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Review

Formulation of blended cement by the combination of two pozzolans: Calcined clay and finely ground sand

W. Mechti [a,*], T. Mnif [a], M. Chaabouni [b], J. Rouis [a]

[a] Unité de Recherche de Géothechniques Environnementale et Matériaux Civil, Ecole Nationale d'Ingénieur de Sfax, BP W 3038 Sfax, Tunisia
[b] Laboratoire de Chimie Industrielle, Ecole Nationale d'Ingénieur de Sfax, BP W 3038 Sfax, Tunisia

HIGHLIGHTS

- Use of a kaolinitic clay as a pozzolanic material for cements.
- Use of ground sand as a pozzolanic material for cements.
- Optimization of a blended cement formula by using a cross mixture design.

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ABSTRACT

The aim of this study was to investigate and optimize the properties of mortars in which calcined clay and finely ground sand are employed as a partial substitution of Portland cement. For this, a cross mixture design containing 28 runs was set up to study the influence of the mixture proportions of Portland cement, calcined clay and finely ground sand in the blended cement and also two process variables namely: fineness of ground sand and calcination temperature of clay. It was demonstrated that finely ground sand, despite its crystalline nature, presents a pozzolanic reactivity. It was also proven that the compressive strength of hardened mortars can be improved by increasing clay calcination temperature in the explored domain. Finally, analysis of isoresponse contour plots of the combined mixture design allowed the choice of the optimum formula giving the high values of compressive strength at 28 and 90 days which is 15% of ground sand using a sieve size of 40 μm fineness.

Contents

* Corresponding author. Tel.: +216 24177462.
E-mail address: wafamechti@gmail.com (W. Mechti).

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1. Introduction

By using supplementary cementing materials to replace a maximum amount of the cement in concrete, we can reduce energy and resources consumption, reduce CO_2 emissions and lessen the negative environmental impact [1]. These supplementary cementitious materials such as silica fume [2], blast furnace slag [3] and metakaolin [4–9], which possess pozzolanic properties, have been successfully used in concrete mixtures. Indeed, the strength and durability of conventional cement-based materials can be significantly improved when additives based on thermally activated kaolin are used [10–12]. Recently, several studies [13,14] have demonstrated that in addition to the filler effect of sand powder by improving the compactness of the mixture and the mechanical performance of the hardened material, the latter presents a pozzolanic reactivity [15–18]: the introduction of fine siliceous particles contribute to the increase in the strength and the durability of the concretes that they are and not built-in [19,20].

To look for the optimal formulae of the blended cement containing ground sand and calcined clay as additive, a cross mixture design has been set up and exploited. In reviews, many experimental designs were set up to formulate blended cements with calcined clay [21,22] or silica fume [23] or blast-furnace slag [3] but there is no experimental designs to formulate blended cements with these two pozzolanic materials.

In this context, the objective of this study is to evaluate, through a cross mixture design, the combined contribution of both the mixture proportions (% of Portland cement,% of calcined kaolin and% of sand) and two process variables (fineness of ground sand and calcination temperature of calcined kaolin) on the compressive strength and hydration of blended cements.

2. Raw materials and experimental techniques

2.1. Raw materials

The blended cements used in this study are composed of three raw materials: Portland cement, calcined kaolin and finely ground sand.

- Portland cement: the cement that was used is a typical commercial Type I 42.5 (ASTM C 150-04) and composed of approximately 95% clinker and 5% gypsum. Its chemical and mineralogical compositions are presented in Table 1.
- Clay: the studied clay is a local one, collected from the region of Tabarka. It is used in hand-made pottery. Its chemical composition is shown in Table 2.
- Sand: the sand powder is obtained by crushing and grinding the washed sand destined to the construction industry. The crushing is carried out using a conventional ball crusher. After that, sieving is carried out to obtain the desired particle size. To study the effect of fineness, the following classes of ground sand having the given particle sizes are used:
  (A) between 60 μm to 80 μm, and
  (B) between 40 μm to 60 μm, and
  (C) lower than 40 μm, and
  (D) lower than 20 μm.

