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Characterization of some key Industrial Waste products for sustainable Concrete production

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Abstract. The use of environmentally friendly or "green" concrete to enable worldwide infrastructural development without increase in carbon dioxide (CO2) emission is at the focal point of the global issues concerning sustainability. Aside from the concerted efforts by the key players in the construction industry to successfully replace in part or in whole, the conventional Portland cement with green or eco-friendly cementitious materials, the challenges of ensuring that the so called green or eco-friendly concrete performs up to the required expectation has been the focus of many researches. This study therefore, provides an overview of the various processing techniques for the industrial waste materials as well as the determination of the physical and chemical characteristics of the powders prepared from the respective waste materials. The materials were characterized using BET surface area analysis, X-ray diffraction (XRD), Chemical analysis by X-ray fluorescence (XRF), 45-µm wet sieving, 75-µm and 150-µm dry sieving, Specific gravity using density bottle and reactivity index (RI). The results show that FA and PBC are very similar in terms of their physical and chemical characteristic in comparism with POFA. Notwithstanding, all the materials satisfy the basic requirements of the relevant ASTM specifications and also falls within the limit specified by ASTM C 618 for class F fly ash.

Introduction

Cement is an important industrial product that is manufactured in commercial quantity, amounting to about 10 billion tones in over 120 countries in the world [1,2]. When mixed with aggregate and water, cement forms the ubiquitous concrete which is used in the construction of buildings, roads, bridges, dams and other structures [2]. Over the decades, concrete made with ordinary Portland cement (OPC) has remained one of the most popular and preferred construction materials globally, with a remarkable excelling status as a yard stick for measuring the growth rate and development of any nation. Notwithstanding, the search for durable and sustainable building materials has been a key motivating factor for the development in the world of concrete [3].

Although Concrete tend to exhibit superior characteristics over other materials such as wood and steel, cement production is very energy intensive and is a major contributor to CO2 emission into the atmosphere, accounting for about 7%-10% of global emission annually[1,4]. Consequently, the use of environmentally friendly or "green" concrete to enable worldwide infrastructural development without increase in CO2 emission is of paramount importance [1]. In line with this new global trend, the implementation of the Kyoto protocol in February 2005 mandated 35 countries to reduce their gaseous emissions between 2008 and 2012 with the sole aim of achieving the fixed quantitative objectives for the reduction of CO2 and other gases that are related to the greenhouse effect [5] In fact, while agitating for the reduction in the global CO2 emission in relation to cement manufacture, emphasis must not only be placed on the cement manufacturing process but also on where and how the raw materials can be found, on where and how the product will be used and with what overall impact on the global community [6] Nonetheless, the use of supplementary cementitious materials has been advocated to be a viable solution [5,7]. Within the last decade, the use of both natural and artificial pozzolans such as volcanic ash (VA), pulverized fuel ash (PFA), ground granulated blast furnace slag (GGBFS), Metakaolin (MK), calcined clay, silica fume (SF), pulverized burnt clay (PBC), palm oil fuel ash (POFA), rice husk ash (RHA) and a host of others, predominantly in the form of industrial by-products and waste materials, as construction materials has indeed gained appreciable level of acceptance as their use offers beneficial effects from both environmental and thermal points of view [1,5,9,10,11].

Previous study have shown that powders provide the highest surface area in any concrete mix and as such shows dominant effect on the fresh properties as well as hardened properties such as strength, deformation and durability. Consequently, the knowledge of powder properties is necessary in order to ensure high degree of quality control, optimum product performance as well as improved powder production process [15]. Although extensive research work has been carried out on the utilization of FA for the production of different types of concrete, work on the utilization of POFA and PBC is still at the early stage. In fact, there is no published work that correlates the characteristics of these key industrial waste materials for sustainable concrete production. It is in the light of this development that this paper seeks to establish the relationship among these three distinct but similar industrial waste materials with respect to their physical and chemical properties.

