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Utilization of Blended Waste Materials in Bricks

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Abstract: Cement is considered as the main raw material for the brick production. However, excessive use of the cement has negative environment impact. Therefore, cement can be replaced by using locally available waste materials and it can become a significant potential in the construction industries for cleaner production. The objective of this research is to investigate the performance of a brick when cement is replaced by the waste materials such as fly ash & palm oil fuel ash which are available in Malaysia. To determine the performance of the bricks, the compressive strength test, the water absorption test and the thermogravimetric analysis were carried out at different percentage combinations of fly ash & palm oil fuel ash. The results reveal that both the fly ash & palm oil fuel ash incorporated bricks satisfied the Class 1 and Class 2 load-bearing brick requirements according to the Malaysian Standard MS76:1972 and the water absorption requirements, according to the ASTM C55-11. The thermogravimetric analysis study confirms that the Ca(OH)2 gradually decreases due to the increase of pozzolanic material contents (fly ash & palm oil fuel ash). Moreover, these newly developed bricks cost less than the conventional bricks.

Keywords: Brick, Fly Ash, Palm Oil Fuel Ash, Waste Material

1. Introduction

In the construction industries bricks are one of the most important element, and there are various forms of bricks available in the world (Da Silva Almeida et al., 2013). Among them, using fired bricks and cement bricks are considered to be more reliable. Malaysia uses both the fired bricks and cement bricks and they have an important and relevant impact throughout the ASEAN region. To produce a large quantity of cement bricks due to its high demand, a significant amount of cement are required. However, this approach leads to environmental problems, such as increased carbon emission to the atmosphere. Incorporation of more sustainable or waste materials in the production of bricks can partially address this large issue.

Malaysia produces and exports large quantity of palm oil (Yusuf, 2006) and it was found that approximately four kg of waste materials are produced to obtain one kg of palm oil (Ng et al., 2012). As a result, waste materials, including empty fruit branch, oil palm shell and Palm Oil Fuel Ash (POFA) are generated significantly and it is expected that 100 million tonnes of dry waste materials will be generated by 2020 (National Biomass Strategy 2020, 2011). Generally empty fruit branch and oil palm shell are burnt to produce POFA for disposal purpose, however, it would be a great attempt to reuse this POFA in brick industries. Therefore, using palm oil industry based waste materials or any other waste materials in construction industry and in any composite materials will increase sustainability and will reduce environmental pollution (Al-Oqla and Sapuan, 2014 and Rahman et al., 2014a).

Fly ash is produced in furnaces of coal-burning power plants. Fly ash is predominantly very fine spherical glassy particles collected in the dust collection systems from the exhaust gases of fossil fuel power plants. The main chemical constituents in fly ash are silica, alumina and oxides of iron and calcium.

Despite environmental problems associated with the disposal of POFA, fly ash and other waste materials, they have a potential use as a partial substitute of cement in concrete and bricks due to their high pozzolanic content as well as in other composite materials and demand for environmental sustainability (Al-Oqla and Sapuan, 2015, Al-Oqla et al. 2015 a, b, Tangchirapat et al., 2007, Cicek and Tanrıverdi 2007, Rahman et. al. 2014a). Previous research data explained that there are lot of applications for using different types of waste materials such as POFA, Fly ash, lime-stone powder, rice husk, sugarcane bagasse, date palm fibre etc. for different purposes (Al-Oqla et al, 2014, Al-Oqla et al 2015 a, b, Tay, 1990, Muntohar and Rahman, 2014). Some of them were utilized specifically for the brick production which accomplished to produce light weight brick with high compressive strength (Shakir et al., 2013, Turgut, 2012, Gokhan and Osman, 2013, Rahman, 1987, Malhotra and Tehri,1996, Bilgin et al., 2012, Weng et al., 2003, Faria et al., 2012, Gencel et al., 2013).

For commercial production, it is very important to maintain the proper proportion of waste materials to replace cement, however; there is a lack of inadequate standard guidelines for the commercial production and application purposes. Therefore, further research needs to be conducted to develop the proper guidelines for incorporating the natural waste materials in brick (Zhang, 2013, Rahman et al., 2014a).

According to the previous literature, it is anticipated that there is a lack of research to measure the performance of the bricks utilizing blended POFA and fly ash. Therefore, there is a great chance to explore the technical background for the development and implementation of such bricks leading to cleaner production in the construction industry sector. (Rahman et al., 2014a, Taaffe et al., 2014, Rahman et al., 2014b).

In order to assess the cleaner production of the bricks, the aim of this research is to utilize the blended fly ash and POFA as a pozzolanic materials that not only improve the overall quality of the bricks but also reduce the environmental impact of these waste materials. Furthermore, this research data will be supportive to produce a proper guideline for brick production.

2. Materials and Methods

2.1. Materials

Locally available materials such as water, cement, POFA, fly ash and river sand were used for the production of the bricks. The POFA and fly ash are free of cost and are treated as waste materials.

2.1.1. Ordinary Portland cement (OPC)

Ordinary Portland Cement (OPC) grade 42.5 produced in Sarawak, Malaysia was used in this project. The OPC satisfied the quality requirements of the ASTM C150/C150M-12 (ASTM Standard C150, 2012).

2.1.2. Palm Oil Fuel Ash (POFA)

POFA was obtained from the palm oil industry located at Lambir, Miri, Malaysia. Then laboratory ball mill was used to make the acceptable fineness. In order to reduce the particle size to 300 μm, the process of grinding was conducted for 6 hours. Sieve analysis was then carried out and it was used to reduce the particle size up to 75 μm or smaller. All sieved POFA were then kept in clean, dry and airtight container and stored in humidity controlled room.

2.1.3. Fly Ash

Fly ash was obtained from a coal-fired power plant at Kuching, Sarawak, Malaysia. Fly ash used in this research conforms to Class F requirements set by ASTM C618-12a (ASTM Standard C618, 2012) Chemical Specifications (Brabha et al. (2012)).

