Strength and Physical Properties of Concrete Brick at Elevated Temperature

N I M Yassin\textsuperscript{1}, S H Adnan\textsuperscript{2}\textsuperscript{*}, S Shahidan\textsuperscript{1} and S S Ayop\textsuperscript{1}

\textsuperscript{1}Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, MALAYSIA
\textsuperscript{2}Department of Civil Engineering, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh, Johor, MALAYSIA
*Corresponding author: suraya@uthm.edu.my

Abstract. This paper discusses the strength and physical properties of lightweight concrete brick before and after being exposed to fire. For this study, lightweight concrete brick was made up of cement, sand, expanded polystyrene (EPS) and palm oil fuel ash (POFA). EPS and POFA are replacement materials used as sand and cement replacement respectively. The percentage of replacement materials was varied, which 0%, 20%, 30%, 40% and 50% for EPS and 0%, 10% and 25% for POFA. The strength and physical properties of bricks were observed and tested before and after being exposed to elevated temperature. Fire performance test of bricks was tested using electronic furnace where the temperature of fire was 300\textdegree C, 500\textdegree C and 700\textdegree C with heating rate 10\textdegree C/min. The duration of fire test was conducted for 2 hours. Among the physical properties that have been observed are deformation of shape, discoloration and surface cracking of brick samples. Generally, the brick strength were decreased as the percentage of materials replacement increase. The reduction of strength was continued when bricks were exposed to high temperature. However, the strength of the bricks was fluctuated when been exposed to different temperature.

1. Introduction
Fire resistance properties of building materials is one of the vital parameter that should not be neglected. This is to ensure the stability and serviceability state of building structure during and after been exposed to fire. Every structural building materials should satisfy the fire safety requirements specified in buildings codes. For example, referring to National Concrete Masonry Association, the compartment (wall) of a house should have a fire resistance rating of at least two hours and should be constructed of non-combustible materials that are capable of preserving the structural stability through-out the duration of fire. In Malaysia, ‘Undang-undang Kecil Bangunan Seragam’ has stated that concrete or clay brick with 200 mm and 100 mm width should certified with 4 hours and 2 hours fire rated respectively.

The fire resistance performance of building materials such as concrete brick or block have been studied by many researchers. The changes of concrete properties exposed to fire are depend on several factors such as heating rate, duration of fire exposed, degree of temperature, types of replacement or additive materials in concrete and cooling regime [1].

According to previous studies on fire resistance performance, there were various types of replacement materials used in concrete materials. Among those materials are marble waste, ground pumice, metakoalin, fly ash, bottom ash, expanded shale and palm oil fuel ash [1-5]. These different
types of concrete had went through fire resistance test in which the concrete have been exposed to different level of temperature varied from 200°C to 900°C. Other than temperature, heating rate also one of vital parameter that have to take into consideration during the firing process. The heating rate used in previous studies are 2.5°C/min, 5°C/min and 10°C/min whereas, some studied used temperature-time curve from ASTM standard [1-7]. Next, the duration of the test also different for each studies. For example, based on study conducted by Rashid et al [7], the duration of the fire resistance test was only 30 minutes for every concrete samples. On the other hand, Ismail et al [8], Ahn et al [3] and Aydin & Baradan [5] have conducted fire resistance test on concrete with duration of test 1 hour, 2 hours and 3 hours respectively. Finally, for cooling regime there were many different method have been used. Among the cooling regime used are air cooling inside the laboratory, water cooling, natural breeze and cooled at room temperature inside the furnace [4-5, 8-9]. Different cooling regime also give different effects on concrete materials especially on strength properties and surface cracking.

In this study, two different types of replacement materials which is expanded polystyrene (EPS) and palm oil fuel ash (POFA) are used in the production of lightweight concrete brick. The brick samples have been subjected to different level of temperature in order to identify its fire resistance performance at elevated temperature. Fire resistance performance of the bricks were identified from the physical and strength properties of the bricks after been exposed to fire.

2. Sample preparation

2.1. Materials preparation

In this study, the lightweight concrete bricks are made up of Ordinary Portland Cement (OPC), fine aggregates (river sand), expanded polystyrene (EPS), palm oil fuel ash (POFA), tap water and superplasticizer.

