Sound absorption of lightweight brick containing expanded polystyrene beads and palm oil fuel ash

S H Adnan¹, N A Kamarulzaman¹, K A Mohd Sari¹, M H Osman¹, Z Jamellodin², N A Abdul Hamid², A Alisibramulisi², N Abdul Roni³, N I Mohd Yassin² and M N A Wahee Anuar⁴

¹Dept. of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh Muar, Johor, Malaysia
²Dept. of Civil Engineering, Faculty of Civil Engineering and Environmental, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia
³Faculty of Civil Engineering, UiTM Shah Alam, 40000 Shah Alam, Selangor, Malaysia
⁴Melayu Jati Enterprise, 83100 Batu Pahat, Johor Malaysia

Abstract. Bricks are considered as important and strongest materials being used over the years. Commonly, bricks are made of clay mineral and usually used in construction of building wall. The purpose of this study is to assess the effectiveness of palm oil fuel ash (POFA) and expanded polystyrene beads (EPS) as a brick and its suitability as sound absorption material. POFA is used as partial replacement of cement while EPS as partial replacement of sand in the mortar mixture. Various percentages of EPS and POFA have been used which include 0%, 20%, 30%, 40% and 50% as sand replacement and from 0%, 5%, 10%, 15%, 20% and 25% as cement replacement respectively. Sound absorption tests were conducted using impedance tube. From this study, it has been identified that for sound absorption test, lowest result recorded is at maximum 25% POFA replacement with 50% EPS replacement with 0.011 sound absorption coefficient at frequency of 3500 Hz. The best sound absorption coefficient recorded is 0.998 at frequency of 250 Hz for sample with 0% EPS and 20% POFA replacement. It can be recognized that the brick produced have the excellent sound absorption.

1. Introduction

Common brick used in construction nowadays is clay brick. However, the production of clay brick consumed high energy such as burning of fossil fuels and also caused the ongoing mining of clay soil which is not sustainable to the industry. Due to this unsustainable mining, the industry comes with new alternative of cement brick. Nevertheless, the production of cement brick needs large amount of cement which is not environmentally friendly because the manufacturing of cement consumes high energy and each tonne of cement produced will releases approximately one tonne of carbon dioxide (CO₂) into the environment.

Nowadays, recycled materials are often been used as replacement or as an admixture in concrete or mortar due to the environmental pollution caused by existing materials. According to Alsubari et al [1], environmental and greenhouse gas problem is caused by the cement production process which contributes about 7% of the global CO₂ emission. Malaysia is one of the largest producers in palm oil industry [2]. This agriculture-industry has been generating great deal of waste which becomes one of the major contributors to the nation’s pollution problem. Palm Oil Fuel Ash (POFA) is produced from...
the industry and has been discharged in the palm oil mill. Improper disposal of the large quantity of palm oil fuel ash may contribute to future environmental problem [3].

EPS is an industrial solid waste that has been facing a serious problem for disposal. The problem of increase of solid waste is an ecological issue concerned by the world today. Usually, waste materials are burnt or sent to landfills, but the burning of these waste materials caused serious air pollution and the disposal of EPS in landfills also does not provide an environmental-friendly solution since EPS is not biodegradable [4]. According to Kamarulzaman et al [5] and Musab [6], EPS is widely used in packaging world but after it had been used, it becomes waste that cannot decompose naturally. It is light weight, not harmful to human health and it can be found easily. EPS is a plastic category that is used extensively as food containers and packaging. EPS waste is generated from sources of industrial solid waste and municipal alike. It has become a major environmental source of concern because of the increasing amount and volume of solid waste to be disposed of in landfills. The usage of polystyrene to produce concrete brick is definitely to help in reducing amount and volume of solid waste in landfills. Polystyrene is low density, light weight, inexpensive and easily to produce compared to the normal use of sand.