2.1.4. Local River Sand

The sand used in the production of the brick was collected from the local river. In order to satisfy grading requirement of AS 2758.1 (AS 2758.1, 1998), sieve analysis was carried out. The fineness modulus of the sand was 1.52. Figure 1 shows that the grading curve of the sample falls within upper limit and lower limit recommended by AS 2758.1 (AS2758.1, 1998). Consequently, the sand is deemed suitable for brick production.

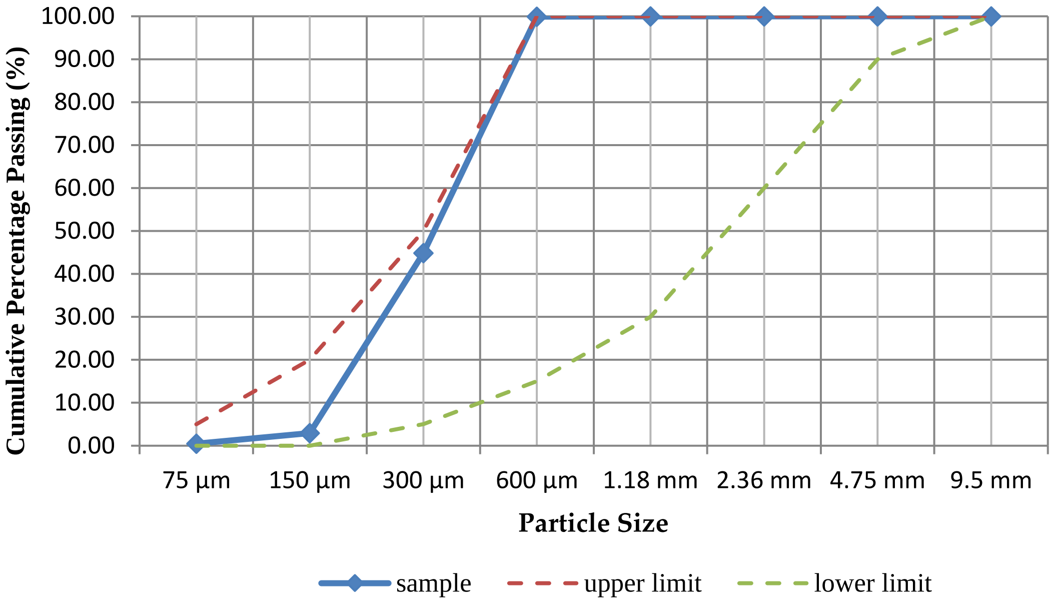


Figure 1. Local River Sand Grading Curve

2.2. Brick Mix

Five batches of bricks were prepared for this research and each batch of brick underwent curing process. Curing periods were planned for 28days and 90days in order to achieve potential strength and durability. The dimension of each brick was 200mm long, 100mm wide and 70mm thick. Table 1 shows the five different ratios of brick mixtures used in this study. For this research, the tests carried out were compressive strength test, breaking load test, water absorption test and thermogravimetric analysis (TGA). These tests were conducted in accordance with ASTM C67-11 (ASTM StandardC67, 2011) which is the standard test method for sampling and testing of brick and structural clay tile except thermogravimetric analysis (TGA) which is based on ASTM E1131-08 (ASTM Standard E1131, 2008).

Table 1: Brick Mix Ratio

Batch	Ratio	Curing Condition
Batch 1	C : S = 1 : 3	90 days 28 days
Batch 2	C + POFA[10%] : S = 1 : 3	90 days 28 days
Batch 3	C + POFA[10%] + FA[10%] : S = 1 : 3	90 days 28 days
Batch 4	C + POFA[10%] + FA[20%] : S = 1 : 3	90 days 28 days
Batch 5	C + POFA[10%] + FA[30%] : S = 1 : 3	90 days 28 days

Where: C = Cement; S = Sand; POFA = Palm Oil Fuel Ash; FA = Fly Ash

2.3. Preparation of Bricks

Traditional method of brick production was employed in this project. First, the Portland cement and sand were measured and blended using the Hobart A200 mixer for 3mins, in order to obtain a homogeneous mixture. The sieved POFA and fly ash were then measured and added into the mixture. At the same time, water was constantly added into the mixture until the substances in the mixture were equally distributed. The entire mixing process took approximately 6mins.

The mortar mix from the mixture bowl was then placed into a 200 x 100 x 80 mm timber mould in three equal layers. Each layer was then manually compacted using a timber plate. The moulds were then slightly overfilled with the mixtures, leaving not more than a 5mm thick layer. Again, the mixtures in the mould were placed in the hydraulic press machine and pressed with a force of up to 7MPa for further compaction. The specimens were finally dismantled from the mould and cured. Once the bricks were made, they were wrapped with plastic and kept in the lab for either 28days or 90days (M. E. Rahman et al., 2014a).

2.4. Testing Methods

The laboratory tests were divided into two categories - soaked and unsoaked conditions of bricks. The distinction between the two categories is that the soaked bricks underwent the water absorption test.

The experimental program began with the water absorption test, after the curing periods of 28days and 90days were completed. Following the water absorption test, the bricks were tested for compressive strength and breaking load (M. E. Rahman et al., 2014a). At the end of compression test, the unsoaked bricks were crushed into a fine powder and then heated by the TGA instrument.

2.4.1 Compression Test

To obtain the compressive strength of the bricks for 28days and 90days, the compression tests were carried out using a Universal testing machine (UTM). First the brick specimens were placed on the top of the steel plate, then the vertical loads are applied to the upper surface of the specimen. During the test, the loading rate was maintained at 1.25mm/min and it was applying until the failure occurred in the bricks. The failure load of the specimen was recorded and the compressive strength of each specimen was calculated in terms of MPa.

