

Acoustical Performance of Palm Oil Clinker Sand Sound Absorber

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Abstract. This paper presents the results of a study in which the performance of palm oil clinker (POC) sand as an alternative acoustic material for controlling noise problems was investigated. The specimens were prepared using the basic mortar mixture of cement-to-river sand ratio of 1:4. The five mixtures used in the study contained POC sand at the amounts of 0%, 25%, 50%, 75% and 100% of the total weight of the sand. Hardened mortar properties of density and compressive strength as well as acoustic performance were measured. The results show that the specimens containing POC sand gave an average noise reduction coefficient of 0.30, which is larger than the corresponding value of 0.25 for the specimens with river sand only. The combination of 50% POC and 50% river sand achieved the highest sound absorption coefficient of 0.5 at 315 Hz and 0.4 at 1000 Hz. It was also found that although POC sand reduced the compressive strength of specimens, the values obtained were still within the strength limit of non-load bearing structures. The findings suggest that POC sand has the potential to be used in the construction of non-structural wall in reducing the noise pollution.

Keywords: Palm oil clinker, mortar, sound absorption, sound barrier, sound absorber

1. Introduction

The sound absorption capacity of building walls is an important element in reducing noise in an urban environment. The façades of most buildings have low sound absorption capacity, thus creating street canyons. Vertical walls covered by mosaic can be considered as reflective materials with sound absorption coefficient (SAC) between 0.028 and 0.1 in the frequency range of 400–8000 Hz [1]. Concrete walls have SAC between 0.03 and 0.09 in the range of 400–4000 Hz [2]. SAC indicates the capability of material absorption on a scale of 0 to 1, with the former value representing perfect reflection while the latter indicates perfect absorption. If building façades on both sides of a street have low SAC, traffic noise will be reflected many times to create a street canyon. According to [2], street canyons produce reverberant condition with RT30 between 1.2 and 1.4. RT30 is the time needed for a noise to be reduced from its initial value by as much as 30 dB.

Previous research shows that multiple sound reflections from building façades can be reduced by making the walls sound absorbing [3]. Low-speed traffic noise usually exhibits a high sound pressure



level of 500 Hz to 700 Hz while high-speed traffic noise can go as high as 900 Hz to 1100 Hz [4]. For this purpose, a reasonable value of SAC at both 500 Hz and 1000 Hz is needed to absorb sound waves at low and high traffic volumes, respectively. Previously, most research related to building façades concentrated on indoor comfort issues, often forgetting that improving the noise condition outdoors also has a positive impact on people's well-being. For example, high noise levels can contribute to speech interference and sleep disturbance, especially for people living at higher floor levels. Thus, there is a need for construction materials with sufficient acoustic characteristics to be incorporated in building façade construction to help reduce noise pollution caused by the canyon effect. This paper proposes the use of palm oil clinker (POC) cementitious material for building façades.

POC is a by-product of the incineration of palm oil fibre and palm oil shell to generate electricity at palm oil mills [5]. Most research in relation to palm oil clinker is focused on its properties and strength. The unit weight of the POC aggregate is approximately 25% lighter than river sand and 48% lighter than crushed granite stone, making it suitable as a lightweight aggregate [6]. The density of mortar containing 100% POC sand reduces by 7% compared to that of river sand [7]. This is due to the physical properties of POC that contains micropores in internal aggregate structures, and having aggregate crushing value (ACV) of 15 kN to 30 kN, which is considerably lower than the values for river sand. POC inclusion in concrete may reduce compressive and tensile strength [8]. However, coating of macropores of POC slightly increases the compressive strength [8].

Pores are an important characteristic that influences sound absorption. Based on the properties of POC that contains internal pores, it may be preferable for acoustical purposes. This paper focuses on the investigation of acoustical performance of 200 mm thickness of cementitious material with POC sand as river sand replacement that could be used as sound absorber for reducing the street canyon effect. Microstructures and porosity are used to explain the behaviour of compressive strength and acoustical performance.

2. Methodology

2.1. Preparation of material

The oil palm clinker used in this study was obtained from palm oil processing plants in Johor. The material was crushed into a fine aggregate using a crushing machine in the laboratory. It was then passed through a 2.36 mm sieve to obtain the required size according to [9]. Figure 1 shows the POC sand and natural river sand grading. It was found that the POC has smaller particle sizes than the sand as a higher percentage of the POC passed through the sieve in each grade compared to the sand. However, both were well graded and could be used for the mixture.

