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Characterizing supplementary cementing materials in blended mortars

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HIGHLIGHTS

- The physical and chemical effects of SCMs on cementitious mortars can be decoupled.
- Neither too coarse nor too fine SCM particles produce optimal physical contribution.
- Chemical contribution from SCMs is more from siliceous than calcareous fly ashes.
- Role of particle packing in strength development is more for lower w/b systems.
- Physical filler effect always has a positive influence on the bound water content.

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ABSTRACT

Studies on understanding the reactivity of alternative materials are typically performed on paste mixtures. This study attempts to explore the contribution of supplementary cementing materials (SCMs) to the properties of blended cementitious mortars. The strength and microstructural development of mortars are investigated through parameters such as compressive strength, porosity and chemically bound water. In addition, an attempt is made to decouple the physical and chemical contribution of SCMs with the help of inert fillers. The results indicate that there is a desired level of fineness at which an optimal performance from mineral additives is obtained. Further, the decoupling methodology was able to bring out the rate of chemical contribution from the different mineral additives; the delayed pozzolanic activity of Class 'F' fly ash led to significant chemical contribution at later ages. Unlike the compressive strength, where the physical filler effect did not uniformly result in a contribution to strength, the results for bound water always show a positive contribution from the filler effect.

1. Introduction

Good quality concrete can be produced mainly from appropriate design of the mixture, and adequate compaction after placing, and proper curing [1]. 'Supplementary Cementitious Materials' (SCM) are generally incorporated as a replacement to cement to enhance the concrete characteristics.

Binary blends are widely used in practice, where cement is partially replaced by a SCM. However, ternary blends are also prepared, when there is a necessity to make use of the advantages imparted by two SCMs with different properties. For instance, the two SCMs may have different particle size ranges, and this allows the voids between the SCM and cement particles to get filled up by another ultrafine SCM resulting in a denser structure. The other possibility is that, when two different SCMs exhibit varied chemical properties, and if there is a necessity to employ the good features of both the materials in a particular mix, ternary blends can be chosen.

The chemical composition, fineness, crystalline structure, presence of alkalis, etc. are some of the factors influencing the rate and extent of reactions of various mineral admixtures. Based on the chemical composition, they can be broadly classified into pozzolanic, latent hydraulic, and cementitious materials [2]. Pozzolanic materials such as Class 'F' fly ash, silica fume, etc. contain reactive silica which undergoes pozzolanic reaction; whereas, materials such as slag, Class 'C' fly ash, etc. have both reactive silica and also considerable quantity of lime and possess cementitious characteristics. In general, the fineness of pozzolans is almost equal to, or even lesser than that of cement, which helps in filling the voids. Further, the additional nucleation of cement hydration products, coupled with the chemical reactivity of the SCMs leads to an improvement in the packing density of the resulting cementitious systems. The chemical and microstructural changes caused due to the addition of SCMs are important, since they ultimately influence the engineering properties of the blended systems [3].

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Besides compressive strength, which is used in several standard tests [2,4–7], there are a lot of other methods available for characterizing the SCMs. Investigations into the reactivity of SCMs adopting these techniques have been carried out for many years, and a compilation is presented in Table 1.

Scrivener et al. [8] classified the techniques into direct and indirect methods. In direct methods, the amount of residual SCM after a certain period of time is measured directly and hence the quantity of SCM reacted is found out, as in the case of selective dissolution, back-scattered scanning electron microscopy (BSE-SEM) with image analysis, X-ray diffraction (XRD) with Rietveld analysis, etc. On the other hand, in indirect methods, some associated observations such as estimating the voids, measuring the amount of portlandite consumption, bound water content, etc. are carried out, followed by the computation of the amount of reacted SCM using the available postulates on reaction products of cement and SCM.

A recent study on fly ash based mortars [9] engaged fly ash in 2 different design methods: 1) as an inert material and 2) as a reactive material. The experimental results proved that the design method where fly ash was treated as reactive, led to better properties in terms of workability, strength and

Table 1
Characterization techniques adopted for SCMs.

Technique	Previous Studies	Reference	Year	Remarks
Selective Dissolution	Kocaba	[4]	2009	Does not yield accurate results mainly due to incomplete dissolution.
	Scrivener et al.	[8]	2015	
	Dyson et al.	[17]	2007	
	Ben Haha et al.	[18]	2010	
	Kocaba et al.	[19]	2012	
	Durdzinski et al.	[20]	2017	
BSE-SEM coupled with image analysis	Berodier	[2]	2015	Reliable and accurate method;
	Deschner et al.	[6]	2012	Provides only 2-dimensional images of a 3-dimensional microstructure; Differentiation of grey levels is difficult with some phases, but can be distinguished by suitable filters or chemical mapping by energy dispersive X-ray spectroscopy (EDX).
	Gruyaert	[7]	2011	
	Scrivener et al.	[8]	2015	
	Ben Haha et al.	[18]	2010	
	Kocaba et al.	[19]	2012	
	Durdzinski et al.	[20]	2017	
	Scrivener	[21]	2004	
	Durdzinski et al.	[22]	2015	
	ASTM C1723	[23]		
XRD with Rietveld analysis	Kocaba	[4]	2009	Imprecise for blended cements; Technique with partial or no known crystal structure method (PONKCS) is now developed.
	Scrivener et al.	[8]	2015	
	Durdzinski et al.	[20]	2017	
	ASTM C1365	[24]		
Thermal analysis	Berodier	[2]	2015	Calorimeters are used to study the early phase of hydration; Differential thermal analysis combined with thermogravimetric analysis is more appropriate for hydration studies at later ages.
	Kocaba	[4]	2009	
	Deschner et al.	[6]	2012	
	Gruyaert	[7]	2011	
	Scrivener et al.	[8]	2015	
	Durdzinski et al.	[20]	2017	
	Pane and Hansen	[25]	2005	
	ASTM C186	[26]		
Calcium hydroxide depletion	Hewlett	[3]	2004	The reduction in portlandite content is an indicator of the reactivity of the SCM.
	Kocaba	[4]	2009	
	Deschner et al.	[6]	2012	
	Durdzinski et al.	[17]	2017	
	Ben Haha et al.	[18]	2010	
Bound water content	Kocaba	[4]	2009	The overall degree of reaction of blended cements from bound water content is still a challenging issue due to unknown stoichiometries.
	Deschner et al.	[6]	2012	
	Garcia	[27]	2003	
	Schwarz and Neithalath	[28]	2008	
	Fagerlund	[29]	2009	