2.4.2 Water Absorption Test

Before the compression test, a total of 39 bricks specimens were subjected to water absorption test. To do the absorption test three steps were maintained. First, the brick specimen was weighed as Wd, Second, it was immersed in water at the room temperature for 24h, Third, it was removed from the water tank and patted dry with a lint free cloth. After removing from the water, these specimen again weighed and expressed this value as Ws. The percentage value of water absorption was calculated by using equation 1.

$$\text{Water Absorption } (\%) = 100(Ws - Wd)/Wd \quad (1)$$

2.4.3 Thermogravimetric Analysis Test

Thermogravimetric analysis was performed to determine the mass change in the powder samples. These powder samples are taken from brick specimens after undergoing curing for 28days and 90days. A total of 10 brick specimens were tested for thermogravimetric analysis. The tests were carried out using Mettler Toledo TGA/DSCI Star System. After the compression test the brick was placed in the mortar (bowl), then downward pressure was applied to the crushed brick with a pestle (pounder) until it became a fine powder. The powder samples were tested from 35^{o} to 1100^{o}C at heating rates of 10oC/min under a nitrogen atmosphere. The signal produced from the TGA instrument was used to calculate the weight loss of the powder sample during heating and to estimate the content of calcium hydroxide $Ca(OH)2$. In essence, the $Ca(OH)2$ content was calculated from the weight loss at 400^{o}C-500^{o}C and 600^{o}C-750^{o}C (Borges et al., 2010).

3 Results and Discussions

3.1 Density

The average densities of the bricks from each batch are shown in Figure 2. It can be seen that the density of the brick increases moderately with the replacement of fly ash because of its fineness. Fine spherical fly ashes are able to fill the void between the particles which results in denser packing (Ranjbar et al 2014). The increase in dry density indicated that the substitution of fly ash for Portland cement in the brick would be possible to produce a denser brick. All bricks were in the ranges of 1680 – 2000 kg/m3 and according to ASTM C55-11 (ASTM Standard C55, 2011), all are considered as medium weight bricks. Overall, the density of blended POFA and fly ash based bricks are significantly higher than that of the control bricks.

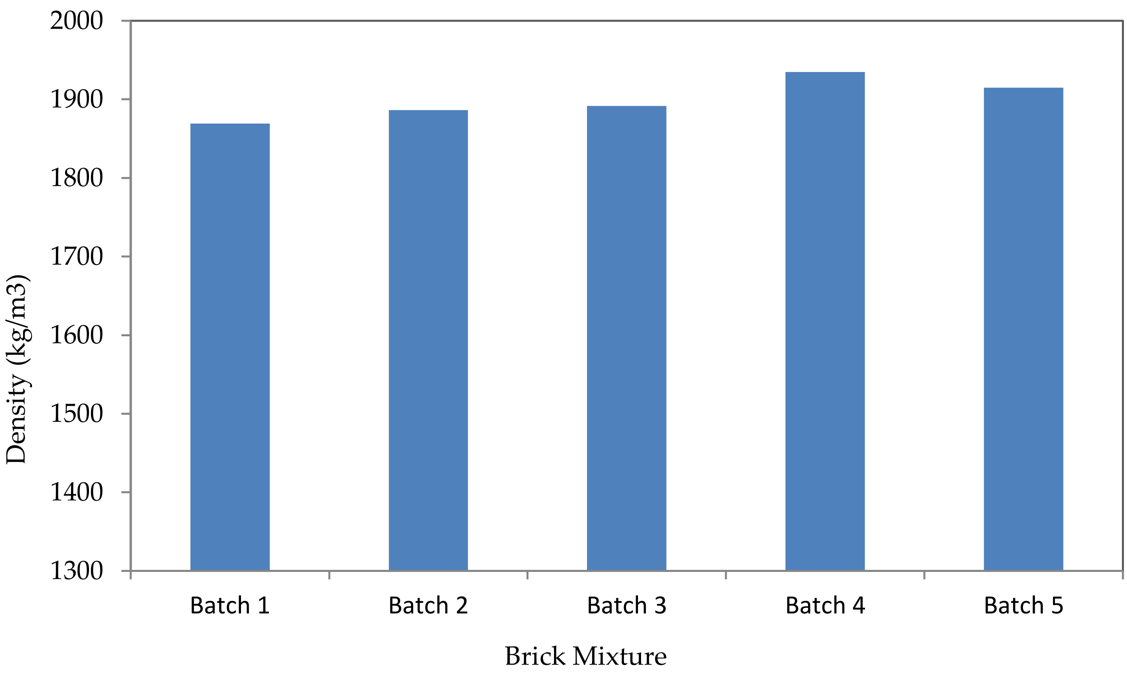


Figure 2. Average densities of different mixes

3.2 Compressive Strength

The compressive strength of the bricks for 28days and 90days of curing are presented in Figure 3 and Figure 4 respectively. It can be seen that the compressive strength of the bricks are exaggerated by the blended POFA and fly ash replacement and also by immersion.

3.2.2 Effect of Blended POFA & fly ash Replacement

Figure 3 shows the average results obtained from the compressive strength tests after the curing of 28 days. The amount of blended ash is limited to 0% POFA & 0% fly ash, 10% POFA & 0% fly ash, 10% POFA & 10% fly ash, 10% POFA & 20% fly ash and 10% POFA & 30% fly ash by mass of the total cementitious material in the brick. It is observed that the compressive strength decreased with the adding of blended ash. This is caused due to the slow rate of the pozzolanic reaction of ash. The compressive strength results of bricks after 90 days curing are shown in Figure 4. This figure shows that the Batch 3, which containing 10% of POFA and 10% of fly ash, achieved the highest strength of all the mixtures (22.5 MPa). However, the addition of further fly ash content resulted in the reduction of strength of the bricks. The possible reason for the decreasing strength is due to the low content of Portland cement in the cement mortar mixture. The decrease of the Portland cement content would cause a low calcium hydroxide content being generated from the cement hydration and this would also reduce the binding component calcium-silicate-hydrate (C-S-H gel) (Altwair et al 2011). Therefore, it became weak in binding the aggregate particles. Previous researches showed that the shape of ground POFA particles is irregular and angular. Therefore, it required a higher water demand in order to maintain a given workability of cement mortar mixture (Chindaprasirt et al, 2007). In contrast, fly ash consisted of particles that are spherical shape and thus, it required less water to lubricate for maintaining the given workability of cement mortar mixture. Consequently, these results showed that the combination of POFA and fly ash with the same cement replacement level in cement mortar mixture achieved a less water-binder ratio compared to only POFA replacement.