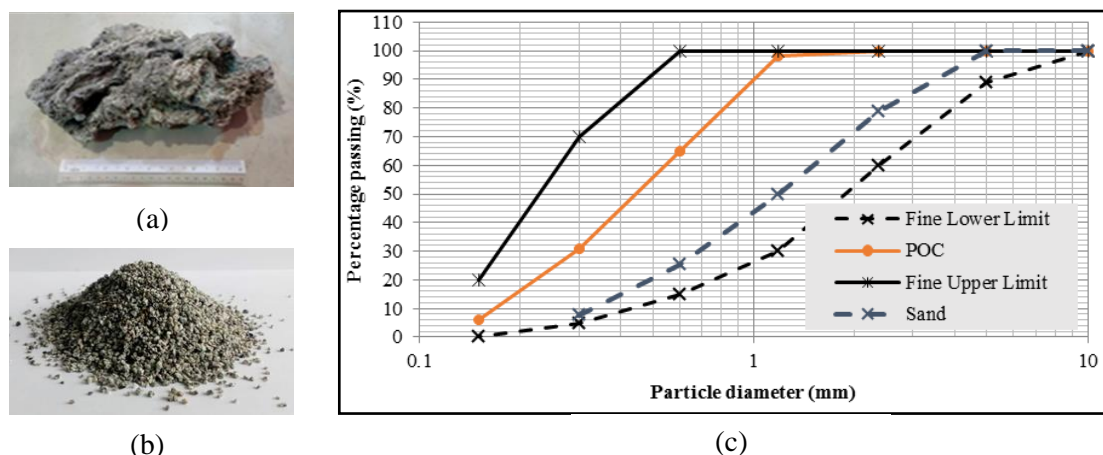


Figure 1. Palm oil clinker: (a) large chunk of POC, (b) fine POC and (c) size distribution.

2.2. Sample preparation and testing

The mortar of 1:4 mix proportion (one part cement to four parts fine aggregate by weight) was adopted in this investigation. Table 1 summarises the five mixes used in which the content of the POC sand replacing the river sand was varied. The mixing was carried out for about five minutes in a concrete mixer to obtain a homogeneous mix. The cement and fine aggregate were first mixed for about two minutes, followed by another three minutes with water. Three 50x50x50 mm cubic specimens from each mix were moulded for density, porosity and compressive strength testing. Additionally, three 200 mm high cylindrical specimens for each mix were prepared for sound absorption testing. All specimens were compacted using the vibrating table. After demoulding the specimens on the following day, they were all cured in water at room temperature.

The compressive test for all specimens was carried out on the concrete 28 days after moist curing in accordance with ASTM C109[10]. The porosity test was done by applying the water displacement method to measure the level of porosity of porous concrete specimens. The porosity of porous concrete was determined by using Eq. 1.

$$P = 1 - \left[\frac{w_1 - w_2}{\rho_w - v} \right] * 100 \quad (1)$$

where, w_1 : weight of dry porous concrete sample (kg), w_2 : weight of the porous sample underwater (kg), ρ_w : density of water (kg/mm^3), v : volume of porous concrete sample (mm^3).

Acoustical performance was tested through SAC in the frequency range of 160 Hz to 2000 Hz using impedance tube in accordance with ASTM E1050 - 12[11]. This study applied the transfer-function method to determine the SAC at normal incidence since this approach is capable of obtaining SAC and impedance of the surface for all frequencies. Noise reduction coefficient (NRC) was then obtained by calculating the arithmetic mean of the absorption coefficients at 250 Hz, 500 Hz, 1000Hz and 2000 Hz. A scanning electron microscope (SEM) was used to observe the specimens' microstructures.

Table 1. Proportion of mixtures

Mixture	Mixture 1 (0% POC) (g)	Mixture 2 (25% POC) (g)	Mixture 3 (50% POC) (g)	Mixture 4 (75% POC) (g)	Mixture 5 (100% POC) (g)
Cement	2610	2610	2610	2610	2610
Riversand	8980	6740	4490	2250	0
POC sand	0	2420	4840	7260	9690
Water	1450	1450	1450	1450	1450

3. Result and discussions

3.1. Microstructures of materials and porosity

Figures 2(a) and 2(b) evidence some macropores and macro-craters existing in POC. Based on these SEM micrographs, it is expected that the spheroid-like pores have diameters between 12 μm and 15 μm while craters between 14 μm and 61 μm . A higher magnification (8000) of the craters characterised dispersed fine pores with size of 0.2 μm (Figure 2(c)).