In this developing era, noise from surrounding is a common problem. Noise is an unwanted sound or called as sound pollution. This sound pollution has led to an increase in the need of the materials that can absorb sound to reduce noise. Current sound absorbing materials usually used are made of synthetic, glass and mineral fibers. Glass and mineral fibers are risking human health, such as skin problems and respiratory disorders [7]. Noise is an unwanted sound. Currently, sound absorbing materials capable of commercially available acoustic treatment used in the construction industry building materials containing fibrous materials. The materials applied in building industry are such as asbestos, rock wool and acoustic fiberglass. However, more attention in the health and safety-related issues because of the potential health risks associated with these fibers when exposed to humans as a result of the fiber material into human lungs.

According to the review conducted by Nelson [8], Crystalline silica and asbestos are common minerals that occur throughout South Africa, exposure to either causes respiratory disease. Related issues provide an opportunity to find another alternative material to be developed as a replacement material for the absorption of sound [9]. At this moment, most of the studies regarding sound absorption material were focused preparing sound absorption panel from waste material such as natural fiber, fabric waste and agriculture waste. The panels are usually applied for ceiling and as additional layer for walls. However, the studies of sound absorption in the brick with replacement materials itself are still lacking. This study focuses on producing lightweight brick containing waste replacement and investigating the sound absorption coefficient of the brick. The utilization of EPS and POFA in the concrete mix will also reduce the waste as both materials are industrial by-products that usually being thrown or burned, and this utilization are expected to help in enhancing the sustainability as well as will solve an environmentally problem issue.

2. Experimental study

2.1. Materials
The materials used in this study consist of Ordinary Portland Cement (OPC), fine aggregate (sand), POFA, EPS, water and superplasticizer. The materials were tested for its physical properties.

2.1.1. Cement. In this study, type of cement use as a binder is Ordinary Portland cement referred to Malaysia Standard Specification MS 522: Part 1: 2003 as shown in Figure 1. The particle density of the cement is 1254 kg/m³.
2.1.2. Fine aggregate. Fine aggregate used in this study was natural sand passing through 2 mm sieve as shown in Figure 2. Before it being sieved, the sand were dried in oven for 24 hours at 100°C. The particle density of the sand is 1597.5 kg/m$^3$. Figure 3 shows sieve machine in the laboratory.

2.1.3. Palm oil fuel ash. Palm oil fuel ash used in this study as partial replacement of cement into the mortar mix due to its pozzolanic content. POFA was collected from palm oil processing factory at Pontian, Johor. POFA were produced from burning of palm oil husk and palm oil kernel in the boiler. The raw POFA as shown in Figure 4 was dried in oven at the temperature of 100°C ± 5 for 24 hours to remove the moisture before it is being sieved to size of passing 300 μm. The density of this POFA is
987.49 kg/m³. POFA was also subjected to XRF analysis to determine its chemical composition which is shown in Table 1.

| Chemical Composition | SiO₂   | Al₂O₃  | Fe₂O₃  | CaO   | K₂O   | MgO   | Na₂O   | SO₃  |
|----------------------|--------|--------|--------|-------|-------|-------|--------|------|
| Percentage (%)       | 55.2   | 34.48  | 5.44   | 4.12  | 2.28  | 2.25  | 0.1    | 2.55 |

**Figure 4.** POFA dried in oven.

2.1.4. *Expanded polystyrene beads.* Expanded polystyrene beads used in this study is set to size between 1.18 to 2.36 mm as shown in Figure 5. This EPS was supplied by ST Polyfoam Industries Sdn. Bhd. located in Sri Gading, Batu Pahat. Its particle density is 17.92 kg/m³, while the bulk density and specific gravity of the EPS is 30kg/m³ and 0.01 respectively. EPS is used partial replacement of sand.

**Figure 5.** EPS from the factory.

2.1.5. *Water.* Water is an important material to be added in cement. Reaction between this two materials will achieve cementing property as binder. Water used should be clean and free of any foreign substances because any dirt or impurity can affect the chemical reaction of cement and water. Potable tap water is used for mixing. The ratio of water to cement is determined by weight with ratio of 0.5.

2.1.6. *Superplasticizer.* Superplasticizer is an additional material to improve the workability of the mix. The superplasticizer use is from ESTOP brand. The amount of superplasticizer used was 8 mL per 1 kg of cement. The liquid was added into the mixture after all other materials were mixed together.
Superplasticiser works in such that the molecules in superplasticizer wrapping themselves around the cement particles and induce highly negative charge on the surface. Inter-particle repulsion leads to deflocculation and dispersion of cement particles. Thus, more water is available to improve the workability of the concrete mix [10-11].