3.2.3 Effect of Immersion

The compressive strength of the bricks at 28days and 90days are categorized into two groups: soaked and un-soaked and shown in Figure 3 and Figure 4. It is observed that the wet specimens produced a lower compressive strength compared to the air dry specimens because of the higher water absorption in the bricks during the submersion in water. As a result, this softens the fine aggregates slowly, leading to lower strength (Rahman et al. 2014a).

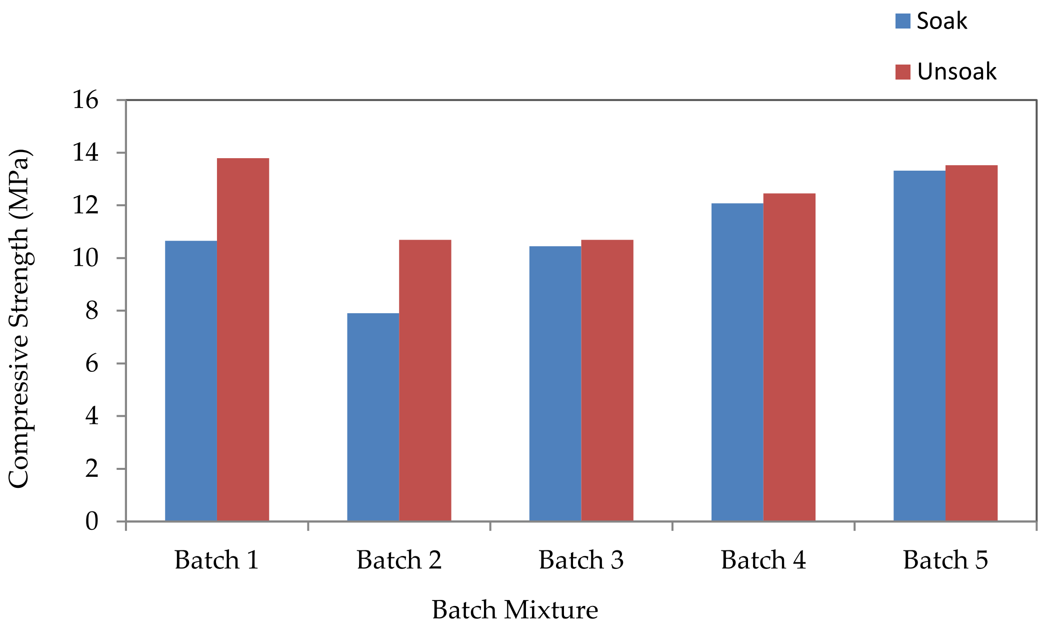


Figure 3.Compressive strength of bricks at 28 days for soaked and unsoaked conditions.

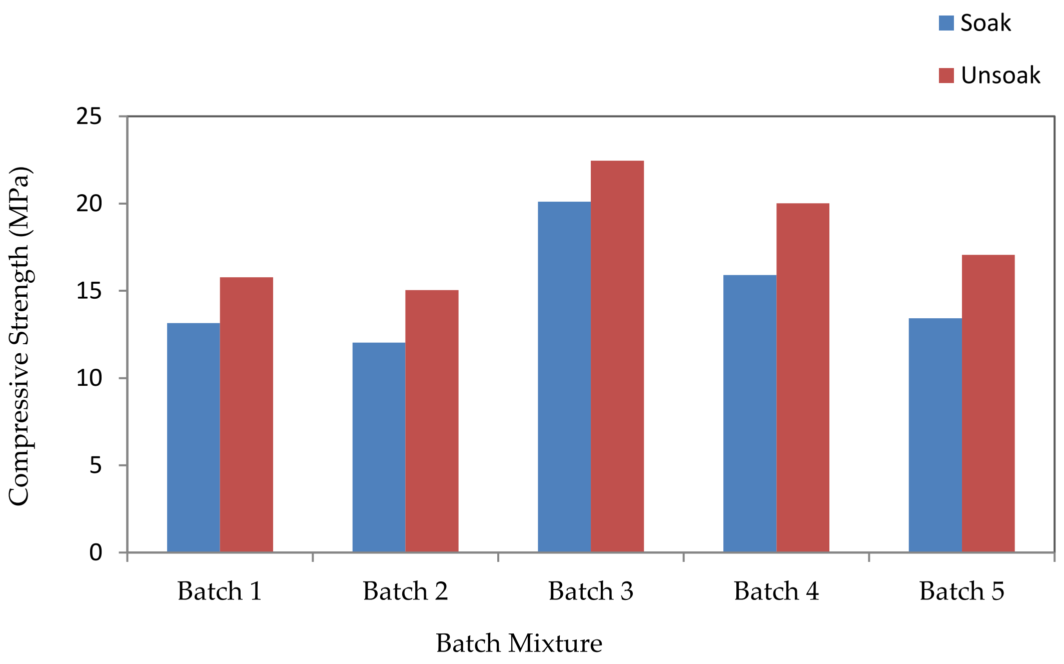


Figure 4. Compressive strength of bricks at 90 days for soaked and unsoaked conditions

3.4 Water Absorption

The water absorption results for after 28days and 90days of air curing are presented in Figures 5 and 6. It is observed that the water absorption of all batches of brick samples are lower than the requirements set by ASTM C55-11 (ASTM Standard C55, 2011). The requirements set under ASTM C55 states that the utmost water absorption is 208 kg/m3, 240 kg/m3 and 288 kg/m3 for normal weight brick, medium weight brick and light weight brick respectively. Hence in terms of water absorption, all batches of brick samples are classified as normal weight bricks.

