# CHAPTER 20

# Impact of heat of Hydration of Blended Palm Oil Fuel Ash and Pulverised Burnt clay on the Sustainability of Self Consolidating Concrete

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## Introduction

Industrialisation has availed humanity the opportunity to produce commodities in commercial quantity. In the process, a substantial amount of waste is being generated and in most cases deposited in open landfills thereby constituting environmental pollution. For instance, the generation of power from agro-industrial waste after the extraction of palm oil is usually associated with millions of tons of palm oil fuel ash (POFA). In Malaysia alone, about 5.6 million tons of POFA is generated annually [1]. Also, another industrialisation product that is noteworthy is clay brick. In fact, it accounts for about 25% of the total building materials requirement by mass [2, 3]. Additionally, it constitutes about 40% of the total demolition waste annually. Like any other waste, it is in most cases deposited in open landfills thereby adding to the environmental burden. To reduce the impact of these wastes on the environment without jeopardizing the output of the industries, series of research efforts have been geared towards their potential application [4,5]. Consequently, these waste materials have been used to improve the fresh and hardened properties of concrete.

Heat of hydration is primarily the property of fresh cement paste in its hardening state. It is in most cases associated with the evolution of heat. This implies that when cement comes in contact with water, the cement grains became hydrated and began to undergo a chemical reaction which gradually resulted in the dissipation of energy in the form of heat. Thus, the amount of heat generated upon complete hydration of a certain quantity of

un-hydrated cement at a given temperature is referred to as the heat of hydration [5].

The heat of hydration is a very important phenomenon that has direct bearing on the mechanical, deformation and durability properties of concrete. Supplementary cementing materials (SCMs) with high pozzolanic activity, such as silica fume (SF) and metakaolin (MK), react with calcium hydroxide (CH) released during the hydration of ordinary Portland cement (OPC). This reaction leads to increase in the heat of hydration due to the exothermic effect of the pozzolanic reaction in comparison with mixtures containing 100% OPC [6]. The pozzolanic activity of the SCMs is usually evaluated through the strength activity index, which is referred to as the ratio between the 28 days compressive strength of two specimen mortars containing 20% SCM and 0% SCM (100% OPC).

The acceleration in OPC hydration was observed to be obvious as a result of increased rates of heat evolution in OPC-SF and OPC-MK mortar mixes [6]. For example, Ambroise et al., [7] attributed the increase in the heat of hydration of MK mortars in relation to that of plain OPC mortar to the accelerating effect of MK on OPC hydration. It is therefore pertinent to note that the maximum observed temperature rise occurs in mortar mixes containing 10% MK as partial replacement of the OPC. It has been reported that the inclusion of finely divided SCM into concrete systems can accelerate OPC hydration, particularly, if the material exhibits high pozzolanic activity [7].

Consequently, an increase in the heat of hydration can have a negative effect on the general performance (mechanical, deformation and durability) of the mortar and concrete systems. This is primarily due to volume changes (shrinkage) and micro-crack formation as a result of induced thermal stresses. Contrary to this assertion, investigation of the effect of the addition of POFA in mortar and concrete mixes revealed that it does not only reduce the heat of hydration but also delayed the time at which the peak temperature occurred [8]. In other research, it was found that high volume replacement of OPC with POFA is specifically suitable for mass concrete where thermal cracking due to excessive heat generation is a serious concern [9].

Although POFA has been successfully used to control the heat of hydration in cement based mixtures, its application above 15% impact negatively on

the fresh properties of normal self-consolidating concrete (SCC), high strength self-consolidating concrete (HSSCC) and self-consolidating high performance concrete (SCHPC). Furthermore, owing to the application of SCHPC in very large pre-cast and pre-stressed concrete elements and also other areas of mass concreting, heat generation must be given due consideration. Nonetheless, literature in the area of heat of hydration associated with SCHPC is very limited. In fact, there is no literature on the effect of binary or a ternary blend of POFA and PBC on the heat of hydration of SCHPC. It is in this regard that this research work seeks to exploit the benefits of the addition of calcined clay in the form of PBC and POFA in controlling the heat generated during the production of SCHPC.

## Materials and methods
## Materials sourcing and processing
### Palm oil fuel ash
Palm oil fuel ash (POFA), is a waste product obtained in the form of ash on burning palm oil husk or fibre and palm kernel shell as fuel in palm oil mill boilers. In the present study, POFA was obtained from a factory in Johor, southern state of Malaysia. The material was collected directly at the foot of the flue tower where all the fine ashes are trapped while escaping from the burning chamber of the boiler. The ashes were then dried in the oven at 105°C for 48 hours in the laboratory and then sieved through a 150μm sieve and then ground to a very fine powder using a Los Angeles abrasion machine. Afterword, various tests were carried out to evaluate the suitability of the ashes.

### Pulverised burnt clay
The pulverised burnt clay that was used in this study consisted of fragments of fire clay bricks that were calcined at about 1000°C and were discarded as waste in a clay brick factory in Malaysia. The fragments were of different sizes, as such, they were reduced to smaller sizes with the help of a jaw crusher and the material was then dried in the oven at 105°C for 24 hours. After that, the material was then reduced to much smaller grain sizes using milling machine; it was then sieved and then ground to a very fine powder using a modified Los Angeles abrasion machine.

### Test details of the Supplementary cementing materials
The respective powders were tested using three different replicates each for physical appearance by visual inspection, specific gravity using the density bottle; particle size analysis using CILAS 1180 particle size analyser; 45

μm wet sieving, 75 μm dry sieving, 150 μm dry sieving and specific surface area by Brunauer Emmet and Teller (BET) method using Micromeritics ASAP 2020 model. Oxide composition was determined using Flame atomic absorption spectroscopy (FAAS) using the Bruker S4 Pioneer model [10], and loss on ignition. Also, accelerated pozzolanic activity was carried out in accordance with the procedure used for silica fume, as provided in [11]. Furthermore, the morphological and microscopic analysis was carried out by scanning electron microscopy (SEM). The SEM device was SUPRA FESEM versatile ultra-high resolution with a variable pressure solution, equipped with an energy dispersive X-ray analyser (EDX). The EDX was used to analyse the glassy phase (amorphous) and the elemental composition of the respective powders.

## Concrete materials and mixes

The cement used for this work is an Ordinary Portland cement Type I, conforming to ASTM C 150 [12] specification, palm oil fuel ash (POFA) and pulverized burnt clay brick (PBC) were used as SCMs. Well graded pit sand and 12 mm maximum sized coarse aggregate with characteristics as shown in Table 1 were used.

A polycarboxylic-based polymer was used as the high range water reducer (HRWR). The HRWR is amber in colour in addition to other characteristics as shown in Table 1. Normal tap water conforming to ASTM C1602/C1602M[13] specification was used to produce the SCHPC systems throughout the research work.

In this study, a total no of 5 different concrete mixes were prepared using 0.3 W/B and a blended POFA and PBC content of 10%, 15%, 20% and 30% respectively as cement replacement. The concrete mixtures were prepared using the revolving type pan mixer with a nominal capacity of 0.015m³ conforming to ASTM C192/C192M[14] specification. The mixture composition of the respective SCHPCs is as shown in Table 2.

