Performance in Thermal Conductivity of Bricks Containing Palm Oil Fuel Ash and Expanded Polystyrene Beads

S H Adnan¹, N K Zolkefli¹, M H Osman¹, M L Ahmad Jeni¹, Z Jamellodin², N A Abdul Hamid², A Alisibramulisi², N Abdul Roni¹ and M N A Nor Akasyah⁴

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
*Corresponding author:suraya@uthm.edu.my

Abstract. Sustainable development has encouraged us to sustain the balance between the development of the country and the biodiversity conservation. Productions of lightweight bricks with thermal conductivity and density that have acceptable compressive strength are accomplished. Palm oil fuel ash (POFA) was used as partial cement replacement and an expanded polystyrene (EPS) beads was used as sand replacement to manufacture of bricks. In this study, the control sample with a Cement: POFA: Sand: EPS ratio of 1.0: 0: 3.0: 0 were produce. The cement in the sample is replace by 25% of POFA and 0%, 20%, 30%, 40%, 50% of EPS. In this study, the test conducted was a thermal conductivity test and density test of the POFA, EPS beads and brick raw material. This sample was cured under full air-dry curing conditions were applied in this experiment. The density of bricks containing 0% of EPS Beads with 25% of POFA are higher than that of brick containing 50% of EPS Beads with 25% of POFA which are 1850 kg/m³ and 1357.14 kg/m³, respectively. The higher the percentage of EPS beads, the lower the brick’s density. The thermal conductivity of bricks containing 0%, 20%, 30%, 40% and 50% EPS with 25% POFA show that brick containing 50% EPS with 25% POFA have a lower thermal conductivity with 0.09 W/m°C due to the density of the sample.

1. Introduction

Bricks are small and rectangular blocks that can be used to form parts of buildings, typically walls. The use of bricks dates back to before 7000 BC, when the earliest bricks were formed from hand-moulded mud and dried sun. Bricks are usually laid flat and bonded forming a structure to increase its stability and strength. It was divided into two types of bricks which are clay brick and sand lime brick. The clay brick is produced by using clay and it will be fired at high temperatures. Clay bricks are used in walls; they are required plastering or rendering. Sand lime bricks are made by mixing sand, fly ash and lime followed by a chemical process during wet mixing.

The reuse of waste that is incorporated into construction materials is a good way to preserve natural raw materials, save energy, reduce pollutant emissions and eliminate landfill costs. Expanded polystyrene (EPS) beads is a waste material which is used in sustainable quantities as a packaging material or as an insulating material. EPS has a very low density [1]. Palm oil fuel ash (POFA) is one of the agro waste ashes whose chemical composition contains a large amount of silica and can be used
as cement replacement [2]. The used of palm oil fuel ash (POFA) can reduced the production cost of building material and reduce the environmental impact from the waste.

2. Experimental Study

2.1. Materials

The materials used in this study are Ordinary Portland Cement (OPC), fine aggregate (sand), palm oil fuel ash (POFA), expanded polystyrene (EPS), tap water and superplasticizer.

2.1.1. Cement

In this study, type of cement used is Ordinary Portland cement (OPC) which referred to Malaysia Standard Specification MS 522: Part 1: 2003.

2.1.2. Fine Aggregate

Fine aggregate used in this study is river sand.

2.1.3. Palm Oil Fuel Ash (POFA)

In this study, POFA has been used as a replacement material of cement in the brick mix due to its pozzolanic characteristic [3]. The percentage of replacement is 0% and 25% from the cement content. POFA was collected from palm oil processing factory at Pontian, Johor. POFA was produced from the burning of palm oil husk and palm oil kernel in the boiler. The raw POFA as shown in Figure 1 was dried in oven at the temperature of 100 °C ± 5 for 24 hours to remove the moisture before it being sieved to size of passing 300μm.

![Figure 1. Palm Oil Fuel Ash (POFA)](image)

2.1.4. Expanded Polystyrene (EPS)

Expanded polystyrene used in this study is spherical in shape. The diameter of the EPS is between 1.18 mm to 2.36 mm as shown in Figure 2. This EPS was supplied by ST Polyfoam Industries Sdn. Bhd. located in Sri Gading, Batu Pahat. It density is 17.92 kg/m³. It has been used as replacement material of sand in which the percentage of replacement was varied from 0%, 20%, 30%, 40% and 50% from the sand volume. Bulk density and specific gravity of the EPS is 30 kg/m³ and 0.01, respectively.
2.1.5. Water
In this study, tap water was used for mixing whilst the water-cement ratio used is 0.5.

2.2. Samples Preparation
For this study, there are two sizes of bricks have been produced. The rectangular bricks with dimension of 215 mm × 102.5 mm × 65 mm have been prepared for density test. On the other hand, for the thermal conductivity test, the size bricks used are 300 mm x 300 mm x 25 mm. Table 1 and Table 2 shows the mix ratio of cement brick with various percentages of EPS and POFA.

