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Review

Durability of mortar and concrete containing alkali-activated binder with pozzolans: A review

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HIGHLIGHTS

- Durability of mortar/concrete containing pozzolans activated by alkali is reviewed.
- Water absorption, permeability, porosity, sorptivity and shrinkage are discussed.
- Chloride, carbonation, corrosion, sulphate and acid resistance are highlighted.
- Durability of alkali-activated mortar/concrete is compared with the ordinary one.
- Based on past researches, a few potential studies are suggested for future research.

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ABSTRACT

Although ordinary Portland cement (OPC) is immensely popular and an essential ingredient for concrete based constructions, it is responsible for the emission of a huge amount of carbon dioxide (CO_2) in course of its production. In order to reduce the increasing emission of CO_2, researchers both in academia and industry have been working on a cement-free alternative sustainable binder using pozzolans such as slag, fly ash (FA), palm oil fuel ash (POFA), metakaolin (MK), rice husk ash (RHA) etc. alongside alkali-activator. A number of researchers have reported that alkali-activated (AA) alumino-silicate materials have the potential to achieve certain mechanical properties such as the compressive strength, elastic modulus and splitting tensile strength in mortar and concrete at early ages of curing with a low energy consumption and low CO_2 emission. Most of the researchers have reported that durability of mortar and concrete containing alkali-activated binder (AAB) with the aforementioned pozzolanic materials is superior to that of the conventional mortar and concrete while others are not fully convinced and call for further studies. Based on the previously published works, this paper reviews the current state of knowledge on the durability of mortar and concrete made from the above mentioned pozzolans associated with AAB. Several properties of mortar and concrete including water absorption, permeability, porosity, sorptivity, sulphate resistance, chloride penetration, carbonation, corrosion resistance, drying shrinkage and acid resistance have been discussed. Moreover, a few potential studies have been suggested for the future research.

Contents

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1. Introduction

The world is now eagerly awaiting the emergence of a new binder that will hopefully replace the traditional OPC not only to enhance environmental sustainability but also to ensure the durability of structures. A major portion of the discharged CO_2 in the atmosphere stems from the decarbonisation of calcite (0.53 kg) in cement clinker, burning process (0.33 kg) and required electrical power (0.12 kg). Thus, in order to produce each ton of cement clinker, on an average the same quantity of CO_2 will be discharged into the environment [1]. In fact, the already built OPC structures over the past several decades are going through a disintegration phase which is unavoidable in some places [1]. Indeed, durability of OPC is connected to the properties of its constituent ingredients which among others are around 60–65% CaO while its hydration product contains about 25% $Ca(OH)_2$. This $Ca(OH)_2$ responds to acidic environments and as a result, OPC is found to have poor resistance against any aggressive environment [2]. Moreover, the water resulting from fusion of ice and its subsequent contraction takes on CO_2 which may react with $Ca(OH)_2$ of both concrete and mortar leading to erosion [3]. On the other hand, pozzolans lead to over-strengthening of gel and also produce a minimum amount of $Ca(OH)_2$ that offers more resistance to concrete against an aggressive environment [3]. Moreover, the disposal of these pozzolans is an environmental issue.

Among those pozzolanic materials, FA and slag are widely used in AAB to enhance strength and durability properties [4]. Khater [5] reported that alkali-activated slag (AAS) exhibited significant changes in case of compressive strength on an increase in temperature (300–1000 °C) accompanied by a better thermal stability in comparison with OPC concrete. Specimens made from the replacement of granulated blast furnace slag (GBFS) with a 15% air cooled slag withstood a thermal deterioration up to 1000 °C. However, the author [5] reported a less fixity upon subjection to various concentrations of HNO_3 and HCl solutions. Bernal et al. [6] reported that it is feasible to improve durability properties such as permeability, water sorption and carbonation of AAS concretes compared to OPC concretes by regulating mix design. The authors [6] also reported a minimum charge passed values in chloride ion permeable test for AAS specimens compared to reference OPC specimens. On the other hand, in terms of sulphate resistance, El-Sayed et al. [7] reported that durability of water cooled slag in 5% $MgSO_4$ showed a better microstructure and high resistivity when it was activated by 3:3 NaOH and Na_2SiO_3 mixture.

Malviya and Goliya [8] reported that the OPC concrete deteriorated much more both in acid and sulphate solution compared to FA concrete activated by alkaline solution (NaOH and Na_2SiO_3). They also reported that FA based concrete activated by alkaline solution is much more durable than the OPC concrete. On the other hand, Thokchom et al. [9] reported that specimens having a lower alkali content showed much higher porosity values, water absorption and water sorptivity. The authors [9] studied a low calcium based class-F FA that was activated by the solution of NaOH and Na_2SiO_3. However, after completion of a 24-week immersion period in H_2SO_4, the compressive strength observed was found ranging from 29.4% to 54.8%. Superior corrosion resistance of FA based (activated by NaOH) AA and geopolymer concrete compared to OPC concrete was reported by some researchers [10,11]. But AA–FA mixtures with a higher sodium and silica content exhibited a higher drying shrinkage as stated by Ma [12]. On the other hand, the length change rate increased with the increase in age and liquid to binder ratio for AA composite blend of FA with slag and also rate was found higher than OPC mortars at all ages as observed by Chi et al. [13]. They [13] also observed that with the same liquid to binder ratio, AAS mortars exhibited a higher length change compared to AA composite mortars. Several observations were also made by Rashad [14] for AA composite blend of FA with slag mortars and concrete. The author [14] found an increasing trend of drying shrinkages with increasing quantity of slag in the mixture.

Adam [15] reported that FA based AA concrete performed better in sorptivity and chloride penetration tests in comparison with OPC concrete, AAS concrete as well as composite blended concrete of slag with OPC. The author [15] also observed a higher charge passed and higher conductivity values for the FA based AA concretes in accelerated chloride diffusion tests. Durability of AA blended slag with MK was examined by Bernal et al. [16]. The authors [16] observed a lower sorptivity and chloride permeability with increasing MK quantity and concentration of the activator used. On the other hand, a reduction trend was observed for compressive strength as well as permeability in accelerated carbonation testing. Drying shrinkage and sulphate expansion of partially replaced MK by POFA were studied by Hawa et al. [17]. The authors [17] reported that AA mortars containing POFA had decreasing drying shrinkage on the increase in curing time at an elevated temperature due to the well-developed strength. They also concluded that by submersing AA mortars in sodium and magnesium salt solutions and being cured for one hour at an elevated temperature can reduce expansion of mortars.

On the other hand, RHA used with NaOH and Na_2SiO_3 has a great potential as a substitute for OPC concrete as reported by Kim et al. [18]. They studied durability in acid and sulphate media such as H_2SO_4, HCl, Na_2SO_4 and $MgSO_4$ environments and found a very less weight loss compared to steam-cured mortar specimens. The above mentioned pozzolanic materials with OPC in construction projects have been steadily adopted by industries worldwide according to the existing standards [19]. Thus, establishment of durability properties of these AA concrete and mortar is a must now to fix the standard. Therefore, the current paper summarises the most relevant erudition regarding the durability performance of AAB by using pozzolans such as slag, FA, POFA, MK and RHA.