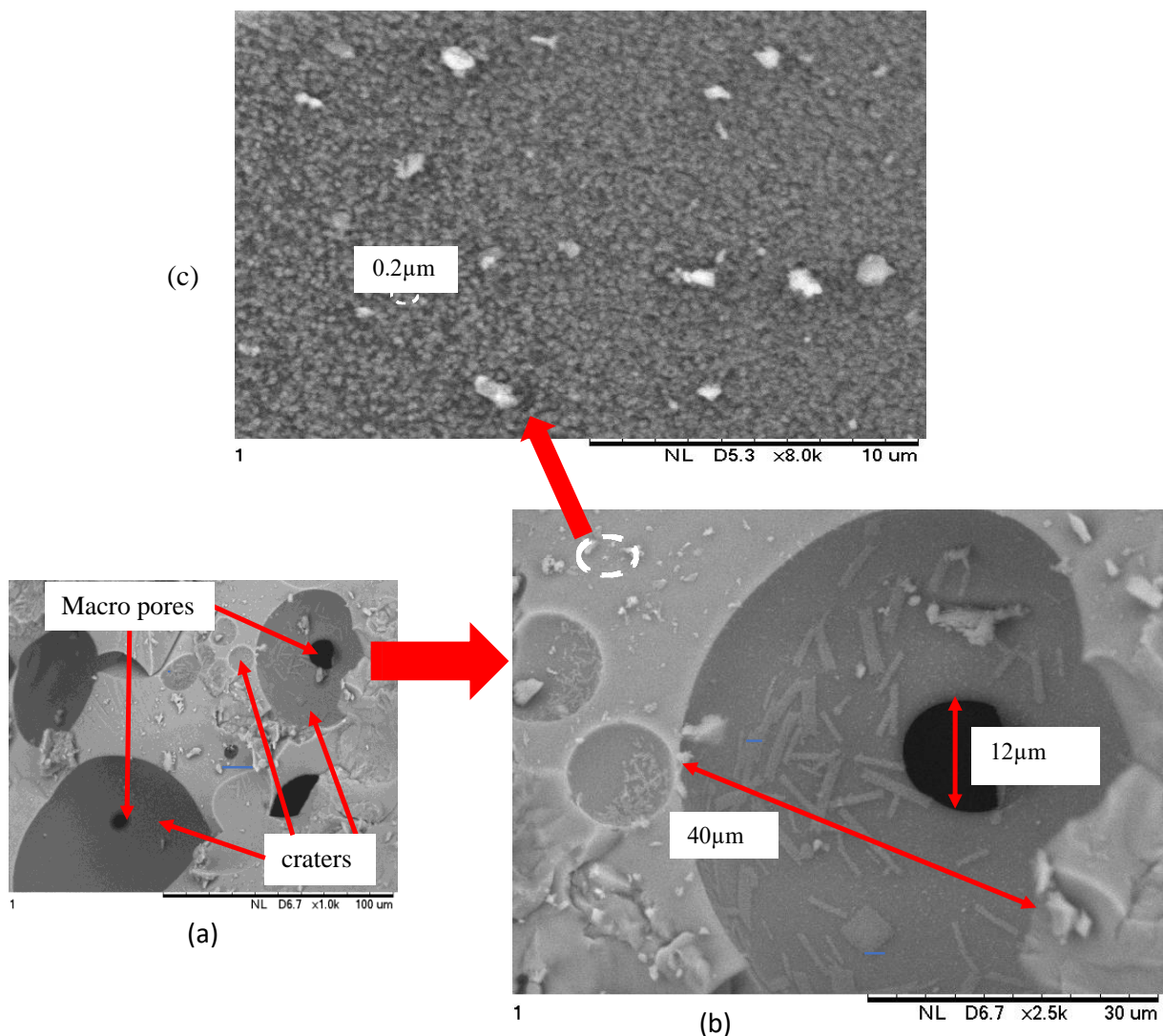


Figure 2. Presence of micropores in POC structures (a) SEM for macro pores under 1000x, (b) Macro pores under SEM 2500x and (c) Macro pores under SEM 8000x.

