The Sound Absorption Coefficient of Railway Concrete Sleepers Containing Palm Oil Fuel Ash (POFA) As a Cement Replacement Material

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Abstract. Major noise and vibration during train operation can cause disturbance to the surrounding. One of the methods to reduce this disturbance are by installing concrete sleepers. The use of railway concrete sleepers may be a high potential to reduce the noise and vibration. To produce concrete sleepers cement usage will be used with greater volume. Approximately 100 million tons of Palm Oil Fuel Ash (POFA) was disposed to the landfill currently. POFA contains high silica content and porous particles which indicated its pozzolanic properties and sound absorption characteristics. Therefore, this study was to determine the sound absorption coefficient of railway concrete sleepers containing POFA as a cement replacement material. Concrete sleepers with a strength grade of 55 and a w/c ratio of 0.35 were prepared in this study. Three design mixes with 0% (control), 20%, and 40% of POFA tested by using an impedance tube test at 28 days of curing age. The results show, the sound absorption coefficient and noise reduction coefficient increases as the percentage of POFA increases. The best performance was obtained by concrete sleepers containing 40% of POFA, with a recorded sound absorption coefficient of 0.10 for low frequency and 0.44 for high frequency. Meanwhile, the noise reduction coefficient recorded was 0.33, which reduce 32% of noise compared to OPC.

1. Introduction

During train operation, a major source of noise pollution is produced by the vibration of concrete sleepers due to wheel and rail interaction [1]. Furthermore, sleepers also radiate their noise during the vibration process, making sleepers the dominant component of track radiation up to 1000 Hz [2,3]. The Malaysian Environment Department laid down regulations for a noise limit of 55 dB in housing areas. The study carried out on electricity trains (ETS) between Gemas and Padang Besar throughout the electrified dual-tracks sectors recorded that, at speed from 140 to 160 km/h, the maximum produced noise level was 72.2 dB(A), which is greater than the allowable noise level [4]. In May 2019, in Petaling Jaya, the residents launched an online petition for Prasarana Malaysia Bhd to reduce their train speed
and noise in residential areas sections 5, 9, and 10 [5]. Moreover, the use of cement in the production of railway sleepers was the major contributor to carbon emissions and energy consumption in the construction stage, followed by gravel and steel bars [6]. Thus, various additives and substitution materials were studied to produce sustainable concrete sleepers, such as polymer concretes, fibre-reinforced foamed urethane (FFU), and crumb rubber, to improve their vibrations and noise performance [7–9].

Meanwhile, the palm oil industry is one of Malaysia’s largest agro-industries. According to the National Biomass Strategy, the waste will rise to 100 million tonnes in 2020, and this produces an end product in the form of palm oil fuel ash (POFA) which causes a burden to our landfill [10–12]. As shown in Figure 1 shows the waste disposal site of the palm oil mill located at Muar, Johore, Malaysia.

![Figure 1. A disposal site for POFA at Muar palm oil mill](image)

POFA consists of high silica content which indicates that it has pozzolanic properties. Studies of high strength concrete (HSC) have shown that the inclusion of POFA can produce HSC of up to 46 to 105 MPa compressive strength within 28 days [13,14]. According to Jusli et al. [15], Amares et al. [16], and Freitas et al. [17], higher porosity and lower density material would have better sound absorption performance [15–17]. Since POFA consists of porous materials and tends to produce lower density concrete, hence, POFA may have good noise absorption characteristic [18–20]. However, a limited study has been conducted on the noise performance of POFA concrete. Razali et al. [21] conducted a sound absorption test on the POFA in concrete grade 25 with a w/c ratio of 0.45. They found that the highest noise absorption was recorded at 10% of cement replacement, which was 0.08. This high sound absorption was due to the greater air void in the concrete, which lead to higher acoustic performance in concrete POFA [21]. However, the noise absorption performance of the POFA at higher content has not yet been assessed in concrete sleepers. Therefore, it leads to the aims of this studied which was to investigate the potential use of POFA as cement replacement material, producing sustainable railway’s concrete sleepers with a lower noise generation.

