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# Effect of cooling regime on the residual performance of high-volume palm oil fuel ash concrete exposed to high temperatures

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## HIGHLIGHTS

- Concrete containing high volume palm oil fuel ash was exposed to high temperature.
- Thermally treated concrete specimens were cooled by air and water.
- Effect of cooling method on residual properties of concrete was monitored and compared.
- Better performance of air-cooling in recovering structural properties of concrete is highlighted.

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## ABSTRACT

This paper presents the experimental findings of a study on the effect of cooling method on the residual performance of concrete containing a high volume of palm oil fuel ash (POFA) exposed to high temperatures. In this study, concrete samples were made in which the ordinary Portland cement was replaced by 50%, 60% and 70% POFA. The test specimens were then thermally treated to elevated temperatures of 200, 400, 600 and 800 °C in an electric furnace for a period of 1 h. The specimens were cured by air cooling or water cooling and examined for ultrasonic pulse velocity and changes in weight and residual compressive strength. At higher temperatures, the reduction in the ultrasonic pulse velocity of concrete was higher for all of the mixes. Along with the loss of weight, the residual compressive strength of concrete was also reduced. Of the two regimes, the air-cooling system exhibited better performance in recovering the structural properties of concrete containing a high volume of POFA.



## 1. Introduction

With the increasing demand for supplementary cementing materials, smart and efficient preservation of building materials containing various waste products have received more attention for the sustainability in green construction. One of the challenging factors in concrete construction, however, is its long-term performance against extreme environmental loadings. The most severe environmental condition to which a concrete structure can be exposed, either by design or by accident, is fire. Although concrete does not burn and emits no smoke or toxic gases, fire is one of the most severe environmental issues to which a structure may be exposed. When fire acts on concrete, the temperature of the concrete increases slowly. However, after long and intense exposure to high temperatures, concrete deteriorates [1–3]. Resistance to fire or high temperatures is therefore an important property of concrete to preserve its structural performance over a period of time. In some situations, concrete structures are exposed to very high temperatures and pressures during their service for a considerable period of time, such as concrete in a reactor vessel, nuclear plant, coal gasification and some industrial applications [4–6].

When exposed to elevated temperatures, a concrete element undergoes progressive changes in terms of physical, mechanical and microstructural properties. Characteristics such as color, surface texture, volume, strength and elastic properties are largely influenced by heat, resulting in a decrease in the structural stability of concrete [7–9]. Over the decades, a great deal of effort has been made and several techniques have been employed to manage high temperature as well as to assess the residual performance of concrete. Indeed, pozzolanic materials have shown excellent performance in improving the fire resistance capacity of concrete structures [10–14].

Over the decades, ashes from various waste generations have established their credentials in their usage as efficient and eco-

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friendly construction materials. One of the latest additions to the ash family is palm oil fuel ash (POFA), a waste material obtained from burning palm oil husks and palm kernel shells as fuel in palm oil mill boilers. In general practice, this ash is thrown away near the milling area and creates pollution (Fig. 1). Research work over the years has shown that POFA is a good pozzolanic material with high performance in the development of strength and durability properties of concrete at both indoor and outdoor exposure conditions. Among the oil palm growing countries in Africa and Southeast Asia, Malaysia is the largest producer of oil palm and palm oil products in the world. It has been estimated that the total solid waste generated by the industry in some two hundred palm oil mills in the country has amounted to approximately 10 million tons per year [15,16].

The increasing pressure to reduce the $CO_2$ emission associated with the production of Portland cement has led to the application of high volume fly ash replacement of cement in concrete, which has been in practice for the last few decades. The high volume utilization reduces the amount of solid waste, minimizes the greenhouse gas emissions during cement manufacture and conserves natural resources. Although there is no fixed limit on high volume fly ash concrete, in general, it refers to structural concrete with fly ash substantially higher than that used in conventional fly ash concrete, typically 50% and above of the weight of the binder. This practice has been shown to be successful in both normal and high strength concrete and has influenced various properties of concrete from fresh to hardened state without compromising strength or durability requirements. Despite additional costs for grinding of ash, delay in formwork removal and extended construction time, the utilization of high volume fly ash has been shown to be highly advantageous in terms of technical and ecological benefits [17–20].

Considering the availability and the inherent quality of the ash as a potential building material, extensive research work on the use of high volume palm oil fuel ash have been carried out by the Department of Structure and Materials of the University of Technology Malaysia, and the application has been found to be successful in enhancing the properties of concrete [21–23]. To extend the concept and use of high volume ash in concrete construction and to study the effect of exposure to extreme environmental conditions, such as fire, this paper highlights the influence of the air- and water-cooling regimes on the residual performance of concrete containing higher quantities of palm oil fuel ash.

## 2. Materials and test methods

### 2.1. Test materials

In this study, palm oil fuel ash was collected from PPNJ Kahang Palm Oil Mill, located in the state of Johor, Malaysia. The air-dried ash was sieved using a BS standard sieve number 150 μm to remove larger particles as well as to reduce the carbon content. The sieved ash was then ground using a Los Angeles milling machine with 10 stainless steel bars with a diameter of 12 mm and a length of 800 mm for 2 h per 4 kg of POFA to obtain a sample with a maximum of 34% retained on a 45-μm sieve.

A saturated surface dry river sand with a fineness modulus of 2.9, passing through a sieve size of 4.75 mm with 2.60 specific gravity and water absorption of 0.70% was used as the fine aggregate. The coarse aggregate used was crushed granite of 10 mm maximum size with a specific gravity of 2.7 and a water absorption of 0.5%. Ordinary Portland cement (OPC) was employed throughout the study and a polymer based superplasticizer of trade name RHEOBUILD 1100 (HG) was used to improve the workability and strength of concrete.

### 2.2. Manufacturing of concrete

The mixture proportion of concrete along with the workability and the strength are shown in Table 1. Ordinary Portland cement was replaced by POFA at replacement levels of 50%, 60% and 70% by weight. Concrete cube specimens with a standard nominal size of 100 mm were used for the determination of compressive strength. After casting, the specimens were covered with a plastic sheet, demoulded after 24 h and cured in water at a temperature of 25 ± 2 °C with 85% RH until exposed to elevated temperature at the age of 28 days.

### 2.3. Heating of concrete specimens

All of the specimens were weighed, and the control specimen was tested for compressive strength without any heat treatment

Oil mill Ash disposal

**Fig. 1.** Generation and disposal of ash from a typical palm oil mill.