Effects of Curing Conditions on Properties of Lightweight Concrete Brick Containing Expanded Polystyrene and Palm Oil Fuel Ash

N I M Yassin\textsuperscript{1}, S H Adnan\textsuperscript{2}, S Shahidan\textsuperscript{1}, S S Ayop\textsuperscript{1}, N A Kamarulzaman\textsuperscript{2} M H Osman\textsuperscript{2}, Z Jameloddin\textsuperscript{1}, M Majid\textsuperscript{1}, N Salleh\textsuperscript{1}, A Alisibramulisi\textsuperscript{1}, M N A Wahee Anuar\textsuperscript{4}

\textsuperscript{1}Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, MALAYSIA
\textsuperscript{2} Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh, Johor, MALAYSIA
\textsuperscript{3}Faculty of Civil Engineering, UiTM Shah Alam, 40450 Shah Alam, Selangor, MALAYSIA.
\textsuperscript{4}Melayu Jati Enterprise, Batu Pahat, 83000 Johor, MALAYSIA.

Corresponding author: suraya@uthm.edu.my

Abstract. This study presents the effect of curing conditions towards properties of lightweight concrete brick made up of cement, sand and some replacement materials. The replacement materials used in this study is Expanded Polystyrene (EPS) as sand replacement and Palm Oil Fuel Ash (POFA) as cement replacement. The percentage of replacement for POFA is 0%, 10% and 20% whilst 0%, 30% and 50% for EPS. The brick samples have been exposed to different types of curing conditions that is air curing and water curing until the day of test. Among the tests that have been conducted are hardened brick density, compressive strength and water absorption. Based on the findings, it has been proved that the replacement percentage of EPS and POFA has significant impacts towards the brick properties. In addition, it is found that hardened brick density and compressive strength of air curing samples are lower as compared to water curing samples meanwhile the water absorption for air curing samples are higher that water curing samples.

1. Introduction
Sustainability awareness become great concern in every construction industries in Malaysia. Due to high demand in sustainable building materials from industries, Malaysian researchers have done abundance of research on the production of sustainable building materials such as concrete and bricks. The production of sustainable building materials can be produced by lessen the usage of natural resources such as cement and replace it with waste materials such as palm oil fuel ash (POFA), rice husk ash (RHA), silica fume and fly ash [1–4].

In addition, the production of lightweight building materials is equally important. This is because it could reduce the manufacturing and transportation cost as well as minimize the total dead load of a building [5]. One of the most preferable lightweight material use in the production of lightweight building materials is Expanded Polystyrene (EPS). Therefore, this study is focusing on the production of sustainable lightweight building materials which is lightweight concrete brick containing EPS and POFA.
According to Babu et al [6] EPS is stable low density foam of non-absorbent, hydrophobic and closed cell structure which is suitable to be used as lightweight aggregates in the production of lightweight building materials. Furthermore, based on Ferrandiz-Mas et al [7], the use of EPS will not cause any hazardous to environment. Until now, EPS has been widely used as lightweight building material due to its characteristic which is extremely light. Previous researches show that EPS has significantly contribute to the reduction of brick density [2] [4-5] [7-21].

Meanwhile, POFA is one of the agricultural waste vastly generated by palm oil industries from the burning process of extracted palm oil fibers and shells in the palm oil mill. Since Malaysia is known as one of the largest palm oil producer in the world, hence vast amount of POFA has been generated annually. Rapid generation of POFA causes increase in the landfill areas. Besides, the waste did not give any profit to industries because it could not be used as fertilizer. Therefore, due to these problems, Malaysian researchers have conducted many of studies on the potential of POFA as the replacement of cement in the construction materials since POFA can act as the pozzolanic materials [22].

Based on previous research, an optimum amount of POFA could enhance the strength performance of concrete. For instance, 10% of cement replacement by POFA has increased the concrete strength as compared to normal concrete [23, 24].

Hence, this study has focus on properties of concrete brick containing EPS and POFA that has been exposed to different types of curing conditions. Among brick properties that has been tested are density, compressive strength and rate of water absorption.