2. Materials

The materials that have been used were Ordinary Portland Cement (OPC), Palm Oil Fuel Ash (POFA), river sand, coarse aggregate, and tap water. POFA was used as a cement replacement material to improve the noise absorption in railway concrete sleepers.

2.1 Ordinary Portland Cement (OPC)

The OPC used for this study was CEM 1 type with a minimum strength class of 52.5 which compliance with EN 197-1 [22].
2.2 Palm Oil Fuel Ash (POFA)
POFA was collected from the palm oil mill located at Muar, Johore. The raw POFA was dried in the oven at 105 ± 5 °C for 24 ± 1 hr to remove the moisture content and reduce the carbon content. As shown in figure 2 shows the POFA change its colour from black to light grey after the heating process. The colour change may due to reduced carbon content during the burning process [13]. Next, POFA was sieved using a 0.30 mm (300μm) mesh according to ASTM C136 to remove the coarse particles that were incompletely combusted in the boiler [23].

![Figure 2. The heated POFA had turned from (a) black to (b) light grey](image)

2.3 Fine and coarse aggregates
The sand was used as a fine aggregate with a particle size less than 5 mm. It was dried in the oven at 110 °C ± 5 for 24 hr to remove moisture content. Meanwhile, the coarse aggregate used was gravel with a size range from 5 mm to a maximum size of 20 mm. All the aggregates used have complied with BS EN 12620 [24].

3. Methodology
3.1 Concrete sleeper preparation
The general requirement of concrete sleepers was conformed to BS EN 13230-1, where the minimum compressive strength was 55 MPa at 28 days [25]. The proportion of the control sample was derived based on the design of the experiment (DOE) method with a water-cement ratio (w/c) was 0.35. Three design mixes with 0%, 20%, and 40% of POFA content were tested and assigned as OPC, POFA20, and POFA40, respectively. A mixture with 0% of POFA was assigned as a control sample. The details of the concrete mix design are as shown as in Table 1.

| Table 1: Mix design using DOE Method |
|-------------------------------------|
| Materials  | POFA (%) | OPC (Kg) | POFA (Kg) | Aggregates | Water (Kg or litres) |
| CONTROL    | 0        | 577.14   | 0         | 389.77     | 1285.33       | 195 |
| POFA20     | 20       | 461.71   | 115.43    | 389.77     | 1285.33       | 195 |
| POFA40     | 40       | 346.28   | 230.86    | 389.77     | 1285.33       | 195 |
3.2 Impedance tube test

An impedance tube test was conducted to obtain the sound absorption coefficient, \( \alpha \), and noise reduction coefficient (NRC) of railway concrete sleepers containing various percentages of POFA. The test was conducted following BS EN ISO 10534 [26]. Since the range of railway noise frequencies that were most evident for the human ear was from 125 to 4000 Hz, therefore, the sound frequency of this test was controlled within the range of 80 to 5000 Hz [27]. Two sizes of samples were prepared. Samples with a diameter of 100 mm were used for low frequency. Meanwhile, for high frequency, a sample with a diameter of 28 mm was used. Both of the samples have a thickness of 100 mm. Figure 3 shows the impedance tube equipment used. For data acquisition and signal processing, an amplifier, signal platform, and a desktop computer equipped with AFD 100 software were used.

The noise reduction coefficient (NRC) measures the ability of the materials to absorb the sound. It was obtained from the average value of sound absorption coefficients at frequencies of 250, 500, 1000, and 2000 Hz calculated by Equation 1.

\[
NRC = \frac{(\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000})}{4}
\]

(1)

Where NRC = Noise reduction coefficient, \( \alpha \) = sound absorption coefficient

4. Results and Discussions

4.1 Sound absorption coefficient for low frequency

From the results of the impedance tube test for low frequency, it was found that the sound absorption coefficient of the concrete sleepers increases with increased POFA replacement level. The sound absorption coefficient recorded were 0.04, 0.08, and 0.10 for OPC, POFA20, and POFA40, respectively. This was illustrated in Figure 4, the highest sound absorption coefficient recorded by POFA40. It improved the sound absorption by 150% compared to OPC sleepers.

