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Review

Pozzolanic reactivity of ultrafine palm oil fuel ash waste on strength and durability performances of high strength concrete

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A B S T R A C T

Palm oil fuel ash (POFA) was utilized as a pozzolanic material in varied quantities to produce high-strength concretes (HSC_x) of above 90 MPa, with significant improvement in its engineering and fluid transport properties. The chemical and physical characteristics of ultrafine POFA (U-POFA) utilized in HSC_x were investigated along with its concomitant fresh, strength and durability characteristics compared to ordinary Portland cement based type (OPC-HSC). The U-POFA had high surface area of (1.136 m^2/g-Blaine), mean particle size (2.06 μm), and glassy phase (70.59%). The HSC_x that had replacement level of 0, 20, 40 and 60% of U-POFA recorded the 90-day strength of 100.5, 105.2, 109.0 and 108.5 MPa. Utilizing high volume of POFA in HSC_x is possible with improved fineness and heat-treatment at 500 ± 50 °C, and could retard water absorption/permeability, setting and chloride penetration/migration rates and achieve better strength. This makes HSC_x a better choice in terms of strength and durability for hot weather and underwater concreting, and in corrosive or aggressive environment.

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1. Introduction

Palm oil is one of the biggest agro industry in countries like Malaysia, Indonesia, Thailand, Nigeria and Columbia. These countries are major producers of palm oil in the world as shown in Fig.1. (GPD, 2011). The United States Department of Agriculture estimates that the global palm oil production in 2016 and 2017 combined will be approximately 64.5 million metric tons (USDA, 2016). The extraction of the palm oil results in the production of large amount of waste in the form of remnants of fibers and kernels. These wastes are typically used as fuel in the form of steam produced by heating boilers to generate electricity in the palm oil mills. In 2010, approximately 3.14 and 3.7 million tons of POFA was produced in Malaysia and Indonesia, respectively (M.P.O.B., 2010), whereas the estimated annual production in Thailand is more than 100,000 tons, and this quantity is expected to further increase due to expansion in palm oil production (Chindaprasirt et al., 2007). The ash from this combustion process is popularly known as palm oil fuel ash (POFA) (Awal and Hussin, 1997). Therefore, production of POFA large quantities could contribute to future environmental and public health problems if it is not properly disposed.

Early study on the use of POFA in concrete indicates that POFA in its original form has low pozzolanic properties, and it is suggested that not more than 10% by cement mass should be used for partial cement replacement in mortar or concrete productions (Tay, 1990). Muthusamy and Azzimah (2015) examined the utilization of POFA in light weight concrete and found out that 20% partial replacement gave the maximum compressive strength, though up to 50% could still be used for structural application. The results of these earlier studies highlighted the limitation of POFA when used in HSC_x, which could be mainly due to the coarser particle size, high content of unburned carbon, and greater loss on ignition (LOI) of untreated POFA.

Some other researchers also utilized substantial amount of treated POFA in the production of mortar and concretes. The utilization of up to 80% in partial substitution with slag in alkaline activated mortar and concrete is worthy to mention (Yusuf et al., 2014, 2015). In addition, treated POFA has also been used to improve the durability characteristic of concrete in various capacities. It was also reported that using POFA in concrete reduced the potency of chloride migration though with more quantity of superplasticizers compared to the use of rice husk ash (Chindaprasirt et al., 2008). Further, POFA based concrete had lower chloride diffusion coefficient; (Kroehong et al., 2016). Tay (1990) also reported the reduce heat development during cement hydration, increase resistance to acidic environment and improvement in the sulphate resistance of concrete especially when it is ground to fineness (Jaturapitakkul et al., 2007) in addition to excellent pozzolanic properties (Tangchirapat et al., 2007). Moreover, it has also been shown that POFA has good potential to suppress expansion associated with alkali-silica reaction in concrete (Awal and Hussin, 1997).

On the utilization of POFA in high strength concretes (HSC_x), Sata et al. (2004) utilized a binder content of 560 kg/m^3, water/binder ratio of 0.28 and POFA replacement levels of 10, 20 and 30% and the 28-day compressive strengths of 77.5, 81.3, 85.9 and 79.8 MPa for OPC, POFA10, POFA20 and POFA30 were reported (Sata et al., 2004). Similarly, Tangchirapat et al. (2009) reported the 28-day compressive strengths of 58.5, 59.5, 60.9 and 58.8 MPa for OPC, POFA10, POFA20 and POFA30 by using the binder content of 550 kg/m^3 and water/binder ratio of 0.32. It was observed that the maximum strength obtained was 85.9 MPa at a replacement level of 20% (Tangchirapat et al., 2009).

Therefore, it is not sufficient to get rid of POFA by utilizing it in concrete production in the limited amount, but efforts are also required to improve the properties of POFA in order to allow more volume utilization, and to reduce damage to the environment through its accumulation in landfills. In this work, POFA is utilized in the production of HSC_x by improving the properties of POFA via grinding and heat treatment. Furthermore, investigations are carried out to ascertain the influence of the resulting ultrafine POFA (U-POFA) on the strength and permeability characteristics of HSC_x containing high volume of U-POFA. The study is not only going to contribute to environmental waste reduction but will also shed more lights on the microstructures and activation temperature at which POFA could be better processed to facilitate its utilization in larger quantities in the production of HSC_x. The rationale behind the recommendation of the developed U-POFA blended HSC (HSC_x) is to improve the concreting practice in hot weather and subsea structures application in the light of its retarded slump loss and chloride migration.

2. Experimental details

2.1. Materials

Palm oil fuel ash (POFA) was obtained from palm oil mill at Nibong Tebal, Malaysia. The POFA was dried in an oven at 105 ± 5 °C for 24 h to remove moisture. The moisture free POFA was passed through a 300-μm sieve to remove coarser particles, fiber and kernels, which were incompletely burnt during the combustion in the palm oil mill. Next, the POFA was grinded to a sufficient fineness using a laboratory scale ball mill to increase the efficiency of the subsequent heat treatment at 500 ± 50 °C for 90 min in a gas furnace to remove excessive unburned carbon, which will affect the potential pozzolanic properties (Fig. 2). This approach has been reported to be effective in removing the excessive unburned carbon in POFA (Chandara et al., 2010). Lastly, the heat treated POFA was subjected to further grinding via the same laboratory ball mill to obtain the treated ultrafine POFA (U-POFA). Fig. 3 (a, b, c and d) shows the change in colour of the POFA before and after heat treatment.

High strength concrete (HSC) is prepared with the ordinary Portland cement (OPC) that complies with the requirements of

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