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Fabrication of Bricks From Paper Sludge And Palm Oil Fuel Ash

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Abstract

Increasing amount of disposed paper sludge and palm oil fuel ash (POFA) from industries has recently attracted concern for an alternative environmentally sustainable application. This paper presents results of laboratory work carried out on these by-products in order to evaluate application performance. Brick specimens made with various proportions of cement, paper sludge and POFA were fabricated and studied under laboratory conditions. Curing periods of 7, 28 and 84 days were applied followed by compressive strength test. Leaching and water absorption capacities were also assessed as prime steps towards monitoring durability in service. It was found that paper sludge-POFA brick made with 60% cement, 20% sludge and 20% POFA satisfies the strength requirements of BS 6073 Part 2: 2008 and that the amount of copper as well as lead resulting from leaching are within the acceptable limits of 'Malaysia Environmental Waste Disposal Act'.

Keywords: Brick; Paper sludge; POFA, Leaching; Water absorption.

1. Introduction

In order to reduce non renewable material consumption as well as maintaining natural resources concepts of recycling and sustainability were globally introduced. Paper recycling and utilization of palm oil wastes as fuel source in palm oil mills for instance were currently exercised. Unfortunately, recycling paper and combustion of palm oil waste will produce wastes such as paper sludge and palm oil fuel ash, which generally have no other places to go, except landfill [1, 2]. Therefore, it is imperative to investigate alternative environmentally sustainable application for these waste materials.

Paper sludge mainly consists of cellulose fibre and inorganic materials. The moisture content normally present in paper sludge may vary from 60-75% [3, 4]. However, this value can be reduced to as low as 35% by dewatering processes. The inorganic components are mainly kaolinite and calcium carbonate which reflects surface coating agents during the original paper making [4]. In addition, paper sludge also contains heavy metals from inking activities such as writing and painting.

Previous attempts on reusing paper sludge include cement-bonded sludge board, paper sludge cellucrete, filler-substance in natural rubber [5-7] and paper sludge bricks for masonry construction

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[3]. In the production of the masonry bricks for instance, only 5% fine aggregate replacement by paper sludge acting as mineral filler was achieved. Although, the result shows that such a replacement can yield compressive strength of 8 N/mm^2, but the percentage of paper sludge utilized in the production was apparently small.

POFA on the other hand is obtained from burning of palm oil husk and shell. Currently, thousands tonnes of ash are produced annually and cost of disposal in addition to environmental menace was high. Meanwhile, investigations so far conducted have suggested pozzolanic properties associated with this by-product, thereby identified as having an active role towards producing strong and durable concrete [8]. In fact, durability characteristics of POFA include resistance to chloride penetration and ability to suppress expansion due to alkali-silica reaction [9, 10].

Like other fly ashes, palm oil fuel ash is greyish in colour, becoming dark with increasing proportions of unburnt carbon [9]. Its chemical composition indicated presence of high mount of silica, thus considered to possess high potentials of serving as a cement replacement [11].

The present investigation therefore seeks to find a means of utilizing higher amount of paper sludge in the presence of POFA for masonry brick fabrication. Experimental parameters involved include compressive strength, density, water absorption and leaching.

2. Materials

OPC conforming to BS 12: 1996 [12] was used throughout. Paper sludge was obtained from a local paper making factory. The sludge was disintegrated using mortar mixer for 30 minutes and sieved through 2.36 mm openings and it has a moisture content of about 35%. Figure 1 shows the paper sludge in its prepared condition. POFA was collected from a Malaysian palm oil mill, dried in an oven at 105 ± 5 ^{o}C for 24 h, followed by grounding in a modified Los Angeles abrasion machine [9,13], so that the percent passing 600 μm openings was 50% at 519 m^2/kg Blaine fineness.

Chemical compositions of the OPC, paper sludge and POFA are given in Table 1. However, heavy metal contents present in the paper sludge which include copper (Cu), lead (Pb) and iron (Fe) were evaluated as 141 ppm, 241 ppm and 4088 ppm respectively. High range water reducing admixture (HRWRA) with brown-yellowish powdery form was also used and this has met the requirements of ASTM C 494-99 [14].

Figure 1. Paper sludge

TABLE 1: CEMICAL COMPOSITION OF CEMENT, PAPER SLUDGE AND POFA

Material (%)	Constituent						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	N_2O	LOI
Cement	19.76	5.59	3.39	62.56	1.23	0.02	2.14
POFA	48.99	3.78	4.89	11.69	1.22	0.73	10.51
Sludge	0.45	-	-	-	-	-	64.5

3.0 Experimental procedure

The trial mix proportions were as shown in Table 2. Water/cementitious material (w/cm) ratio was 0.4. In this case, cement and POFA are considered cementitious in conformity with BS 4550 Part 3.4:1978 [15]. The cementitious materials and HRWRA were thoroughly mixed before paper sludge was added. Since paper sludge can easily absorb moisture, this mixing sequence is deemed essential so that shortage of water necessary for a complete cement hydration is avoided. Cubes of nominal size 70.7 mm were used and these were initially cured in moist condition for the first 24 hours, followed by complete immersion in water, both at 20 ± 2 ^{o}C and 85% RH until day for compression test.