2.1.1 Ordinary Portland Cement (OPC)

OPC used in this study is classified in type 1 based on the ASTM C150 [10]. The supplier for this cement is Tasek Corporation Berhad which certified by SIRIM. Cement has been stored in an air tight container to prevent any moisture contact. The chemical composition of OPC has shown in Table 1.

Table 1. Chemical Composition of OPC

| Chemical Composition       | Percentage (%) |
|----------------------------|---------------|
| Silicon Dioxide (SiO₂)     | 14.6          |
| Aluminium Oxide (Al₂O₃)    | 3.95          |
| Ferric Oxide (Fe₂O₃)       | 3.46          |
| Calcium Oxide (CaO)        | 57.1          |
| Potassium Oxide (K₂O)      | 0.51          |
| Magnesium Oxide (MgO)      | 1.62          |
| Sodium Oxide (Na₂O)        | -             |
| Sulfur Trioxide (SO₃)      | 3.43          |

2.1.2 Fine aggregates (river 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 136-06 [11].
2.1.3 Expanded polystyrene (EPS)
For this study, EPS has been used as the lightweight materials that partially replaced the fine aggregates (sand). EPS beads are in spherical shape with white in colour. The range of EPS size is between 1.18 mm to 2.36 mm. The EPS was fully supplied by the ST Polyfoam Industries Sdn. Bhd which located in Batu Pahat, Johor. Bulk density and specific gravity of the EPS is 19 kg/m$^3$ and 0.02 respectively. Figure 1 shows the EPS beads that have been used as the replacement of the fine aggregates.

![Figure 1. Expanded polystyrene (EPS) beads](image1)

2.1.4 Palm oil fuel ash (POFA)
Palm oil fuel ash (POFA) that has been used in this research is an agriculture waste produced from the combustion of the palm oil fiber and shell from the palm oil mill located in Parit Sulong, Batu Pahat, Johor. For this study, the POFA was untreated in which it is directly used after it was collected from the palm oil mill. Initially, POFA was dried in the oven at 105°C ± 5 for 24 hours in order to remove the moisture content. Then, POFA was sieved to remove all the large particles before it stored in an airtight container. The size of the POFA with 300 µm sieve passing was used in this study. In this study, POFA was partially replaced the cement content in the brick. Figure 2 (a) and (b) show the raw POFA from the palm oil mill and POFA with 300 µm sieve passing respectively. Meanwhile Table 2 shows the chemical composition of POFA from the XRF analysis.

![Figure 2. Expanded polystyrene (EPS) beads](image2)
Table 2. Chemical Composition of POFA

| Chemical Composition       | Percentage (%) |
|---------------------------|----------------|
| Silicon Dioxide (SiO$_2$) | 55.20          |
| Aluminium Oxide (Al$_2$O$_3$) | 4.48       |
| Ferric Oxide (Fe$_2$O$_3$) | 5.44          |
| Calcium Oxide (CaO)      | 4.12           |
| Potassium Oxide (K$_2$O) | 2.28           |
| Magnesium Oxide (MgO)    | 2.25           |
| Sodium Oxide (Na$_2$O)   | 0.1            |
| Sulfur Trioxide (SO$_3$) | 2.25           |

2.2. Brick sample preparation

The mix ratio of the brick is 1:3 (cement: sand). For this study, there are 18 different types of brick samples which varied in percentage of EPS and POFA replacement. The bricks have been divided into 3 groups. The first group (I) is EPS bricks, the second group (II) is POFA bricks and finally the third group (III) is EPS-POFA brick. The water-cement ratio is 0.5 and super plasticizer is 8 ml for every 1 kg binder. The size of the brick is 215 mm x 103 mm x 65 mm. Figure 3 shows the shape and dimension of brick whilst Table 3 shows the mix proportions of concrete mix for each brick. Total brick samples for this study is 54 samples.