Figure 3 shows the irregular pores in both 100% river sand and 50% replacement in mixture samples. From these SEM micrographs, the C-H crystal and C-S-H could be identified, with C-H having a particular morphological aspect and orientation while C-S-H having an amorphous form as mentioned in previous studies [12], [13]. Based on these SEM micrographs, it is expected that the irregular pores for 100% river sand have smaller diameters at about 0.2 μm while those of 50% POC replacement have a larger diameter of 0.6 μm. Larger pores were created because of the decrease of free water due to C-S-H bond formation and C-H gel crystallisation, and also POC's macropores absorption.

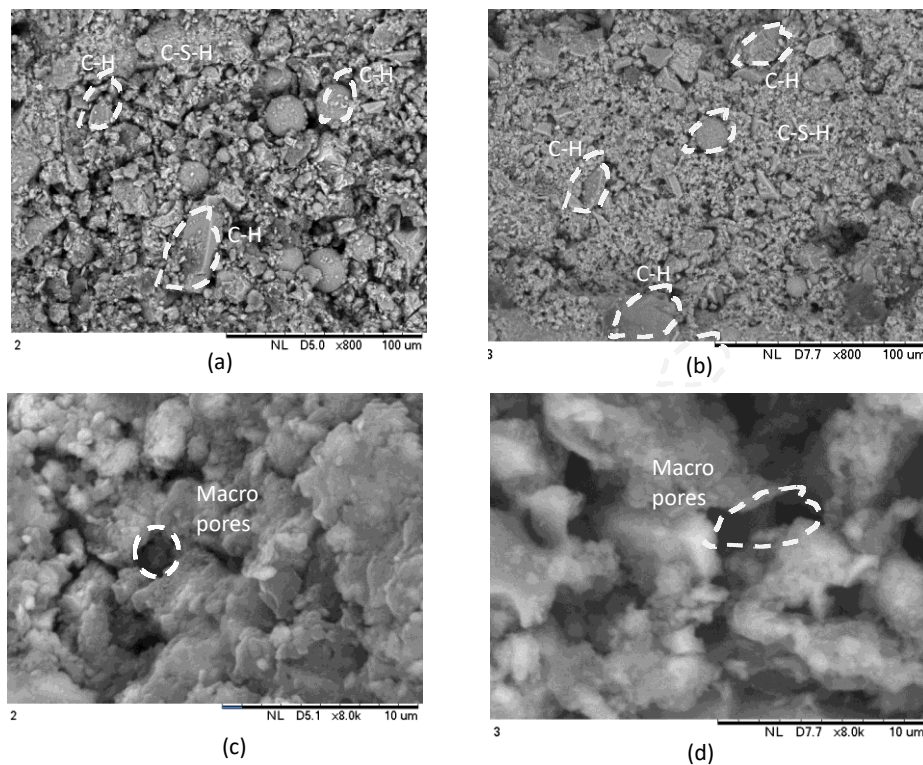


Figure 3. Presence of voids (a) in 100% riversand and (b) 50% POC replacement with higher porous nature.

Porosity of specimens with 0%, 25%, 50%, 75% and 100% POC replacement is shown in Figure 4. It was revealed that the porosity values increased when the sand replacement was 50% POS and above. It was evident that porosity of 50% POC increased due to larger macropores as can be seen in SEM Figure 2(d).