**Table 1**
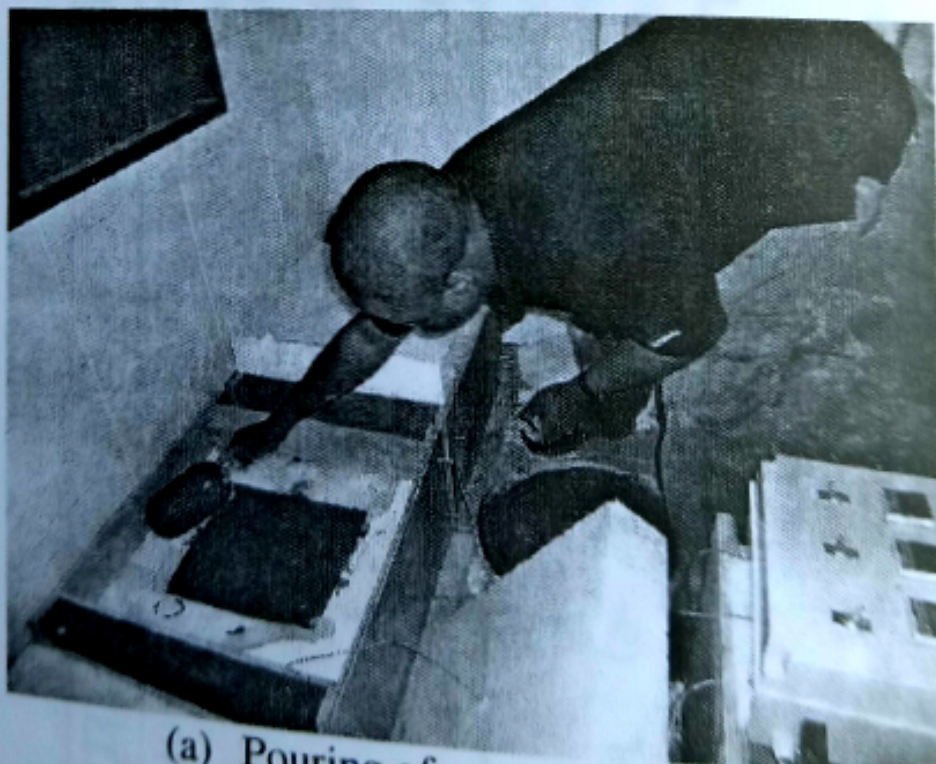Physical properties of the constituent materials

| Material | Properties |
|---|---|
| Coarse aggregate | Specific gravity on saturated surface dry basis: 2.56<br>Oven-dry basis, bulk density: 1609 kg/m3<br>Absorption: 1.6%<br>Total evaporable moisture content: 0.1%<br>Void content: 37% |
| Fine aggregate | Specific gravity on saturated surface dry basis: 2.55<br>Oven-dry basis, bulk density: 1682 kg/m3<br>Absorption: 1.8%<br>Total evaporable moisture content: 1.0%<br>Fines modulus: 2.4<br>Void content: 33.4% |
| High range water reducer (HRWR) | Specific gravity: 1.10<br>pH value: 8<br>Solid content: 42% |

**Table 2**
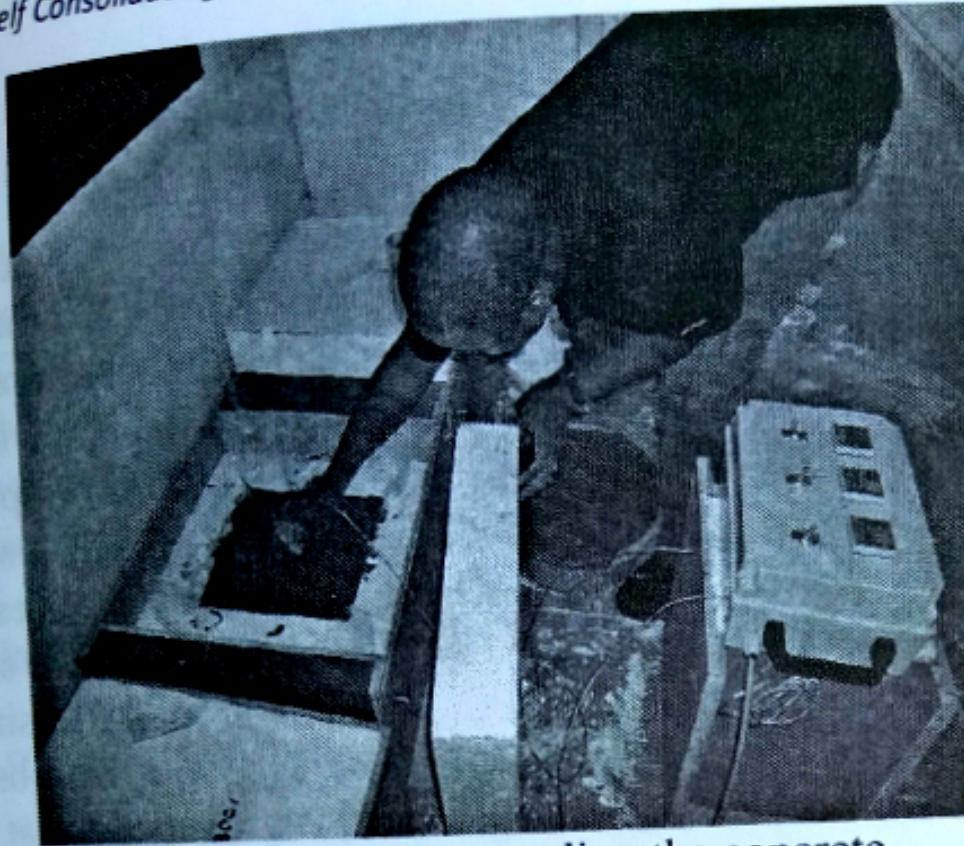Mixture composition of the respective self-consolidating high performance concrete

| Concrete Nomenclature | POFA (% of B) | PBC (% of B) | W/B Ratio | Coarse aggregate (kg) | Fine aggregate (kg) | Cement (kg) | POFA (kg) | PBC (kg) | Water (kg) | HRWR (% of B) |
|---|---|---|---|---|---|---|---|---|---|---|
| 30C1P0:0 | 0 | 0 | 0.30 | 811.20 | 811.20 | 532.99 | 0.00 | 0.00 | 181.27 | 1.50 |
| 30C2P5:5 | 5 | 5 | 0.30 | 811.20 | 811.20 | 473.93 | 26.33 | 26.33 | 178.64 | 1.75 |
| 30C3P10:5 | 10 | 5 | 0.30 | 811.20 | 811.20 | 444.26 | 52.27 | 26.13 | 176.74 | 2.00 |
| 30C410:10 | 10 | 10 | 0.30 | 811.20 | 811.20 | 416.28 | 52.04 | 52.04 | 175.32 | 2.25 |
| 30C5P15:15 | 15 | 15 | 0.30 | 811.20 | 811.20 | 359.98 | 77.14 | 77.14 | 172.82 | 2.50 |

## Measurement of heat of hydration and early age characteristics

The experimental setup consisted of cubical plywood of sides 500 mm. The internal surfaces were well insulated with 76 mm thick expanded polystyrene. Before the concrete was cast into the box, a thermocouple was passed through into the centre of the box through a hole that was drilled through the polypropylene foam that was used as the lid as shown in Fig. 1 (a) and 1 (b). It was then connected to a data acquisition system (data logger). Immediately after the setup, the room temperature was recorded and fresh concrete was cast into the box while maintaining the thermocouple in the centre of the mass. The lid was properly secured in place and the initial reading of the temperature of the concrete mass was recorded. The temperature profile was monitored within very close intervals during the first 24 hours and subsequently at wider intervals, until the temperature drops as close as possible to the initial reading. The temperature profile was monitored for 120 hours and all the readings were recorded and the profile was plotted. The experimental setup is as shown in Fig. 2.