Experimental Work

Materials Processing. The materials used for this study include pulverized burnt clay (PBC), palm oil fuel ash (POFA) and fly ash (FA). The pulverized burnt clay that was used in this study consisted of fragments of fired clay bricks that were calcined at about 900^0C-1000^0C and were discarded as waste in a clay brick factory at Kota Tingi area of Johor, 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 105^0C for 24 hours. Palm oil fuel ash is a by-product of palm oil processing industry. The material was obtained from a palm oil processing industry around Johor area in Malaysia. It was dried in the oven at 1050C for 48 hours. Thereafter, both materials were sieved separately and then grind to a very fine powder using Los-Angelis abrasion machine. Furthermore, the fly ash used for this study was obtained from a coal power plant that supplies power to some parts of Johor city in Malaysia. Since the material generally consist of fine powder, no further processing was carried out.

Materials testing. To effectively characterize the materials, essential tests as specified by relevant standards were carried out. These tests include; test on the physical properties, chemical analysis and x-ray diffraction.

Test on the physical properties. Physical properties of the respective powders were determined using the stipulated standard procedures. The tests carried out include visual inspection; specific gravity using the density bottle; 45µm wet sieving, 75µm dry sieving, 150µm dry sieving, Pozzolanic activity test and specific surface area by Brunauer Emmet and Teller (BET) method using Micromeritics ASAP 2020 model.

Chemical analysis or X-ray fluorescence (XRF). The chemical analysis of the three different samples was carried out using Flame atomic absorption spectroscopy (FAAS) using Bruker S4 Pioneer model. The analysis was carried out so as to identify the major elements responsible for Pozzolanic activity.

X-ray diffraction (XRD). X-ray diffraction test was carried out in other to evaluate the level of amorphousness of the respective powders by identifying which elements in the powders still exist in their crystalline state. The XRD test was carried out using Bruker-D8 Pioneer XRD machine.

Results and Discussion

Physical properties and Strength Activity Index. Table 1 shows the physical properties of the respective powder samples in relation to that of OPC. From the physical observation, Fly ash appears to be lighter than both OPC and POFA which shows grey and dark grey colors respectively. The dark grey color of POFA is due to the presence of un-burnt carbon. On the other hand, PBC maintains the reddish color of the parent brick from which it was obtained. The specific gravity of POFA is 2.42, which is lesser than PBC and FA which have the values of 2.69 and 2.62 respectively. Nonetheless, the three industrial west materials have specific gravity less than that of OPC which has a value of 3.15. These lower values of specific gravity of the supplementary cementitious materials are in most cases, responsible for the reduction of density of paste, mortar and concrete. Even though PBC has a specific gravity higher than POFA and FA, it has the least BET surface area and consequently lower strength activity index of 96.5%. Notwithstanding, all the materials satisfy the basic requirements of ASTM C 618. In terms of the percentage of the fine powder passing 45-µm wet sieve, as well as 75-µm and 150-µm dry sieving, all materials falls well within the range specified ASTM C311 and ASTM C430 of 66%.

Chemical characterization. The chemical composition of the respective powders is provided in table2. The major chemical component is SiO2, which is 68.60%, 63.70%, 53.60% for PBC, POFA and FA respectively. Other Pozzolanic components are Al2O3 and Fe2O3. The combined oxide content; SiO2, Al2O3 and Fe2O3 falls within the limit specified by ASTM C 618 for class F fly ash. In effect, these properties make them suitable materials to be used as supplementary cementitious materials for the production of different type concrete and mortar. Notably, FA and PBC contain high amount of alumina (Al2O3), in the range of 26.6 and 20.6 respectively. This high alumina content is due largely to the calcination of clay materials.

Table1. Physical properties of powders.