As seen in Figure 6, the rate of water absorption decreases significantly with increasing percentage of fly ash replacement and these results are consistent with the published results by Naganathan and Linda (2013). Based on these findings, it can be concluded that the small particles of spherical fly ash is able to fill the voids, as a result it makes a denser packing which leads to lower water absorption of the brick.

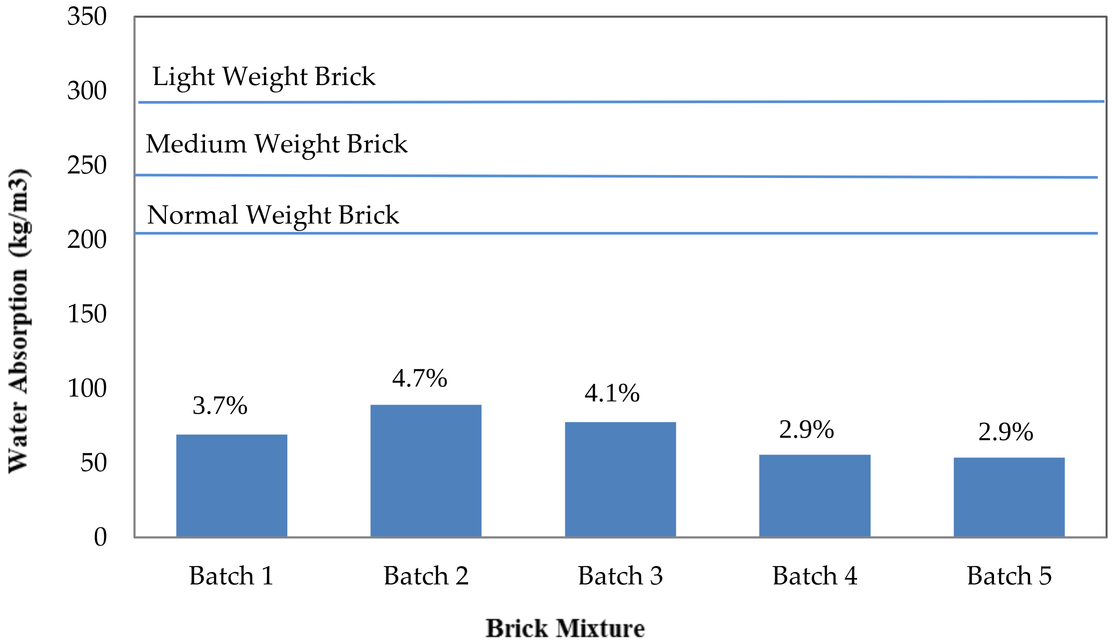


Figure 5.Water absorption of bricks at 28 days for different batches of samples

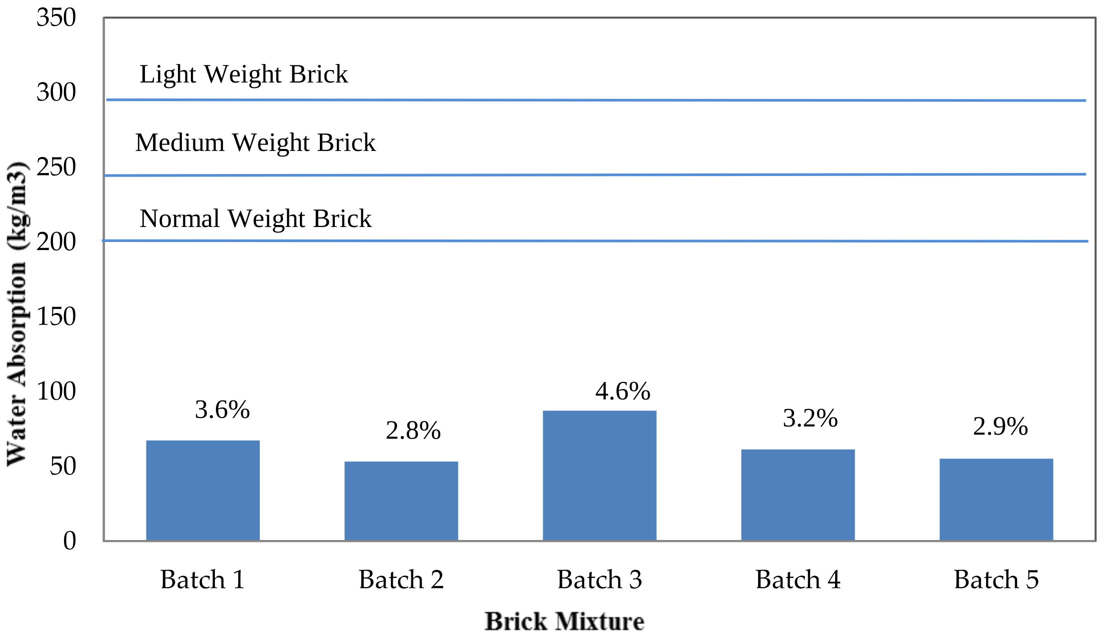


Figure 6.Water absorption of bricks at 90 days for different batches of samples

3.5 Thermogravimetric analysis

Figure 7 presents Thermogravimetric Analysis (TGA) and Derivative Thermogravimetric analysis (DTG) as a cumulative mass loss of the powder samples, taken from the brick specimens, while the temperature increases. The step analysis of cement pastes obtained from TG analysis indicates all samples are experienced mass losses in four different steps. The first mass drop in TG curve (Figure 7(a)), which is related to distinguished peaks before 150^{o}C in DTG curves (Figure 7(b)), are referred to the moisture evaporation of concrete pastes samples. Table 2 illustrates the mass losses of the next three steps of all batches taken from TGA test. Gabrovseka et al. (2006) showed that dehydration of portlandite started from 414^{o}C and completed at 470^{o}C with a decomposition temperatures peak at 451^{o}C for 7 days hydration. It has also been reported (Dweck et al. 2000, Gabrovseka et al. 2006, Ramachandran et al 2001 and Li et al. 2003) that decomposition of carbonates shows two peaks in DTG curve where the first peak was appeared between 470^{o}C-720^{o}C with maximum at 651^{o}C referred to the amorphous calcium carbonate and the second peak was appeared between 720^{o}C-950^{o}C with maximum at 754^{o}C denoted to the de-carbonation of well crystallized calcite.