TABLE 2: MIX PROPORTIONS OF CEMENT, POFA AND PAPER SLUDGE

Mix Designation	Material %		
	Cement	POFA	Sludge
M-1	90	5	5
M-2	80	10	10
M-3	70	15	15
M-4	60	20	20
M-5	50	25	25

Compressive strength test on all mixes was performed in accordance with BS EN 12390-3: 2002 [16]. However, upon realizing the marginal acceptable mix for masonry bricks, further compressive tests were conducted in accordance with BS 6073 Part 1 [17]. In this case, 215 mm x 103 mm x 65 mm brick size was adopted.

While water absorption test was carried out in accordance with ASTM C140 [18], leaching characteristics of bricks was evaluated using 'Montgomery's method'. 25.4 mm cubes were employed. Air treatment at room temperature for 28 days was given, followed by immersed in 100 ml of distilled water and subsequent testing at the end of 1, 3, 7, 15 and 31 days curing periods. The parameters tested were copper and lead, and these were compared with the 'Malaysian Guidelines for Waste Disposal' [19].

4.0 Results and discussion

4.1 Compressive Strength - Cubes

Compressive strength result for all mixes was shown in Figure 2. Generally, strength values were observed to decrease as the percentage of paper sludge increases. However, there was a continuous increase in strength with time. Even though, highest compressive strength of 26.0 N/mm^2 at 28 days was realized through M-1 mix, but M-4 which contains 20% sludge and POFA each was observed to gain strength of up to 8.89 N/mm^2. This value slightly exceeded the minimum compressive strength requirement of 7 N/mm^2 as prescribed in BS 6073 Part 2: 2008 [20]. Thus, in addition to fulfilling strength requirements, M-4 mix provides an opportunity of utilizing high amount of both paper sludge and POFA.

Obviously, the main factor responsible for the fall in strength as witnessed in the mixes especially M-5 is the decrease in cement content or inversely, the increase in sludge content. Actually, sludge does not contribute to the strength development instead it requires sufficient cement paste for complete homogeneity in the blended matrix. Therefore, where cement paste is less or sludge content is raised, the consequence could be that of weak bonds especially around sludge particles with eventual early cracks development during compressive tests.

Presence of kaolinite clay and heavy metals might also contribute towards retarding cement hydration or acting as deleterious materials, thereby hindering proper bond between particles. In fact, previous reports have indicated resolubilized actions caused by Pb from waste during hydration which delayed the formation of new silicate products [8, 21].

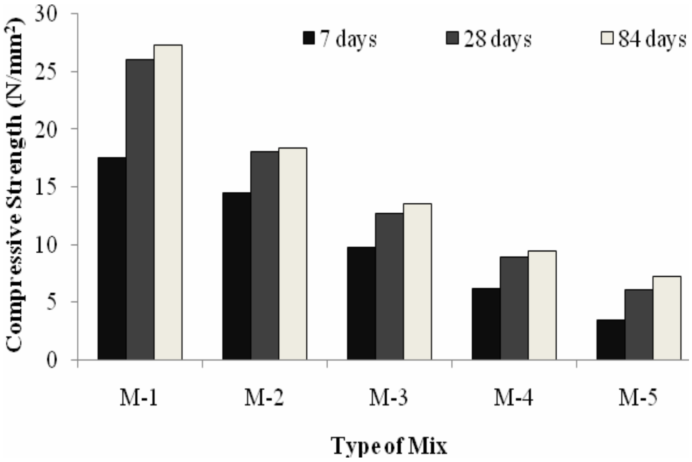

Figure2. Compressive Strength of Mixes

4.2 Density – Cubes

Figure 3 shows the bulk density of the mixes after 28 days curing. Values were evaluated as weight per unit volume. In a similar manner to strength, density was also noticed to decrease with increasing paper sludge percent. This correlates previous findings associated with changes in paper sludge contents where bulk densities were reported to depreciate with increasing paper sludge [6]. Paper sludge in its semi-dry or dry state is quite lighter than hardened cement paste and this is considered as the key factor responsible for the significant decrease in density.

