Determining the Suitability of POFA as Partial Replacement to Cement in Concrete for Acoustic Properties: Sounds Transmission Loss and Sounds Absorption Assessment

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Abstract. Abundance of palm oil fuel ash (POFA) produced by the process of burning fibers and fruit bunches as fuel has contribute to several problems related to the space and environmental control. By having an alternative to manage and control the POFA as agricultural waste, it can give great benefits in construction industry for replacing the dependence of Ordinary Portland Cement (OPC) as binder in concrete. The properties of POFA itself are close to the OPC as binder in concrete yet there are some other unique characteristic of POFA in providing a better acoustical performance in a concrete. In this study shown that by replacing some part of cement with POFA in concrete mixture, it contribute to greater acoustical performance due to the high sound transmission loss and sound absorption found in this study. This study focus on single concrete mix with water cement ratio of 0.45 for concrete grade 25 and can be concluded that higher percentage of POFA replacement can enhance the acoustic properties of a concrete block but may reduce the strength of the concrete.

1. Introduction

Palm Oil Fuel Ash (POFA) is a kind of agricultural waste produced by the combustion process in steam boiler at the Palm Oil Mill and the waste were not really useful to industry as they contain not enough nutrients and left dumped near the palm oil mill [1]. Palm oil industry is the biggest agricultural industry in Malaysia and it produces approximately 41% of world palm oil production and 47% of world exports as stated by Malaysian Palm Oil Council (MPOC) and for every 100 tons of fresh fruit bunches processed, approximately 52 tons of nut shells, fibers and empty bunches discharged from the mills [2]. Several studies and experiments were conducted to determine the effect of using agricultural waste as cement replacement in concrete [1][2]. POFA will act as replacement to cement in concrete mix these ashes have been precisely studied on its properties and proved that it has cementitious properties which called as pozzolanic materials but the capabilities of the ashes must be examined before being commercialized [1].

As the biggest agricultural industry in Malaysia, palm oil mills produced huge number of waste in solid form [3]. The alternatives to take the benefit of POFA as substitute or replacement for cement in concrete mixture leads to optimize the utilization of oil palm waste and also to produce low cost
mineral admixture sufficiently pozzolanic material that could be used in pozzolanic cement. 10% of ultra-fine sand (UFS) replacement generates higher sound absorption coefficient due to excessive amount of micro silica which resulting in higher amount of pore formation hence increased the void in the concrete [4]. The finer particle indicates the best results where the finer particle can easily vibrate compared to the coarse particle. This happened because the low inertia made the particles vibrate smoothly and drive the energy away. Vibrated rubber can dissipate energy easily. The frequency and the content of the rubber can dissipate the elastic energy. Thus, since the rubber has a good ability to dissipate sound energy, it produced a better airborne sound insulation performance against the cork granulates in gypsum where the rubber has a great elasticity [5]. Higher fineness of POFA exhibit higher resistance towards sulphate attack compared to less fineness of POFA where pozzolanic reaction in concrete mix form secondary C-S-H gel in shorter time [6].

Nowadays, designing building with good acoustical properties has become popular as the regulations are more demanding [7]. This study is about to assess the acoustical performance for concrete block with POFA in the mixture. There are two acoustical aspects been studied which are the sound transmission loss and sound absorption coefficient. An improvement of sound transmission loss in building element can help to reduce the interior noise from the transmission path [8].

Today, porous materials such as fibers are famously used as sound absorptive materials for a better acoustical performance [9]. There was a study on the crumb rubber replacement in concrete resulting the sound energy can be absorbed easily when the percentage of crumb rubber replacement increased causing incremented in air void in the crumb rubber concrete [10]. The amount of recycle aggregate in the porous concrete had less effect towards the absorption characteristic. The main factors contribute to the higher absorption coefficient is the surface area of the voids. As the surface area of the voids increased, the absorption coefficient also increased [11]. It is good if a concrete block with some part of POFA replacement in cement can act as a partition in an enclosed space having a lightweight characteristic and great in acoustical performance. This can help to benefit the surplus of POFA as agricultural waste to something useful in construction industry.

A field measurement of apparent airborne sound reduction index for interior wall was conducted by using software dB Bati 32 [12] and another field measurement for floor sound insulation impact have been carried out according to ISO 140-7 standard and by using software of analysis and elaboration dB BATTI 32 [13]. By referring to ISO 140-8, the impact sound reduction for each of floor covering were measured and tested using software of analysis and elaboration data dB BATI 32 [12].