Table 1. Samples and mix proportions for density test

| Sample name | Cement (kg) | POFA (kg) | Sand (kg) | Polystyrene beads (g) |
|-------------|-------------|-----------|-----------|-----------------------|
| Control     | 0.713       | 0         | 2.14      | 0                     |
| E0P25       | 0.535       | 0.178     | 2.14      | 0                     |
| E20P25      | 0.535       | 0.178     | 2.13      | 5.74                  |
| E30P25      | 0.535       | 0.178     | 2.13      | 8.61                  |
| E40P25      | 0.535       | 0.178     | 2.125     | 11.43                 |
| E50P25      | 0.535       | 0.178     | 2.125     | 14.35                 |

Table 2. Samples and mix proportions for thermal conductivity test

| Sample name | Cement (kg) | POFA (kg) | Sand (kg) | Polystyrene beads (g) |
|-------------|-------------|-----------|-----------|-----------------------|
| Control     | 1.114       | 0         | 3.341     | 0                     |
| E0P25       | 0.835       | 0.279     | 3.341     | 0                     |
| E20P25      | 0.835       | 0.279     | 3.338     | 2.98                  |
| E30P25      | 0.835       | 0.279     | 3.337     | 4.47                  |
| E40P25      | 0.835       | 0.279     | 3.335     | 5.96                  |
| E50P25      | 0.835       | 0.279     | 3.334     | 7.45                  |
2.3. Testing

2.3.1. Density Test
Density test is to carry a formal and fresh density check of concrete. The purpose of density test is to obtain the yield of the mix. The density is calculated as mass per unit volume as given by the following equation (1):

\[
\text{Density} = \frac{\text{Mass (M)}}{\text{Volume (V)}}
\]  

(1)

2.3.2. Thermal Conductivity Test
Thermal Conductivity is a molecular process that compromises an exchange of kinetic energy from one molecule to the next. For metals, thermal conduction takes place, along with molecular oscillations, also due to electron flows that increase the conductance. In such materials, electrons are not bound in a fixed place, but wander around the lattice structure where this is the reason which cause the electrical conductors have significantly higher thermal conductivity than electrical insulators.

2.3.3. Compressive Strength
For compressive strength test was done to determine the strength of concrete cube. The calculation for compressive strength was measured by maximum load per area of cube mould as shown by equation (2).

\[
\text{Compressive strength (N/mm}^2\text{) = } \frac{\text{Maximum load (kN) x 1000}}{\text{Area of cube mould (mm}^2\text{)}}
\]  

(2)

3. Results and Discussion

3.1. Density Test
The density results of the samples is obtained from the testing of 7 days and 28 days with different percentage of Palm Oil Fuel Ash (POFA) and Expanded Polystyrene beads (EPS) are detailed in this chapter respectively.

3.1.1 Density with various percentage EPS and 25% of POFA
The result of density at ages of (7 and 28) days for all the bricks containing 0%, 20%, 30%, 40% and 50% of EPS Beads with 25% of POFA and the relationships between the density and the all specimens respectively as shows at Figure 3. In this work, it can easily be said that density decreases with the amount of POFA [3] and EPS beads contains of bricks [4-5]. The higher the percentage of EPS Beads, density of brick will be lower than control sample. Bricks containing 0% of EPS beads with 25% of POFA are more values than brick containing 50% of EPS beads with 25% of POFA.
3.2. **Thermal Conductivity Test**

The thermal conductivity results of the samples is obtained from the testing of 28 days with 25% of Palm Oil Fuel Ash (POFA) and different percentage of Expanded Polystyrene beads (EPS) are detailed in this chapter respectively.

3.2.1. **Thermal Conductivity with various percentage EPS and 25% of POFA**

Building material vary in their ability to transfer the heat. Thermal conductivity is defined as the amount of heat transmitted through the unit of area by the unit of thickness. In general, most of the published research about the thermal properties of lightweight concrete has been concerned with thermal conductivity. The reasons for this are thermal conductivity a good indicator of the thermal performance of concrete. Many studies have pointed out that the thermal conductivity of lightweight brick varied with the density. This normally due to the lower thermal conductivity of air, this occupies a considerable mass with in lightweight brick.

