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Effect of elevated temperatures on compressive strength and microstructure of cement paste containing palm oil clinker powder

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HIGHLIGHTS

- C-S-H gels are more stable in palm oil clinker containing cement paste.
- Higher residual compressive strength shows in palm oil clinker containing cement.
- Palm oil clinker powder consists with mixture of inorganic oxides.

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ABSTRACT

Residual compressive strength of cement after exposure to elevated temperatures is important when introduces a new supplementary cementitious material for cement based applications. Palm oil clinker (POC) is a residue produced upon burning of palm oil shells and fibres in a boiler of palm oil mill. The aim of this work is to evaluate the high temperature effect on compressive strength and microstructure change of palm oil clinker powder (POCP) containing cement paste. The palm oil clinker powder containing cement (POCPC) was prepared for 30% replacement of ordinary Portland cement (OPC). Elevated temperatures at 300 °C, 600 °C, and 800 °C have been maintained for 3 h for both OPC and POCPC paste. The compressive strengths of OPC and POCPC were measured at the curing age of 7, 28, 56 and 90 days. The mineralogy, IR spectroscopy, thermal analysis and microstructure were investigated using XRD, FTIR, TGA and FESEM, respectively. The compressive strength of POCPC is significantly higher than that of OPC sample when thermally activated at 600 °C and 800 °C for 3 h. The XRD, FTIR, TGA and FESEM results reveal that more hydration products (C-S-H) sustain in POCPC compare with OPC after exposure to elevated temperature that is the causes behind higher compressive strength in POCPC.

1. Introduction

Fire protection safety of a building largely depends on the stability of ingredient of concrete at elevated temperature [1,2]. For the past few decades, extensive studies have been carried out the utilization of by-product materials or recycled waste as a supplementary cementitious material in concrete for sustainable development [3–6].

The reactivity of cement clinker, consisting of a mixture of silicates i.e., belite ($2CaO{\cdot}SiO_2$), alite ($3CaO{\cdot}SiO_2$), tricalcium aluminate ($3CaO{\cdot}Al_2O_3$), tetracalcium aluminiferrite ($4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$) and oxides [7] depends on the crystallographic characteristics, particle size, foreign ions and chemical composition [8]. The active phases of cement react with water and form mainly C-S-H phases, portlandite (CH) and small rod-like crystals of ettringite that ultimately help to develop compressive strength of cement [7,9–11]. In addition, the active ingredients of waste react with Portlandite to produce C-S-H that turn increases the density of the matrix that leads to develop compressive strength in later age [9–11]. The thermal stability of hydration products of clinoptilolite [12], metakaolin [13,14], fly ash [13,14], silica fume [13], slag [13,15], sewage sludge ash [16] , recycle glass [17] based binary as well as nano materials and waste based ternary composite cement [4,18] have been investigated using the micro analytical methods, viz. XRF, XRD, TGA, FTIR, FESEM, NMR, and TEM [7,9–12]. The XRD result reveals that nano silica effectively increases the formation rate of C-S-H of granulated blast furnace slag (GBFS) contained composite paste

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when thermally treated at 650 °C for 2 h that filled pore of matrix as a result leads of higher compressive strength compare to OPC [4]. Similar treads of the increase of residual compressive strength of clinoptlolite [12], metakaolin [13,14], fly ash [13,14], fly ash with microsilica [18], silica fume [13], silica fume with Vermiculite [19], slag [13,15,20], recycle glass [17], sewage sludge ash [16] and sand [21] when it is treated at elevated temperature. The microscopic observation shows the aggregate is less affected than that of paste of concrete at elevated temperature [12]. The XRD result reveals new phases of calcium aluminate (CAH_{10}), calcium silicates (C_2SH, and $C_3S_2H_3$), and calcium aluminosilicate (CAS_2H_4) in metakaolin based composite cement that increase the thermal stability of concrete. Moreover, composite cement does not disintrigate at 600 °C like OPC [12–14]. The afwillite ($C_3S_2H_3$), CAH_{10}, and stratlingite (C_2ASH_8) compounds were formed at elevated temperature in fly ash composite, whereas, slag is produced the calcium aluminate (CAH_{10}), calcium silicate (C_2SH, and $C_3S_2H_3$), calcium aluminosilicate (CAS_2H_4), merwinite (C_3MS_2), akermanite (C_2MS_2), and the spinel magnesium aluminate ($MgAl_2O_4$) heat resistive compounds at higher temperature [13,14]. Besides, fewer cracks were observed in slag cement compared with control sample [13,14]. The melting and re-solidification of glass waste help to fill the micro pore of the matrix as a result of increase in residual compressive strength [17]. The crystalline CH, needle like of C-S-H is condensed in SEM micrograph of microsilica contained fly ash composite after heated at 450 °C [18]. Similarly, nano carbon as well as silica fume play important role to fill the micro pore of the cement paste matrix [5,19,22] . The TGA observation shows that the microstructure was stable of micro silica contained mortar up to 500 °C [21]. XRD and SEM observations show the cross linked of calcium silicate in sewage sludge ash contained cement matrix which is to due to its high pozzolanic activity at elevated temperature [16,23]. The heating condition is one of the factors which is associated with the compressive strength. The compressive strength of composite cement was increased at 300 °C due to accelerated hydration at self-autoclaving condition, whereas, it was decreased at 600 °C–900 °C as a result of the decomposition of hydration products, calcitie along with formation of C_2S and C_3S. The ettrigite are unstable at heating temperature over 120 °C [24]. The intensity of portlandite peak in XRD was decreased with the increasing in the formation of C-S-H as well as the conversion into carbonate or quick lime (CaO) with treatment temperature [18,25]. Besides that, the anhydrous alite and belite phases were decreased due to the continuous of the hydration when was exposed to 600 °C, but increased when treated at 800 °C [18,26–28]. The C-S-H was completely destroyed and formed thermally stable alite and belite [4,18,29]. The $CaCO_3$ was decomposed to CaO and CO_2 as shows in Refs. [18,30–32]. Previous studies show that the wastes, i.e. slag, GBFS, fly ash, containing cement pastes exhibited better compressive strength compared to OPC when treated at elevated temperature. The micropores of the hydrated cement paste matrix are filled by the C-S-H which was produced as a result of pozzolanic activity of adding waste materials are the fact behind the higher strength in wastes blended cement. Moreover, the additive materials also deactivate the crack formation in cement paste compare to OPC.

