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Review

The present state of the use of palm oil fuel ash (POFA) in concrete

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HIGHLIGHTS

- Palm oil fuel ash (POFA), a waste by-product, can be used to partially replace cement in concrete production.
- POFA is rich in SiO_2, therefore, is a good pozzolanic material.
- Ultrafine and Nano POFA increase the compressive strength of concrete.
- POFA reduces drying shrinkage as well as workability of concrete.
- The use of POFA in concrete is favourable to the environment.

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ABSTRACT

Concrete industry consumes considerably large quantities of natural resources in addition to generating toxic gases, such as CO_2, in the atmosphere. In order to achieve more sustainability in the concrete sector, research should focus on using alternative renewable resources such as palm oil waste for concrete production purpose. Palm oil fuel ash (POFA) is a by-product obtained during the burning of waste materials such as palm kernel shell, palm oil fiber, and palm oil husk; it can be utilized to partially replace cement in a concrete mix. This paper presents a review of the applications and effects of POFA on concrete properties as reported by previous studies that have been conducted to find out POFA properties and its effects under various conditions. Chemical and physical properties of the resulting concrete have been illustrated depending on the POFA characteristics in several sources. Many studies have shown that concrete containing POFA has better compressive strength, durability and other properties than concrete containing Ordinary Portland Cement (OPC) only. Other researchers have shown more advantages of POFA replacement in concrete in specific proportions, especially minimizing CO_2 gas emissions and thus improving environmental conditions.

Contents

1. Introduction . . . 27
   1.1. Preparation of POFA . . . 28
   1.2. Environmental benefits of POFA . . . 28
   1.3. Nano POFA . . . 29
   1.4. Nano silica with POFA . . . 30
2. Utilization of POFA in concrete . . . 30
3. Utilization of POFA . . . 31
   3.1. POFA as SCM . . . 31
   3.2. POFA in self-compacting concrete (SCC) . . . 31
4. POFA properties . . . 32
   4.1. Chemical composition of POFA . . . 32
   4.2. Physical properties . . . 32

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4.2.1. Specific gravity . . . 32
4.2.2. Color . . . 33
4.2.3. Size and shape . . . 33
4.2.4. Fineness . . . 34
4.2.5. Absorption of water . . . 35
5. Effects of POFA on the concrete properties . . . 35
5.1. Effects of POFA on fresh concrete properties . . . 35
5.1.1. Workability . . . 35
5.1.2. Heat of hydration . . . 35
5.2. Effect of POFA on hardened concrete properties . . . 36
5.2.1. Drying shrinkage . . . 36
5.2.2. Compressive strength . . . 36
6. Discussion and conclusions . . . 36
Conflict of interest . . . 37
References . . . 37

1. Introduction

Concrete industry presents a challenge to the global environment as it consumes significantly large quantities of natural resources in addition to generating toxic gases, such as CO_2. In order to achieve more sustainability in the building construction sector, researchers in this field need to focus on using alternative renewable resources, such as palm oil waste. Malaysian Palm Oil Board (MPOB) in 2012 reported that the plantation area of palm oil covers about 5.07 million hectares in Malaysia [1]. The United States Department of Agriculture reported that the production of palm oil in years 2016 and 2017 was estimated to be 64.5 million metric tons [2]. Southeast Asian countries are the main palm oil producers. Palm oil fuel ash (POFA) is one of the significant materials produced as a byproduct of the palm oil industry [3,4], which is obtained by burning the waste materials such as palm oil fiber, kernels, empty fruit bunches, and shells in the power plants to generate energy [4]. POFA can be utilized to partially replace cement in concrete production [5]. The quantity of POFA being produced is increasing with time due to the increase in the production of palm oil. Leaving this waste material without any further utilization is in itself an environmental challenge. Malaysia is one of the largest exporters and producers of palm oil all over the world [6]. Production of POFA in Malaysia alone is approximately 10 Million tons/year [7,8]. Whereas, just 104 tons/year of POFA are being produced in Thailand, which continue to increase with time [4].

Recently, there has been an increasing interest in the use of industrial and agricultural waste materials in the construction industry, especially during the concrete preparation [9]. There is an urgent need for disposal of harmful residual agricultural and industrial products which has become a threat for human life. In recent years, many studies have emerged that indicate to use the agricultural residues in the concrete industry [5,10–12]. From environmental perspective, agricultural waste materials have been investigated by many researchers and have been shown to have better properties in concrete than the cement materials, whereas the latter also generates a high amount of CO_2, which is harmful for environment [9]. Due to the fact that POFA is a geopolymer, it is environmentally friendly and consumes less amount of energy than traditional materials during production [13,14]. In Malaysia, more than 1000 tons of POFA have been dumped into lagoons and landfills without exploiting the use of this material in other industries [15]. In terms of cost saving, using POFA as partial cement replacement will reduce the cost of cement production as well as transportation of the same from cement plants to the stores. Moreover, this will improve the environment by mitigating and reducing waste materials in landfills.

POFA is also one of the ash family of materials resulting from the burning of waste materials such as palm kernel shell and palm oil husk [7]. POFA is usually disposed in landfills, which results in the increased amount of ash deposits every year and now has become a burden [16]. Therefore, it is needed to devise new ways to benefit from these waste materials and avoid the potential risks. In the 1990s, Tay [17] started studying the properties of palm oil fuel ash as a concrete material. The study was conducted by replacing Portland cement with POFA ranging between 10 and 50%. It was noted that the compressive strength of the specimens decreased when between 20 and 50% of cement was replaced by POFA. Since then, many studies have been conducted to enhance the concrete properties, for example, Awal and Hussin [15] discovered that POFA has a significant impact to prevent and reduce the sulfate attack. In 2011, Kroehong et al. [18] conducted a study to find out the effects of POFA fineness on pozzolanic reaction of cement paste. The Ground Palm Oil Fuel Ash (GPOFA) and Ground River Sand (GRS) were used to replace the Portland cement by GPOFA or GRS at 10%, 20%, 30% and 40% by weight of cementitious materials, whereas the water to binder ratio (W/B) was 0.35 for the mixes of cement pastes. It was concluded that the effects of POFA on the cement paste and concrete mixtures increase when POFA is of higher fineness.

In 2015, Rajak et al. [19] conducted research to determine the morphological characteristics of hardened cement pastes which contain Nano-POFA with particle sizes ranging between 20 nm and 90 nm. It was discovered that Nano-POFA particles have a significant effect on pozzolanic reactions in the pastes because of the filling effect. In Thailand, P. Chindaprasirt et al. [18] used the POFA and Rice-husk Bark Ash (RBA) to determine the water permeability and strength of concrete replacing the cement in the concrete by various percentages ranging between 20%, 40%, and 55% by weight. It was concluded that replacing 20% of ordinary Portland cement by POFA and RBA leads to increasing the compressive strength and workability, while the value of compressive strength decreases when the replacement quantity increases up to 40% due to the increased requirement of water [16].

The above discussion leads to the objectives of the present paper to review the state of the use of POFA in the production of concrete. In this regard, the process of the preparation of ground and nano POFA has been reviewed first. This has been followed by a review of the chemical and physical properties of POFA itself. The effects of the use of POFA in concrete on the properties of fresh concrete and hardened concrete have been discussed in the latter half of the paper. Finally, at the end, a section of discussion and conclusions has been provided that includes a few directions for the future research in this field.