Meanwhile, Figure 5 shows the sound absorption coefficient recorded at various low frequencies. From the result, the concrete sleepers containing POFA recorded a higher sound absorption coefficient compared to OPC at all frequencies. The highest sound absorption coefficient recorded for all concrete sleepers was at a frequency of 400 Hz. At this frequency, the highest sound absorption was recorded by POFA40 which improved the sound absorption from 0.11 to 0.46 compared to OPC. This provides a significant performance as the impact of noise and vibration from the train operation was obvious at a frequency below 500 Hz [28,29].
Figure 4. Sound absorption coefficient ($\alpha$) versus POFA replacement (%).

Figure 5. Sound absorption coefficient ($\alpha$) versus Frequency (Hz)

4.2 Sound absorption coefficient for high frequency

It is showed that for the high-frequency impedance tube test, the sound absorption coefficient increases as the percentage of POFA replacement increased, as illustrated from Figure 6. The sound absorption coefficient of the concrete sleepers increased from 0.32 for OPC sleepers to 0.36, and 0.44 for POFA20 and POFA40, respectively. The highest sound absorption recorded by 40% of POFA replacement which increased the sound absorption coefficient up to 38% compared to OPC sleepers.
Meanwhile, the sound absorption coefficient recorded at various high frequencies was shown in Figure 7. The highest sound absorption coefficient recorded for OPC was 0.54 at a frequency of 2000 Hz. Meanwhile, POFA20 recorded the highest sound absorption coefficient of 0.52 at a frequency of 4000 Hz. The highest sound absorption was recorded by POFA40 with a sound absorption coefficient up to 0.62 at 5000 Hz. At this frequency of 5000 Hz, POFA40 increased the sound absorption up to 72% compared to normal OPC sleepers. Hence, the results indicate that POFA40 has better sound absorption performance against rolling noise where dominated train operation at high frequency [28,29].

From the results of both low and high-frequency impedance tube tests, the sound absorption coefficient was directly proportional to the POFA replacement level. As the POFA content increases, the sound absorption coefficient increase. These findings were in line with the study conducted by [21] where the sound absorption performance increased with increased POFA content. The optimum POFA content that produces the highest sound absorption was at 40% of cement replacement, with a recorded sound absorption coefficient of 0.10 for low frequency and 0.44 for high frequency. This may due to
higher POFA content which contributes to higher porosity and void in the concrete sleepers, producing a sleeper with lower density and thus, have higher sound absorption [15–17].

4.3 Noise Reduction Coefficient (NRC)

The NRC value was calculated to determine the sound absorption performance of a material. As shown in Figure 8, the NRC increases with an increase of POFA replacement level. As 20% of POFA was replaced, the NRC increases from 0.25 to 0.31, compared to OPC. The highest value of NRC was recorded by POFA40 which was 0.33, hence, POFA40 has higher sound absorption performance compared to other sleepers. It, therefore, possesses a high potential to reduce noise during train operations and could be used as a low noise railway’s sleepers.

![Figure 8. Noise reduction coefficient (NRC) of concrete sleepers](image)

5. Conclusions

The use of POFA improved the sound absorption performance of the concrete sleepers. As the POFA content increases, the sound absorption coefficient increase. The optimum POFA content that produces the highest sound absorption and noise reduction was at 40% of cement replacement, with a recorded sound absorption coefficient of 0.10 for low frequency and 0.44 for high frequency. Meanwhile, the noise reduction coefficient recorded was 0.33, which was 32% higher than OPC. This may due to higher POFA content which contributes to higher porosity and void in the concrete sleepers, producing a sleeper with lower density and thus, have higher sound absorption.

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