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Strength and water absorption properties of lightweight concrete brick containing expanded polystyrene and palm oil fuel ash

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Abstract. This paper is focusing on strength and water absorption properties of lightweight concrete brick containing Expanded Polystyrene (EPS) and Palm Oil Fuel Ash (POFA) as partial replacement materials of fine aggregates and cement respectively. EPS has been chosen as lightweight aggregates material due to its characteristic which is extremely light. Meanwhile, POFA has been chosen as cement replacement due to the cementitious characteristic which could act as the binder in the concrete mixture. The replacement percentage of EPS is 0%, 20%, 30%, 40% and 50% whilst the replacement percentage of POFA is 0%, 5%, 10%, 15%, 20% and 25%. The brick properties that have been investigated in this study are density, water absorption and compressive strength. Based on the experimental results, the density and compressive strength of the brick is decreased as the percentage of the replacement increased. Meanwhile, for water absorption, it was found that the percentage of water absorption of brick was increased as the percentage of POFA increased, and it was decreased as the percentage of EPS increased. Based on the findings, the properties obtained has satisfied the requirement where the brick density for lightweight should be less than 1680 kg/m³ and the strength for load bearing and non-load bearing brick is 11.7 MPa and 3.45 MPa for each individual unit. Meanwhile, for water absorption, the percentage of water absorption of brick should be less than 12% [1,2]. From this study, it was found that, the replacement of sand and cement by EPS and POFA give significant impact towards density, strength and water absorption performance of concrete brick.

1. Introduction

Due to rapid growth of population in Malaysia, Malaysian government is focusing on low and medium cost housing project as stated in the Eleventh Malaysia Plan (2016-2020) in the third strategic thrusts where government is uplifting B40 households towards middle-class society by increasing the provision of affordable housing. However, in the effort of increasing the number of housing, government strictly aware on the sustainable issues especially in the construction industries. Therefore, due to high demand in



housing and sustainability awareness, construction industries and Malaysia researchers has collaborates in the production of sustainable building materials such as lightweight concrete brick.

Abundance of research on the production of lightweight concrete brick has been conducted [3-5]. One of the most preferable lightweight aggregates materials that have been widely used is EPS. This is due to its characteristic which is extremely light. EPS has significantly contribute to the reduction of brick density [3-13]. However, based on findings by previous researches, EPS concrete or EPS brick has low in strength [3-13]. Due to this, researchers have extend their research in improvising the EPS concrete brick strength with the addition of pozzolanic materials such as fly ash, rice husk ask and silica fume [14-20]. The ability of these pozzolanic materials in enhancing the strength of brick or concrete has been proven. For instance, in a study conducted by Ling & Teo [3] has shown that, replacement of cement by 10% of Rice Husk Ash (RHA) has increased the brick strength from 13 MPa (normal brick) up to 17 MPa. In other study, by Sadrmomtazi et al [14], 10% of silica fume has increased the strength of concrete from 43 MPa to 47.6 MPa. It has proven that, optimum replacement percentage by pozzolanic materials could enhance the strength performance of brick or concrete.

Therefore, for this study another pozzolanic material which is POFA has been used as cement replacement in the production of lightweight concrete brick. POFA is an agricultural waste produced by the palm oil industries. Malaysia has known as one of the biggest palm oil producer in the world. The vast production of POFA by these industries has become one of the environmental issues in Malaysia. This is because this waste could not be used as fertilizer. Therefore, from time to time, the generation of this waste has increase the landfill area. In order to overcome this problems, researcher has extended their research on POFA as cement replacement [20-24]. Hence, this study has focus on production of concrete brick containing EPS and POFA with different percentage of replacement. Among the brick properties that has been tested are density, compressive strength and rate of water absorption.

2. Materials and brick sample preparation

2.1. Materials

In this study, raw materials that have been used for the production of brick are Ordinary Portland Cement (OPC), river sand, Palm Oil Fuel Ash (POFA), Expanded Polystyrene (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 [25]. 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.