2. Sample preparation

2.1. Materials Preparation

In this study, raw materials that have been used for the production of brick are Ordinary Portland Cement (OPC), river sand, POFA, EPS, tap water and super plasticizer.

2.1.1 Ordinary Portland cement (OPC)

The classification of OPC used in this study is type 1 based on the ASTM C150. The supplier for this cement is Tasek Corporation Berhad which certified by SIRIM. Cement need to be stored in an air tight container to prevent any moisture contact. The chemical composition of OPC has shown in Table 1.

2.1.2 Palm Oil Fuel Ash (POFA)

POFA was obtained from one of Palm Oil mill in Batu Pahat, Johor. Initially, the ash was dried in oven at 105°C for 24 hours in order to remove the moisture content. After dried, POFA was sieved by 300µm sieve passing. Table 1 shows the chemical composition of POFA obtained from the XRF analysis meanwhile Figure 1 shows the scanning electron microstructure of POFA.

| Chemical Composition         | OPC   | POFA  |
|-----------------------------|-------|-------|
| Silicon Dioxide (SiO$_2$)   | 14.6  | 55.20 |
| Aluminium Oxide (Al$_2$O$_3$)| 3.95  | 4.48  |
| Ferric Oxide (Fe$_2$O$_3$)  | 3.46  | 5.44  |
| Calcium Oxide (CaO)         | 57.1  | 4.12  |
| Potassium Oxide (K$_2$O)    | 0.51  | 2.28  |
| Magnesium Oxide (MgO)       | 1.62  | 2.25  |
| Sodium Oxide (Na$_2$O)      | -     | 0.1   |
| Sulfur Trioxide (SO$_3$)    | 3.43  | 2.25  |
2.1.3 Fine Aggregates (sand)
In this study, river sand has been used as fine aggregates. River sand was sieved by sieve plate to ensure that it does not consist any impurities and in order to have a consistent size. Earlier than that, a process of oven dried for a minimum of 24 hours at the temperature of 105±5 °C was conducted. In this research, the sieve analysis of sand was as accordance to ASTM C 136.

2.1.4 Expanded Polystyrene (EPS)
The size of EPS used in this study was between 1.18mm to 2.36mm. EPS used was collected from ST Polyfoam Industries Sdn. Bhd which located in Batu Pahat, Johor.

2.2. Brick sample preparation
For this study, 9 types of concrete brick samples were prepared. The bricks were divided into 3 different group (I, II and III) according to percentage of EPS which is 0% for group I, 30% for group II and 50% for group III. Meanwhile the percentage of POFA is 0%, 10% and 20%. Water cement ratio for this study is 0.5 and super plasticizer is 8 ml for every 1 kg binder. The size of the brick for this study is 215 mm x 103 mm x 65 mm. The mix proportion of bricks as shown in Table 2.

| Table 2. Mix proportions of brick (kg/m³) |
|------------------------------------------|
| group | samples | cement | POFA | sand | EPS | Total |
|-------|---------|--------|------|------|-----|-------|
|       |         |        |      |      |     | samples |
| I     | E0P0(c) | 495.34 | -    | 1484.72 | - | 15 |
|       | E0P10   | 445.14 | 50   | 1484.72 | - | 15 |
|       | E0P20   | 395.83 | 100  | 1484.72 | - | 15 |
| II    | E30P0   | 495.34 | -    | 1038.19 | 5.98 | 15 |
|       | E30P10  | 445.14 | 50   | 1038.19 | 5.98 | 15 |
|       | E30P20  | 395.83 | 100  | 1038.19 | 5.98 | 15 |
| III   | E50P0   | 495.34 | -    | 744.44  | 9.96 | 15 |
|       | E50P10  | 445.14 | 50   | 744.44  | 9.96 | 15 |
|       | E50P20  | 395.83 | 100  | 744.44  | 9.96 | 15 |

2.2.1 Mixing and casting process of bricks
Due to the tendency of EPS to float during mixing process, the sequence of mixing process should be followed in order to avoid the occurrence of segregation. Therefore, sand, POFA and cement were first added and mixed well before water and superplasticizer were added. After 5 minutes of mixing, the EPS was added and thoroughly mixed in the concrete mixture for another 3 minutes. The concrete mix was then casted into timber moulds. To minimize the segregation of EPS, the mix was compacted by hand.
tamping instead of vibration compaction. Once the concrete mix was fully compacted into the moulds, the samples were directly covered by plastic sheet for 24 hours before they were demoulded.