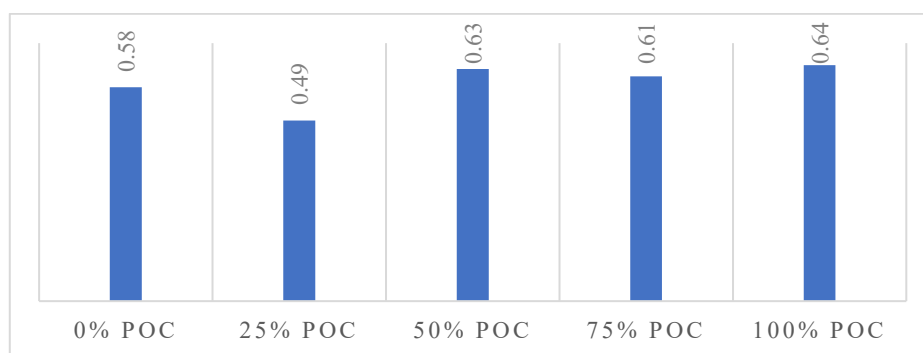


Figure 4. Porosity of specimens without and with POC replacement

3.2. Density and compressive strength of specimens

Figure 5 shows the change of density of the mortar with 25% to 100% POC replacement of river sand. It was revealed that POC replacement linearly reduced the density of mortar from 2113 kg/m³ (0% POC) to 1878 kg/m³ (100% POC). This result was in agreement with those found by [14], [7], which revealed that POC aggregate produced lightweight concrete with a density below 2000 kg/m³. This implies that specimens with POC are much lighter than the typical mortar. The reduction of density by 11% when the river sand was fully replaced by POC was slightly higher than the 7.0% in the work of [7]. The lower density was due to high porosity and void content of POC sand as well as in the matrix as shown in Figures 2 and 3.

Figure 6 shows that the compressive strength of samples reduced drastically to 10 N/mm² (non-structural use category) for mortar with 75% and 100% POC due to macropores in POC and in the cement matrix. The pores possess the available voids that allow cracks to occur rapidly. Compared to mortar with 0% POC, the compressive strength reduced by 44% when 100% POC was used as aggregate. In addition, compressive strength reduction may also be due to the low ACV of POC, which greatly affects the load-bearing capacity. This is consistent with the earlier finding by [7] that pores cause the crack to occur in the aggregate itself beforehand the cement paste.