(a) Pouring of concrete into the box

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(b) Thermo-coupling the concrete

**Fig. 1.**Operational procedure for the determination of heat of hydration (a) & (b)



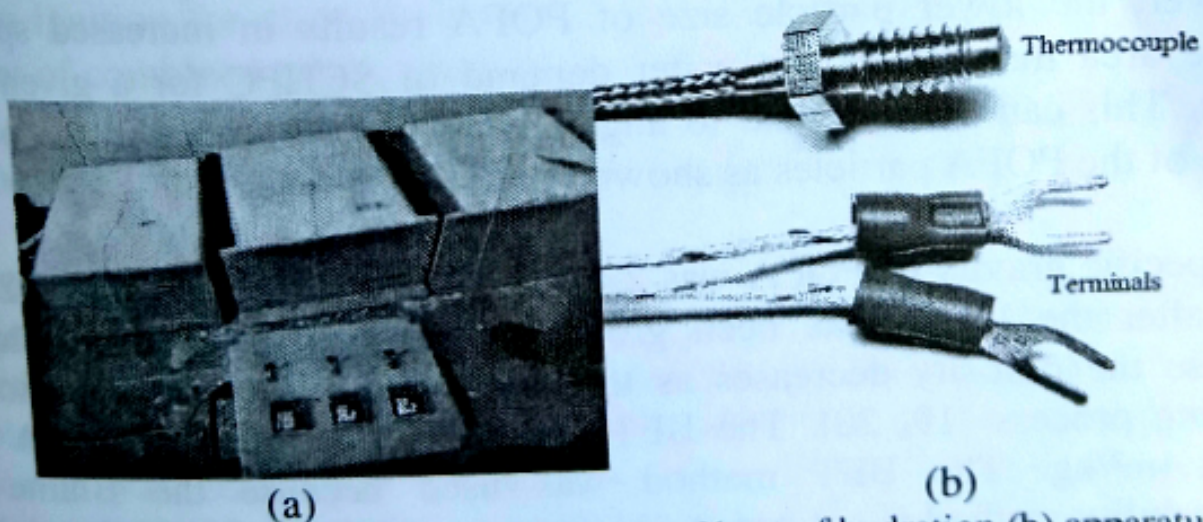(a)                                                                 (b)

**Fig. 2.** (a) Set up for the determination of heat of hydration (b) apparatus

The filling ability of the respective concrete mixtures was determined by slump and slump flow using Abram's cone in accordance with ASTM C 143/C143M[15] specification. In addition, after the curing period of three days, compressive strength of the concretes was determined. Samples from the crushed concrete specimens were immediately immersed in acetone to stop the hydration process. Subsequently, the sample were prepared the microstructures were investigated in order to evaluate the effect of temperature rise on the early age properties of the concrete.

# Results and discussion
## Properties of Supplementary cementing materials
### Palm oil fuel ash

Palm oil fuel ash is dark grey in colour after it has passed through the required processing. The coefficient of gradation of POFA as determined from the result of the particle size analysis in Fig. 3 was approximately 1. Hence it was considered to be well-graded. The diameter of the POFA particles at 10, 30 and 60% were 1.34, 5.24 and 15.28 µm respectively. The median particle size was 11µm. A median diameter of SCM in the range of 5 to 15µm is preferred with respect to workability, cohesiveness and stability of the concrete systems [16, 17]. The median particle size of POFA was 1.4 times finer than that of OPC. The lower particle size of POFA played an important role in the reduction of bleeding by obstructing the movement of rising water. Kroehong, et al.[18] reported that the smaller particle size of POFA improves the particle packing in binder paste. Thereby, refining the micro pore structure and consequently enhancing the compressive strength of the paste, mortar and the parent concrete. However, the lower particle size of POFA results in increased specific surface area that affects the water demand of SCHPC for a given flow ability. This can be attributed to angular particle structure and the porous nature of the POFA particles as shown in Fig. 4.

The specific gravity of POFA was 2.42. It generally ranges between 2.22 - 2.78 after the POFA has been ground to reasonable fineness. This is because the porosity decreases as the particle size decreases due to the grinding process [19, 20]. The BET specific surface area of POFA was 23751.4m²/kg. The BET method was used because the Blaine air permeability method is not convenient to measure the high specific surface area of POFA. This is a recommendation by [11]. The BET specific surface area of POFA was about 4.69 times that of OPC.

The accelerated pozzolanic activity index was 103% for 7 days and 117% for 28 days hydration respectively. Both cases are much higher than 75%, which is the minimum requirement for types N, F or C fly ash [21]. The pozzolanic activity of POFA is generally greater than that of other supplementary cementing materials such as fly ash [22]. This is due to extremely high specific surface area of POFA. Nonetheless, the high pozzolanic activity index of POFA is an indication that it has a very high tendency of accelerating the strength development at the early ages of paste, mortar and concrete.

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The chemical composition of POFA is presented in Table 4. The major component of POFA is silicon dioxide or silica ($SiO_2$). The mass content of silica was 63.7%. This is the main oxide component that contributes to the pozzolanic reaction or secondary hydration in concrete containing pozzolanic material such as POFA. There were other key oxides such as Alumina ($SiO_2$) and Iron oxide ($Fe_2O_3$) in reasonable quantities. In addition to the key oxide components, a substantial amount of sulphur trioxide is also present, about 1.59%. The sulphur level is the second point of consideration in the classification of POFA with respect Fly ash (FA). ASTM C618 [21] recommended a maximum value of 4% for class-N FA and 5% for class F and C FA respectively.

Although ASTM does not provide the specification for the chemical composition of POFA, the requirements for FA can be applied due to close similarities. The POFA used in this study has a moisture content of 0.35, loss on ignition (LOI) of 6.0 and combined silica, aluminium and Iron oxide content of 73.65%. The maximum permissible moisture content and loss on ignition for class-F FA are 3 and 6% respectively. The minimum amount of combined silica, aluminium and Iron oxides required for class-F FA is 70% [21]. Therefore, POFA was classified as equivalent to class-F FA and thus found suitable for the production of SCHPC.

## Pulverised burnt clay

Calcined clay, usually vary in colour from off-white to dark brown. Nonetheless, the PBC used in this research, was reddish brown in colour (Table 3). The coefficient of grading of PBC was also approximately 1. Hence it was considered to be well-graded. The diameter of the PBC particles at 10, 30 and 60% were 1.24, 4.26 and 15.08 μm respectively. The median particle size was 10μm (Fig. 3). Generally, a median diameter of SCM in the range of 5 to 15μm is preferred with respect to workability, cohesiveness and stability of the concrete systems [17]. The median particle size of PBC was 1.5 times finer than that of OPC and 0.9 times finer than that of POFA.

