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Introducing an effective curing method for mortar containing high volume cementitious materials

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HIGHLIGHTS

- The characteristics of wastes that are used as cementitious material were investigated.
- The combination of OPC–GGBFS is better than OPC–fly ash in all ages.
- The PRF mix is the best combination for ternary blended cement.
- HAC condition has good potential to be used as an effective curing method for mortar.
- Local waste like POFA and RHA have good potential to be used as alternative cementitious material in cement based materials.

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ABSTRACT

This study reported an on-going research project of producing sustainable construction material for precast industry. This paper studies the physical and chemical properties of materials, compressive strength, flexural strength, water absorption and porosity of multi blended cements under different curing methods. Fly ash (FA), ground granulated blast furnace slag (GGBFS) and rice husk ash (RHA) were used to replace with 50% ordinary Portland cement by mass. Specimens were cured in water (WC), air under room temperature (AC), the combination of hot-water at 60 °C for 24 h followed by curing in water (HWC), and air (HAC). The results showed that HAC could be an effective curing method with higher compressive and flexural strengths, lower water absorption and porosity for blended cement mortars. Mortars containing GGBFS in binder had higher enhancement on compressive strength under early hot water curing. While, at 24 h hot water curing mortar containing OPC–RHA–FA binder showed better quality in properties compared to the other binders.

1. Introduction

Nowadays, the cement industry is direct to be environmentally-friendly. It is due to a magnitude number of mortar and concrete used in construction all over the world. In 2013 (Fig. 1), 4 billion tons of cement produced, as estimated concrete production exceed 4000 million tons annually [1]. A growing number of concrete productions per year will lead to increase manufactured cement significantly. Since, one of major contributor to CO_2 emission is cement production, it affected to climate change and global warming. This environmental problem will most likely be increased due to exponential demand of Portland cement. By 2050, demand is expected to rise by 200% from 2010 levels, reaching 6000 million tons/year [39]. To eliminate the effect of OPC production on climate changes, the use of Portland cement and non-renewable materials should be reduced. In recent years, blended cement with pozzolanic or supplementary cementitious materials is widely used in cement and concrete construction by replacing part of cement [2,3,11]. The main reasons for using this kind of alternative materials are environmental, economic, or technical benefits. Mineral admixtures such as fly ash (FA), rice husk ash (RHA) and silica fume (SF) are silica-based pozzolanic materials and renewable so they can partially replace by Portland cement [4]. The kind of alternative material that is used often depends on the availability and on the field of application [9]. However the common alternative materials used include GGBFS and FA. The utilization of mineral admixtures improved the compressive strength, pore structure, and permeability of the mortars and concretes with time [4,5]. This is because the total porosity decrease with increasing hydration time [4–7].

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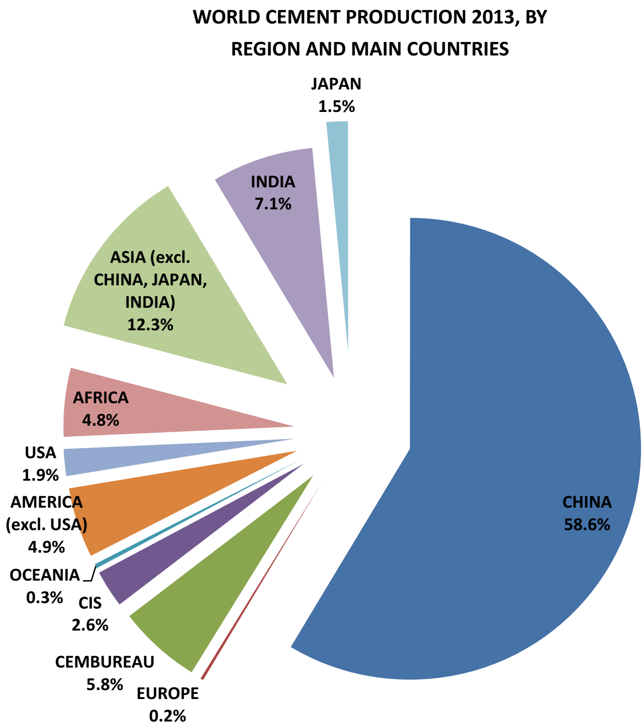

Fig. 1. The cement production around the world in 2013 [1].