The chemical composition of sand is also illustrated in Table 2.

Table 1
Chemical and mineralogical composition of cement.

Chemical composition %								Bogue composition			
CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	K_2O	CaO free	L.O.I at 500 °C	C_3S	C_2S	C_3A	C_4AF
65.3	21.1	4.7	2.8	2.3	0.5	0.8	0.9	59.3	15.8	7.76	8.59

Table 2
Chemical composition of clay and sand.

%	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	K_2O	MgO	Na_2O	L.O.I at 500 °C
Clay	0.85	58.38	27.08	2.60	0.03	0.88	1.14	0.11	6.26
Sand	0.63	96.94	0.68	1.55	0.04	0.2	0.22	0.02	–

Table 3
Variable level limits.

Variables	Mixture variables		
	Lower constraint		Upper constraint
Z_1: Cement	0.7		0.9
Z_2: Sand	0.05		0.25
Z_3: Clay	0.05		0.25
	Process variables		
	Unit	Low level ($X_j = -1$)[a]	High level ($X_j = +1$)[a]
U_4: Fineness	μm	20	40
U_5: Calcination temperature	°C	650	750

$X_j = (U_j - U_j(0))/\Delta U_j$. $U_j(0)$: is the mean value of U_j and ΔU_j is the variation path equal to $U_j^{high} - U_j(0)$.
[a] X_j: coded variable related to the natural variable U_j.

2.2. Experimental techniques

The chemical analyses are determined by X-ray fluorescence (ARL 8400 apparatus); characteristics of the mineralogical composition of the crude and the calcined samples are studied by an X-ray diffractometer (Philips X 'Pert Pro System).

Each blended cement is prepared by mixing and shaking for few minutes a mixture of Portland cement, calcined clay (fineness lower than 100 μm) and sand. The strength tests are carried out on standard mortar bars (40 × 40 × 160 mm) in compliance with the EN 196-1 norm [24].

3. Methodology

In this study, there are two kinds of variables: variable related to the composition of the blended cement (% of Portland cement, % of calcined clay and% of sand) and process variables namely the fineness of crushed sand and the calcination temperature of the clay.

The purpose of this work is to determine, using a cross mixture design, the best experimental conditions allowing the maximization of the compressive strength of the blended cement at 28 and 90 days. For this, a cross mixture design combining the proportions of components with process variable levels is achieved. The measured responses are used to fit a mathematical model as shown in the following equations.

$$\hat{y}_{mixture} = b_1Z_1 + b_2Z_2 + b_3Z_3 + b_{12}Z_1Z_2 + b_{13}Z_1Z_3 + b_{23}Z_2Z_3 \quad (1)$$

$$\hat{y}_{factorial} = a_0 + a_1X_4 + a_2X_5 \quad (2)$$

$\hat{y}_{mixture}$ is a reduced cubic model related to the mixture design and $\hat{y}_{factorial}$ is an additive linear first order polynomial model related

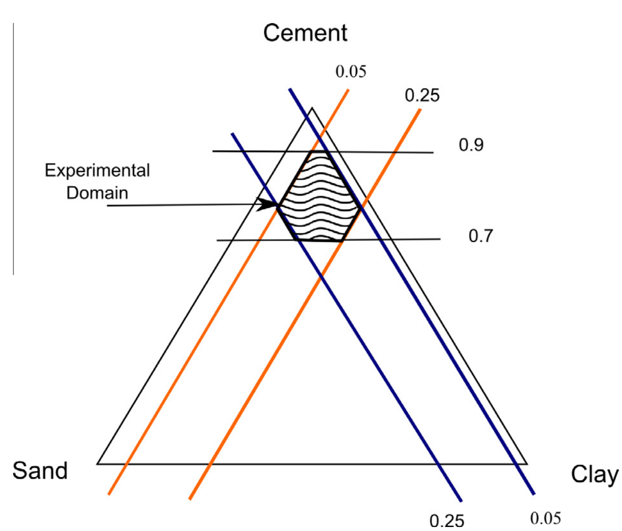

Fig. 1. Experimental domain (hachured zone).