Table 2: Step analysis of de-hydroxylation and de-carbonation stages from TGA curves

Cement Pastes Sample	Second Stage			Third Stage			Fourth Stage		
	Temperature Range /°C	Mass Loss /%		Temperature Range /°C	Mass Loss /%		Temperature Range /°C	Mass loss /%	
		28 days	90 days		28 days	90 days		28 days	90 days
Batch 1	419 – 442	5.02	3.90	505 -733	2.10	5.80	733 – 950	1.64	1.87
Batch 2	415 – 437	3.57	4.80	626 - 677	2.80	2.71	735 – 950	1.12	2.12
Batch 3	421 – 441	3.69	4.05	620 - 675	2.92	4.08	733 – 950	1.54	1.55
Batch 4	419 – 437	2.72	3.03	692 - 697	2.54	2.27	720 – 950	2.04	1.57
Batch 5	428 – 442	2.27	2.37	518 - 654	2.29	2.13	727 - 950	1.98	1.59

Based on Table 2 and Figure7, the de-hydroxylation stage occurs in the range of 415 to 442^{o}C for all batches without any significant changes in the degradation temperature range. In addition the broad peak in the third stage, which occurs due to the de-carbonation of amorphous calcium carbonate, is shorted due to adding POFA and fly ash. Table 2 also illustrates the mass losses of well-crystallized calcite (fourth stage), which occurs in the range of 720 to 950^{o}C, declines by increasing POFA and fly ash content for 90days curing samples. Although, samples with 28days curing show a fluctuation in this stage, which might be due to the low cement hydration compared to the 90days curing time.

3.5.1 Hydrated Phased of Cement Pastes Containing Blended POFA and Fly Ash

Based on the TG and DTG results, the percentage of mass loss of calcium hydroxide Ca(OH)2 can be calculated by using the equation from (Paulo et al. 2010 and Mohammed et al. 2013). The equation for calculating the total amount of calcium hydroxide in the powder samples is shown in Equation 4:

$$\text{Amount of Ca(OH)2} = \text{CH\% de-hydroxylation} + \text{CH\% de-carbonation}$$

$$= 74/18\ \text{dhloss} + 74/44\ \text{dcloss} \qquad (2)$$

Where dhloss = total mass lost due to the de-hydroxylation of calcium hydroxide at a temperature between 400 and 500oC.

$Ca(OH)_2$ $CaO + H_2O$ [de-hydroxylation of calcium hydroxide]

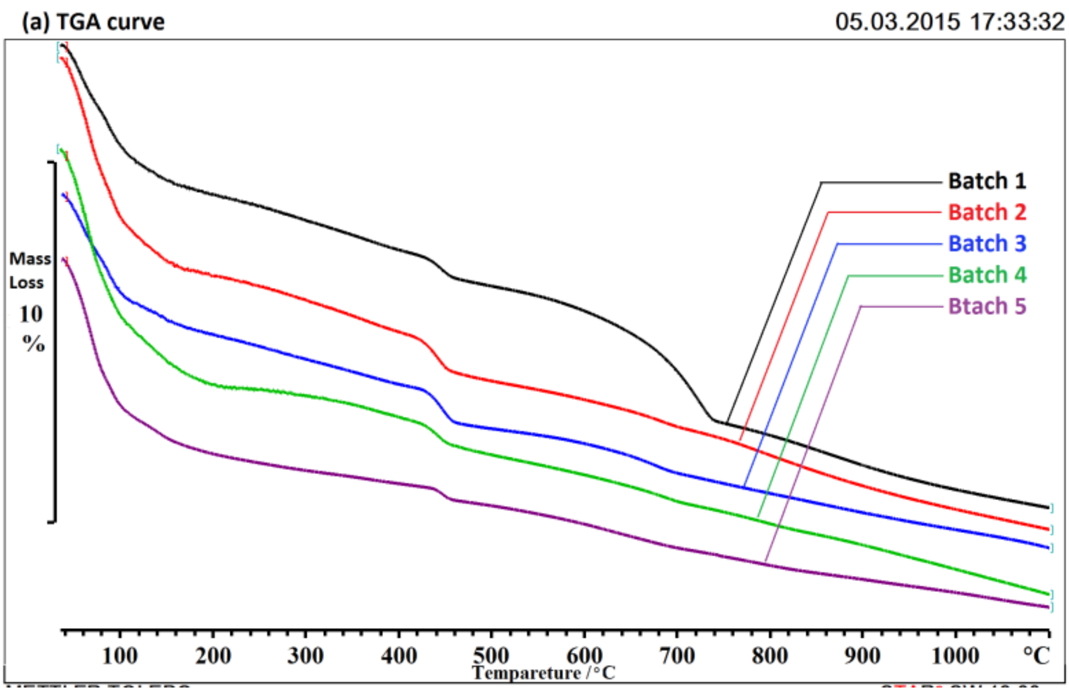
And dcloss = total mass lost due to the de-carbonate reaction at a temperature between 500 and 733oC

$CaCO_3$ $CaO + CO_2$ [de-carbonation of calcium carbonate]

Where 74, 18 and 44 are the molecular weights of CH, H_2O and CO_2 respectively.

