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Sustainable concrete containing palm oil fuel ash as a supplementary cementitious material – A review

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ABSTRACT

Palm oil fuel ash (POFA) is a waste material generated in power plants as a result of the combustion of palm oil industry waste for the generation of electricity. They are generally disposed to open fields causing traffic hazards besides potential of health hazards and environmental pollution problems. Due to its abundance and high pozzolanic characteristics, many researchers have evaluated its potential as a construction material. This paper presents an overview of some of the published results on the successful utilization of palm oil fuel ash as a supplementary cementitious material and the properties of such concrete at fresh and hardened stages. Studies indicate that there is a promising future for the use of POFA in normal, high strength and self compacting concrete as it shows high strength, low shrinkage and permeability, high resistance to carbonation, chloride, sulfate and acidic environments. At elevated temperature, the POFA concrete perform better than the ordinary Portland cement (OPC) concrete. The summery and discussions provided in this paper should provide new information and knowledge on the applications of greener and sustainable palm oil fuel ash concrete.

1. Introduction

The world's growing demand for energy has pushed the prices of the non-renewable resources such as petro-chemicals, natural gases and coal. As these fuels emit toxic gases, they are huge contributors towards global warming. Also, several studies indicated that the current reserves of petroleum and natural gases are depleting day by day. Alternative renewable energy sources include the solar, wind, hydro, nuclear etc [98]. The alternative fuel must be technically feasible, environmentally acceptable, economically competitive and readily available. One of the possible solutions is to use alternative fuels like vegetable oils and tree borne oil seeds and it can be a renewable source of energy. These alternative fuels are termed as Bio-diesels. It is chemically defined as a methyl ester, which can be prepared from triglycerides in vegetable oils by transesterification with methanol [55]. Bio-diesels are considered alternative to such non-renewable fuels owing to the fact that they are bio-degradable, non-toxic, clean, renewable, have low emission profile (burning can lead to a total recyclable CO_2), are safer in handling and can reduce the dependency on the non-renewable fossil fuels [104,54,77].

Oil palm tree (Elaeis guineensis), a native to Africa, were planted in countries like Malaysia, Indonesia etc as an ornamental plant and later emerged as one of the World's most profitable agricultural commodities with an average life span of 25 years. Palm oil is the most produced vegetable oil in the world with a global production of about 60 million tones and the vegetable market share of more than 35% by weight in 2012 [35,61]. Olanipekun et al. [67] reported that oil palm trees can be found in large quantities in America, Asia and Africa, especially in Nigeria. Malaysia and Indonesia produces almost 80% of the total palm oil in the world and more than 90% of the total productions are exported. In the year 2011, there were about 410 palm oil mills in Malaysia [26]. Recently the cultivation of oil palm trees is being expanded in West Africa and Latin America. In palm nut, there are two kinds of oil. Palm kernel oil is extracted from the inner core of the palm nut (known as palm kernel), while the palm oil is obtained from the outer core of the nut. Oil palm is considered as the highest yielding edible oil crop in the world as it produces about 4–5.5 t of palm oil and palm kernel oil per hectare of oil palm plantation. It was pointed out that the use of palm oil based biodiesels can reduce the current rate of green house gas emissions by 62% [1]. In Malaysia, the oil palm cultivation was limited to 54,000 ha in the year of 1960, which dramatically increased to 4.85 million hectares in 2010 and 5.39 million hectares in 2014, while the oil palm cultivation of Indonesia was 6.5 million hectares in 2012. Now it is the backbone of the

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Fig. 1. Palm oil fruit-bunches, fibres and kernel shells [62].

economic growth of Indonesia and Malaysia. Statics of 2011 indicates the world's production of palm oil as Indonesia-48%, Malaysia-38%, Thailand-3%, Nigeria-2%, Columbia-1%, Papua New Guinea-1%, others-7% [18,34,78].

The main problem related to the oil palm cultivation is the huge quantity of biomass wastes like empty fruit bunches, mesocarp fibre, palm kernel shell, oil palm trunks, oil palm leaves, palm oil mill effluent and oil palm fronds generated after the harvesting of oil palm fruits, palm oil processing or re-plantation of palm oil trees (Fig. 1). The World's generation of biomass in dry basis was about 80 million tons in 2010 and is estimated to increase to 110 million tons by 2020 [3,37]. For each bunch of fresh palm fruit, approximately 21% of palm oil, 6–7% palm kernels, 14–15% of palm fibres, 6–7% of palm shells and 23% of empty fruit bunches can be obtained [32]. As a rough estimate, the production of 1 kg of palm oil generates about 4 kg of dry biomass [101,47,6,79]. Oil palm trunks and oil palm fronds constitute about 75% of these wastes and they are left rotten in the plantations for mulching and nutrient recycling. The remaining 25% (palm kernel shells, mesocarp fibre and empty fruit bunches) are dried and used in palm oil mills or power plants to generate electricity through combustion at 800–1000 °C [100,63].

Some of the research has shown the use of palm oil shells as a potential light weight aggregate in the place of conventional granite aggregates [4,22,58,75,99,102], while some other research has shown the use of palm oil clinker to produce sustainable green concrete [2,12,39,44,60]. The combustion technique leads to the formation of oil palm ash (or palm oil fuel ash) that creates a lot of environmental pollution and attracted criticisms due to its carcinogenic and bio-accumulative effects [33,76]. Almost 5% by weight of the biomass gets converted to ash (Fig. 2) which is disposed to open fields as they cannot be used as fertilizer due to its less nutrient value. The ash can easily get carried by wind and result in smog on a humid day causing traffic hazards besides potential of health hazards leading to bronchi and lung diseases [59,85,86].

Conventional OPC-concrete is one of the most versatile and extensively used construction materials in the world. The global cement production reached to 2.9 billion tons annually and it is predicted to increase to 4 billion tons by 2020. The production of one ton of OPC liberates approximately one ton of CO_2, which increase the global warming. It was estimated that 7% of the CO_2 emissions in the world are due to the production of OPC. Thus OPC contributes to climate change, which is an environmental issue that affects the current and future generations (Karim et al. [45]). Several industrial by-products such as fly ash, condensed silica fume, blast furnace slag, copper slag, steel scrap, stone wastes, tire ash, fibres etc., and some of the agricultural by products like palm oil shells, bagasse ash, corn cob, elephant grass ash, wood waste ash, coconut shell & fibres, rice husk ash, tobacco waste, etc have been found useful as additions or substitutions to cement and/or aggregates [49,56,57,89–95]. Thus, the use of alternative pozzolanic materials is the need of the hour. One of the possible solutions for the reuse of the palm oil fuel ash is to incorporate them into cement based materials, as a partial substitute for cement (Fig. 3). Due to its abundance and high pozzolanic characteristics, many researchers have evaluated its potential as a construction material. This attempt can enhance sustainability, is environmental friendly, as substituting cement with such a waste product ash can reduce global warming and proves to be economical when a part of the costly cement is replaced with the waste ash, the overall cost of construction get reduced.

2. Properties and characteristics of palm oil fuel ash

The physical properties, chemical composition and morphology of the palm oil fuel ash are given below.

2.1. Physical properties

The physical properties of POFA are given in Table 1. Palm oil fuel

Fig. 2. Palm oil residues and POFA [80].