![Figure 3. Shape and dimension of brick sample](image)

2.2.1 Mixing and casting process of brick

For the mixing process, cement, POFA and sand were mixed be-fore water and super plasticizer were added. After 10 to 15 minutes of mixing, the EPS was added and thoroughly mixed in the concrete mixture. Lastly, superplasticizer was poured into the mixture in the ratio of 8 ml for every 1 kg of cement. The same steps were repeated for every mix proportion. Then, the concrete mix was casted into the timber moulds and was left inside the laboratory for 24 hours. After, 24 hours all the brick samples were demoulded and again all the brick samples were left inside the laboratory for curing process until the day of test. Figure 4, 5 and 6 show the mixing process, casted bricks and the curing process respectively.
Table 3. Mix proportions of brick (kg/m$^3$)

| Brick types | Brick samples | Cement | POFA | Sand | EPS |
|-------------|---------------|--------|------|------|-----|
| I (EPS)     | E0P0          | 495.34 | -    | 1484.72 | -  |
|             | E20P0         | 495.34 | -    | 1186.81 | 3.98 |
|             | E30P0         | 495.34 | -    | 1038.19 | 5.98 |
|             | E40P0         | 495.34 | -    | 888.88  | 7.97 |
|             | E50P0         | 495.34 | -    | 744.44  | 9.96 |
| II (POFA)   | E0P5          | 470.13 | 25   | 1484.72 | -  |
|             | E0P10         | 445.14 | 50   | 1484.72 | -  |
|             | E0P15         | 420.83 | 75   | 1484.72 | -  |
|             | E0P20         | 395.83 | 100  | 1484.72 | -  |
|             | E0P25         | 370.53 | 125  | 1484.72 | -  |
| III (EPS-POFA) | E20P10 | 445.14 | 50   | 1186.81 | 3.98 |
|              | E30P10        | 445.14 | 50   | 1038.19 | 5.98 |
|              | E40P10        | 445.14 | 50   | 888.88  | 7.97 |
|              | E50P10        | 445.14 | 50   | 744.44  | 9.96 |
|              | E20P25        | 370.53 | 125  | 1186.81 | 3.98 |
|              | E30P25        | 370.53 | 125  | 1038.19 | 5.98 |
|              | E40P25        | 370.53 | 125  | 888.88  | 7.97 |
|              | E50P25        | 370.53 | 125  | 744.44  | 9.96 |

*E = EPS, P = POFA

3. Test methods

3.1. Fire resistance test
In this study, fire resistance test of brick has been conducted on selected bricks by using electric furnace has shown in Figure 7. Unstressed residual test was conducted where the brick sample is heated in unloaded condition to the targeted temperature. After the cooling period, the load is applied on the brick sample. The selected brick samples have been exposed to various temperature which is starting from room temperature to 300°C, 500°C and 700°C. Duration of fire exposed and the heating rate for this fire test was 2 hours and 10 min°C respectively. The range of temperature, the duration of test and the heating rate was determined based on previous studies. Later, after the bricks have been exposed to the elevated temperature for 2 hours, the bricks were left in the electric furnace for another 24 hours for cooling down process. After all the bricks were cooled, they were taken out from the electric furnace. The physical changes of bricks such as deformation of shape, surface cracking and colour changes were observed and recorded. Then, all the bricks were tested for their residual
compressive strength performance. The strength test has been conducted in order to investigate the
effect of elevated temperature towards residual compressive strength of bricks.

3.2. Residual compressive strength test
Compressive strength test was conducted on the brick samples that have been exposed to elevated
temperature. After the bricks were cooled down for 24 hours, the bricks were underwent compressive
strength test in order to identify its strength performance after been exposed to fire.

The compressive strength test has been conducted is accordance to the ASTM C140-11a [12] by
using the hydraulic compression machine with a maximum load capacity of 3000 kN as shown in
Figure 8. For this test, three samples have been prepared for every mix proportion and all the samples
tested are full-sized. Any excess moisture or any particles must be removed from the surface of the
specimens and the loading plate of the machine before conducting the test.

4. Results and discussions
Fire resistance test of the brick samples were divided into three phase. The first phase is for EPS
bricks, second phase is for POFA bricks and third phase is for EPS-POFA bricks. About 18 different
types of brick samples with different mix proportion were selected for the test. All the tested bricks are
as listed in the Table 3. Among the parameter that were observed are the residual compressive strength
and the physical structure of brick samples after been subjected to fire.

