Construction and Building Materials 138 (2017) 174–184

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Durability properties of a non-cement binder made up of pozzolans with sodium hydroxide

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HIGHLIGHTS

- Strength, water absorption and porosity of a non-cement mortar were determined.
- Chloride penetration, sulfate, thermal and corrosion of mortar also investigated.
- Non-cem was produced from slag, POFA and RHA with NaOH at 2.5 M solution.
- Water absorption and porosity were found as 8.1% and 16.3% respectively at 28-days.
- Chloride, sulfate, thermal and corrosion resistance of mortar were found well.

ARTICLE INFO

Article history:
Received 3 January 2015
Received in revised form 3 January 2017
Accepted 30 January 2017

Keywords:
Non-cement mortar
NaOH
Water absorption
Porosity
Chloride penetration
Sulfate
Corrosion and thermal resistance

ABSTRACT

The durability property of a mortar is the second most important concerns next to its strength. This study investigates some durability properties of a Non-cement binder (Non-cem). The Non-cem was produced from pozzolans such as slag, palm oil fuel ash, and rice husk ash alongside a 2.5 M sodium hydroxide solution. The mortar of Non-cem was tested for its compressive strength, water absorption, porosity, chloride penetration, sulfate, corrosion, and thermal resistance (heated at 700 °C for 2 h) as well as compared to that of ordinary Portland cement (OPC) mortar. The results reveal that Non-cem mortar gains compressive strength of 42.84 MPa (93.36% of OPC) at 28 days. Water absorption and porosity at 28 days are found to be 8.1% and 16.3% for Non-cem mortar whereas 6.2% and 13.5% for OPC mortar, respectively. The chloride penetration of Non-cem and OPC mortars are found to be 11.5 mm and 10.1 mm respectively at 28 days. The sulfate resistance of Non-cem mortar is much higher than that of OPC (i.e., the reduction in compressive strength of Non-cem and OPC mortars were 12.6% and 14.1% respectively because of immersion in 5% magnesium sulfate solution after one month). In case of corrosion resistance, cracks are shown in OPC mortars earlier than Non-cem mortars and in case of thermal resistance of Non-cem mortars lose their strengths by 19.21% whereas OPC mortars lose their strengths by 32.87%. These test results indicate that Non-cem could be used as an alternative of cement.

1. Introduction

The increasing demand and consumption of cement have necessitated the use of pozzolanic materials (e.g., slag, palm oil fuel ash (POFA), and rice husk ash (RHA)) in concrete construction. Besides the compressive strength of concrete, the durability properties are another vital engineering concern. Previous studies concluded that the strength and durability properties of concrete can be improved by the incorporation of pozzolans as a partial replacement of cement [1–4]. However, the present academic and industrial research are moving forward regarding the development of a cement-free new alternative sustainable binder by using pozzolans in the field of alkali-activated binder (AAB) or geopolymer concrete. It is well documented that compared with OPC, AAB has the potential to impart mechanical properties such as the compressive strength, elastic modulus and splitting tensile strength at early ages of curing with a low energy consumption and a low CO_2 emission [5–7]. A number of researchers reported that AAB containing slag [8–13], POFA [14], RHA [15,16] show effective strength and

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http://dx.doi.org/10.1016/j.conbuildmat.2017.01.130
0950-0618/

mechanical properties as well as durability properties. AAB containing a binary composition with slag/fly ash [17–20], slag/silica fume [21], slag/metakaoline [22], Slag/Sugar Cane Bagasse ash [23], POFA/fly ash [24] and POFA/metakaoline [25] shows a very good strength, thermal and other durability properties compared to OPC mortar/concrete. In fact, the properties of mortar/concrete are greatly influenced by the doses of alkali and the curing temperature, duration, and methods employed [26,9].

It is time to an establish new technology using materials with binary, ternary and quaternary compositions with Alkali-activated composites (AAC) which may really deal with the utilization of waste materials and also reduce the emission of greenhouse gases. Karim et al. reported a preliminary idea for the development of an alternative cementitious binder in the case of AAB by using slag and POFA and/or RHA (binary and/or ternary compositions among the materials) with sodium hydroxide (NaOH) [27] and calcium hydroxide ($Ca(OH)_2$) [28] by weight of binder. Based on the preliminary observations of improved compressive strength and mechanical properties, authors concluded that in presence of chemical activator like NaOH and $Ca(OH)_2$ a binary or ternary composition of slag, POFA, FA and RHA can be used as an alternative of OPC.