The lower particle size of PBC played an important role in the reduction of bleeding by obstructing the movement of rising water. Kroehong *et al.,* and Heikal *et al* [18, 23] reported that the smaller particle size of SCM like POFA and PBC improves the particle packing in binder paste. Thereby, refining the micro pore structure and consequently enhancing the compressive strength of the paste, mortar and the parent concrete. However, unlike POFA, the lower particle size of PBC does not result in

increased specific surface area. This is therefore an interesting discovery that makes PBC a very good viscosity modifier and good filler. It has low water demand and consequently improves the rheology and flowing ability of mortar [24]. Heikal, et al.[23]also reported the same behaviour in self-consolidating systems. These unique characteristics could be attributed to some important particle characteristics. These are; high content of smaller glassy particles, non-porous particles structure and agglomeration of the particles due to the temperature of calcination as can be seen in Fig 5.
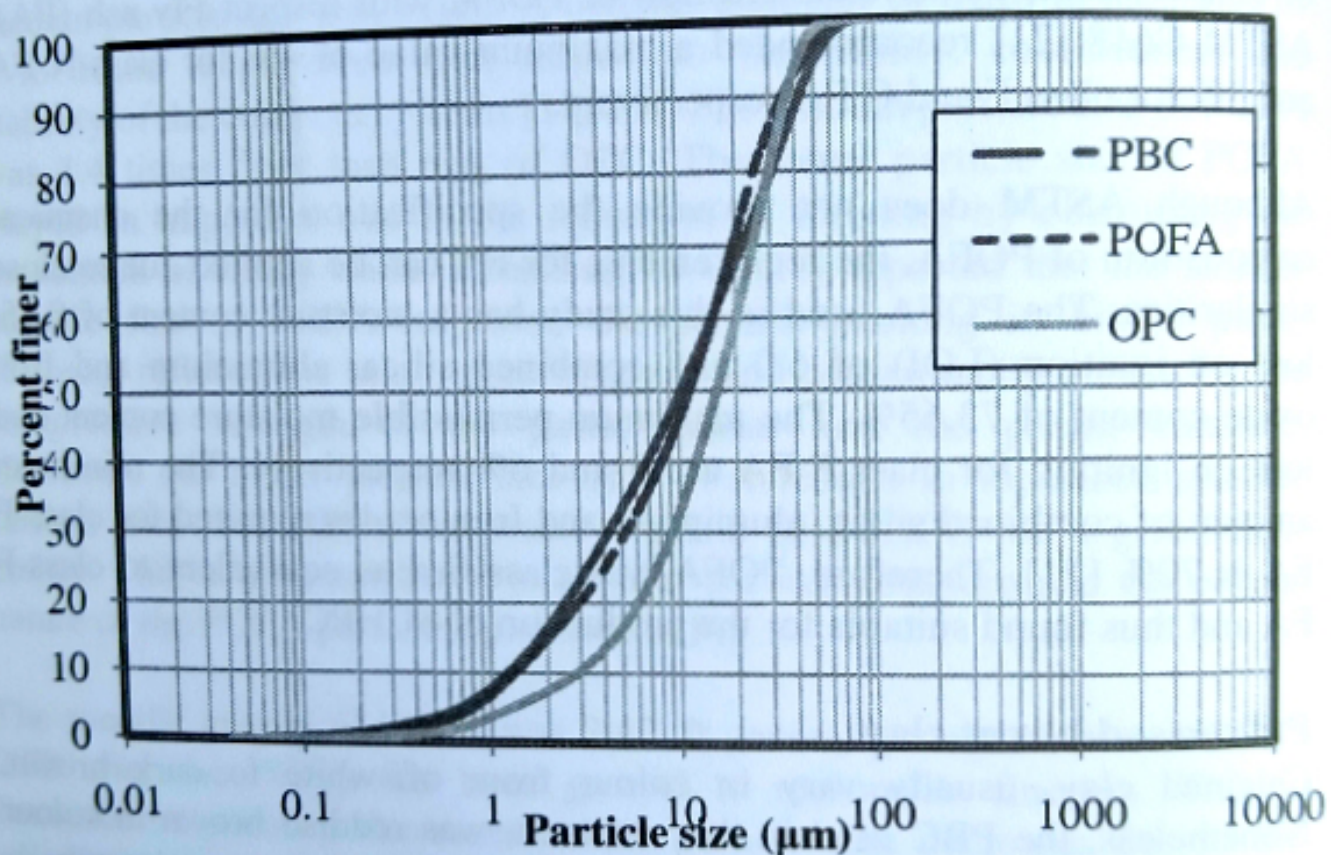


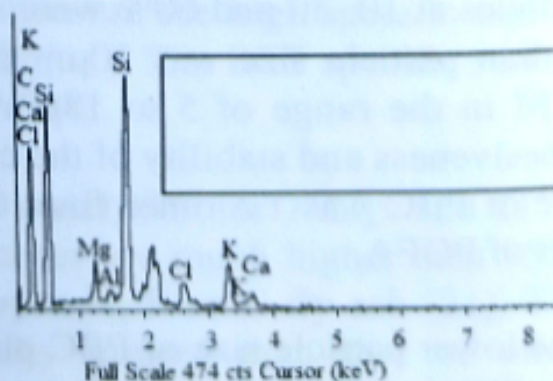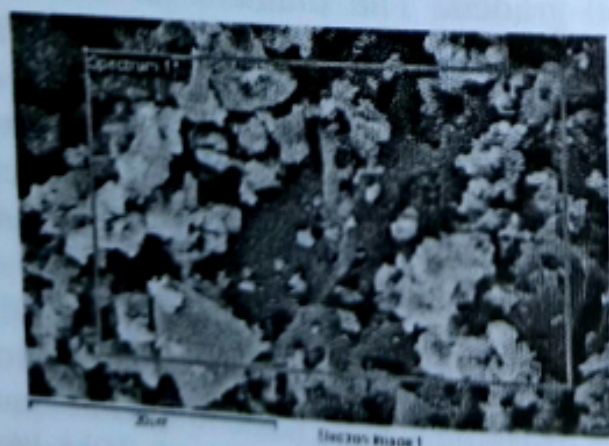Fig. 3. Particle size distributions of OPC, POFA and PBC



(a)    (b)

Fig 4. (a) Scanning electron microscopy of POFA (b) Energy dispersive X-ray of the spectrum from SEM of POFA

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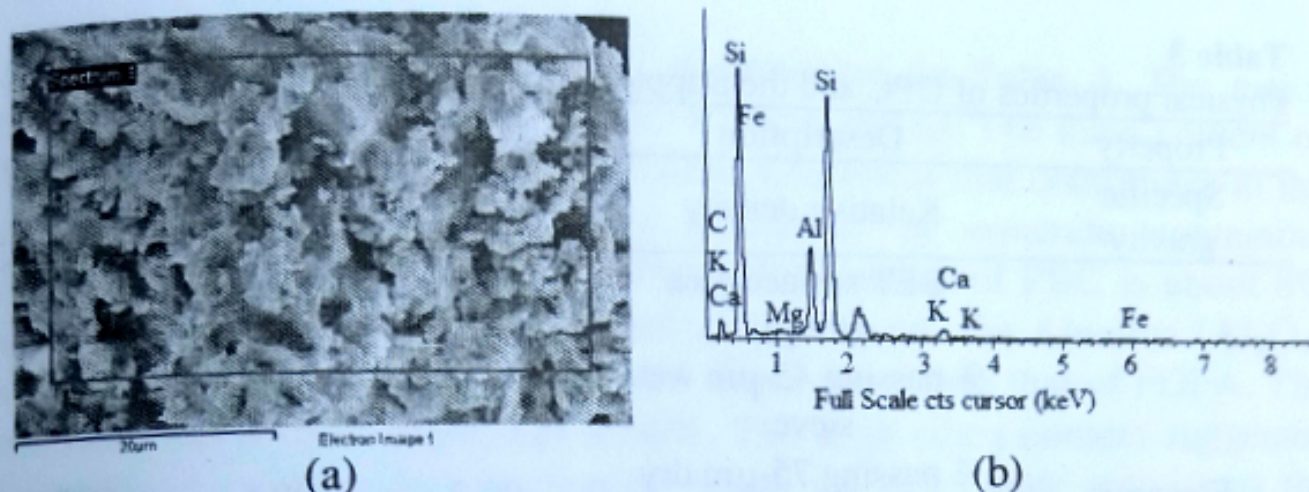**319**