2.2. Sample preparation

Sample size is according to standard brick size of 215 mm × 102.5 mm × 65 mm. This dimension is according to BS 4729–1990 standard for brick. Sample of size Ø100 mm and Ø28 mm with thickness of 102.5 mm were produce for sound absorption testing. Various mixes of cement mortar with different percentage of EPS and POFA will be prepare to produce bricks. The mortar mix was design based on 1:3 mixes complies with BS EN 196-1. Water cement ratio was set for 0.5. Control samples without any replacement of EPS and POFA were cast to compare with other samples with replacement of EPS and POFA. Table 2 shows the mix design of cement mortar with various percentages of EPS and POFA.

Table 2. Mix design of cement mortar with various percentages of EPS and POFA.

| EPS | POFA |
|-----|------|
| 0%  | 0%   | 5%   | 10%  | 15%  | 20%  | 25%  |
| 0%  | 1 : 3 | 0.95 : 0.05 | 0.9 : 0.1 : 3 | 0.85 : 0.15 : 3 | 0.8 : 0.2 : 3 | 0.75 : 0.25 : 3 |
| 20% | 1 : 2.4 : 0.6 | 0.95 : 0.05 | 0.9 : 0.1 : 3 | 0.85 : 0.15 | 0.8 : 0.2 : 2.4 | 0.75 : 0.25 : 2.4 |
| 30% | 1 : 2.1 : 0.9 | 0.95 : 0.05 | 0.9 : 0.1 : 3 | 0.85 : 0.15 | 0.8 : 0.2 : 2.1 | 0.75 : 0.25 : 2.1 |
| 40% | 1 : 1.8 : 1.2 | 0.95 : 0.05 | 0.9 : 0.1 : 3 | 0.85 : 0.15 | 0.8 : 0.2 : 1.8 | 0.75 : 0.25 : 1.8 |
| 50% | 1 : 1.5 : 1.5 | 0.95 : 0.05 | 0.9 : 0.1 : 3 | 0.85 : 0.15 | 0.8 : 0.2 : 1.5 | 0.75 : 0.25 : 1.5 |

2.3. Testing

2.3.1 Sound Absorption testing. This test was conducted to measure the level of sound that can be absorbed by the sample. The apparatus used for this testing is impedance tube. This testing complies with standard of ASTM E1050. Two size of sample is produced for this for this testing. Sample of size Ø100 mm is used to measure sound absorption for low frequency between 0 Hz to 1500 Hz while sample of size Ø28 mm is used to measure sound absorption for high frequency between 1500 Hz to 5000 Hz.

3. Results and discussion

The test was conducted for all mix proportions with various percentages of EPS and POFA replacement at age of 28 days.

3.1. Effect of EPS and POFA replacement on sound absorption

This section discussed the result of sound absorption coefficient for all samples of all mix design. The result of sound absorption coefficient test for various EPS and POFA replacement were demonstrated in Figure 6, Figure 7, Figure 8, Figure 9, Figure 10 and Figure 11. From all the result obtained, most of the samples is good in absorbing sound at lower frequency. The maximum sound absorbed is at frequency of 250 Hz with coefficient between 0.783 to 0.998. This value is considered good as it is near to the maximum value of sound absorption coefficient. The maximum absorption recorded is for sample E0P20 at 0.998. At low frequency, the lower sound absorption coefficient is for sample E50P20 at 0.011 only. The lowest coefficient obtained is at higher frequency of 1500 Hz. However, the sound absorption coefficient were started to decrease at frequency of 750 Hz and continue to decrease at higher frequency.
of 1500 Hz to 5000 Hz. At high frequency, the lower sound absorption coefficient is for sample E50P25 at 0.017 only. The lower coefficient obtained is at frequency of 4250 Hz. Meanwhile the higher sound absorption coefficient at higher frequency recorded is 0.419 at frequency of 2500 Hz.