2. Methodology
In assessing the acoustic properties of Concrete with POFA-cement replacement for this study, there were 2 tests conducted which were the sound transmission loss test and sound absorption test. Materials for concrete such as Ordinary Portland Cement (OPC), fine aggregates (<600 µm), coarse aggregates and water are the main materials prepared and being used for all the concrete block samples. POFA used for this study was supplied from Palm oil mill at Samarahan belongs to the Sarawak Land Consolidation and Rehabilitation Authority (SALCRA). The design mix for the study is using concrete grade 25 with water cement ratio 0.45. There were 5 different samples of concrete mix design consists of control sample (the normal mixture without replacing part of cement with POFA in the mixture), 2.5% POFA-cement replacement, 5%, 7.5% and 10%. There were 100 concrete blocks size 240mm x 190mm x 100mm and tested on 7, 14 and 28 days for the sound transmission loss test and sound absorption test. Same materials compositions were used for casting the concrete blocks to conduct the tests.

2.1. Sound Transmission Loss Test
Concrete block size 240mm x 190mm x 100mm with different mixtures with POFA added according to the different percentage for every sample tested were prepared. This part of BS EN ISO 140-3:1995 lays down specifications towards laboratory test facilities for sound insulation measurements of building elements. The laboratory test facility consists of two adjacent reverberant rooms with a test
opening between them in which the test specimen is inserted. When measuring walls or floors that the specimen should cover a total partition wall or ceiling of the test room, i.e. the test opening should extend from wall to wall. Reverberant chamber used for this study has opening size 1m x 1m in area. Twenty units of concrete blocks needed to enclose and cover the whole opening. To prevent any sound infiltration, blocks were sealed with lime mortar. Three tests on acoustical aspects conducted to measure the sound transmission losses which were the reverberation time (RT), Background Noise and Emi/Rec.

First test conducted was the reverberation time for every samples. Then, the measurement of background noise levels shall be made to ensure that the observations in the receiving room are not affected by noise from outside the test room, electrical noise in the receiving system, or electrical cross-talk between the source and the receiving systems. Then the results for transmission loss can be determined by using Buildings Acoustic Software (dBBati 32-bit Version 4.532).

2.2. Sound Absorption

Sound absorption test was tested at the receiver’s room only. The entire test specimen (concrete blocks) were placed on the floor and the opening was sealed with steel plate to prevent sound transmission loss. The test must be conducted four times with different position of the microphone. Concrete blocks were placed on the floor under almost the same conditions of temperature and humidity. The reason is to ensure the air absorption not differ significantly and the microphone was mounted on a tripod and placed on the concrete blocks which are at least 1.5 m apart, 2 m from any sound source and 1 m from any room surface and the tested samples. After the measurement done, the microphone is rotated in 4 different directions (clockwise). Concrete block was covered with aluminum foil at all side. The sound in the reverberation room was generated from sound source which is noise source with an omni-directional radiation pattern. Using Buildings Acoustic Software (dBBati 32-bit Version 4.532).

3. Results and Discussions

3.1. Sound Transmission Loss

There are 5 different samples of concrete blocks mix with POFA. The cement content of the concrete mixture was replaced with 2.5%, 5%, 7.5% and 10% POFA. For each sample, there were 20 blocks produced and tested on 7 days, 14 days and 28 days. Total concrete blocks for sound transmission loss test are 100 units. Table 1 shows the results of sound reduction for 5 different samples with different ages of concrete blocks. The range of frequency used to determine the transmission losses towards the concrete blocks are from 100Hz to 5,000Hz. Control samples show 37dB, 37dB and 39dB transmission loss recorded for 7, 14 and 28 days of concrete ages tested respectively. Transmission loss increased for 2.5% POFA replacement samples as results 45dB, 45dB and 47dB were recorded for 3 different ages of concrete respectively and positively increase for 5% POFA replacement samples as the results for 3 different days of concrete age’s recorded 48dB, 48dB and 49dB sound transmission loss. 7.50% POFA replacement show almost similar results as 48dB sound transmission loss for 7 days and 49dB sound transmission loss for 14 and 28 days were recorded. Highest sound transmission loss was recorded by 10% POFA replacement as the amount of 49dB for 7 and 14 days and 50dB were recorded for the last 28 days of concrete age.

