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Review

Durability of mortar and concrete made up of pozzolans as a partial replacement of cement: A review

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HIGHLIGHTS

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

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ABSTRACT

In recent years, researchers have been focusing on developing more sustainable cementitious systems in order to curb the negative environmental impacts and disintegration of concrete structures associated with ordinary Portland cement (OPC). Several attempts have been made to develop sustainable binders through the use of pozzolans such as slag, fly ash (FA), palm oil fuel ash (POFA), metakaolin (MK), silica fume (SF), rice husk ash (RHA) etc. with a relatively larger amount of replacement of OPC. A certain level of cement replacement with those pozzolans is highly advantageous in terms of cost, energy efficiency, ecological and environmental benefits as well as durability properties. More recently, researchers have mainly focused on the possibility of practical use of pozzolans (Slag, POFA, FA, SF, MK and RHA) as a partial replacement of cement in quest for improved long-term strength and durability properties. Based on published documents, this paper reviews the current state of knowledge on durability of mortar and concrete made up of pozzolans as a partial replacement of cement. A number of important properties of the made mortar and concrete among others compressive strength, sorptivity, permeability, water absorption, chloride penetration, sulfate resistance, carbonation, drying shrinkage, corrosion resistance, and resistance to acid attack have been discussed here. Finally, several potential studies have been suggested for the future research.

Contents

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1. Introduction

Over the past years, many industrial waste materials like FA, slag and other ashes produced from various agricultural wastes such as POFA, RHA, groundnut husk ash, millet husk ash and corncob ash have been tried as pozzolanic or secondary cementitious materials [1–6]. These supplementary cementing materials (SCMs) play a significant role when incorporated in the OPC at a certain proportion. Usually SCMs in concrete minimize the permeability of concrete by altering the pore structure and the resulting concrete shows a significant resistance against reinforcement corrosion, acid attack and sulfate attack [7]. Shiathas et al. [8] also reported that these Pozzolanic materials such as ground granulated blast furnace slag (GGBS), RHA, pulverised fuel ash (PFA), SF, FA, POFA generally improve durability properties, reduce adverse environmental effects and also cost of concrete.

Hale et al. [9] reported that cement with a replacement amount of 25% by slag and 15% by FA improved long-term properties of concrete with significant early age properties. An improvement in strength, reduction in permeability as well as reduction in chloride penetration were observed by Thomas and Mathews [10] after adding PFA with OPC in concrete. Authors [10] also observed an improved strength and porosity values for ternary (three-component) blended OPC, RHA and PFA concrete in which strength at a lower replacement level and porosity at a higher replacement level was a significant factor for OPC concrete. Another observation was also reported that the inclusion of PFA and SF in concrete as a partial replacement of cement reduces chloride permeability of concrete [11]. According to Dhir and Byars [12], the construction industry has been steadily regulated to use SCMs with OPC recently as reflected in several standards worldwide. Therefore, durability properties of concrete and mortar by using pozzolanic materials could be established. This paper summarizes the latest advances regarding the durability properties of sustainable binder by using these SCMs as replacement of OPC.

2. Historical background

Investigation of durability properties of mortar and concrete by using pozzolans as a partial replacement of cement was one of the vital issues for researchers over the past few decades. Table 1 presents some recent investigations on durability properties by using SCMs in singular, binary (two-component) and ternary (three-component) blended concrete. The development of using SCMs was a major achievement led by the work of Purdon in 1940s [13]. But the durability studies are the recent issues as they showed a superior compressive strength, splitting tensile strength as well as modulus of elasticity at various ages.

Collepardi et al. [14] showed the influence of mineral additives in the form of FA, slag and ground limestone incorporated as a partial replacement of Portland cement on the CO_2 penetration rate of concrete. The results indicated that there was an increasing trend in the carbonation rate in concretes with increasing mineral additives, except when the amount of OPC replacement was relatively low (15%). On the other hand, when the comparison of the carbonation rate was made on concrete specimens at the same strength level, no significant difference was found between specimens with Portland cement and those with replacement by mineral additives up to 50%. Al-Akhras [15] investigated sulfate resistance of concrete produced from blended MK with OPC to observe the effect of MK where MK was mixed at the replacement levels of 5%, 10%, and 15% by weight of OPC. Concrete specimens were dipped in 5% aqueous solution of sodium sulfate (Na_2SO_4) for 18 months after being moist cured for the desired periods. Sulfate resistance was evaluated in terms of visual observation (for any cracks if initiated), compressive strength reduction and expansion of concrete prisms. The authors [15] reported that replacement of OPC with MK enhanced sulfate resistance of blended concrete specimens in which sulfate resistance increased with increasing MK content in the blend.

In 2007, Ramezanianpour et al. [16] performed chloride permeability/penetration test on concrete incorporated with RHA as a partial replacement of OPC. OPC concrete specimens and specimens by replacing OPC with RHA by the amount of 7%, 10% and 15% (by weight) were prepared. A very low chloride permeability was observed for the specimens prepared using 15% RHA with

Table 1
Some recent studies on durability properties of mortar and concrete containing pozzolans.

Durability properties	Pozzolans used as partial replacement of cement	Author
Carbonation	FA, slag and ground limestone	Collepardi et al. [14]
Sulfate resistance	MK	Al-Akhras et al [15]
Chloride permeability	RHA	Ramezanianpour et al. [16]
Water absorption, drying shrinkage and porosity	MK	Guneyisi et al. [17]
Acid resistance	FA and SF	Murthi et al. [18]
Chloride permeability and Corrosion resistance	RHA and POFA	Rukzon et al. [2]
Sulfate resistance	Black RHA	Chatveera et al. [19]
Modulus of elasticity and Shrinkage	POFA	Awal et al. [5]
Acid resistance	POFA	Budiea et al. [20]
Sorptivity and Carbonation	Slag	Adam et al. [21]
Chloride permeability	RHA, Slag and FA	Gastaldini et al. [22]
Chloride permeability	Slag	Fapohunda et al. [23]
Water permeability, water absorption & chloride ion penetration	RHA	Kartini [24]
Water permeability and porosity	RHA	Jaya et al. [25]
Modulus of elasticity	FA and SF	Turk [26]
Drying shrinkage	FA	Kate et al. [27]
Water absorption and Sorptivity	FA	Pitroda et al. [28]
Carbonation and Chloride permeability	Slag and MK	Duan et al. [29]
Corrosion resistance	POFA	Yahaya et al. [30]
Sulfate resistance	Slag and FA	Nie et al. [31]

FA: Fly ash; MK: Metakaolin; RHA: Rice husk ash; SF: Silica fume; POFA: Palm oil fuel ash.