Now the present situation demands the establishment of durability of composite binder which in turn depends on the interfacial transition zone characteristics and tortuosity of flow path of concrete [29]. Karim et al. [30] investigated water absorption, porosity and thermal resistance (heating at 700 °C) of composite binder produced from a ternary blend of slag 70%, POFA 20% and RHA 10% with NaOH solution of 1.0 M, 2.5 M and 5.0 M concentration. Although water absorption and porosity of the AAB mortar were slightly high, it shows an excellent thermal resistance compared to OPC mortar. The present study investigates the durability properties (i.e., water absorption, porosity, chloride penetration, sulfate, corrosion and thermal resistance) of Non-cement mortar which is produced from slag 42%, POFA 28%, and RHA 30% with 2.5 M NaOH solution. It is well known that mortar and concrete show different characteristics in the interfacial transition zone and tortuosity of flow path due to variation of their constituent ingredients [31]. The volume of void in concrete could be more than that of mortar because concrete contains coarse aggregate but mortar does not. Although the chemical and mineralogical effects of cementitious binders could be obtained by studying mortar, the durability of concrete cannot be quantified by studying mortar only [32]. However, instead of concrete, the durability of mortar was studied in this research due to the convenience of handling sample sizes, amount of activator (NaOH), slag, POFA, RHA. Moreover, it provides a scope to make comparison of few data with literature values [15,23,30,33] where mortar was used as the key component.

2. Materials and methodology

2.1. Materials and properties of materials

Three different pozzolanic materials including ground granulated blast furnace slag, POFA, and RHA were used as constituents of Non-cement binder (Non-cem). OPC type I (42.5 N) was used as obtained from Tasek Cement Sdn Bhd, Malaysia, to compare the different properties of the Non-cem. The slag was provided by local industry named Slag Cement Sdn Bhd, Malaysia. POFA was taken from Ulu Langat palm oil mill, Selangor, Malaysia. RHA was made using a special type of furnace available in the concrete and structure lab at University Kebangsaan Malaysia. The details of the furnace were reported by Zain et al. [34]. The standard sand as required by BS EN196-1 [35] was used as fine aggregate for the preparation of mortar. As a chemical activator, NaOH flakes of analytical grade were purchased from Merck. A superplasticizer (SP) Darex Super 20 brand obtained from Grace Manufacturer was used to increase and maintain sufficient flow of mortar. Tap water was used for the preparation and curing of mortar specimen. Fineness and grain size of materials were determined using automatic Blaine machine and Malvern Mastersizer respectively. X-ray diffractometer (XRD) analysis was conducted to determine the amorphous or crystalline phase of materials using the Bruker AXS brand XRD machine, D8 advanced model using 40 kV power and 40 mA with Cu Kα source. The 2-theta angle ranges from 5 to 80 degree. Chemical composition of materials was determined using X-ray fluorescence (XRF). The morphological view and shape of the particles of materials were examined using scanning electron microscopy (SEM) images using Supra 55VP, ZEISS. The pore volumes of the materials were determined using Sorptomatic instrument.

2.2. Preparation of mortar

The mixed proportions of the raw materials (i.e., slag, POFA, RHA, SP, NaOH, and sand) are presented in Table 1 for the preparation of Non-cem mortar, as suggested by Karim et al. [30]. The fineness of Non-cem was enhanced significantly by grinding of POFA and RHA in a ball-mill machine. However, the slag was used as received from the industry. A 2.5 M NaOH solution was used as chemical activators. The NaOH solution-to-binder ratio was used as 0.5, and sand-to-binder ratio was kept as 3.0. The required SP was used to maintain a flow of mortars at 70 ± 5% (to maintain the same flow as that of OPC). Mortar was mixed and prepared using a Hobart mixture machine according to ASTM C305 specification [36]. Mortar prism (40 mm × 40 mm × 160 mm) was compacted by using a mechanical shaking table for a uniform compaction. Shaking was done until mortar thoroughly spread inside the prism mold by two layers. Finally, the prism molds of the mortars were opened after one day. The mortar specimens were then immersed in a water tank at a temperature of 25 ± 2 °C for curing until the desired age of testing was achieved.

2.3. Tests on mortar

2.3.1. Flow and strength

The mortar flow spread test was done by using a flow table based on the ASTM C1437 testing standard [37]. The compressive strength of the mortar prism (40 mm × 40 mm × 160 mm) was determined according to the BS EN196-1 [35] testing standard by using Universal testing machine (Unit test brand of capacity 500 kN).

2.3.2. Water absorption

Water absorption of the mortar prism specimens (40 mm × 40 mm × 160 mm) was carried out according to ASTM C642 (1997) standard. Prism specimens (at the desired age of 14, 28, and 90 days) were dried until weight of specimen became constant (W_d). The specimens were then immersed in clean water for 30 min for 1, 3, 6, 24, 48, and 72 h. After the desired immersion period, the specimens were taken out and surfaces were wiped quickly with a wet cloth then weighed (Wa) immediately. Therefore, water absorption of the mortar specimen was determined as $100(W_a - W_d)/W_d$ in percentage. Finally, water absorption of the mortar was taken as the average value of six specimens. This test method was also successfully used in a study by Qureshi et al. [38].

2.3.3. Porosity

For the determination of porosity of mortar, prism specimens of 40 mm × 40 mm × 160 mm size were cast according to BS EN196-