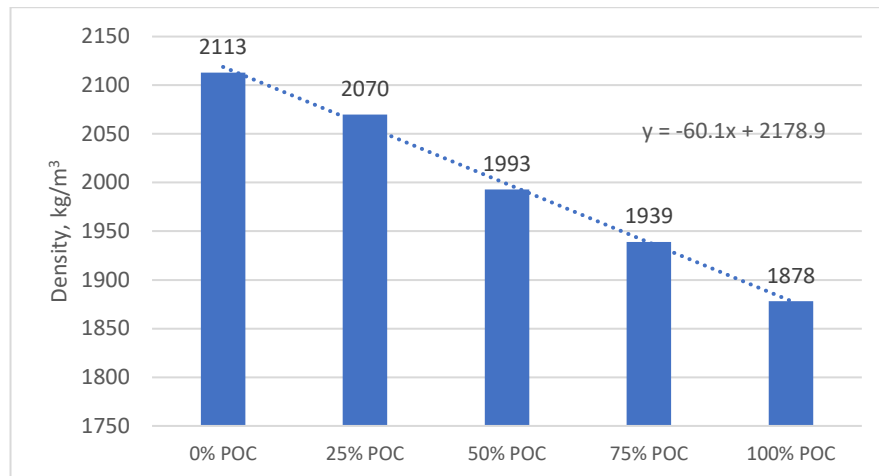


Figure 5. Density of specimens

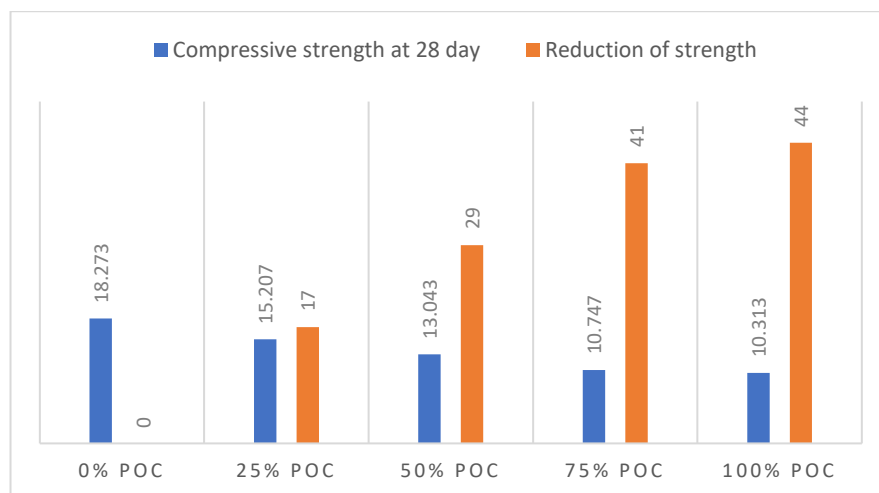


Figure 6. Compressive strength

3.3. Acoustic performance

Figure 7(i) to 7(v) illustrate the SAC spectrum for three specimens each of 0% POC, 25% POC, 50% POC, 75% POC and 100% POC. The trend for the 0% POC specimens revealed uncertain second peaks. However, generally, specimens containing POC revealed the same trend in sound absorption, with the first peak occurring at 315 Hz while the second was at 1000 Hz. Figure 7(vi) depicts the average SAC for each frequency for 0% POC, 25% POC, 50% POC, 75% POC and 100% POC specimens. The SAC for mortar with POC was higher than those with 0% POC for frequencies up to 2000 Hz. It can be noted that specimens containing 50% POC demonstrated higher NRC compared to normal mortar and the specimens with other contents of POC.