Table 1. Chemical Composition of OPC and 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

2.1.2. Palm Oil Fuel Ash (POFA)

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

2.1.3. Fine Aggregates (sand)

Fine aggregates that has been used is river sand. The sieve analysis of sand was conducted in accordance to ASTM C136 [26]. The sand was dried in the oven at 105°C±5 for 24 hours to ensure the moisture content is constant. Then, the sand was sieved through 2.36 mm sieve opening.

2.1.4. Expanded Polystyrene (EPS)

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

2.2. Brick sample preparation

For this study, 30 types of concrete brick samples were prepared. The percentage of EPS is 0%, 20%, 30%, 40% and 50% meanwhile the percentage of POFA is 0%, 5%, 10%, 15%, 20% and 25%. Water cement ratio for this study is 0.5 and super plasticizer is 8ml for every 1 kg binder. The mix proportion of bricks as shown in Table 2.

Table 2. Mix proportions (kg/m³).

Samples	Cement	POFA	Sand	EPS
E0P0 (C)	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
E0P5	470.13	25	1484.72	-
E20P5	470.13	25	1186.81	3.98
E30P5	470.13	25	1038.19	5.98
E40P5	470.13	25	888.88	7.97
E50P5	470.13	25	744.44	9.96
E0P10	445.14	50	1484.72	-
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
E0P15	420.83	75	1484.72	-
E20P15	420.83	75	1186.81	3.98
E30P15	420.83	75	1038.19	5.98
E40P15	420.83	75	888.88	7.97
E50P15	420.83	75	744.44	9.96
E0P20	395.83	100	1484.72	-
E20P20	395.83	100	1186.81	3.98
E30P20	395.83	100	1038.19	5.98
E40P20	395.83	100	888.88	7.97
E50P20	395.83	100	744.44	9.96
E0P25	370.53	125	1484.72	-
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, C = control brick

3. Test methods

3.1. Hardened brick density

In determining the density of the brick samples, the test was conducted accordance to BS EN 12390-7 [27] in which determination of the brick mass will be as-received condition. The measurement of density was conducted at the age of 7 and 28 days. Three samples have been prepared for every mix proportion.

3.2. Compressive strength test

Compressive strength test for this study was conducted according to the ASTM C140-11a [28]. For this test, three brick 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 brick surface and the loading plate of the machine before conducting the test. All the brick samples was cured by air curing process in the laboratory 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 accordance to the BS 1881: 122 [29]. Initially, the brick samples were dried in the oven at $100^{\circ}\text{C} \pm 5^{\circ}\text{C}$ 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.

4. Results and discussion

As already mentioned earlier for density and compressive strength test the tests were conducted at the age of 7 and 28 days whilst for water absorption test, the test was conducted at the age of 28 days. Every types of brick use constant water cement ratio which is 0.5. Following sub sections discuss the outcomes from this study.

4.1. Hardened brick density

Density of 30 samples were determined as shown in Figure 1. Based on the figure, generally the density of the brick samples decreased as the percentages of the replacement materials increased. At 7 days, density of control brick (E0P0) is 2150 kg/m^3 . As the percentage of POFA increased, the brick samples shows slight reduction in density where for each increment of 5% POFA about 2 to 4% of brick density has reduced. For E0P25, where the replacement of POFA is 25% (maximum replacement), the brick density is 1864.29 kg/m^3 which is 13.3% lesser than normal brick. This has shown the contribution of POFA in the reduction of brick density.

Besides, EPS as the lightweight aggregates materials also contribute in the reduction of the brick samples. The contribution of EPS in the reduction of the brick is more significant comparing to POFA. For instance at 7 days, density of E20P0 is 1864 kg/m^3 . This shows that, 20% of EPS has reduced the brick density up to 13%. For E30P0, E40P0, and E50P0 where the percentage of EPS is 30%, 40% and 50% respectively, it was found that the brick density was decreased from 17.3% up to 32.2% from normal brick. This has proven that, the characteristic of EPS which is extremely light give a vast impact towards the reduction of brick density.