4.1. Residual compressive strength

4.1.1 Residual compressive strength of EPS brick (Phase I)
Figure 9 shows the residual compressive strength of concrete bricks containing EPS at the elevated
temperature. From the figure it shows that there are 5 different types of brick samples were tested
which are E0P0 (normal brick), E20P0, E30P0, E40P0 and E50P0. The bricks were exposed to
different temperatures starting from room temperature then followed by 300°C, 500°C and 700°C for 2
hours.

Generally from Figure 9 it is observed that as the percentage of EPS increase, the residual
compressive strength decrease. From the results, it shows that the average decrement of residual
compressive strength of brick as compared to normal brick strength are 14%, 25%, 52.3% and 54.2%
for brick with 20%, 30%, 40% and 50% of EPS respectively. However, it also can been seen that the
rate of decrement of residual compressive strength is low as the percentage of EPS increase.

Meanwhile, similar observation is found as the elevated temperature increase, the residual
compressive strength of brick decrease. From the result, at 300°C the range of strength loss of the
bricks is about 12.9% to 16.4% as compared to brick strength at room temperature. Later, at 500°C the
range of strength loss of brick is 16.3% to 30.1% and finally at 700°C the range of strength loss is 23.7% to 41.8%. This can be seen that, the rate of strength loss is high as the temperature increase.

However, based on the results it shows the residual compressive strength of all brick samples are above the minimum requirement strength for non-loadbearing brick as stated in ASTM C129-11 [13]. It can be concluded that, the replacement of EPS up to 50% did not compromising the strength performance of the non-load bearing brick after been exposed to high temperature.

![Figure 9](image)

**Figure 9.** Residual compressive strength of concrete bricks containing Expanded Polystyrene (EPS) at elevated temperature

### 4.1.2 Residual compressive strength of POFA brick (Phase II)

Figure 10 shows the residual compressive strength of bricks containing POFA at elevated temperature. For this test 6 different types of bricks with different percentage of POFA were selected. From the result, it can be seen that the range of strength loss for 5% POFA brick is 2.7% to 8.1% from room temperature to the maximum 700°C. However, a significant increment in residual compressive strength is observed for brick samples with 10% of POFA. Based on the results, at room temperature, the compressive strength of the brick is 13.14% higher than normal brick. Meanwhile, at 300°C and 500°C the residual compressive strength has increased which is 13.54% and 4% respectively. Finally, at 700°C, the residual compressive strength is slightly decreased which is 1.9% as compared to normal brick yet it is 6.8% higher than E0P5. This shows that, brick with 10% of POFA has better strength performance at elevated temperature.

Later, the residual compressive strength is continue to decrease as the percentage of POFA increase. For example, for 15% POFA brick, the range of strength loss is 38.9% to 59.3% followed by 46.7% to 61.2% for 20% POFA brick and finally 62% to 70.8% for 25% POFA brick. Meanwhile, this figure shows the same observation as previous figure (Figure 9) in which the residual compressive strength of brick decrease as the exposed temperature increase. Based on the result, the range of strength loss for brick at 300°C, 500°C and 700°C are 6.5% to 17%, 10.8% to 26% and 23.7% to 44.8% respectively.

Again, the overall residual compressive strength of POFA brick at elevated temperature is above the minimum requirement strength for non-load bearing brick. This shows that bricks with POFA as cement replacement could maintain a good strength performance at elevated temperature.
4.1.3 Residual compressive strength of EPS-POFA brick (Phase III)

This subsection discusses on the residual compressive strength of EPS-POFA brick after been exposed to elevated temperature. For Phase III, 10 different types of EPS-POFA bricks were selected for the test as shown in Figure 11 and Figure 12.

Figure 11 shows 5 types of bricks which contain varied percentage of EPS with 10% of POFA each. As discussed previously in Fig 10, brick sample of E0P10 has the highest strength not only in room temperature but also at elevated temperature as compared to other bricks. From Fig 11, the decrement of strength is continues as the percentage of EPS increase. For example, for E20P10 the range of strength loss of the brick is 17.2% to 35.5%. Meanwhile, for E30P10 and E40P10 the range of strength loss is 41.2% to 53.5% and 50.6% to 55.8% respectively. For the highest replacement brick which is E50P10, the strength loss is about 70% as compared to E0P10.