There are many reports [2,4,7,11,12,17] that investigated the use of waste and by-product materials as pozzolan in cement replacement. The use of pozzolan as supplementary cementitious materials has been found to provide a visible enhancement on the mechanical properties of mortar. Furthermore, the mitigation damage of mortar became particular concern for durability of cement-based materials. Aldea et al. [2] mentioned two technological developments which can improve the ability of the material to maintain ecological processes in the future. They are the incorporation of several artificial waste materials into the concrete mortar and the use of a superplasticizer (SP) into mix design. Bagel [4] and Boubitsas [7] supported the previous statement by conducting a study about the effect of binary and ternary blended cement on mortar. For instance, the high level portions of slag and silica fume used in the binding system cause the mortars reached relatively satisfactory level of compressive strength and contributed to the significantly denser pore structure [4]. In 2001, Boubitsas [7] evaluated the effect of binary blended cement mortar containing 45% (by mass) GGBFS and 55% OPC with presence of 1% superplasticizer. The results obtained possess the highest improvement of mechanical properties, hydration kinetics and microstructure of hardened mortar. Several reports also explained the technical details for low and moderate level replacement of mortar [8,11–13]. The percentage of low and moderate for cement replacement levels are 5–40% by mass, respectively [11]. In addition, Agarwal [12] has reported that 10% by mass replacement of pozzolan mortar, the compressive strength obtained was 18 MPa in 7 days and 25 MPa in 28 days. Karim et al., [13] investigated a set of mortar specimen which was made with 40% of natural pozzolan as cement replacement. The compressive strength result for 90 days reach up to 39 MPa under constant 40 °C temperature for 6 h hot water curing. On the other hand, high volume replacement levels of cementitious material have been an interesting topic for research and also industry. There is a little information focusing on the use of high volume cementitious materials as a cement replacement [8–10,14]. Varga et al., [8] evaluated properties of mortar containing high volume of type C fly ash under standard curing. Test results indicated that the use of 40% (by mass) type C fly ash in mortar increased at the early age day compressive, but reduced the modulus of elasticity. However, all these strength properties and abrasion resistance showed continuous and significant improvement at the ages of 190 and 365 days, which was most probably due to the pozzolanic reaction of FA at later ages. It was concluded that class C fly ash can be suitably used up to 50% level of cement replacement in mortar for use in precast elements and reinforced concrete construction. Herera et al. [9], studied concrete were produced with mass substitution of cement by fly ash up to 75%. They concluded that using this level of fly ash was not effective to gain the strength of concrete. Then, Sajedi and Razak [14] make an experiment using high volume replacement levels up to 60% of slag, with constant w/c ratio of 0.33 and under water and air curing conditions. They used chemical activation and found that the maximum strength could be achieved about 63 MPa at 56 age days for 50% replacement level. Based on many investigations [8–14] on the effect of using cementitious materials in mortar, it was found that the effect of curing method and the volume level of cement replacement significantly influence the strength and durability.

GGBFS, FA, and RHA are a latent hydraulic binder. It must be activated to react and provide the desirable mechanical properties using several methods. One of these activation methods is the thermal method. The heat curing on cementitious systems and heat treatment of mortar have become a regulated practice in the precast industry [15]. Presently, the most developing countries have developed specifications for the regulation of heat curing for precast concrete. Previous investigations [16–19,24] showed that hot water curing method improves strength at the early ages. However, at a later age, a loss of ultimate strength may be occurred in specimens. This is due to the important numbers of formed hydrates have no time to arrange suitably and this causes a loss of ultimate strength. This behavior has been called the crossover effect [18]. For ordinary Portland cement (OPC), it appears that the ultimate strength decreases with curing temperature linearly [16].

The main objective of this paper is to study the effect of different curing conditions on mechanical properties of mortars containing cementitious materials. In this experimental work, four mixes containing high volume cementitious materials as cement replacement have been used and one mix as a control. Mortar specimens were cured under four curing conditions after demoulding to find the effective curing condition for mortar containing high volume cementitious materials.

2. Experiment

2.1. Properties of materials

2.1.1. Cement

The cement used in all mixes was ordinary Portland cement (OPC). The specific gravity of cement was about 3.14. Based on particle size analysis (PSA) tests (Fig. 2a), the specific surface area (SSA) by BET method for OPC was determined to be 2667.24 m^2/kg. The chemical compositions of OPC have been determined by "X-ray fluorescence spectrometry (XRF)" testing method. The compositions of OPC are given in Table 1.

2.1.2. GGBFS

The specific gravity of GGBFS is approximately 2.87, with its bulk density varying in the range of 1180–1250 kg/m^3. The color of GGBFS is whitish (off-white). Based on PSA tests, the SSA for GGBFS has been determined at 3197.2 m^2/kg (Fig. 2b). It can be seen that SSA GGBFS was 1.90 times of OPC, which means that particles of GGBFS are 90% finer than those of OPC. The chemical compositions of GGBFS are given in Table 1. As with all cementing materials, the reactivity of the GGBFS is determined by its SSA. In general, increased fineness results in better strength development, however, in practice; fineness is limited by economics, performance considerations and factors such as setting time and shrinkage [12,20,22].