23], 100% replacement of natural aggregate in porous concrete has the compressive strength of 3.43 MPa and density 1238 kg/m3 with porosity of 35.18% which is within an acceptable range stated in ACI 522 (15–35%). In comparison, normal porous concrete has compressive strength of 9.2 MPa and porosity 23% which POC reduced by compressive strength by 62 %. This reduction was due to increased porosity thus caused gradual loss in compressive strength of the concrete [23]. Fortunately, for the noise barrier, the minimum requirement for the porous medium are 2–3 N/mm2, thus 100% replacement would be possible to be used as porous medium in noise barrier. In addition to that, the porosity was also determined under the range for good sound absorbing material. Vermiculite can also be utilised to increase mechanical properties of porous concrete as previously used by [24] for their work on increasing mechanical strength of porous concrete with bottom ash [10].

4. Framework of propose development of noise barrier material by using POC

Based on the previous works of [9], [12], [10], [6], [7], [23], it is hypothesised that POC aggregate can be utilised as natural aggregate replacement for both the hard backing layer as well as porous layer of free-standing noise barrier. Its internal pores are the main criteria for enhancing sound absorption especially in porous medium of noise barrier. 1st stage of the framework is the characterization of material properties where Palm Oil Clinker (POC) divided into three different particles sizes which are particle sizes dp>5mm, 1.25<dp<5mm and dp<1.25mm for coarse, medium and fine. Environmentally friendly Blended cement (CPIII) according to [25] will be used. In order to develop the hard backing, the proportion of mix used by [12] will be utilized (Table 1). This mix design will be compared with standard hard backing material concrete with proportion of cement: Fine aggregate: coarse aggregate of 20:50:30.

Second stage of the framework is determination properties of POC concrete as porous sound absorber then determined with medium aggregate (1.25<d_p<5mm) and coarse aggregate (d_p>5mm). Again, the mixed used by the [12] will be used with the target open void ratio of 26%. The suggested mixtures are shown in Table 3. Each mix proportion is designated by a specific code of “POCC, and POCM” representing palm oil clinker coarse aggregate and, palm oil clinker medium aggregate. The second labels, “20”, “40”, “50”, “70”, and “80”, denote the amount of POC aggregate. Each specimen type will be compared with other concrete products usually employed in acoustic barriers, a standard porous concrete (PC) as shown in Table 3 [10].

| Mixture | Cement | POC | Mixture | BC | POC |
|---------|--------|-----|---------|----|-----|
| POCC-20 | 80     | 20  | POCM-20 | 80 | 20  |
| POCC-40 | 60     | 40  | POCM-40 | 60 | 40  |
| POCC-60 | 40     | 60  | POCM-60 | 40 | 60  |
| POCC-80 | 20     | 80  | POCM-80 | 20 | 80  |

The compressive strength of hard backing and porous concrete will be evaluated according to the standard [26]. The sound absorption coefficient and transmission loss will be tested by using impedance tube with 98 mm diameter will be employed for low (50–2000 Hz) and 28 mm diameter for the high acoustic frequency range between 800 and 5000 Hz. The test will be carried out by using impedance tube according to [27]. The physical properties of mixture will also be measured including density, air flow resistivity and porosity.
The best mixture for POCC and POCM will be selected based on specimens that demonstrate the high sound absorption and good compressive strength (>2.0N/mm²) as suggested by [28]. The best mixture can be potentially used as a single layer porous absorber in noise barrier porous medium. High acoustic absorption can be noted by comparing variation of the acoustic absorption coefficient in octave band spectrum for different mix proportions for each type of material together with the reference product i.e normal porous concrete. The relationship with open void ratios, thickness with sound absorption coefficients in the whole range of frequencies will also be studied. Thus, the best mixture in each type of new material will be proceeded to develop multilayer porous concrete by combining hard backing, POCM and POCC. The \( h_{\text{max}} \) that is thickness of samples that given the highest sound absorption will also be obtained.

Third stage of framework is the multilayer layer material characterisation. At this stage a multilayer material using best material representing each type will be developed. The thickness of material that give highest sound absorption for type I (POCC) , \( h_{\text{max}} \) will be used as base line for the thickness of combining layers of best type of each type . The arrangement of the layer will depend on the results. Material with the highest sound absorbing coefficient will be put at the first layer of the product as it will be facing the noise source from road. It is hypothesized that POCC called as BT1 will have highest sound absorption followed by POCM called as BT2. Previous research by [12] found that concrete with coarse bottom ash demonstrated highest sound absorption. Thus, several combinations of BT1 and BT2 will be analysed in the top layers (incident noise face). Figure 7 shows the four suggested composite layer of BT1, BT2 and hard backing material (BT3) namely MLC1 to MLC4. Porous and standard hard backing concrete as a conventional product applied in acoustic barriers [28], MLC5 will be casted for comparison. The optimal composite solution would be the product which presented the best acoustic absorption behaviour.

5. Discussion
A framework for green concrete noise barrier materials by using the entire range of POC particle sizes is proposed. It was based on the previous works by researchers in order to find the ways for reusing and recycling the wastes. Also, it is to help in reducing the environmental noise problem mostly from traffic noise, including motor vehicle, plane and rail noise. However, the most important criteria is that POC itself is internally porous [8], [20] and if it is use in porous concrete it may absorb sound better than standard porous concrete. This will produce new POC noise barrier that would serve as an alternative material to the current concrete barrier incorporated with perforated surface infilled with absorbing material such as fibreglass/ rockwool. It is an environmentally friendly, sustainable, and can be labelled as “green”.  

![Multilayer Composite Material Diagram](image-url)
6. Conclusions
The replacement of palm oil clinker (POC) in different range of particle sizes for natural river sand and aggregate in the development of noise barrier is believed to improve the acoustic performance based on the properties of the POC. The porous concrete layer/s consists of medium or coarse POC aggregate will enhanced the sound absorption of the noise barrier while the replacement of fine POC in hard backing layer will gives better soundproof.

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