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Heat-treated palm oil fuel ash as an effective supplementary cementitious material originating from agriculture waste

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HIGHLIGHTS

- T-POFA was used up to 70% to replace cement in the paste and investigate its microstructure.
- Utilization of T-POFA in paste showed an improvement in the paste microstructure.
- The quantity of $Ca(OH)_2$ was determined for both filler effect and pozzolanic reaction.

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ABSTRACT

Palm oil fuel ash (POFA) is generated from the combustion of oil palm waste. This ash is considered a disturbance to the environment since it is dumped without being profit return or recycled, thus causing environmental problems and human health hazards. However, it has been proven that POFA is a pozzolanic material that can be utilized as cement replacement in concrete. If POFA is heated at high temperature, it exhibits better pozzolanic performance. In this study, the treatment processes as well as microstructure and pozzolanic characteristics of POFA are considered. Ordinary Portland cement was replaced with 0, 30, 50, and 70% treated POFA (T-POFA) in a paste. The hydration products of different hardened pastes were checked by means of simultaneous thermal analysis (STA), X-ray diffraction (XRD), and field emission scanning electron microscopy (FESEM) in order to assess the effect of TPOFA on the paste microstructure. According to the test results, the physical properties and chemical composition of T-POFA greatly enhanced due to heat treatment and the milling process. It was observed that the calcium hydroxide content decreased in pastes containing T-POFA upon hardening, which is evidence of its consumption by the pozzolanic reaction. The FESEM images displayed needle-like and reticular C–S–H phases in the control paste, while floc-like and fibrous-like C–S–H phases well-connected to each other were observed in the pastes containing T-POFA.

1. Introduction

The chemical reactions between cement and water from which hydration products form, involve different microstructure development stages [1]. Over time, this leads to cement paste stiffening, solidification and hardening [2] as shown in Fig. 1 [3].

During the early age of reaction, calcium hydroxide ($Ca(OH)_2$) is produced due to the reaction of tricalcium silicate (C_3S) and dicalcium silicate (C_2S). The resulting calcium hydroxide in solid paste phase is present mainly in the form of portlandite. It creates massive, plate-like hexagonal crystals and forms about 20–25% of the solid paste volume [4]. In addition, ettringite is produced during early hydration due to the reaction of tricalcium aluminate (C_3A) with gypsum in the presence of water [5]. More heat is produced during C_3S hydration, which contributes to strength at an early age (2–3 h to 14 days). However, C_2S hydration occurs more slowly and is responsible for the long-term strength of Portland cement concrete. Over a longer hydration period more C–S–H are produced, comprising 50–60% of the volume of all solid phases [4].

Abbreviations: POFA, Palm oil fuel ash; G-POFA, Ground palm oil fuel ash; T-POFA, Treated palm oil fuel ash; U-POFA, Ungrounded POFA.

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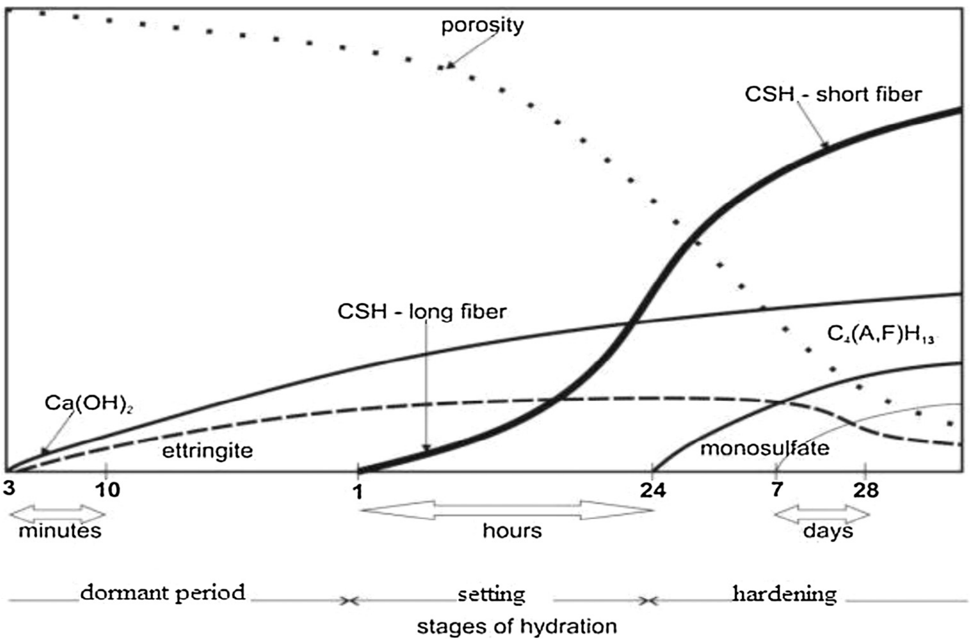

Fig. 1. Different stages in the hydration process of cement [3].

Fig. 2. Original POFA.

Calcium silicate hydrates (C–S–H) are the main binding phases in all Portland cement-based structures [6].

Because supplementary cementitious materials (SCMs) contain high amounts of amorphous silica, they are utilized as mineral admixtures in pastes, mortars and concretes to improve their properties, prolong the service life of structures and reduce cost and CO_2 emissions [7–9]. In cement blended with SCMs two main types of chemical reactions occur: cement hydration and the pozzolanic reaction of the SCM [10]. The pozzolanic reaction occurs when the amorphous silica in SCM reacts chemically with $Ca(OH)_2$ that is produced from cement hydration earlier to form hydration products, mainly C–S–H [11,12]. One of the most commonly utilized SCMSs in concrete is fly ash [7]. When fly ash reacts with $Ca(OH)_2$, it leads to more uniform, less permeable and more durable concrete microstructure [13–15].

Palm oil fuel ash (POFA) is an agro-waste byproduct that is recently recognized as a pozzolanic material [16,17]. The Malaysian Palm Oil Board (MPOB) estimated that the total amount of POFA generated annually is approximately 3 million tons [18]. POFA is dumped in landfills, which could cause environmental problems. Ground POFA (G-POFA) and treated POFA (T-POFA) are proven to contain large amounts of glassy phases [19,20]. Both POFA types have been used to make blended cement pastes. Jaturapitakkul et al. [21] studied the filler effect and pozzolanic reaction of ground river sand and G-POFA. The results revealed that the compressive strength of mortar due to the filler effect of