(a)                                                    (b)

**Fig 5.** (a) Scanning electron microscopy of PBC (b) Energy dispersive X-ray of the spectrum from SEM of PBC

The specific gravity of PBC w̶ _____ of PBC
generally ranges between 2.65-2.6̶ _____ ẁer than
that of OPC [22, 25]. The BET specific surface area of PBC was
2979.1m$^2$/kg, which was 1.7 and 8 times lower than that of OPC and
POFA. This particular characteristic makes PBC a very good viscosity
modifier. This is because the lower surface area tends to reduce the water
demand, thereby enhancing the fluidity and the flowing ability of binder
paste, mortar and SCHPC. This increased fluidity is a direct consequence of
the high amount of free water available in the binder paste. Similar findings
were reported by [26].

The accelerated pozzolanic activity index was 96.7% for 7 days and 99.3%
for 28 days hydration respectively. Both cases are much higher than 75%,
which is the minimum requirement for types N, F or C fly ash [21]. The
pozzolanic activity of PBC was found to be lower than that of POFA. A
similar result was reported by [22]. This is due to lower specific surface
area of PBC. However, pozzolanic activity index of PBC presents an
indication that it might contribute in accelerating the strength development
at the later ages of paste, mortar and concrete.

**Table 3**
Physical properties of OPC and the Supplementary cementing materials

| Property | Description | PBC | POFA | OPC |
|---|---|---|---|---|
| Specific gravity | Relative density | 2.69 | 2.42 | 3.15 |
| Fineness | BET surface area (m²/g) | 2.9791 | 23.7514 | 5.067 |
| | % passing 45-μm wet sieve | 96.4 | 98.4 | 98.6 |
| | % passing 75-μm dry sieve | 99.2 | 99.5 | 99.7 |
| | % passing 150-μm dry sieve | 99.5 | 99.8 | 99.9 |
| | Median Particle size, $d_{50}$ (μm) | 10.0 | 11.0 | 15.0 |
| Pozzolanic Activity Index | 7 days (%) | 96.7 | 103.0 | - |
| | 28days (%) | 99.3 | 117.0 | - |
| Colouration | Visual inspection | Reddish brown | Dark grey | Light Grey |

**Table 4**
Chemical properties of OPC and the Supplementary cementing materials

| Oxide composition | Supplementary cementing material | | |
|---|---|---|---|
| | PBC | POFA | OPC |
| $SiO_2$ | 68.6 | 63.7 | 16.4 |
| $Al_2O_3$ | 20.6 | 3.68 | 4.24 |
| $Fe_2O_3$ | 4.66 | 6.27 | 3.53 |
| $CaO$ | 0.34 | 5.97 | 68.3 |
| $K_2O$ | 3.99 | 9.15 | 0.22 |
| $P_2O_5$ | - | 4.26 | - |
| $MgO$ | 0.34 | 4.11 | 2.39 |
| $SO_3$ | - | 1.59 | 4.39 |
| $Cl$ | - | 0.5 | - |
| $TiO_2$ | 0.63 | 0.3 | 0 < LLD |
| $Na_2O$ | 0.32 | 0 < LLD | - |
| $Mn$ | - | 0 < LLD | 0.15 |
| $CO_2$ | 0.1 | - | 0.1 |
| LOI | 0.74 | 6.0 | 1.27 |

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The chemical composition of PBC is presented in Table 4. The major component of PBC is silicon dioxide or silica ($SiO_2$). The mass content of silica was 68.6%. This is the main oxide component that contributes to the pozzolanic reaction or secondary hydration in concrete containing pozzolanic material such as PBC. The silica content of PBC is about 8% higher than that of POFA. Typical of clay material, the Alumina ($Al_2O_3$) content was 20.6%, which was about 6 times more than that of POFA. The Iron oxide ($Fe_2O_3$) content was 4.66%. The high silica content suggested the possibility of a higher nucleation centre for pozzolanic activity as the curing age progresses. On the other hand, the higher alumina content usually accelerates the hydration reaction at early ages and thus, leading to increase in heat of hydration in blended cement. Similar behaviour was reported by Frías, et al., [6] for mortars containing SF and MK. Interestingly, no trace of sulphur trioxide was found. Although ASTM does not provide the specification for the chemical composition of PBC, the requirements for FA can be applied due to close similarities. PBC has a moisture content, loss on ignition (LOI) and combined silica, aluminium and Iron oxide content of 0.12, 0.74 and 93.86% respectively. The maximum permissible moisture content and loss on ignition for class-N FA are 3 and 10% respectively. The minimum amount of combined silica, aluminium and Iron oxides required for class-N FA is 70% [21]. Therefore, PBC can be classified as equivalent to class-N FA since they are both products of calcinations of clay minerals. This was also reported by [22]. Thus, the PBC used was found suitable for the production of SCHPC.

## Heat of hydration

The time–temperature histories of the respective SCHPC mixes investigated are as presented in Table 5. The increase in temperature due to heat liberation (Fig.6) obtained within the mid depth of the cast in place concrete during the hydration process of the respective SCHPC mixes is shown in Fig. 7. It was observed that the temperature differences were not significant at the beginning of the experiment. But as the hydration progresses, the effect of the replacement of the OPC with blended POFA and PBC became prominent and was clearly observed. Interestingly, concrete containing blended cement exhibited reduction in the total temperature rise in the range of 5.9 to 19% depended on the percentage replacement. In addition, there was also delay at the time at which the peak temperature occurred respectively. Indeed, the addition of POFA in

concrete mixes is associated with delayed hydration due to the reduction in the quantity of cement in the mix as previously reported [9]