3.5.2 $Ca(OH)_2$ content

The $Ca(OH)_2$ contents of the pastes at 28days and 90days of curing are shown in Figure 8 and Figure 9 respectively. It can be seen that the results trend at 28days curing is almost similar to the results at 90days curing. At 90days of curing, the $Ca(OH)_2$ content of the control batch (Batch 1) was approximately at 12.4%, which was the highest value compared to the other batches and this is due to hydration of cement (Altwai et al, 2011). The addition of 10% POFA was found to result in a significant loss of $Ca(OH)_2$. The pozzolanic reaction was found to reduce $Ca(OH)_2$, as it was observed in Batch 2 (Kroehong et al. 2011). However, at higher proportions of fly ash content, that is 30% (Batch 5), $Ca(OH)_2$ content significantly dropped to approximately 6.6%. These results showed that the higher the content of pozzolanic material (POFA and fly ash), the higher the consumption of $Ca(OH)_2$ is as a result of pozzolanic reaction. Furthermore, another possibility for decreasing $Ca(OH)_2$ content is due to the lower content of Portland cement in the POFA-fly ash cement pastes. The decrease of the Portland cement content would cause lower calcium hydroxide content being liberated from the cement hydration. This finding is similar with previous findings of Altwair et al. (2011).



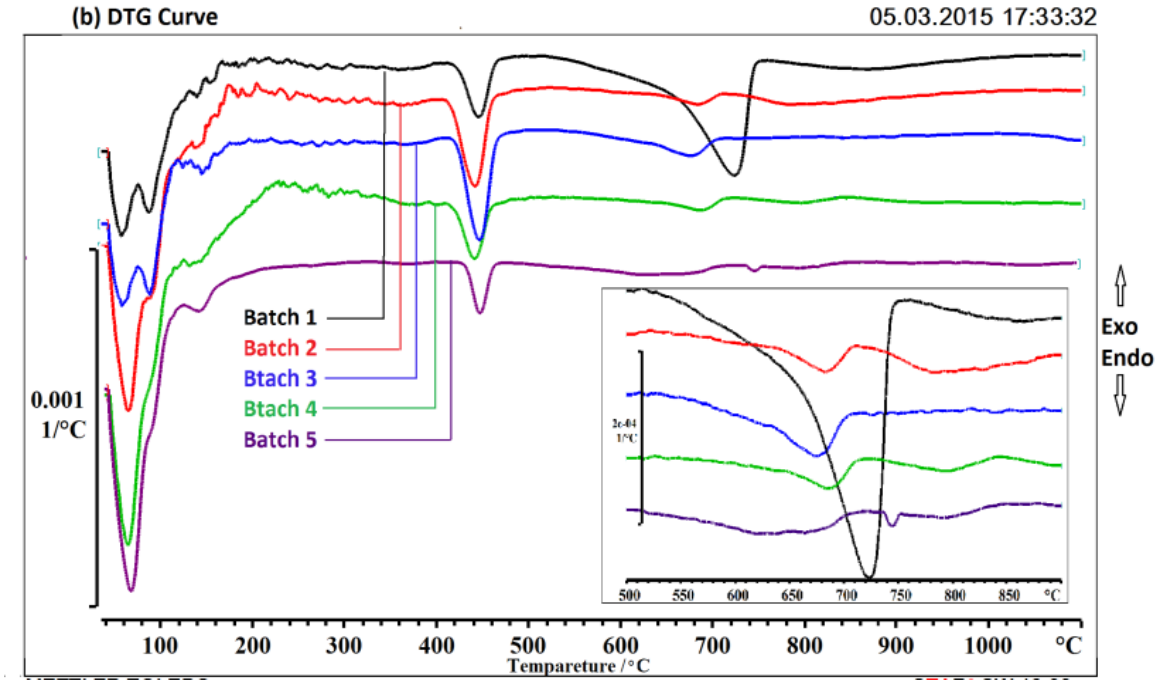


Figure 7. (a) TGA and (b) DTG Results of bricks containing blended POFA and Fly Ash

