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Cement substitution by a recycled cement paste fine: Role of the residual anhydrous clinker

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HIGHLIGHTS

- RCPF just fills the granular gap left by the substituted cement in mortar mixtures.
- RCPF contains around 24% of a reactive residual anhydrous clinker.
- RCPF contributes in the hydration process through its anhydrous clinker.
- RCPF contributes in the mechanical properties through its anhydrous clinker.
- RCPF contributes in the carbonation resistance through its anhydrous clinker.

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ABSTRACT

This paper reports on an experimental study conducted on mortars designed with substitution of Portland cement by a recycled cement paste fine (RCPF) obtained from crushing, grinding and 80-µm sieving of a laboratory-made cement paste. The obtained results show that in terms of fineness, particle size distribution, $CaCO_3$ content, hydration kinetics, total porosity and mechanical properties, the use of RCPF as partial substitution of cement should not provide any additional filler effect and nucleation sites compared to the replaced cement. The results show also that RCPF contains around 24% of a reactive residual anhydrous clinker which contributes in the hydration process, the mechanical properties and the resistance against carbonation.

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1. Introduction

The annual global cement production, which exceeds 4 billion tons [1], is responsible for at least 5% of the global CO_2 emissions [2–4]. In fact, the production of 1 ton of clinker, which is the main component of cement, releases more than 0.7 ton of CO_2 [5]. During the cement production, 65% of the released CO_2 are attributed to the decarbonization process that leads to the clinker creation [6,7] and 35% to the consumed energy [8]. A solution for reducing these CO_2 emissions is to substitute a part of the clinker by mineral additions [9] during cement production [10] or even during concrete mixing [11–13].

The most widely used mineral additions are fly ash, blast-furnace slag, natural pozzolans, silica fume and limestone filler [12–14]. However, recent studies have shown the feasibility to replace some usual mineral additions, such as limestone filler, by a fine obtained only from a mechanical pre-treatment (crushing, grinding and sieving) of an old concrete [15–17]. Indeed, designing new cementitious materials by substituting a part of their cement (clinker) by a fine obtained from demolition concrete (waste) without any thermal pre-treatment, instead of using an ordinary mineral addition, would contribute:

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- to reduce the environmental impact of these materials by reducing the amount of clinker and also by avoiding the heating of the recycled fine [17–20];
- to limit the systematic use of natural resources by reducing the amount of clinker and by avoiding the use of some mineral additions such as limestone filler [9,11,21];
- to limit landfill by reusing the recycled fine [22,23].

Oksri-Nelfia et al. [17] have studied the influence of cement substitution by a recycled crushed concrete fine (RCCF), obtained from a 5 years old concrete, on the properties and performances of mortars with different contents of RCCF. The studied recycled fine, which has low hydraulic properties due its low amount of anhydrous phase, was found to exhibit similar properties than limestone filler with respect to the cement hydration.

A recycled fine obtained from an old concrete or recovered from demolished materials presents a high variability of its properties due to the presence of aggregates and other components. This makes difficult controlling the chemical composition of the fine and thus understanding its real role when used as mineral addition. Moreover, highlighting the potential reactivity of the anhydrous phase depends on its content in the fine.

In the present study, mortar mixtures were then designed with partial or total substitution (0–100% by mass) of Portland cement CEM I 52.5 N type by a recycled cement paste fine (RCPF), obtained from crushing, grinding and 80-μm sieving of a laboratory-made cement paste, instead of a real demolished concrete. The paste used to generate RCPF was itself manufactured with the same Portland cement to better control the chemical composition of the fine. Unlike a fine from an old concrete, the so-obtained fine should contain enough of anhydrous phase to make possible the study of its potential reactivity when incorporated in the mortars composition.

Physical investigations (density, Blaine surface and particle size distribution) were conducted on both the Portland cement and RCPF to check the possible granular effect (filler effect and nucleation sites) in the mortars due to the presence of RCPF. Mineralogical investigations (TGA, FT-IR and XRD) were then conducted on the two binders to highlight the presence of an anhydrous phase in RCPF and thus to quantify it. Finally, hydration, microstructural, mechanical and durability investigations were carried out on the mortars to analyze the influence of the amount of RCPF and to determine the potential reactivity of the anhydrous phase.

2. Experimental program

2.1. Materials

2.1.1. Sand

Mortar mixtures were manufactured with a silico-calcareous sand (0/4 mm) complying with the French NF P 18-545 Standard. The sand has a density of 2.56 g/cm^3 and a water absorption coefficient of 1.4%.

2.1.2. Portland cement

A Portland cement CEM I 52.5 N type complying with the European EN 197-1 Standard was used. Its chemical and mineralogical properties are given in Table 1.

2.1.3. Recycled cement paste fine (RCPF)

The studied mortar mixtures were designed with substitution of Portland cement CEM I 52.5 N type by a fine, denoted in the following "RCPF" (recycled cement paste fine), obtained from crushing, grinding and 80-μm sieving of a laboratory-made cement paste. The latter was itself manufactured with the same Portland cement CEM I 52.5 N type. The choice of using the same cement, and using a laboratory-made cement paste to generate RCPF, instead of a real demolished concrete, allows to better control the chemical composition of the recycled fine by eliminating the variability of its properties when recovered from demolished materials.

Table 1
Chemical and mineralogical properties of the used cement.

Composition [%]	
Clinker	97
Gypsum	3
Clinker mineralogical composition [%]	
C_3S	68
C_2S	10
C_3A	8
C_4AF	8
Chemical composition [%]	
CaO	63.4
SiO_2	20.6
Al_2O_3	4.5
SO_3	3.2
Fe_2O_3	2.4
MgO	1.9

The recycled cement paste (Table 2) was prepared using the following equations:

$$V_C + V_W = 1\ m^3 \tag{1}$$

$$\frac{W}{C} = 0.3 \tag{2}$$

with V_C and V_W [m^3] the Portland cement and water volumes, respectively, W and C [kg] the effective water and Portland cement contents, respectively. The water-to-cement ratio was taken equal to 0.3 (Eq. (2)) in order to limit bleeding and segregation, and to obtain thus a homogeneous paste.

The cement paste was cast into 16 × 32 cm molds (16 cm in diameter and 32 cm in height) and stored in a room at 20 ± 1 °C for 24 h. All cylinders were then demolded 1 day after casting and cured under water at 20 ± 1 °C for 89 days. At the age of 90 days, specimens were first crushed by compression to obtain fragments less than 15 cm and then grinded in a laboratory ball mill until obtaining 80 μm powder after successive sieving. Finally, the so-obtained RCPF was stored under hermetically sealed conditions before use. Such a conservation would limit the exposition of RCPF to the atmospheric humidity and CO_2.

2.2. Mortar mixtures

Eight mortar mixtures (Table 3) were prepared using the mix-design method described by the following equations:

$$V_S + V_C + V_F + V_W = 1\ m^3 \tag{3}$$

$$V_C + V_F + V_W = 0.46\ m^3 \tag{4}$$

$$\frac{W}{F + C} = 0.45 \tag{5}$$

$$\frac{F}{F + C} = j \tag{6}$$

Table 2
Recycled cement paste composition (in kg per cubic meter of paste).

Portland cement (C)	1606
Effective water (W)	482
W/(C) [–]	0.30
C/(W + C) [–]	0.77

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