As stated previously, residual compressive strength is influenced by the degree of exposure. According to Bastami et al [14], the reduction of compressive strength of concrete at elevated temperature was due to the dehydration of concrete by driving out of free water, interlayer water and chemically combined water. The loss of physically bound water significantly affects the strength properties of concrete. Therefore, from this study Fig 11 shows that the residual compressive strength of the bricks decreases steadily with the increase in temperature. At 300°C, the strength loss of the bricks is 10% to 16.13%. Meanwhile, at 500°C, the strength loss of the brick is from 3.5% to 26.7%. However, it is found that at this temperature, E20P10 and E30P10 samples show higher residual compressive strength as compared to the same brick at 300°C. Similar observation was found in study by Awal & Shehu [4] where slight increment of residual compressive strength of POFA brick subjected to temperature up to 400°C. In addition, earlier study by Ismail et al [8] also shows similar observation in which the residual compressive strength of POFA concrete increased with temperature up to 500°C. Perhaps this is due to the loss of water content and increase in binding properties of C-H-S from the samples leading to the pre-hardening state. Finally, at 700°C the residual compressive strength of the bricks are continue to decrease in which E50P10 shows the lowest residual compressive strength which is 5.9 MPa. Nevertheless it is above the minimum strength for non-loadbearing brick regarding to ASTM C129-11 [13].
Figure 11. Residual compressive strength of concrete bricks containing Expanded Polystyrene (EPS) and 10% Palm oil fuel ash (POFA) at elevated temperature

On the other hand, Figure 12 shows another 5 types of bricks which contain varied percentage of EPS with 25% of POFA each. From the figure it can see that, there is significant drop in residual compressive strength between E0P25 to E20P25 where the range of strength loss is 25.8% to 45.9%. Then as the percentage of EPS increase, the residual compressive strength is continues to decrease gradually.

Despite that, based on the figure it shows a significant drop in residual compressive strength of the brick samples at 300oC. In addition, it has found that the residual compressive strength of E40P25 and E50P25 are 3.6 MPa and 3.2 MPa respectively in which both strength are below the minimum requirement for non-loadbearing brick [13]. In addition, at 500°C, it has found that E30P25, E40P25 and E50P25 also have the residual compressive strength below the minimum requirement and finally at 700°C all the brick samples except E0P25 have the residual compressive strength below the minimum requirement. Therefore, this shows that majority of the EPS-POFA bricks containing 25% of POFA are not capable to withstand high temperature. Hence, it is not recommended for the non-loadbearing brick to have POFA replacement with 25% and above.

Figure 12. Residual compressive strength of concrete bricks containing Expanded Polystyrene (EPS) and 25% Palm oil fuel ash (POFA) at elevated temperature
4.2. Physical characteristic

4.2.1 Physical characteristic of EPS brick (Phase I)
Among the physical characteristic that were observed after the firing process are the deformation of shape, discolouration and surface cracking of the bricks. Table 4 shows the summary of the physical characteristics of EPS bricks after been exposed to elevated temperature. From the observation, it can be seen that the shapes of the bricks did not show any alterations at 300°C and 500°C. However, at 700°C rough edges were observed for EPS bricks. This might due to the dissipation of EPS beads during the firing process.

Table 4: Physical structures of EPS bricks subjected to elevated temperature

| Brick samples | Temperature (°C) | Surface characteristics |
|---------------|------------------|-------------------------|
|               |                  | shape | colour | texture      |
| E0P0          | room temperature | original shape | grey | smooth |
|               | 300°C            | original shape | grey | smooth |
|               | 500°C            | original shape | grey | smooth |
|               | 700°C            | original shape | light grey | smooth |
| E20P0         | room temperature | original shape | grey | rough and has voids |
|               | 300°C            | original shape | grey | rough and has voids |
|               | 500°C            | original shape | grey | rough and has voids |
|               | 700°C            | rough edges | light grey | rough and has voids |
| E30P0         | room temperature | original shape | grey | rough and has voids |
|               | 300°C            | original shape | grey | rough and has voids |
|               | 500°C            | original shape | grey | rough and has voids |
|               | 700°C            | rough edges | light grey | rough and has voids |
| E40P0         | room temperature | original shape | grey | rough and has voids |
|               | 300°C            | original shape | grey | rough and has voids |
|               | 500°C            | original shape | grey | rough and has voids |
|               | 700°C            | rough edges | light grey | rough and has voids |
| E50P0         | room temperature | original shape | grey | rough and has voids |
|               | 300°C            | original shape | grey | rough and has voids |
|               | 500°C            | original shape | grey | rough and has voids |
|               | 700°C            | rough edges | light grey | rough and has voids |