**Table 5**
Characteristics of heat of hydration of various SCHPC

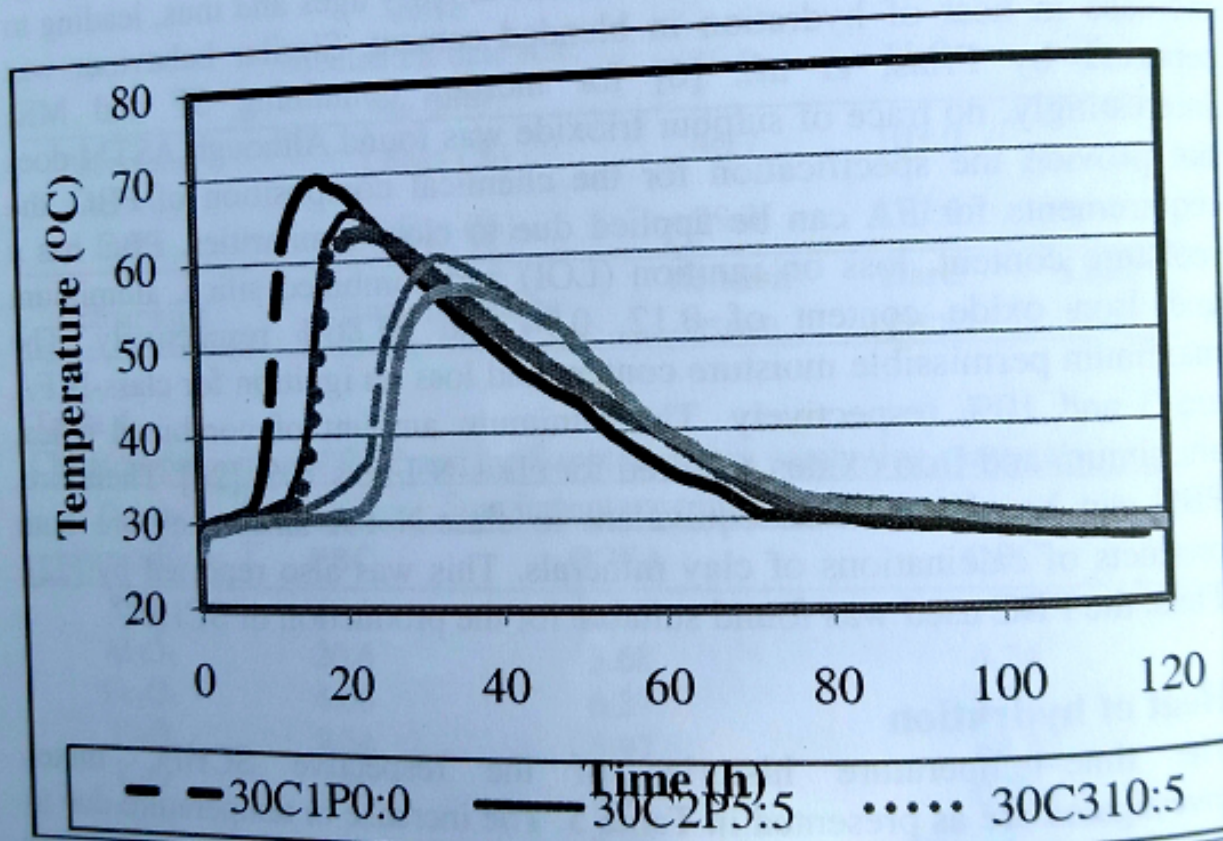| Parameters evaluated | 30C1 P0:0 | 30C2 P5:5 | 30C3 P10:5 | 30C4 P10:10 | 30C5 P15:15 |
|---|---|---|---|---|---|
| Initial temperature (°C) | 28.9 | 28.1 | 27.3 | 27.0 | 26.6 |
| Peak temperature (°C) | 69.6 | 65.5 | 63.3 | 60.1 | 56.4 |
| Time lags between mixing and peak temperature (h) | 17 | 21 | 23 | 32 | 34 |



**Fig. 6.** Temperature profile for various SCHPC mixes over a period of time

Although there were no significant differences in the initial heat generated by the respective mixes, more heat was evolved from the control concrete mix (30C1P0:0) within 24 h after casting as shown in Table 5. Consequently, the peak temperature and heat were observed in the control concrete at 17 h, while for the SCHPC mixes containing 10%, 15%, 20% and 30% (30C2P5:5, 30C3P10:5, 30C4P10:10 and 30C5P15:15) of the blended cement were recorded at 21, 23, 32 and 34 h after casting respectively. The delay in the heat evolved could be strongly attributed to the pozzolanic action of the blended POFA and PBC. Nonetheless, all the

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concrete mixes eventually showed a gradual drop in heat evolution and temperature until a relatively steady state was attained during the period of study. In particular, pozzolanic materials have been reported to be responsible for the delay in setting and heat evolution in blended concrete systems [8, 27]

It has been advocated that at early stages, the sub-micron particles of some pozzolanic materials act as nucleation sites on which the generated hydrates usually precipitate [28]. Also, the fineness of cement has also been acknowledged to influence the rate of heat development to some extent. In spite of the very high surface area of the blend due to the presence of POFA, no adverse effect was noticed in the respective SCHPC mixes. The results of the study clearly revealed that a blend of POFA and PBC could reduce heat of hydration up 19% at a replacement level of 30% and hence very beneficial for mass concrete.

## Fresh properties and early age hardened characteristics

The addition of the blend of POFA and PBC resulted in an improvement in the filling ability of the Self-consolidating systems. For instance, the flowing ability of the mortar component of the SCHPC was improved by 20% when 30% of OPC, was replaced with a blend of POFA and PBC (15%+15%). On the other hand, the flowing ability of the parent SCHPC was improved by 10% when 30% of OPC, was replaced with a blend of POFA and PBC. Further details on the flow characteristics of the mortar and concrete can be found in two different publications [24, 29]. The 3 days and 7 days compressive strength ranges between 43.14 to 71.41MPa. The concrete with a 0% blend (30C1P0:0) exhibited the highest strength of 62.62 MPa at 3 days while 10%, 15%, 20% and 30% blends (30C2P5:5, 30C3P10:5, 30C4P10:10 and 30C5P15:15), presented strength values of 60.6, 54.44, 53.45, 43.14 MPa respectively. While at 7 days, the respective SCHPCs showed a general increase in strength of up to 14.5% as can seen in Fig. 8. This pattern of strength development is commensurate to the amount of heat generated as a result of the cement hydration as shown in Fig. 7.
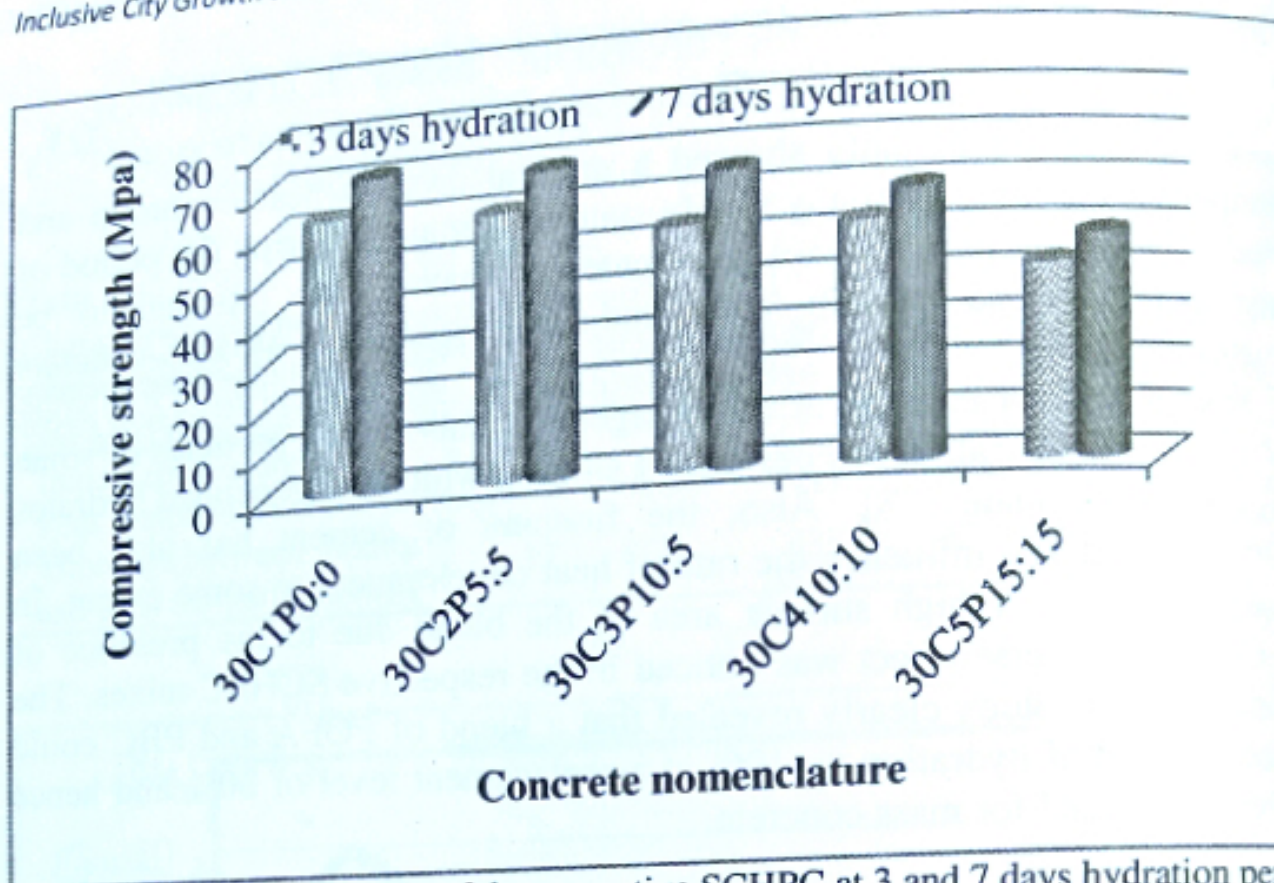
Fig. 7. Compressive strength of the respective SCHPC at 3 and 7 days hydration per