The reduction of the brick density continuous to decrease as the percentage of replacement materials increased. Based on the figure, density of brick with maximum replacement of materials which is E50P25 is 1385.71 kg/m^3 which is 36% lesser than normal brick. From this it can conclude that, the density of the brick has achieve lightweight brick density as stated in ASTM C90 [1] where for lightweight brick, the density should less that 1680 kg/m^3 .

Alongside materials replacement, brick age also contribute in the reduction of density. As can be seen, density of brick at 28 days is slightly lower that brick density at 7 days. For example, for brick

sample E0P25 the density at 7 days is 1864.29 kg/m^3 whilst the density at 28 days is 1850 kg/m^3 . From this it can be seen that, the density was reduced about 0.8%. Another example, for brick E50P0 the density at 7 days is 1457.14 kg/m^3 and the density at 28 days is 1435.71 kg/m^3 . The reduction of density is about 1.5%. Perhaps, the reduction of brick density was due to loss of water content throughout the air curing process.

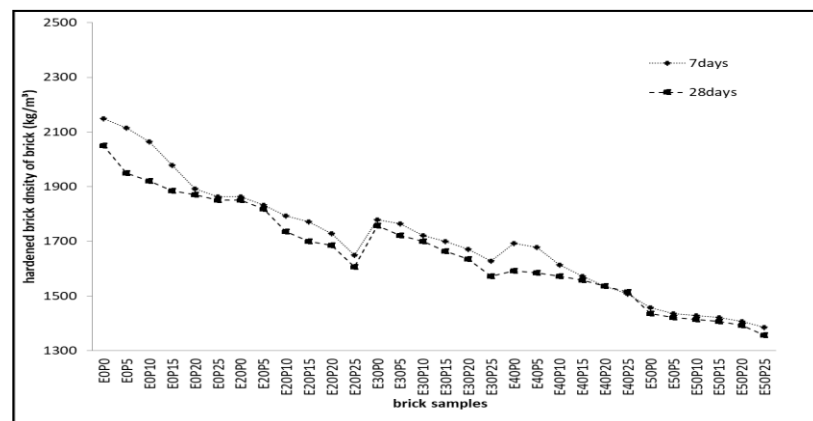


Figure 1. Hardened brick density of bricks.

4.2. Compressive strength

Figure 2 shows brick strength of 30 different types of brick. Based on the figure shown, it can be seen that, overall strength of the brick decrease as the percentage of replacement materials increase. However, it also can be observed that, the brick strengths are fluctuate. The irregular rise and fall of strength is affected by the percentage of replacement materials.

From figure 2, the brick strength of control brick (E0P0) at 7 days is 25.7 MPa. It was observed that brick strength was continuously decreased as the percentage of POFA increase. For example, the strength of E0P25 is 7.4 MPa. The reduction of the strength is about 71% from the normal brick. However, it was found that, brick with 10% of POFA (E0P10) has slightly increase the brick strength comparing to 5% POFA brick (E0P5). The same finding was found at 28 days, where brick with 10% of POFA (E0P10) has increased the brick strength. In addition, at 28 days, brick of E0P10 has higher strength than normal brick where the strength E0P10 is 31 MPa meanwhile, E0P0 is 27.4 MPa. This has shown that, 10% of POFA replacement could enhance the brick strength.

Similarly with density, the existing of EPS has contribute a great impact towards the brick strength. Compressive strength of all brick specimens containing EPS was lower as compared to the control brick. For instance at 28 days, the strength of control brick was 27.4 MPa. The strength was decreased as the percentage of EPS increase. For E20P0 the strength was 23.3MPa, for E30P0 the strength was 21.6 MPa, for E40P0 the strength was 12.6 MPa and lastly for E50P0 the strength was 11.7Mpa. 50% replacement of EPS has reduced the brick strength up to 57%. The great reduction in strength was due to the characteristic of EPS with is extremely low in strength which is almost zero in strength Miled et al [10].