Besides, colour changes on the brick surfaces were observed as bricks exposed to high temperature. It is found that no significant changes on the brick colour at 300°C and 500°C. The brick colour was turned from grey to light grey only after been exposed to 700°C. Similar observation was found by Mohammadhosseini & Yatim [15] in which the colour of ordinary portland cement (OPC) specimens have changed from grey to whitish grey as the specimens been exposed to high temperature up to 800°C. According to Xiao & Falkner [16], the changes of colour could be attributed to the changes of the chemical composition as well as development and destruction of crystal during the firing process.

Aside from shape changes and discolouration, surface texture of the brick also has been observed in order to examine the brick performance after been exposed to fire. Based on the observation, it has found that for normal brick (E0P0), the surface texture was consistently smooth as the temperature increased. However, the surface texture for every EPS bricks were slightly rough due to the present of EPS beads on the brick surface. Later, as the bricks were exposed to elevated temperature, formation of voids on the surface has been observed. The existing of voids was due to the dissipation of EPS beads during the firing process. Therefore, the surface texture of EPS bricks became rougher after have been exposed to elevated temperature.
4.2.2 Physical characteristic of POFA brick (Phase II)

Table 5 shows the summary of the physical characteristics of POFA bricks after been exposed to elevated temperature. From the observations, there is no significant changes of brick shape after been exposed to elevated temperature. For brick samples E0P0, E0P5 and E0P10 the bricks shape were remained as original shape until the temperature reached up to 700°C. However, it has found that for E0P15, E0P20 and E0P25 samples the brick edges became rough as exposed to temperature of 700°C. Then, for the changes of surface colour, it can be seen that for E0P0, E0P5 and E0P10 the colour of the bricks were remained grey as the temperature increased. However, it has been observed that for E0P0 the colour of the brick has changed into light grey at 700°C as mentioned previously. On the other hand, the surface colour of E0P15, E0P20 and E0P25 were initially dim grey. The dim grey colour of the brick is due to the high replacement percentage of POFA in the brick mix. The, the surface colour has changed to grey as the brick samples were exposed to 500°C and finally turned into light grey as the temperature raised up to 700°C.

Then, for the surface texture it has been observed that, most of the bricks have a smooth surface texture as the temperature raised up. However, at 700°C minor hair lines were appeared on the brick surface of E0P15, E0P20 and E0P25. Similar observation was found by Ismail et al [8] in which they have studied the performance of OPC and POFA concrete at elevated temperature. Based on the findings, it shows that at 100°C and 300°C the surface of OPC and POFA concrete were found smooth. However, the hair-lines cracks started to appeared as the temperature raised up to 500°C and the cracks were more significant at 800°C. Another study by Awal & Shehu [4] also shows a similar finding where they have observed hairy cracks on the surface of POFA concrete at 800°C.

Table 5: Physical structures of POFA bricks subjected to elevated temperature

| Brick samples | Temperature (°C) | Surface characteristics |
|---------------|------------------|-------------------------|
|               |                  | shape | colour | texture |
| E0P5          | room temperature | original shape | grey | smooth |
|               | 300°C            | original shape | grey | smooth |
|               | 500°C            | original shape | grey | smooth |
|               | 700°C            | original shape | grey | smooth |
| E0P10         | room temperature | original shape | grey | smooth |
|               | 300°C            | original shape | grey | smooth |
|               | 500°C            | original shape | grey | smooth |
|               | 700°C            | original shape | grey | smooth |
| E0P15         | room temperature | original shape | dim grey | smooth |
|               | 300°C            | original shape | dim grey | smooth |
|               | 500°C            | original shape | grey | smooth |
|               | 700°C            | rough edges | light grey | minor hair lines |
| E0P20         | room temperature | original shape | dim grey | smooth |
|               | 300°C            | original shape | dim grey | smooth |
|               | 500°C            | original shape | grey | smooth |
|               | 700°C            | rough edges | light grey | minor hair lines |
| E0P25         | room temperature | original shape | dim grey | smooth |
|               | 300°C            | original shape | dim grey | smooth |
|               | 500°C            | original shape | grey | smooth |
|               | 700°C            | rough edges | light grey | minor hair lines |