Property	Description	PBC	POFA	FA	OPC
Specific gravity	By density bottle	2.69	2.42	2.62	3.15
Fineness	BET surface area(m^2/g)	2.9791	23.7514	4.9632	5.067
	% passing 45-µm wet sieve	96.40	98.40	96.6	98.60
	% passing 75-µm dry sieve	99.20	99.50	99.4	99.70
	% passing 150-µm dry sieve	99.50	99.80	99.5	99.90
Strength Activity Index	28days (%)	96.70	117	99.30	
Colouration	Visual inspection	Reddish	Dark grey	Light Grey	Grey

Table 2. Chemical composition of powders

Oxide composition	PBC (%)	POFA (%)	FA (%)	OPC (%)
SiO2	68.6	63.7	53.6	16.4
Al2O3	20.6	3.68	26.6	4.24
Fe2O3	4.66	6.27	5.36	3.53
CaO	0.34	5.97	7.28	68.3
K2O	3.99	9.15	1.3	0.22
P2O5	-	4.26	1.51	-
MgO	0.34	4.11	0.67	2.39
SO3	-	1.59	0.63	4.39
Cl	-	0.5	-	-
TiO2	0.63	0.3	1.94	0 < LLD
Na2O	0.32	0 < LLD	-	-
Mn	-	0 < LLD	0 < LLD	0.15
CO2	0.1	-	0.1	0.1
SiO2 + Fe2O3 + Al2O3	93.86	73.65	85.56	

Characterization by X-ray diffraction (XRD)

The X-ray diffraction pattern of the respective powders is as shown in figures 1-3. The major mineral that presents a crystalline structure in the three respective powders is Quartz. PBC shows higher quartz intensity of about 10,000counts in comparism to POFA and FA which have 3500 and 1400 counts respectively; this is due to the fact that sand granules are used to stabilize brick during firing to prevent surface cracks. Although the three powders are similar in terms of their quartz content, FA and PBC are more closely related because they contain crystals of mullite and Quartz, with an approximate mullite intensity of about 1200 counts. These similarities arise because the FA particles are formed from clay during heating just like the brick powder. On the other hand, POFA contains crystals of Opal which are formed from the calcination of organic constituents of the palm oil fibers and shells.

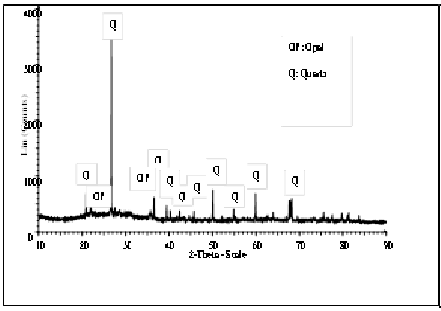

Fig. 1, XRD pattern for POFA

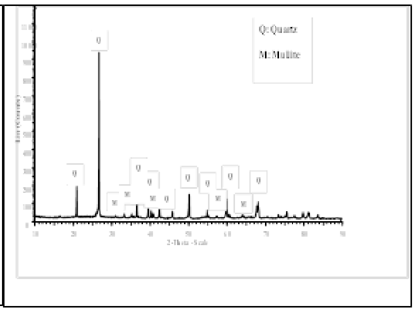

Fig. 2, XRD pattern for PBC

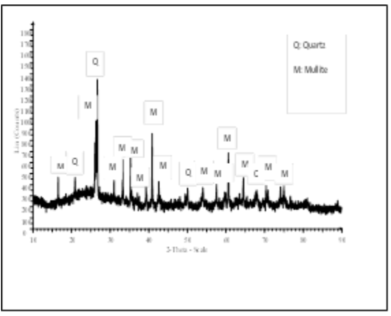

Fig. 3, XRD pattern for FA

Summary

Results of the study has revealed that Palm oil fuel ash (POFA), pulverized burnt clay (PBC) and fly ash (FA) are industrial waste materials that if well processed, will exhibits very similar characteristic and hence fulfill the basic requirement for Pozzolanic materials.

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