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Flow characteristics of ternary blended self-consolidating cement mortars incorporating palm oil fuel ash and pulverised burnt clay

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HIGHLIGHTS

- Flow characteristics of ternary blended self-consolidating mortar.
- Self-consolidating mortar incorporating palm oil fuel ash (POFA) and pulverised burnt clay (PBC).
- Effect of high range water reducer (HRWR) on the blend of POFA and PBC.
- Flow ability of the various mortars with different mix proportion.
- Addition of a blended POFA and PBC prevented the bleeding of the mortars.

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ABSTRACT

This article aims at investigating the flow characteristics of self-consolidating cement mortars incorporating palm oil fuel ash (POFA) and pulverised burnt clay (PBC). These mortars were tested with respect to their flow spread. Fifteen (15) different cement mortar mixtures were prepared containing Ordinary Portland Cement (OPC) and a blend of POFA and PBC at 0%/0%, 5%/5%, 10%/5%, 10%/10% and 15%/15% as a replacement of OPC. Water-to-binder ratio (W/B) of 0.3, 0.35 and 0.4 were used in all the mortar mixtures. The flow spreads of the mortars were determined using a standard flow mould and subsequently the relative flow areas were measured. The effects of different W/B, high range water reducer (HRWR) dosage and the blend percentage of POFA and PBC on flow characteristics of the various mortars were analysed and reported. Results showed that the flow of the mortar increased with the increase in POFA/PBC content and HRWR dosage while it decreased at higher W/B. Nonetheless, higher dosage of HRWR resulted in the bleeding of mortar. This study also showed that blended POFA/PBC can be used up to 30% replacement with a maximum HRWR content of 2.5% to design and produce self-consolidating cement mortar and concrete.

1. Introduction

Self-consolidating concrete (SCC) achieves its compatibility state through consolidation of the constituent materials by the action of natural gravity [1,2]. The chief driver that ensures the attainment of this stable state is the mortar component of the concrete, which occupies about 70% of the total concrete volume. In fact, the rheological properties and flow ability of fresh concrete depend on the characteristics of its mortar component. In effect, optimum mix design of SCC is achieved by adequately proportioning the key constituent materials of the mortar component. Recent studies have advocated that flow ability of self-consolidating mortar is affected by W/B, HRWR dosage and the characteristics of the supplementary cementing materials (SCM). Consequently, understanding the rheological and flow characteristics of self-consolidating cement mortar (SFCM) is the key to the effective design and the characterisation of the resultant concrete [3–5].

Flow is an important workability characteristic of SCC. It enables SCC to reach all the nooks and crannies of formwork. It also passes through congested reinforcement without any compaction or any form of bleeding or segregation under its self-weight [6,7]. The flow characteristic of SFCM is usually obtained by measuring the flow spread of the mortar [7]. Although the flow characteristic of SFCM depends on the water demand of the SCM and the mix proportion, it is greatly influenced by the addition of an

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appropriate dosage of HRWR [7]. Previous researches have indicated that the addition of SCM such as fly ash, silica fume, rice husk ash and ground slate, etc., improves the fluidity and stability of SCC. These materials are used either as binary [7,9–11] or ternary [8,9] blends in most of the cases. It is in this regard that this paper focuses on the use of ternary blend incorporating OPC, POFA and PBC to produce SCC.

Palm oil fuel ash (POFA) is generally classified as an agro-industrial waste. It is obtained from the processing of agricultural product, where the generated waste undergoes further processing by burning at a temperature of about 800-1000 °C to generate electricity [12]. In Malaysia alone, about 3 million tons of ash is generated annually. This quantity of ash is usually dumped in landfills or open fields, thus constituting environmental pollution and health hazard problems [13,14].

The clay brick production process mainly consists of excavation from the borrow pit, followed by crushing, screening, grinding, mixing, extruding, moulding, drying and firing. The most important operation that directly affects the suitability of the clay brick for use as pozzolanic material is the firing process. The strength, durability and chemical characteristic of the brick are determined by the properties of the minerals content and temperature at which it is calcined. This temperature normally ranges between 800 and 1100 °C [15,16]. Analysis of clay calcined at 600-800 °C, revealed that crystalline structure of illite still exists. On the other hand, clay calcined above 900 °C shows complete disintegration of illite. Additionally, significant reductions of anhydrite and quartz as well as growth of plagioclase feldspar were observed. At a calcination temperature of 900-1100 °C, pozzolanic activity is primarily derived from amorphous glassy phase. This phase is associated with reduced amount of residual anhydrite, thus, ensuring long term strength development and better durability [17–20].