After demoulded, all the samples were exposed to two different curing conditions where the first curing condition was air curing (AC) where the samples were stored in the laboratory with room temperature. Meanwhile, the second curing condition was water curing (WC) where the samples were fully immersed into the water tank until the day of test.

3. Test Methods

3.1. Hardened brick density
In determining the density of the brick samples, the test was conducted according to BS EN 12390-7 in which determination of the brick mass will be as-received condition. The density of the sample is calculated by dividing the brick mass with the brick volume. The measurement of density was conducted at the age of 7 and 28 days. For this test, six samples were prepared for every mix proportion.

3.2. Compressive strength test
Compressive strength test for this study was conducted according to ASTM C140-11a. For this test, six brick samples were prepared for every mix proportion and all the samples tested are full-sized. Any excess moisture or any particles must be removed from the brick surface and the loading plate of the machine before conducting the test. The brick samples then exposed to air curing and water curing until the day of test. For this test, the samples were also tested at the age of 7 and 28 days.

3.3. Water Absorption Test
Water absorption test was conducted in order to determine the percentage of the water absorption by the brick. The test was according to the BS 1881: 122. Initially, the brick samples were dried in the oven at 100±5°C for 24 hours. The samples were then left to cool down before been immersed in the water tank for another 24 hours. The weight of samples were taken before and after the samples were immersed in the tank in order to determine the percentage of the water absorption. This test was conducted at the age of 28 days. For this test, three samples were prepared for every mix proportion.

4. Result and Discussion
The following sections discuss the outcomes from this study.

4.1. Hardened brick density
Based on Figure 2, it shows the hardened brick density for group I (a), group II (b) and group III (c). Group I, II and III show hardened brick density for brick samples with 0%, 30% and 50% of EPS respectively. Based on the result, it shows that the density of all samples are decrease as the percentage of POFA increase. The same result was found for each group. This might due to the fineness of POFA which is coarser than cement. Coarser structure of POFA has increased the formation of porosity in the brick. Therefore, this has increased the air voids which contribute in the reduction of the brick density. Similar finding has been found by Rahman et al [25] where they have figured out that, coarser size of POFA has contributed in the reduction of the masonry block density as compared to the ground POFA which are finer in structure.

In group I, it can be seen that for 7 and 28 days, all samples that exposed to air curing condition have lesser density as compared to water curing samples. For example at 7 days, E0P0 (AC) has density of 2150 kg/m³ meanwhile E0P0 (WC) has density of 2161 kg/m³. It shows that, density of water curing samples is 0.5% higher than air curing samples. Meanwhile, at 28 days, it has found that, density of water curing samples is 5% higher than air curing samples. This has shown that, brick ages also give impact towards brick density. This might due to the hardening process where more water were absorbed during the hydration process.

In group II, it was observed that, hardened brick density for each brick was significantly decreased. This is due to 30% of sand replacement by EPS. The same behaviour was observed in this group, where samples that exposed to air curing have lesser density as compared to water curing samples. However,
it is found that, the increment of density of brick in water curing is lesser as compared with the group I. For instance, at 7 days, E30P0 (AC) brick has density of 1778.57 kg/m$^3$ whilst E30P0 (WC) brick has density of 1779.83 kg/m$^3$. The increment of density is 0.07% and for 28 days, the increment is 2 to 3% only. This might due to the characteristic of EPS that is non-absorbent.

Next, for group III, it was observed that all samples have achieved the lightweight brick density accordance to ASTM C90 where lightweight brick density should be less than 1681.94 kg/m$^3$. In this group, the increment of brick density in water curing condition as compare with air curing is same as shown for group II. This is because the behaviour of brick density was affected by the existing of EPS.