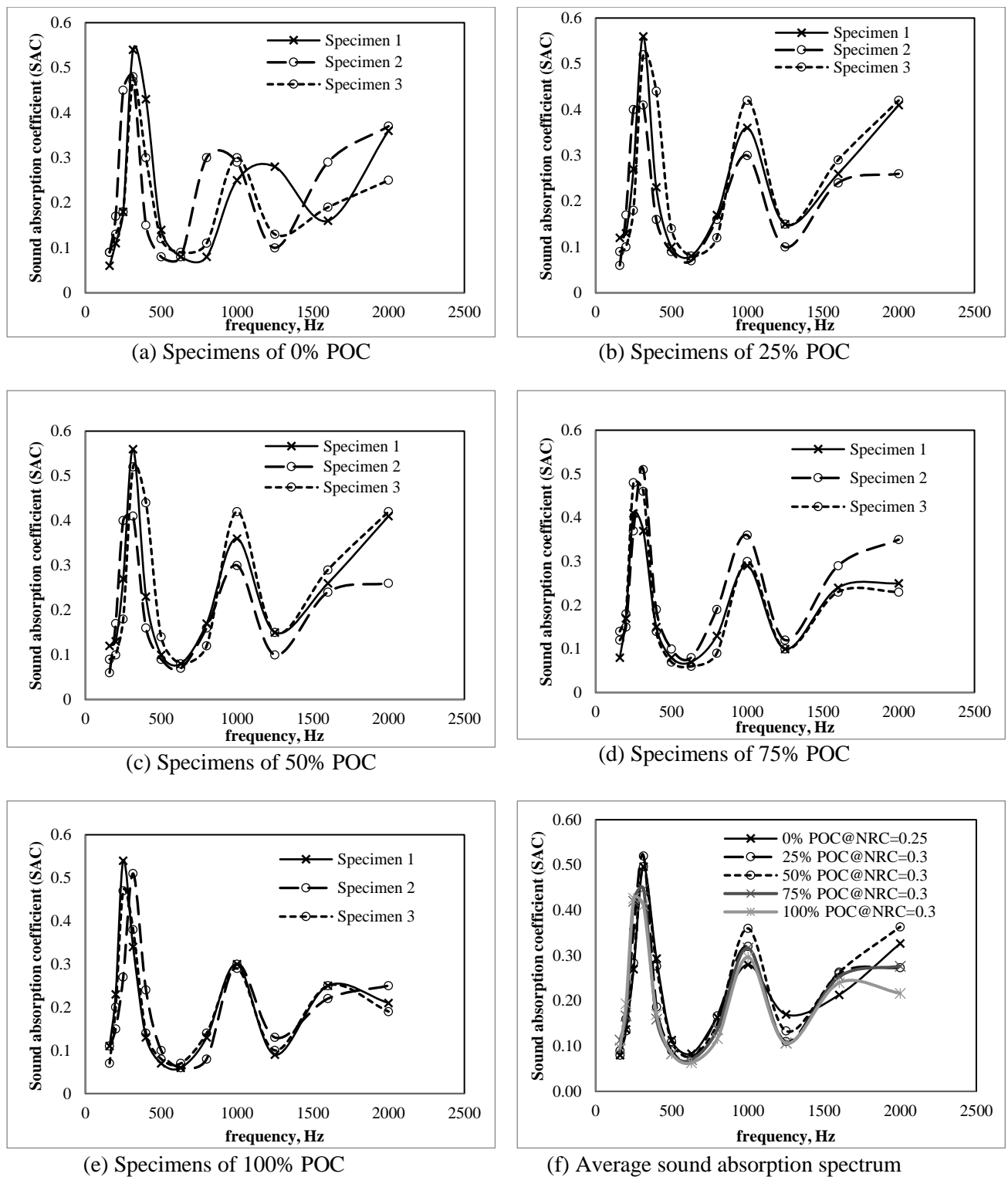


Figure 7. SAC spectrum for all specimens and the average SAC

Figure 8 shows the comparison of SAC at 315 Hz, 500 Hz and 1000 Hz. It was observed that the POC caused slight reduction of percentage of sound absorption at 500 Hz when river sand was replaced by POC sand but improved the capability of absorbing sound energy at 1000 Hz and 2000 Hz, especially for the ones with 50% POC. This reflects the suitability of applying 50% POC as sound absorbers in reducing traffic noise from high traffic volume. The increment of sound absorption capability is due to the high porosity of POC at the macro level (Figure 2), besides the entrapped air in the cement matrix. The irregular shape of POC sand is also capable of producing more pores in cementitious material similarly found in [7]. These pores help in absorbing energy of higher frequency of sound as the wavelength becomes shorter. This corresponds to higher sound absorption. As far as compressive strength is concerned, the specimen containing 50% POC is within the strength limit of non-load bearing structure found in [15], thus it has the potential to be used as non-structural walls in reducing the street canyon effect.

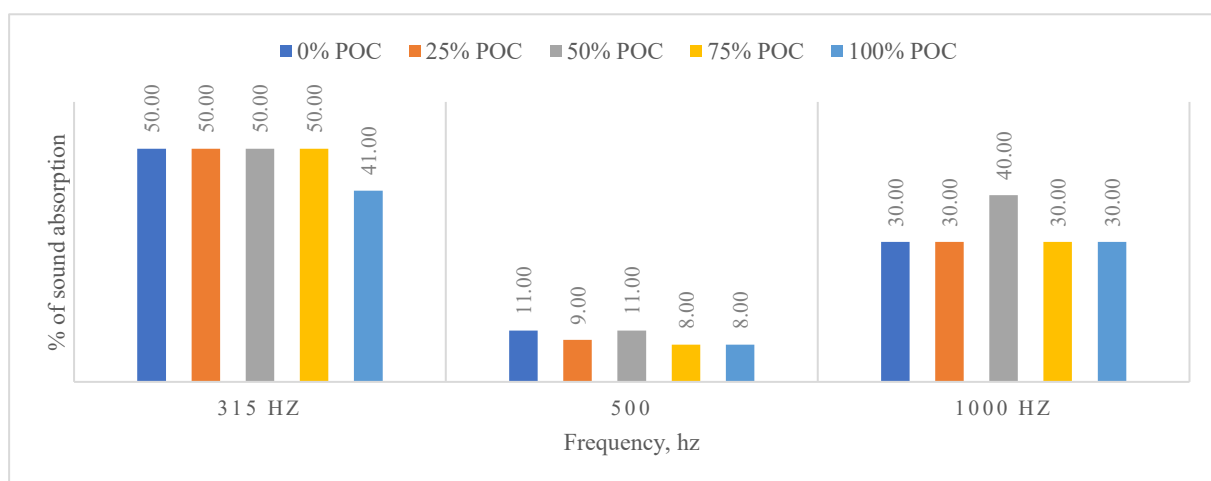


Figure 8. Comparison of percentage of sound absorption for 315 Hz, 500 Hz and 1000 Hz

4. Conclusion

In this paper, the acoustic performance of specimens with and without POC as sound absorber was evaluated. It is found that:

- Specimens with higher content of POC sand have lower density and compressive strength compared with those without POC sand.
- The specimen with full POC replacement has a compressive strength value of 10 N/mm², which is within the limit for non-load bearing material.
- POC sand improves sound absorption at frequency 1000 Hz and noise reduction coefficient.

POC shows good potential to be utilised as acoustic absorber to overcome noise pollution. Additionally, it overcomes the environmental issue of depletion of natural resources used to create traditional construction materials. More research focusing on the effects of thickness of specimen and larger POC size needs to be carried out in order to utilise the existence of macropores and consequently determine the optimum acoustic performance for the purpose of acoustic absorber development.

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