Figure 6 shows the sound absorption coefficient for 0% POFA replacement with various EPS replacement at low and high frequencies. At lower frequency of 0 Hz to 1500 Hz, the control sample recorded the highest coefficient with 0.962 at frequency of 250 Hz. The other samples with 20%, 30%, 40% and 50% EPS replacement also recorded the highest coefficient at frequency of 250 Hz with 0.869, 0.822, 0.817 and 0.802 respectively. The coefficient then decreases dramatically when the frequency increase. However, at high frequency started to 1500 Hz to 5000 Hz the coefficient begin to be constant. The control sample have the highest coefficient between 0.39 to 0.419. The E20P0 and E30P0 samples have coefficient between 0.259 to 0.432. Sample of E40P0 have constant coefficient between 0.219 to 0.272. Meanwhile the maximum EPS replacement recorded the lowest and fluctuated result. The coefficient are between 0.019 to 0.219.

**Figure 6.** Graph of sound absorption coefficient frequencies against frequency for sample with various EPS replacement and 0% POFA replacement

**Figure 7.** Graph of sound absorption coefficient frequencies against frequency for sample with various EPS replacement and 5% POFA replacement.
Figure 7 shows the sound absorption coefficient for 5% POFA replacement with various EPS replacement at low and high frequencies. At frequencies 0 Hz to 1500 Hz sample with 0% EPS have the greatest coefficient of 0.992 followed by 0.892, 0.829, 0.819 and 0.791 for 20%, 30%, 40% and 50% EPS replacement respectively. The highest coefficient for all the samples recorded at frequency of 250 Hz. Besides, at high frequency the coefficient are not as high as at low frequency. However it shows the same pattern as before. The control sample have the best coefficient, while the highest EPS replacement recorded the lowest coefficient. The lowest coefficient is 0.077 at frequencies of 3250 Hz.

Figure 8 shows the sound absorption coefficient for 10% POFA replacement with various EPS replacement at low and high frequencies. The highest sound absorption coefficient recorded at frequencies of 250 Hz. The coefficient obtained for E0P10, E20P10, E30P10, E40P10 and E50P10 were 0.975, 0.888, 0.829, 0.811 and 0.789 respectively. The lowest sound absorption coefficient for E0P10 sample is 0.255 at 5000 Hz, 0.286 at 4500 Hz for E20P10 sample, 0.295 at 2750 Hz for E30P10 sample, 0.14 at 1250 Hz for E40P10 sample and 0.006 at 4250 Hz for E50P10 sample.

Figure 9 shows the sound absorption coefficient for 15% POFA replacement with various EPS replacement at low and high frequencies. The highest coefficient recorded also at 250 Hz which is at low frequency. The coefficient obtained were 0.99 for E0P15 sample, 0.889 for E20P15 and E30P15 sample, 0.812 for E40P15 sample and 0.793 for E50P15 sample. The coefficient decreases as the EPS replacement increase. Sample of E50P15 recorded the lowest coefficient at high frequency which is 0.04 at 4250 Hz.

Figure 10 and Figure 11 shows the sound absorption coefficient for 20% and 25% POFA replacement with various EPS replacement from low to high frequencies. At the frequencies of 250 Hz, all the samples absorb the highest sound. After that, the sound absorption coefficient then started to decrease when the frequency of sound increase. At high frequency of 1500 Hz to 5000 Hz, the coefficient start to become constant. Samples with 0% EPS replacement have the highest coefficient followed by 20%, 30%, 40% and 50% EPS replacement.
Figure 9. Graph of sound absorption coefficient frequencies against frequency for sample with various EPS replacement and 15% POFA replacement.

Figure 10. Graph of sound absorption coefficient frequencies against frequency for sample with various EPS replacement and 20% POFA replacement.