## Microstructure of the concrete

The result of the microstructural analysis provided useful information on the crystallographic properties of hardened cement paste by means of Scanning electron microscopy (SEM). SEM images of the paste component of the SCHPC are presented if Fig. 9 and 10. The concretes with 0 and 30% blend of POFA and PBC were selected to observe the microstructure. This is because SCHPC with 0% blended cement (30C1P0:0) produced the highest temperature while SCHPC with a 30 % blend of POFA and PBC (30C5P15:15) produced the lowest temperature.

The inclusion of the blend of POFA and PBC improved the microstructure of concrete at both early and later ages. Fig. 9 and 10 shows the SEM images of 30C1P0:0 and 30C5P15:15 to establish a comparison between the microstructure of SCHCs with and without POFA at the early ages of 3 and 7 days. Both 30C1P0:0 and 30C5P15:15 were more porous at 3 days than at 7 days respectively, which are obviously seen in Fig. 9 (a) and 9 (b). Nonetheless, the microstructure of the concrete containing 30% of the blended cement was relatively less porous in comparison with the control specimen.

The fine needle-like ettringites were observed in 30C1P0:0 at the ages of 3 and 7 days. Fewer ettringites were observed in 30C5P15:15 at the age of 3
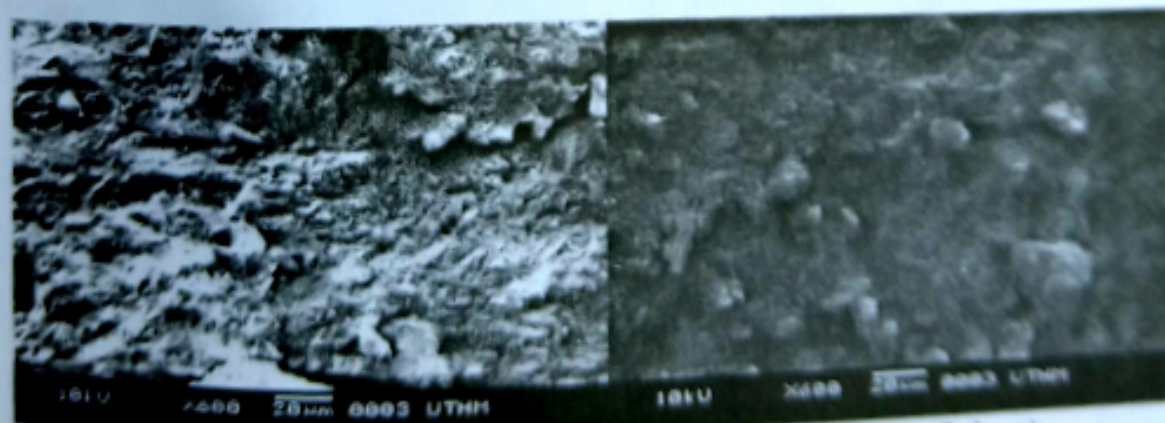
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days; however, they disappeared at the age of 7 days, as evident from Fig. 10 (b). In addition, substantial hexagonal platelets of $Ca(OH)_2$ were seen in 30C1P0:0 at the ages of 3 and 7 days (Fig. 9 (a) and 10 (a). These $Ca(OH)_2$ crystals were significantly reduced in concrete containing 30% blended cement (30C5P15:15), as can be seen from Fig. 9 (b) and 10 (b). Also noticed were traces of unreacted POFA and PBC particles which are slightly covered by fibrous C-S-H gel, as a result, the concrete (30C5P15:15) became less porous. This is in line with the observations reported by [30, 31] concerning POFA concrete and [23] for concrete containing PBC.
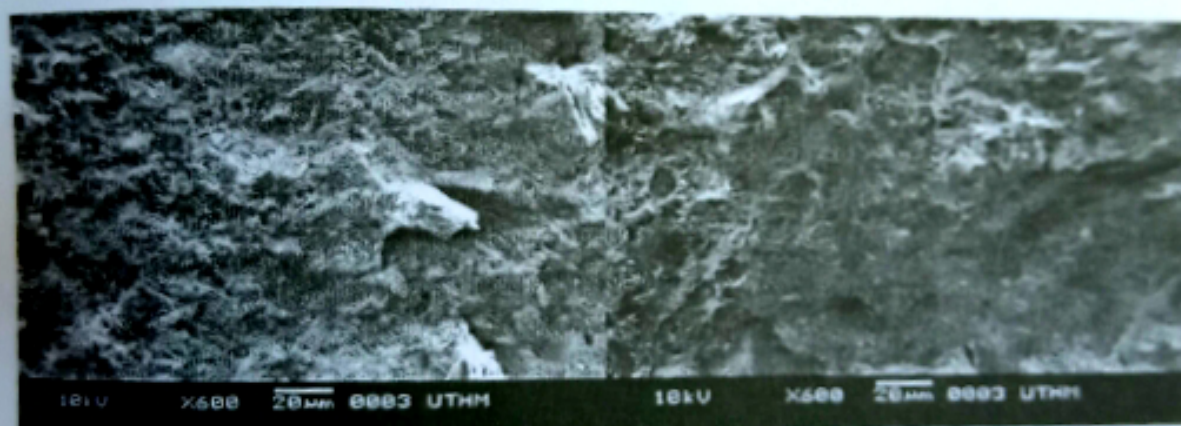


(a) 30C1P0:0 (3 days)     (b) 30C5P15:15 (3 days)
**Fig. 8** Microstructure of 0% and 30% blended SCHPC at 3 days



(a) 30C1P0:0 (7 days)     (b) 30C5P15:15 (7 days)
**Fig. 9** Microstructure of 0% and 30% blended SCHPC at 7 days

## Conclusion

Although palm oil fuel ash has been successfully used to control the heat of hydration of normal concrete, its application in Self-consolidating concrete impact negatively on the flow characteristics thereby, limiting the durability characteristic. Nonetheless, by blending palm oil fuel ash with pulverised burnt clay, excellent fresh properties were achieved. It is therefore pertinent

to note that, even though, the addition of various percentages of the blend of POFA and PBC resulted in slower hydration process and slightly lower compressive strength at early ages, it can be credited with the lowering of heat of hydration and the refinement of the bulk paste matrix. These combined attributes are very essential when concrete durability is of primary importance. It also indicates the significance of the blend of POFA and PBC in the reduction of environmental pollution and global warming.

