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Performance of masonry blocks incorporating Palm Oil Fuel Ash

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ABSTRACT

This paper presents an experimental study on the development of masonry block with Palm Oil Fuel Ash (POFA) as a partial replacement to cement whilst maintaining satisfactory properties of masonry block. The dosages of POFA are limited to 0%, 20%, 40% and 60% by mass of the total cementitious material in the masonry block. The experiments on masonry block investigate the compressive strength and the breaking load for mechanical properties and water absorption and efflorescence for its durability. The compressive strength and the breaking load of the masonry blocks reduce with increasing percentage of POFA replacement. However, it satisfies the requirements of Class 1 and Class 2 load-bearing masonry block according to Malaysian Standard MS76:1972. In terms of durability of the masonry block, water absorption for all the masonry blocks satisfies the requirement of ASTM C55-11 and there is no any sign of efflorescence on all the masonry blocks. POFA based masonry block are also found to be cheaper than the cement sand masonry blocks. The experimental studies indicate that POFA based masonry block has a significant potential for application in the construction industry.

1. Introduction

Masonry blocks such as bricks are well known to be one of the very old and strongest building materials. The blocks are durable and usually require low maintenance (Sousa et al., 2014). Masonry blocks normally are made of clay minerals (Da Silva Almeida et al., 2013) and their application is not limited buildings, due to their popular usage in different types of walls, monuments and other variety of structures (Del Coz Diaz et al., 2007). Even now, masonry blocks are extremely popular for a wide range of construction around the world and are considered as a demanding construction material. Developing countries like Malaysia are undergoing significant infrastructural change and the related demand for masonry blocks is thus very high. The ingredients of masonry block used in Malaysia are sand, cement and water. The cement production industries are liable for approximately 7% of the world's carbon dioxide emission. Consequently, the environmental impact including the carbon footprint of masonry block is significant.

Parallel to the infrastructure boom, Malaysia's agricultural sector has also been developing over time. Palm oil is popular vegetable oil for cooking and food processing (Oosterveer, 2014) and Malaysia is one of the world's largest producers and exporter of palm oil in the world (Yusoff, 2006). As a result, a very significant amount of biomass including empty fruit branch, oil palm shell and POFA are generated every year and it is anticipated to generate about 100 million dry tonnes of solid biomass by 2020 (National Biomass Strategy 2020, 2011). For every kg of palm oil produced, approximately four kg of dry biomass is produced (Ng et al., 2012). POFA is a by-product of palm oil industry and is generated from the combustion of empty fruit branch and oil palm shell. Reuse of POFA in masonry block attempts to utilize solid biomasses from the palm oil industry. Utilization of waste materials from palm oil industry in any composite material will enhance the sustainability as well as will solve an environmentally waste problem issue (AL-Oqla and Sapuan, 2014).

Many researchers have carried out study on masonry blocks using waste materials. Ling and Teo (2011) reported on the potential use of waste rice husk ash (RHA) and expanded polystyrene (EPS) beads in producing lightweight concrete bricks and found that the properties of the bricks are mainly influenced by the

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content of EPS and RHA in the mix and also the curing condition. Muntohar and Rahman (2014) presented the use of oil palm shell waste as masonry block material and found that the maximum strength was obtained by mixing proportion of 1C: 1 sand: 1 OPS. Cicek and Tanrıverdi (2007), Chindaprasirt and Pimraksa (2008) reported that it is possible to produce good quality bricks from fly ash due to pozzolanic properties of fly ash. Shakir et al. (2013) investigated bricks incorporating fly ash, quarry dust, and billet scale and summarised that bricks can be made using these waste materials. Fernández-Pereira et al. (2011) studied bricks made from gasification ash and compared with typical values for commercial bricks and concluded that the bricks could be used commercially. Turgut (2012) used limestone powder, class C fly ash, silica fume and water in masonry brick production and found that the compressive and flexural strengths of the samples containing silica fume were found to increase significantly when the silica fume content in the mixtures was increased. Gokhan and Osman (2013) investigated the effects of rice husk on the porosity and thermal conductivity properties of fired clay bricks and found that samples with coarse rice husk have lower thermal conductivity than samples with ground rice husk. Rahman (1987) made bricks from clay-sand mixes with different percentages of rice husk ash burnt in a furnace at different firing times and concluded that light weight bricks could be made from rice husk ash without compromising the quality of the bricks. Malhotra and Tehri (1996) carried out study on granulated blast furnace slag based bricks and found that good quality bricks can be produced from a slag-lime mixture and sand. Bilgin et al. (2012) investigated the application of waste marble dust as an additive material in industrial brick and found that the marble dust as an additive had positive effect on the physical, chemical and mechanical strength of the produced industrial brick. Weng et al. (2003) investigated bricks made from dried sludge collected from an industrial wastewater treatment plant and found that brick shrinkage, water absorption, and compressive strength decreased with increasing of the sludge content. Faria et al. (2012) reported that recycled sugarcane bagasse ash waste could be used as filler in clay bricks. Gencel et al. (2013) investigated bricks made from clay with ferrochromium slag and natural zeolite and found that the mechanical strengths of bricks were increased and thermal conductivity of samples was decreased than control bricks. Ismail et al. (2010) carried out study on disposed paper sludge and POFA based masonry block. The dosages of paper sludge and POFA were 0%, 5%, 10%, 15%, 20% & 25%. It was found that paper sludge-POFA brick made with 60% cement, 20% sludge and 20% POFA satisfied the strength requirements of BS 6073 Part 2: 2008 and that the amount of copper as well as lead resulting from leaching were within the acceptable limits of Malaysia Environmental Waste Disposal Act.