Figure 11. Graph of sound absorption coefficient frequencies against frequency for sample with various EPS replacement and 25% POFA replacement.
The patterns from both low and high frequencies show that the increasing of POFA replacement affect on decreases the sound absorption coefficient. However, the different are only in minimal range. Meanwhile the increasing of EPS replacement also results in decreasing of sound absorption properties. The EPS replacement give more impact and effect the decreases of sound absorption coefficient. This result shows that the lower density have lower sound absorption coefficient. However, most of the researchers found different result. One of them is Park et al [12] that conducted studies on the sound absorption characteristics of porous concrete based on the content of recycled aggregate and target void ratio. Samples with higher void ratio of 28.3%–31.5% recorded the optimum sound absorption coefficient of 9.7 at low frequency of 700 Hz, while at high frequency of 1750 Hz, the absorption recorded is 0.65. This studied proved that the samples with higher void content will absorb more sound.

Maekawa and Lord [13] in the book of Environmental and Architectural Acoustics stated that when sound wave impinge on a porous material containing capillaries or continuous airway such as found in glass wool, rock wool and porous form, they propagate into the interstices in which a part of the sound energy is dissipated by frictional and viscous losses within the pores and by vibration of small fibres of the material. The absorption is large at high frequencies and small at low frequencies. Another factor might affect the sound absorption coefficient. Such as the surface of the sample. In this study, the brick with less EPS replacement have rough surface compared to brick with more EPS replacement. The brick with high amount of EPS replacement have excess water content as the EPS is hydrophobic. The excess water content caused the surface of the brick become smooth when the brick is harden. This may affect the sound is hard to penetrate into the brick. The smooth surface tend to reflect the sound instead of absorbing it.

4. Conclusion
For sound absorption test, lowest result recorded is at maximum 25% POFA replacement with 50% EPS replacement with 0.011 sound absorption coefficient at frequency of 3500 Hz. According to ISO (1997) at this coefficient value, no sound is absorbed. The best sound absorption coefficient recorded is 0.998 at frequency of 250 Hz for sample with 0% EPS and 20% POFA replacement. The brick have the excellent sound absorption. All the brick sample with various EPS and POFA replacement can absorb maximum sound absorption coefficient at low frequency of 250 Hz. The coefficient recorded are between 0.783 to 0.998. It can be concluded that all the brick sample is good in absorbing sound at lower frequency.

Acknowledgement
The authors gratefully to acknowledge the Ministry of Education and Universiti Tun Hussein Onn Malaysia for providing the financial support through the Fundamental Research Grant Scheme (1618)

References
[1] Alsarari B Shafigh P and Jumaat M Z 2016 J. Clean. Prod. 137 982–996
[2] Raut A N Gomez C P 2015 Constr. Build. Mater. 126 476-483
[3] Megat J M A, Zeyad A M Muhammad B N and Ariffin K S 2012 Constr. Build. Mater. 30 281-288
[4] Ling I H and Teo D C L Teo 2013 Jordan J. of Civ. Eng. 7 4
[5] Kamarulzaman N A Adnan S H Mohd Sari K A Osman M H Ahmad Jeni M L Abdullah M S Ang S E Yahya N F Yassin N I M Wahee Anuar M N A 2018 Journal of Science and Technology 10(4) 41-46
[6] Musab A S A 2016 The Mechanical and Physical Properties of Concrete Containing Polystyrene Beads as Aggregate and Palm Oil Fuel Ash as Cement Replacement Material (Universiti Tun Hussein Onn Malaysia: Master Thesis)
[7] Awal A S M A and Mohammadhosseini H 2016 J. Clean. Prod. 137 157-166
[8] Nelson M E Munthor A L Tanim A S and Pakrashi M N H 2013 J. Clean. Prod. 78 195–201
[9] Kamarudin N H A Hussin M W Mirza J N Ariffin F Ismail M A Lee H S Mohamed A and Jaya R P 2016 Constr. Build. Mater. 102 950-960
[10] Mindess S Francis J Y and Darwin D 2003 Concrete (Upper Saddle River, New Jersey : Pearson Education Inc.) 2nd ed
[11] Neville A M 1995 Properties of Concrete – Fourth and Final Edition (Essex : Addison Wesley Longman Limited)
[12] Park S B Seo D S and Lee J 2005 Cement and Concrete Research 35 1846-1854
[13] Maekawa Z and Peter L 1994 Environmental and Architectural Acoustics (London : E & FN Spon)