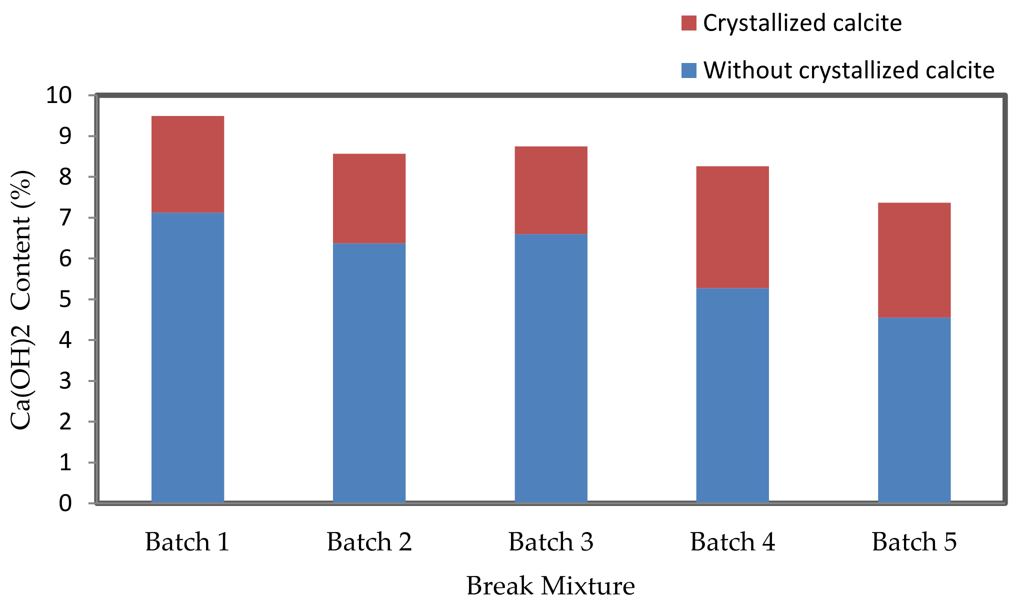


Figure 8. De-hydroxylation and de-carbonation at 28 days

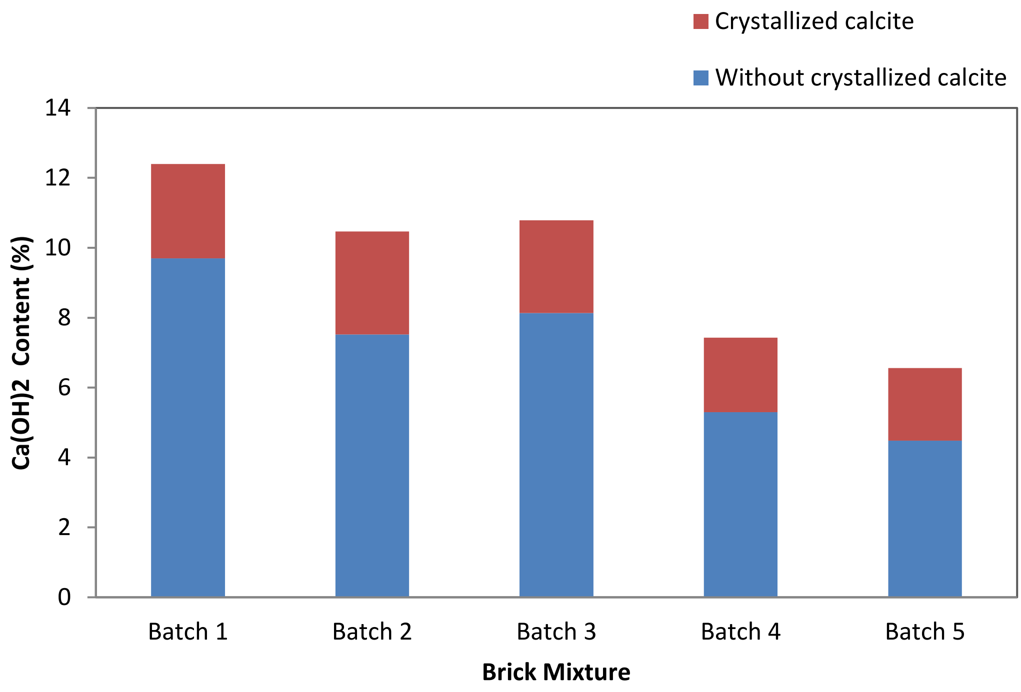


Figure 9. De-hydroxylation and de-carbonation at 90 days

3.6 Cost of Brick

The cost analysis of the bricks is shown in Figure 10. It can be seen that the cost of the control batch is the most expensive, compared to the other batches. The cost of the raw materials is the important factor for the overall cost of the bricks. The brick cost depends on the cost of the cement, however; when it is replaced by these waste materials such as POFA and fly ash, its cost became low. The lower cost creates a commercial interest in moving towards the use of waste materials as a replacement for cement and provides an impetus towards the cleaner production.

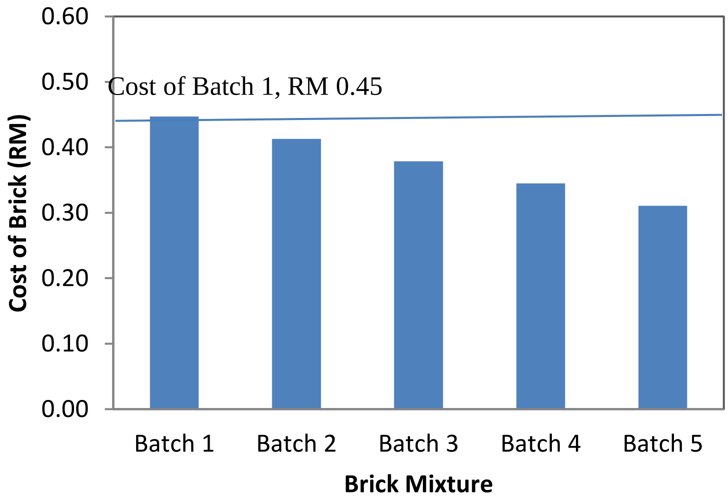


Figure 10.Unit cost of brick

4. Conclusions

An experimental study was carried out to investigate the properties of bricks where cement is replaced by the blended POFA and fly ash in different ratios. The findings in this study emphasize the opportunity for an environmentally friendly method of managing waste products from the palm oil industry and coal-fired power plants. Fly ash bricks showed encouraging improvement after the addition of 10% of POFA. These bricks were found to be suitable for construction of low-cost housing. Some specific conclusions from this study are as follows:

As per ASTM C55-11(ASTM Standard C55, 2011), all the brick specimens were categorized under the medium weight brick category. In essence, the density of the bricks is dependent on the percentage of substitution of the Portland cement. The higher the level of replacement of Portland cement, the greater the density of the bricks.

The compressive strength of the bricks are improved by adding POFA and fly ash. The highest strength value was obtained when the ratio of the POFA and fly ash was maintained as 1:1. However, the compressive strength slightly decreased when the fly ash replacement was more than 10%.

The compressive strength of the bricks decreased approximately by 10% to 15%, after 24 hours of immersion in water. In addition, bricks containing 10% to 30% of fly ash exhibited higher compressive strength than that of the bricks made from Portland cement. However, based on the Malaysian Standard MS 76 (1972), these bricks satisfied the requirements of Class 1 and Class 2 load bearing bricks.

The water absorption of the POFA- fly ash bricks is 208 kg/m3 which is lower than that of ASTM C55-11 (ASTM Standard C55, 2011). However, higher water absorption was found in Batch 3 compared to the control batch at 90 days. Furthermore, the water absorption of POFA-fly ash bricks decreased with increasing fly ash replacement.

At 28 days and 90 days of curing, TGA data confirmed that the Ca(OH)2 gradually decreased due to the increase of pozzolanic content.

POFA and fly ash are considered as waste materials, therefore, the cost of POFA and fly ash containing bricks are lower than that of Portland cement containing bricks.

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