![Group 1](image1)
![Group II](image2)
![Group III](image3)

**Figure 2.** Hardened brick density of group I, II and III under different curing conditions

### 4.2. Compressive strength

Figure 3 summarizes the compressive strength of each group under different curing conditions. Generally, based on those figures it can be seen that, all samples in each group either with air curing or with water curing show decrement in compressive strength as the percentage of POFA increase. However, at 28 days, brick of E0P10 (AC) for group I has higher compressive strength as compared to E0P0 (AC). From this, 10% of POFA is the optimum cement replacement for air curing condition. On the other hand, for water curing, it is observed that E0P0 has the highest compressive strength compared to other samples that contains POFA. This is because, in the existing of water, the hydration process of normal brick (0% of POFA) is faster as compared to POFA brick where the pozzolanic reaction is slower at the early age.

From group I, at 7 days, the strength of E0P10 for AC and WC is same. Meanwhile, for E0P20, the compressive strength is higher at AC compared to WC. At 28days, E0P10 (WC) and E0P20 (WC) have higher strength compared AC samples. This is because, pozzolanic reaction between silicon dioxide of POFA and calcium hydroxide from cement hydration occurred due to the existing of water [2].

For group II, it can be seen that, the compressive strength of all samples is significantly decrease. This is due to the existing of EPS that is extremely low in strength [26]. However, the strength of each sample is increase in the water curing condition as compared to air curing. The same pattern is observed for brick for group III where the strength is decrease due to increase in EPS replacement and yet the
strength shows an increment for water curing conditions. Although the bricks in group III are lower in strength yet the strengths are above the minimum strength for non-load bearing brick which is 3.75 Mpa as stated in ASTM C129.

![Group I](image1.png)  ![Group II](image2.png)  ![Group III](image3.png)

**Figure 3.** Compressive strength of group I, II and III under different curing conditions

### 4.3. Water Absorption

Figure 4 shows the summary of water absorption for 9 types of brick samples with different curing conditions. As stated earlier, water absorption test was conducted only at 28 days. Generally, from the figure, it can be seen that water absorption of air curing samples is higher compared to water curing samples. This is because, samples of air curing condition contained more air capillaries. Therefore, when all the samples immersed in the water for 24 hours, more water was absorbed into the air capillaries. Meanwhile, for water curing samples, all the capillaries were already filled with water. Therefore, water absorption of water curing samples are lower as compared to samples at air curing.

In addition, water absorption of the bricks also influenced by the percentage of replacement materials. As can be seen, the percentage of water absorption of samples increase as the percentage of POFA increase. This is due to the characteristic of POFA which is coarser in structure as compared to cement. Coarser structure of POFA has caused formation of voids in the brick samples. Additionally, POFA also has high water absorption properties. Therefore, samples with high percentage of POFA absorbed more water. On the other hand, water absorption of brick samples decrease as the percentage of EPS increase. For example, water absorption of E0P0 (WC) is 7.6% meanwhile, water absorption of E50P0 (WC) is 2.74%. The reduction of water absorption is due to the increment of EPS that is a non-absorbent materials [27].
5. Conclusion

In conclusion, the replacement of POFA and EPS is significantly affects the density of the brick. As the percentage of replacement materials increase, the density of the brick decrease. In this study, maximum replacement of materials is 50% of EPS and 20% of POFA has reduced the density of the brick up to 34% from normal brick. This indicates that, EPS and POFA are high potential materials for the production of lightweight. Meanwhile, the compressive strength is also highly affected by the existing of EPS and POFA in the brick. Based on the findings, generally the replacement of POFA and EPS has reduced the brick strength. However, it was found that, replacement of 10% of POFA showed an increment in brick strength. For water absorption, the findings shows that, as the percentage of POFA increase, the percentage of water absorption increase. This is due to the coarser structure of POFA which contributed to high formation of porosity in the brick.

6. References

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