Some studies exist on POFA based self compacting concrete (SCC) and normal vibrating concrete. Fresh concrete properties of POFA based SCC have been investigated (Safiuddin et al., 2010) where the dosage of POFA was limited to 15% by mass of the total cementitious material. It was found that the filling ability and passing ability decreased and sieve segregation resistance increased with increasing POFA content. Strength, modulus of elasticity and shrinkage of concrete incorporating POFA have also been studied by researchers (Awal and Hussin, 2009). Laboratory test data based on short-term investigation revealed that the modulus of elasticity of POFA concrete in association with its compressive strength was somewhat lower than that of OPC concrete and the shrinkage strain of POFA concrete was higher than that of OPC concrete. Some investigations into strength increase through the use of POFA in concrete have been studied (Weerachart and Chai, 2010) and it was found that the compressive strength of the concrete increased with the fineness of POFA. Laboratory tests were conducted to evaluate the performance of palm oil fuel ash in concrete and it was found that POFA has a potential in suppressing expansion due to alkali–silica reaction (Awal and Hussin, 1997), controlling heat of hydration of concrete (Abdul Awal and Shehu, 2013), and increased durability and sulphate resistance (Chai et al., 2007). Additionally, the strength & durability properties of high-strength green concrete (HSGC) containing up to 60% of ultrafine POFA have been studied and it was found that ultrafine POFA has the potential to produce HSGC (Johari et al., 2012).

It is observed from existing literature that significant research work exist on masonry block incorporating different types of waste material based ash including limestone powder, fly ash, silica fume, RHA, quarry dust, gasification ash, and sugarcane bagasse ash. Different parameters have been determined in these investigations but compressive strength and water absorption have been determined by most researchers. Although different types of waste material have been used to produce brick for research purposes, commercial production and application is still limited due to lack of standard guidelines. Further research and development are needed to develop guidelines for masonry block incorporating waste material (Zhang, 2013). It can also be seen from the literature review that there are significant research work have been conducted on SCC and normal vibrating concrete incorporating POFA due to their pozzolanic properties.

As per the best knowledge of the authors, there is no existing work on the development of masonry blocks solely employing POFA and it is expected that this research will create the technical background for the development and implementation of such blocks leading to cleaner production in this construction industry sector. This is particularly impactful for geographical regions in the world exposed to anthropogenic pollution due to a booming construction sector or for countries those can expect to see a high industrialisation rate leading to a rapid expansion of construction (Rahman et al., 2014; Taaffe et al., 2014), where measures such as that proposed in this paper can act as an active measure towards controlling pollution employing local resources.

This paper experimentally studies POFA based masonry blocks by examining their mechanical and durability properties. The experiments on masonry block investigate the compressive strength, density and the breaking load for its mechanical properties and water absorption and efflorescence for its durability. The compressive strength and the breaking load test are also conducted under soaked or unsoaked condition. Additionally cost analyses of masonry block and carbon footprint discussion are also presented.

2. Experimental program

2.1. Materials

The materials used for the production of masonry blocks are water, cement, POFA and river sand. All materials are available locally and POFA is a free of cost.

2.1.1. Ordinary Portland Cement (OPC)

Ordinary Portland Cement (OPC) grade 42.5 based on ASTM: C150/C150M − 12 was used in concrete as cementitious material. The particle density of the cement is 2950 kg/m^3 and specific gravity of 3.14. The Blaine specific surface area was 3510 cm^2/g.

2.1.2. Palm Oil Fuel Ash (POFA)

POFA was obtained from a nearby palm oil mill at Lambir, Miri, Sarawak, Malaysia. The POFA obtained was sieved to 75 μm in the laboratory to remove coarse particles. This is to ensure that only small particle sized POFA were used to obtain a better control over