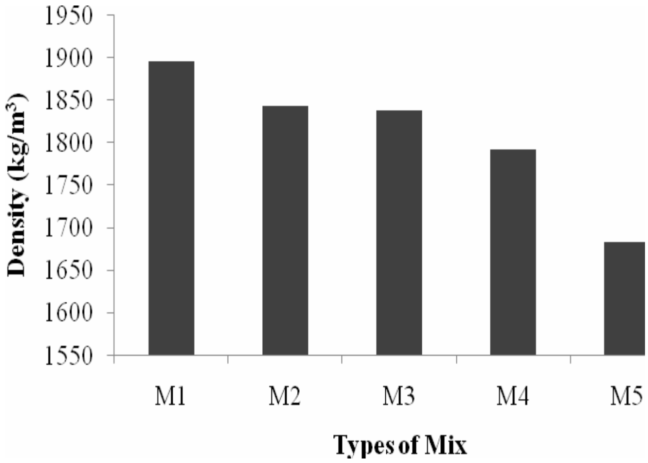

Figure 3. Density of Mixes after 28 days

4.3 Compressive Strength – Bricks

Compressive strength of bricks at 7 and 28 days were observed to be 6.54 N/mm^2 and 10.84 N/mm^2 respectively as shown in Figure 4. The strength was noted to have slightly improved over the cubes strength of similar contents perhaps due to differences in size between cubes and bricks. However, the brick strength was again observed to be quite above the minimum recommended value of 7 N/mm^2.

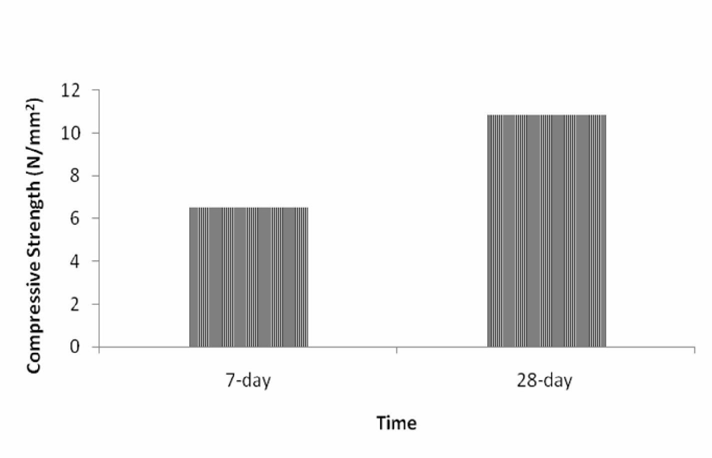

Figure 4. Compressive Strength of Brick

4.4 Density - Bricks

The average weight per brick was 2.44 kg and its corresponding density is 1.7 g/cm^3. Therefore, considering 2.3 g/cm^3 as the average unit weight of normal concrete brick [22], there is about 26.1% decrease in the overall unit weight of the paper sludge-POFA brick and this is relatively quite significant. In fact, this characteristic could be of advantage especially in masonry partition works for high rise buildings where substantial amount of cost can be saved through weight reduction.

4.5 Water Absorption

Water absorption capacity of the paper sludge-POFA bricks was found to be 39.6%. This is relatively high when compared with normal concrete. Cellulose fibre which dominates sludge matrix is believed to play a major role in the high absorption. However, reports have indicated a much higher absorption of up to 60% in autoclave aerated concrete [23]. The present material therefore has a much lower absorption capacity of about 66% only when compared with aerated concrete.

4.6 Leaching

Table 3 presents the results of leaching test which mainly comprises Cu and Pb contents. Even though, the initial observation on these substances as previously indicated in section 2.0 was more than 100 ppm each, but the amount leached with time is quite small. In fact, after 24 h the leachate values were both observed to be less than 0.1%. Thus, progressive leaching of both metal yielded values far below the limit imposed in the guidelines of environmental waste disposal [19] which recommends 100 mg/L and 5 mg/L for Cu and Pb respectively.

TABLE 3: CONCENTRATIONS OF HEAVY METALS FOUND IN LEACHATE

Parameter	Heavy Metal Leachate (mg/L)				
	Day 1	Day 3	Day 7	Day 15	Day 31
Copper (Cu)	0.0388	0.0397	0.0379	0.0186	0.0074
Lead (Pb)	0.1373	0.1493	0.1330	0.0295	0.0010

Reduction of leachate is attributed to the highly alkaline environment of the solidification and stabilization matrix where the metals exists as metal hydrated phases, metal hydroxides and calcium-metal compounds [24]. In addition, alkaline environment of this nature often develop Pb from hydroxide precipitate which later becomes the more insoluble PbO. As a result, the amount of Pb leachate detected is reduced [25].

From the test results observed, it could be concluded that the heavy metals tested, effectively solidified and stabilized in the cement-based matrix. Hence, bricks fabricated from paper sludge-POFA have strong chemical stabilization abilities of suppressing the release of unacceptable amount of heavy metals through leaching.

4. Conclusions and Future Research

The main conclusions that can be drawn from this experimental study may be summarised as follows:

1. Bricks fabricated by incorporating 20% paper sludge and 20% POFA into cement provide adequate compressive strength, tolerable water absorption and acceptable heavy metals leachate, thereby depicting significant potentialities to serve as masonry unit elements.

2. Paper sludge-POFA brick has about 26.1% weight reduction when compared with normal brick. This characteristic could be of advantage especially in masonry partition works for high rise buildings where substantial amount of cost can be saved.

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