Recent studies found that palm oil clinker (POC) is a supplementary cementitious material in cement-based applications and also a promising way to convert waste into resources, thereby contributing to cleaner environment and producing low carbon footprint concrete [9–12,33,34]. POC which is a stonelike afterburn residue produced in palm oil mills as a result of combustion of palm oil shell and fibre at 400–800 °C [35]. Feasibility of POC in different concretes, such as self compacting [36], normal [37], lightweight [38], pervious [39] concretes as well as supplementary cementitious materials [9–11,40] have been proven, but limited information is reported on the performance at high temperature, thereby this study is investigated the effect of high temperature on the microstructure properties and its consequential influences on compressive strength and palm oil clinker powder containing cement paste. The finding of this work ultimately leads to provide fire resistive cement for ensuring the safety of a building.

2. Materials and methods

2.1. Materials

The palm oil clinker (POC) used in this study was collected from a local palm oil mill, Kuala Lumpur, Malaysia. The palm oil clinker (POC) is produced as residue in the heating zone of a steam boiler after burning of palm shell and fibre at 100 °C–800 °C. The POC is cooled at air atmosphere after remove from burning zone of a boiler [41]. Fig. 1(A) shows that the POC is blackish in color and non biodegradable solid waste material. The solid chunk of POC was first crushed into small particles using jaw crusher. A mini ball mill was used for grinding the small particles into a powder form operated at 160 RPM for 4 h. The photograph of palm oil clinker powder (POCP) is shown in the Fig. 1(B). Ordinary Portland cement (CEM 42.5N) was supplied by a local cement company.

The XRF spectrometer (Epsilon-5) was used for chemical composition analysis. The specific surface area, loss of ignition (LOI), residue on 90μ sieve and chemical composition were determined and depicted in the Table 1.

The scanning electron microscopy (model: tabletop) result shows that the particles of POCP are porous in nature, irregular in shape. The porous and fibrous particles are indicated by the marks 'A' and 'B' in the Fig. 2.

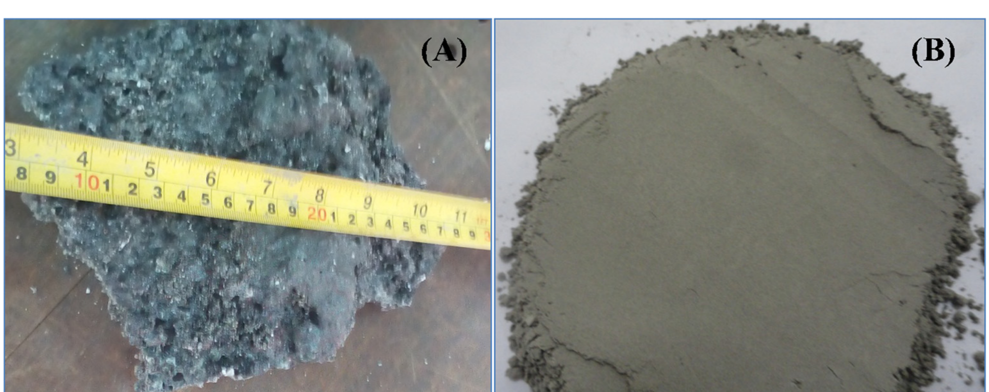

Fig. 1. Photographs of (A) large POC chunk and (B) POCP.