Higher number of sound transmission loss indicates a good acoustic performance due to the sound wave and sound energy that will less transmit through the concrete block. This will reduce the amount of noise to be transmitted from outside into the enclosed space in the building. Less amount of air void will prevent he sound wave passed through the concrete easily. And by adding up of higher amount of silica fume the reduction in sound transmission loss (STC) can be partially recover [11] It can best be concluded that the best POFA replacement for achieving high sound transmission loss is by 10%.
3.2. Sound Absorption Test

There are 5 different samples of concrete blocks mix with POFA. The cement content of the concrete mixture was replaced with 2.5%, 5%, 7.5% and 10% POFA. For each sample, there were 20 blocks produced and tested on 7 days, 14 days and 28 days. The total concrete blocks for sound transmission test is 100 units. Table 2 shows sound absorption coefficient for three different concrete sample’s ages against the percentage of POFA replacement in samples. The sound absorption coefficient for control samples are 0.05, 0.02 and 0.02 for 7, 14 and 28 days. According to the Table 2, when 5.0% POFA replacement samples were tested for 7, 14 and 28 days of ages, the results show that the sound absorption coefficients are 0.05, 0.04 and 0.06. It continued increased when 5.0% POFA replacement tested as 0.05, 0.06 and 0.07 of sound absorption coefficient were recorded. The results for 7.5% POFA replacement show inconsistency results due to the inconsistency preparation of concrete samples mixture affecting the concrete become weak in sound absorption. Highest sound absorption coefficient recorded for 10% POFA replacement as 0.05 sound absorption coefficient recorded for 7 days, 0.1 for 14 days and 0.08 for 28 days age of concrete tested. Sound absorption coefficient for concrete blocks with POFA replacement give better results due to the higher fiber content in the concrete blocks.

Result shows that the sound absorption coefficient increased over the percentage of POFA replacement. Higher fiber or POFA in the concrete can improve the sound absorption characteristic in concrete. The void exists inside concrete blocks due to the existence of POFA can absorb the sound energy that transmitted through the surface of concrete blocks. The main factors contribute to the higher absorption coefficient is the surface area of the voids. As the surface area of the voids increased, the absorption coefficient also increased [14]. It can be concluded that 10% POFA replacement is best for sound absorption coefficient in concrete.

| TABLE 1. SOUND TRANSMISSION LOSS RESULT FOR ALL SAMPLES |
|-------------------------------------------------------|
| 7 Days (dB) | 14 Days (dB) | 28 Days (dB) |
| Control Sample | 37.0 | 37.0 | 39.0 |
| 2.50% | 45.0 | 45.0 | 47.0 |
| 5.0% | 48.0 | 48.0 | 49.0 |
| 7.50% | 48.0 | 49.0 | 49.0 |
| 10.0% | 49.0 | 49.0 | 50.0 |

| TABLE 2. SOUND ABSORPTION COEFFICIENT RESULTS FOR ALL SAMPLES |
|--------------------------------------------------------------|
| 7 Days | 14 Days | 28 Days |
| Control Sample | 0.05 | 0.02 | 0.02 |
| 2.50% | 0.05 | 0.04 | 0.06 |
| 5.0% | 0.05 | 0.06 | 0.07 |
| 7.50% | 0.1 | 0.02 | 0.07 |
| 10.0% | 0.05 | 0.1 | 0.08 |

4. Conclusion

Higher percentage of POFA increased the sound transmission loss and sound absorption coefficient. By looking at the results for transmission loss, it clearly stated that 10% of the POFA replacement produces better sound insulation for the concrete blocks which is 50 dB. In the mean time, higher POFA replacement also exhibited better sound absorption where the absorption coefficient for 10% replacement is 0.08. This indicates that higher amount of POFA in concrete can produce a better acoustic performance rather than control sample with 0% POFA replacement. Also to be concluded,
higher amount or higher percentage of POFA replacement in concrete can improve and increase the acoustic performance due to the air voids in the concrete where the sound energy can be absorbed and reflected when passing through the concrete blocks mixed with POFA.

It requires further research and analysis to dig into the relationship between concrete properties and acoustical properties of concrete blocks with POFA replacement as alternative for cement as binder. In a positive perspective, higher POFA replacement in concrete can contribute to the greater acoustical performance in a concrete. Both sound insulation and sound absorption were in a good condition when replacing cement with POFA as alternative. In conclusion, higher percentage of POFA can be an alternative for providing a partition with greater acoustical performance.

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