4.2.3 Physical characteristic of EPS-POFA brick (Phase III)

Table 6 shows the summary of the physical characteristics of EPS-POFA bricks after been exposed to elevated temperature. Based on the summary, the EPS-POFA bricks did not show any significant changes in shape when they were exposed into elevated temperature. Only minor changes in shape were identified as the bricks been exposed to 700°C where the edges of the bricks became rougher.
Table 6: Physical structures of EPS-POFA bricks subjected to elevated temperature

| Brick samples | Temperature (°C) | Surface characteristics |
|---------------|-----------------|------------------------|
|               |                 | shape | colour | texture |               |
| E20P10        | room temperature| original shape | grey | rough |               |
|               | 300°C           | original shape | grey | rough and has voids |               |
|               | 500°C           | original shape | grey | rough and has voids |               |
|               | 700°C           | rough edges  | light grey | rough and has voids |               |
| E30P10        | room temperature| original shape | grey | rough |               |
|               | 300°C           | original shape | grey | rough and has voids |               |
|               | 500°C           | original shape | grey | rough and has voids |               |
|               | 700°C           | rough edges  | light grey | rough and has voids |               |
| E40P10        | room temperature| original shape | grey | rough |               |
|               | 300°C           | original shape | grey | rough and has voids |               |
|               | 500°C           | original shape | grey | rough and has voids |               |
|               | 700°C           | rough edges  | light grey | rough and has voids |               |
| E50P10        | room temperature| original shape | grey | rough |               |
|               | 300°C           | original shape | grey | rough and has voids |               |
|               | 500°C           | original shape | grey | rough and has voids |               |
|               | 700°C           | rough edges  | light grey | rough and has voids |               |
| E20P25        | room temperature| original shape | dim grey | rough |               |
|               | 300°C           | original shape | dim grey | rough and has voids |               |
|               | 500°C           | original shape | dim grey | rough and has voids |               |
|               | 700°C           | rough edges  | light grey | rough and has voids |               |
| E30P25        | room temperature| original shape | dim grey | rough |               |
|               | 300°C           | original shape | dim grey | rough and has voids |               |
|               | 500°C           | original shape | dim grey | rough and has voids |               |
|               | 700°C           | rough edges  | light grey | rough and has voids |               |
| E40P25        | room temperature| original shape | dim grey | rough |               |
|               | 300°C           | original shape | dim grey | rough and has voids |               |
|               | 500°C           | original shape | dim grey | rough and has voids |               |
|               | 700°C           | rough edges  | light grey | rough and has voids |               |
| E50P25        | room temperature| original shape | dim grey | rough |               |
|               | 300°C           | original shape | dim grey | rough and has voids |               |
|               | 500°C           | original shape | dim grey | rough and has voids |               |
|               | 700°C           | rough edges  | light grey | rough and has voids |               |

Distinct on surface colour was observed for brick with 10% and 25% of POFA. It has been noticed that the surface colour of bricks with 10% of POFA is grey whilst for bricks with 25% of POFA is dim grey. Then again, the surface colour became lighter when the degree of temperature is higher.

Lastly, for the surface texture the observation did not show any significant differences from the EPS brick and POFA brick that has been discussed previously. Generally E0P10 and E0P25 have smooth surface textures and only minor hair-lines cracks appeared at 700°C. On the other hand, bricks containing EPS has some voids and rough surface when exposed to the elevated temperature. Over-all, from the observation of the physical characteristics of EPS-POFA bricks at elevated temperature, it can be concluded that the existing of both replacement materials did not give any significant destruction or damages towards the physical characteristic of the bricks. Figure 13 shows the different surface characteristic of bricks at elevated temperature.
5.0 Conclusion

The following are several conclusions that can be made from this study:

1. The residual compressive strength of EPS brick at elevated temperature decrease as the percentage of EPS increase. 50% replacement of EPS has reduced the brick strength up to 54.2%. Whereas, it shows that at maximum temperature, E50P0 brick has lost approximately 42% of its strength. This clearly shows that, the existing of EPS in the brick has contributed a significant reduction in brick strength. However, it has found that the strength of EPS bricks subjected to elevated temperature is above the minimum requirement for non-load bearing strength brick.