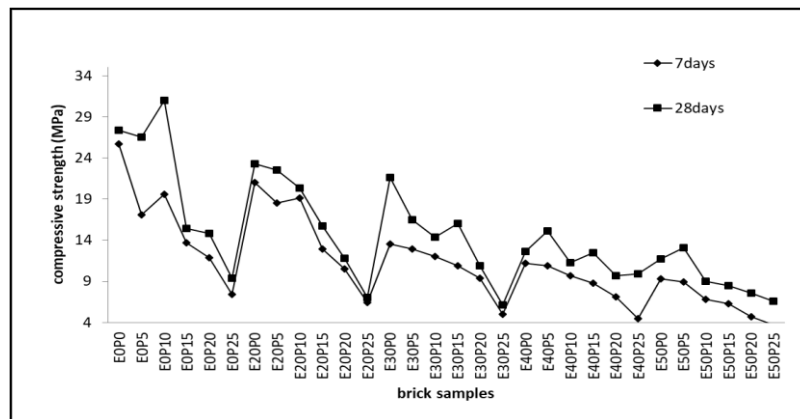


Figure 2. Compressive strength of bricks.

4.3. Water Absorption

Figure 3 shows the percentage of water absorption of 30 different types of brick. As can be seen, water absorption of E0P0 (control brick) was 11.23%. The percentage of water absorption was increased as the percentage of POFA increased. For specimen E0P5 which is 5% replacement of POFA, the water absorption of brick has increased about 1.6% from the control brick. The following specimens which are E0P10, E0P15, E0P20 and E0P25 show that the percentage of water absorption was increased about 0.5 to 0.7% for every 5% increment of POFA.

However, opposite findings was observed where the percentage of water absorption of brick decreased as the percentage of EPS increased. Brick samples with EPS had lower percentage of water absorption as compared to control brick. For instance, the percentage of water absorption for E20P0 was 6.95% which was 4.28% less than E0P0. Percentage of water absorption continuous to decrease where percentage of water absorption of brick samples E30P0, E40P0 and E50P0 were 6.1%, 5.82% and 4.37% respectively.

This can be conclude that, the increment for percentage of water absorption as the percentage of POFA increased was due to the characteristic of POFA which was coarser in structure and highly absorbent material. Meanwhile, the reduction of water absorption with the increment of EPS was due to non-absorbent characteristic of EPS.

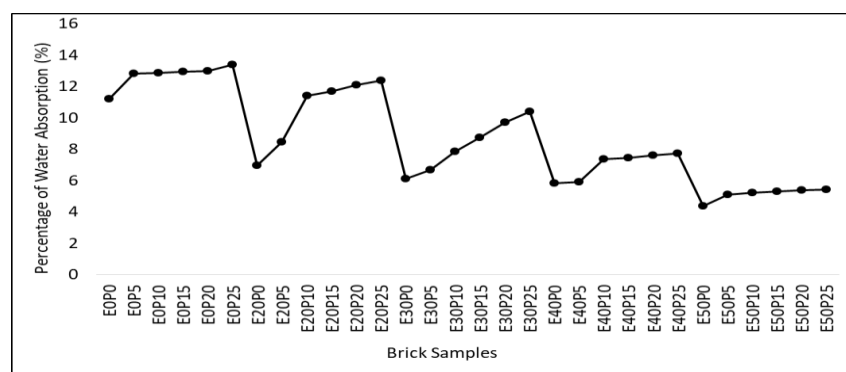


Figure 3. Water absorption of bricks.

5. Conclusion

- The density of the brick was affected by the replacement of POFA and EPS in 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 25% of POFA has reduced the density of the brick up to 34% from normal brick. This indicates that, EPS and POFA are highly potential materials for the production of lightweight.

- The mechanical properties of brick which is 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. This has proven the potential of POFA as pozzolanic material to enhance the strength of brick.
- For water absorption properties, 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. Meanwhile, opposite findings was observed when the replacement of EPS increase, the percentage of water absorption decrease. This is believed due to characteristic of EPS which is non-absorbent that helps in reduction of water absorption.

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