Brick remained the second most dominant material in the construction of residential houses, accounting for about 25% of the total building materials requirement by mass [21,22]. Bricks are largely classified as waste when broken or damaged from its production line, construction and demolition sites. Brick and concrete usually constitute up to 75% of construction and demolition waste that are, in most cases, dumped on open landfills. Hence, they contribute significantly to the environmental health hazard [23–26].

Review of literature on SCC revealed that limited research has been conducted on the use of POFA or PBC for its production. Report on the available research shows that the addition of POFA in excess of 20% induces segregation and bleeding [27]. On the other hand, the addition of PBC up to 37.5% improves the rheological properties [28]. In view of these complimentary characteristics, blended POFA and PBC could be used to improve the fresh properties of SFCM and the parent SCC. In fact, no published work exists on the application of the blended POFA and PBC to produce SCC. Hence, investigating the effect of blended POFA and PBC on the workability or flow characteristics of SCC is an important prerequisite. But as advocated by past researchers, carrying out flow test on concrete is often very difficult and time-consuming. The difficulty arises from the need to cover a wide range of variables associated with numerous trial mixes having relatively large batch sizes [3,5,7].

In this study, the flow characteristic of various mixes of SFCM incorporating a ternary blend of OPC, POFA and PBC is presented. The effects of HRWR dosage, blended POFA and PBC contents and W/B on the flow spread as well as the relative flow area of mortars are studied. The results of this research would provide useful performance data that will facilitate effective and appropriate mix design of SCC incorporating POFA and PBC. This approach is, therefore, very important because it reduces both the volume and time of laboratory work since it is limited to the mortar component of the concrete.

2. Experimental

2.1. Constituent materials

Ordinary Portland Type I cement, conforming to ASTM C 150 [29] was used in this study. Its specific surface area was 5.067 m^2/g determined by using Brunauer Emmet and Teller (BET) method. POFA and PBC with a specific gravity of 2.42 and 2.69 and BET surface area of 23.751 and 2.979 m^2/g, respectively, were used. A well graded pit sand having a fineness modulus of 2.4, a specific gravity of 2.55, and absorption value of 1.8% was used. The superplasticizer (SP) used is an ASTM C494 [30] class F polycarboxylic-based HRWR. It is amber in colour and has a specific gravity of 1.10 at 25 °C with a pH value of 8. The major chemical and physical properties of the constituent materials are given in Tables 1 and 2, respectively.

2.2. Mortar formulation and nomenclature

The formulated mortars were classified into three groups based on the W/B and in accordance with the parent SCCs. The W/B, POFA and PBC contents were the same as those used in the parent concretes. The same goes for the proportions of cement, POFA, PBC, sand and water in the respective mortar mixes.

The respective mortars nomenclature was based on the W/B and the proportions of the SCM as present in the parent SCCs. For instance, "30M1P0:0" designation was used for mortar prepared with W/B ratio of 0.3, 0% POFA and 0% PBC. The mix proportion and the designation of the various mortars are presented in Table 3.

Table 1
Chemical properties of powders used as binder.

Oxide composition	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

Table 2
Physical properties of powders used as binder.

Material	Properties
Fine aggregate	Specific gravity on saturated surface dry bases: 2.55 Absorption: 1.8% Total evaporable moisture content: 1.0% Finesse modulus: 2.4 Void content: 33.4%
Ordinary Portland Cement (OPC)	Specific gravity: 3.15 Percentage passing 45-μm wet sieve: 98.6% Specific surface area (BET): 5.067 m^2/g Median particle size: 15 μm
Palm oil fuel ash (POFA)	Specific gravity: 2.42 Percentage passing 45-μm wet sieve: 98.4% Specific surface area (BET): 23.7514 m^2/g Median particle size: 11 μm
Pulverised burnt clay brick (PBC)	Specific gravity: 2.69 Percentage passing 45-μm wet sieve: 96.4% Specific surface area (BET): 2.9791 m^2/g Median particle size: 10 μm
High range water reducer (HRWR)	Specific gravity: 1.10 pH value: 8 Solid content: 42%