## Acknowledgement

## References

[1] Safiuddin M, Abdus SalamM, JumaatMZ. Utilization of Palm Oil Fuel Ash in Concrete: A Review. J. Civ. Eng. Manag. 2011. **17**(2): p. 234-247.

[2] Page I. The rise and fall of claddings, in Build, June/July 2007. 2007. p. 68-69.

[3] RMIT. Scoping Study to Investigate Measures for Improving the Environmental Sustainability of Building Materials. 2006, Australian Greenhouse Office, Commonwealth of Australia, 2006: Melbourne, Australia.

[4] Yu R, ShuiZ. Efficient reuse of the recycled construction waste cementitious materials. J. Clean.Prod. 2014. **78**(0): p. 202-207.

[5] Neville AM. Properties of Concrete. 5th ed. 2011, Harlow, England: Pearson Education Limited. 846.

[6] Frías M, Sánchez de Rojas,MI, CabreraJ. The effect that the pozzolanic reaction of metakaolin has on the heat evolution in metakaolin-cement mortars. Cem. Concr.Res.2000. **30**: p. 209–216.

[7] Ambroise J, MaximilienS, PeraJ. Properties of metakaolin blended cements. Adv. Cem. Base. Mater. 1994. **1** p. 161–168.

[8] Abdul Awal ASM,Warid HussinM. Effect of Palm Oil Fuel Ash in Controlling Heat of Hydration of Concrete. Proced. Eng. 2011. **14**(0): p. 2650-2657.

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[9] Abdul Awal ASM, ShehuIA. Evaluation of heat of hydration of concrete containing high volume palm oil fuel ash. Fuel, 2013. **105**: p. 728-731.

[10] ASTMC114. Test methods for chemical analysis of hydraulic cement in Annual Book of ASTM Standards,Vol.04.01 2004., American Society for Testing and Materials: Philadelphia, USA p. 31.

[11] ASTMC1240/C1240M. Standard Specification for Silica Fume Used in Cementitious Mixtures1, in Annual Book of ASTM Standards, Vol.04.02. 2012, American Society for Testing and Materials: Philadelphia, USA. p. 7.

[12] ASTMC150/C150M. Standard Specification for Portland Cement, in Annual Book of ASTM Standards, Vol.04.02 2012, American Society for Testing and Materials: Philadelphia, USA. p. 9.

[13] ASTMC1602/C1602M. Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete, in Annual Book of ASTM Standards, Vol.04.02 2012, American Society for Testing and Materials: Philadelphia, USA. p. 5.

[14] ASTMC192/C192M. Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory, in Annual Book of ASTM Standards, Vol.04.02. 2013, American Society for Testing and Materials: Philadelphia, USA. p. 8.

[15] ASTMC143/C143M. Standard Test Method for Slump of Hydraulic-Cement Concrete, in Annual Book of ASTM Standards, Vol.04.02 2012, American Society for Testing and Materials: Philadelphia, USA. p. 4.

[16] Givi AN, Abdul Rashid S, A.Aziz FN, Mohd Salleh MA. Assessment of the effects of rice husk ash particle size on strength, water permeability and workability of binary blended concrete. Constr. Build. Mater. 2010. 24: p. 2145-2150.

[17] Mehta PK. Method for Producing a Blended Cementitious Composition, U.S. Patent, Editor. 2002. p. 13.

[18] Kroehong W, Sinsiri T, Jaturapitakkul C, Chindaprasirt P. Effect of palm oil fuel ash fineness on the microstructure of blended cement paste. Constr. Build.Mater. 2011. 25(11): p. 4095-4104.

[19] Sata, V, JaturapitakkulC, Kiattikomol K. Utilization of palm oil fuel ash in high-strength concrete. J. Mater. Civ. Eng. ASCE, 2004. **16**(6): p. 623-628.

[20] Tangchirapat W, Jaturapitakkul C, chindaprasirtP. Use of palm oil fuel ash as suplementary cementitious material for producing high-strength concrete. Constr. Build.Mater. 2009. 23(7): p. 2641-2646.

[21] ASTM C618. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, in Annual Book of ASTM Standards, Vol.04.02. 2012, American Society for Testing and Materials: Philadelphia, USA. p. 3.

[22] Hassan IO, Ismail M, Noruzman AH, Yusuf TO, Mehmannavaz T, Usman J. Characterization of some key Industrial Waste products for sustainable Concrete production. Adv. Mater. Res. 2013. 690-693: p. 1091-1094.

[23] Heikal M, Zohdy KM, AbdelkreemM. Mechanical, microstructure and rheological characteristics of high performance self-compacting cement pastes and concrete containing ground clay bricks. Constr. Build.Mater. 2013. 38(0): p. 101-109.

[24] Hassan IO, Ismail M, Forouzani P, AbdulMajid, Z, Jahangir MirzaJ. Flow characteristics of ternary blended self-consolidating cement mortars incorporating palm oil fuel ash and pulverised burnt clay. Constr. Build.Mater. 2014. 64(0): p. 253-260.

[25] Gonçalves JP, Tavares LM, Toledo Filho RD, Fairbairn EMR. Performance evaluation of cement mortars modified with metakaolin or ground brick. Constr. Build. Mater.2009. 23(5): p. 1971-1979.

[26] Ismail M, Hassan IO, Abdulrahman AS, Forouzani P, Noruzman AH, Yusuf TO. Effect of micro-structure and mineralogical compositin on the water demand and super plasticiser content of ternary blended self-consolidating paste. Proceedings of The Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction. 2013. Sapporo, Japan: Hokkaido University.

[27] Chandara C, Mohd Azizli KA, Ahmad ZA, Saiyid Hashim SF, Sakai E. Heat of hydration of blended cement containing treated ground palm oil fuel ash. Constr. Build.Mater. 2012. 27(1): p. 78-81.

[28] Kadri, E.-H., Kenai S, Ezziane K, Siddique R, De Schutter G. Influence of metakaolin and silica fume on the heat of hydration and compressive strength development of mortar. Appl. Clay Sci. 2011. 53(4): p. 704-708.

[29] Hassan IO, Yusuf TO, Noruzman AH, Forouzani P, Ismail M. An Evaluation of The Relationship Between Fresh Properties of Self-Consolidating Concrete Incorporating Blended Palm Oil Fuel Ash and Pulverised Burnt Clay. in National Seminar on Civil Engineering Research (SEPKA 2014). 2014. UTM Johor Bahru, Johor, Malaysia.

Impact of heat of Hydration of Blended Palm Oil Fuel Ash and Pulverised Burnt clay on the
Sustainability of Self Consolidating Concrete

**329**

[30] Eldagal OEA. Study on the behaviour of high-strength palm oil fuel ash (POFA) concrete, in Structures and materials. 2008, Universiti Technologi Malaysia: Skudai, Malaysia.

[31] Salam MA, Safiuddin M, JumaatM.Z. Microstructure of Self-Consolidating High Strength Concrete Incorporating Palm Oil Fuel Ash. Phys Rev ResInt. 2013. 3(4): p. 674-687.