2. Next, for POFA bricks it has found that the replacement of 10% POFA could increase the compressive strength of the brick up to 13.4%. In addition, it has found that 10% of POFA has also increased the residual strength of brick at elevated temperature and only 1.9% of the strength dropped as the temperature reach to 700°C.

3. Generally, for EPS-POFA bricks the residual compressive strength of brick decreased as the replacement materials increased. However, it has found that the percentage of strength loss of EPS-POFA bricks were lesser than EPS bricks. This shows that POFA could reduce the strength loss of EPS brick.

4. For physical characteristic, majority of brick samples did not show any significant changes after been subjected to high temperature up to 500°C. Slight changes in shape, colour and texture were found at 700°C. The study of physical characteristic of brick at elevated temperature is important because it could be a preliminary assessment of damage caused by the fire hazard so that intensity of fire can be comprehended.

6. References

[1] Sudarshan D K and Vyas A K 2017 Impact of fire on mechanical properties of concrete containing marble waste *Journal of King Saud University-Engineering Sciences*
[2] Saridemir M, Severcan M H, Ciflikli M, Celikten S, Ozcan F and Atis C D 2016 The influence of elevated temperature on strength and microstructure of high strength concrete containing ground pumice and metakaolin Constr. Build. Mater. 124 244-257

[3] Ahn Y B, Jang J G and Lee H K 2016 Mechanical properties of lightweight concrete made with coal ashes after exposure to elevated temperatures Cement and Concrete Composites 72 27-38

[4] Awal A S M and Shehu I A 2014 Deformation characteristics of concrete containing high volume palm oil fuel ash Applied Mechanics and Materials 534 9-15

[5] Aydin S and Baradan B 2007 Effect of pumice and fly ash incorporation on high temperature resistance of cement based mortars Cement and Concrete Research 37(6) 988-995

[6] Hossain K M A 2006 High strength blended cement concrete incorporating volcanic ash: Performance at high temperatures Cement and Concrete Composites 28(6) 535-545

[7] Givi A N, Rashid S A, Aziz F N A and Salleh M A M 2010 Contribution of rice husk ash to the properties of mortar and concrete: A review Journal of American Science 6(3) 157-165

[8] Ismail M, Ismail M E and Muhammad B 2011 Influence of elevated temperatures on physical and compressive strength properties of concrete containing palm oil fuel ash Constr. Build. Mater. 25(5) 2358-2364

[9] Ranjbar M M and Mousavi S Y 2015 Strength and durability assessment of self-compacted lightweight concrete containing expanded polystyrene Mater. Struct. 48(4) 1001-1011

[10] ASTM C150/C150M-11 Standard Specification for Portland Cement. ASTM Masonry Standard for the Building Industry 7th Edition (2012)

[11] ASTM C136 2012 Test Method for Sieve Analysis of Fine and Coarse Aggregates (West Conshohocken: ASTM International)

[12] ASTM C140 2012 Standard Test Method for Sampling and Testing Concrete Masonry Units and Related Units (West Conshohocken: ASTM International)

[13] ASTM C129 2012. Standard Specification for Nonloadbearing Concrete Masonry Units (West Conshohocken: ASTM International)

[14] Bastami M, Chaboki-Khiabani A, Baghbadrani M and Kordi M 2011 Performance of high strength concretes at elevated temperatures Scientia Iranica 18(5) 1028-1036

[15] Mohammadhosseini H and Yatim J M 2017 Microstructure and residual properties of green concrete composites incorpo-rating waste carpet fibers and palm oil fuel ash at elevated temperatures J. Cleaner Prod. 144 8-21

[16] Xiao J and Falkner H 2006 On residual strength of high-performance concrete with and without polypropylene fibres at elevated temperatures Fire Safe. J 41(2) 115-121

Acknowledgments
The authors gratefully acknowledge the Universiti Tun Hussein Onn Malaysia for providing the financial support through the Post-graduate Research Grant (GPPS), Vot U77.