The thermal conductivity results with various percentages of EPS beads and POFA are shown in Figure 4. The percentages of EPS are 20%, 30%, 40% and 50% containing 25% of POFA cured in air for 28 days. These results showed that the brick containing E0P25 have the lower thermal conductivity than control sample which are 0.15 W/m°C for E0P25 and 0.18 W/m°C for control. The lowest thermal conductivity was E50P25 which have a value 0.09 W/m°C. Therefore, thermal conductivity of brick containing 50% of EPS beads and 25% of POFA is one of the most important indicators in thermal design. The porosity in E50P25 has the greatest influence on thermal conductivity. Good brick should have low thermal conductivity, so that the buildings that use this brick keep cool in summer and warm in winter. The main reason behind this result is due to the density of the specimens. It is well known by lowering the density of brick, a lower thermal conductivity is achieved. In addition, increasing of porous and voids number in the specimen decreases the thermal conductivity because those porous and voids obstruct thermal transmission through the specimen. The standard value of thermal conductivity of bricks that can be used in the outside world is 0.69 W / m °C and down and for bricks containing EPS the value is 0.033-0.046 W / m °C.
3.3. Compressive Strength

The compressive strength results of the samples is obtained from the testing of 7 and 28 days with 25% of Palm Oil Fuel Ash (POFA) and different percentages of Expanded Polystyrene beads (EPS) are detailed in this chapter respectively.

3.3.1. Compressive Strength with 25% of POFA and various percentages of EPS Beads

The compressive strength results with various percentages of EPS beads and POFA are shown in Table 3. The percentages of EPS are 0%, 20%, 30%, 40% and 50% containing 25% POFA. It can be seen from Figure 5 that the control sample have maximum compressive strength other than other sample. The compressive strength of samples increases with increase in age of the samples but decreased with increasing of EPS beads content. It can be seen that the sample with 0% EPS beads containing 25% POFA have highest compressive strength after control sample. This is due to greater bonding contributes from POFA [6]. Control sample has a higher compressive strength than E0P25 because the result water absorption E0P25 is related to the brick strength. This is due to the absence of EPS content, so absorbing water is POFA. POFA has absorbed a lot of water and causes lower pozzolanic reactions [3]. So compressive strength dropped sharply.

For sample that replaced 20%, 30%, 40% and 50% EPS containing 25% of POFA at 28 days, the result shows that 20% EPS containing 25% POFA have the highest compressive strength with 6.9 MPa and 50% EPS containing 25% POFA have the lowest compressive strength with 5.4 MPa. According to Adnan et al [6], the result shows that the sample with the replacement of 50% EPS beads containing 10% POFA have higher compressive strength with 11.8 MPa than the sample containing 15% and 20% POFA for concrete at 28 days. The increase in strength of polystyrene lightweight concrete with POFA could be attributed to the improvement in the bond between the hydrated cement matrix and the fine aggregate.
Table 3. Result of compressive strength with various percentages of EPS and 25% of POFA on 7 and 28 days

| Sample  | 7 days | 28 days |
|---------|--------|---------|
| Control | 25.7   | 27.4    |
| E0P25   | 7.4    | 9.3     |
| E20P25  | 6.4    | 6.9     |
| E30P25  | 5.1    | 6.3     |
| E40P25  | 4.5    | 5.6     |
| E50P25  | 3.7    | 5.4     |

Figure 5. Compressive strength with various percentages of EPS and POFA on 7 and 28 days

4. Conclusion
For the conclusion, the thermal conductivity of bricks containing 0%, 20%, 30%, 40% and 50% EPS with 25% POFA show that brick that containing 50% EPS with 25% POFA have a lower thermal conductivity with 0.09 W/m°C due to the density of the sample. It is well known by lowering the density of brick, a lower thermal conductivity is achieved. It was conclude that the density of bricks containing 0% of EPS beads with 25% of POFA are more values than brick containing 50% of EPS beads with 25% of POFA which are 1850 kg/m³ and 1357.14 kg/m³ respectively. The higher the percentage of EPS beads, density of brick will be lower. The compressive strength of 0%, 20%, 30%, 40% and 50% of EPS beads containing 25% POFA show that 0% of EPS beads containing 25% POFA have higher compressive strength with 9.3% after control sample due to greater bonding contributes from POFA.

5. References
[1] Ling I H and Teo D C L 2011 Properties of EPS RHA lightweight concrete bricks under different curing conditions Constr. Building Mater. 25(8) 3648–3655
[2] Ahmad M H, Omar R C, Malek M A, Md Noor N and Thiruselvam S 2008 Compressive Strength of Palm Oil Fuel Ash Concrete International Conference On Construction and Building Technology 27 297–30
[3] Ekhlasur M, Lye A, Setyo A, Hashem N and Pakrashi V 2014 Performance of masonry blocks incorporating Palm Oil Fuel Ash J. Cleaner Prod. 78 195–201

[4] Chen B, Liu J and Chen L Z 2010 Experimental study of lightweight expanded polystyrene aggregate concrete containing silica fume and polypropylene fibers Journal of Shanghai Jiaotong University (Science) 15(2) 129-137

[5] Fang C and Chen B 2011 Mechanical properties of EPS lightweight concrete Proceedings of the Institution of Civil Engineers - Construction Materials 164 173–180

[6] Adnan S H, Alfatih M, Abadalla S and Jamellodin Z 2017 The Mechanical and Physical Properties of Concrete Containing Polystyrene Beads as Aggregate and Palm Oil Fuel Ash as Cement Replacement Material AIP Conference Proceedings 1891 020016