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Long-term effects of waste brick powder addition in the microstructure and service properties of mortars

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HIGHLIGHTS

- The addition of brick powder produced a higher microstructure refinement of mortars.
- Impedance spectroscopy results show the joint pozzolanic and filler effect of the addition.
- The brick powder addition up to 20% of the binder would improve mortars durability.
- 10% and 20% brick powder mortars showed good service properties in the long-term.
- After 400 days the behaviour of mortars with brick powder was better than OPC ones.

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ABSTRACT

One way to reach a more sustainable cement industry is replacing clinker by additions, such as waste brick powder. The objective of this research is to analyse the influence in the long-term (until 400 days) of waste brick powder in the microstructure, durability and mechanical properties of mortars which incorporate up to 20% of this addition as a clinker replacement. The microstructure has been studied with the non-destructive impedance spectroscopy technique. According to the obtained results, mortars with 10% and 20% of brick powder, showed good service properties in the long-term, even better than those made with ordinary Portland cement.

1. Introduction

Nowadays, one of the industrial sectors which more pollution produces worldwide is the cement manufacture. Therefore, reaching a more environmentally sustainable cement industry still constitutes an important challenge, especially in search of reducing the CO_2 emissions generated along the cement production. One of the most common ways to lessen those emissions is replacing partially, or even totally, clinker by supplementary cementitious materials or other additions in general [1–3]. Ground granulated blast-furnace slag, fly ash and silica fume are now some of the most popular additions [4–6], and cements including those additions are produced at industrial scale. Furthermore, many additions, such as the abovementioned ones, are pollutant wastes produced during other industrial processes, so their reuse would partly solve other environmental problems, like their storage.

For those reasons, the research about new suitable cement additions is still the topic of many studies [7,8]. Among those additions, the study of brick powder as clinker replacement has been the topic of recent researches [9–12]. In the abovementioned studies, the effects of brick powder in cement-based materials properties have overall been studied in the short-term (up to 120 hardening days), and this addition came from construction and demolition wastes, as well as from defective bricks rejected along the manufacturing works.

Regarding this addition, several studies [9,11,13–16] have determined that brick powder is a pozzolanic material. Its pozzolanic activity is produced as a consequence of the transformation

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of crystalline structures of clay silicates in amorphous compounds along the manufacture process of bricks [17], in which clay is exposed to high temperatures, ranging from 600 °C to 1000 °C. Other researches about the use of brick powder in mortars and concretes [10,18–20] have pointed out that a cement replacement up to a 20% of brick powder could be suitable, and it would not affect the physical and mechanical properties of the material. Moreover, it has been noted that the particle size is an important factor in order to insure an adequate behaviour of this addition [21], and it has also been pointed out that the best mechanical strength performance is obtained when the particle size of brick powder is less than 0.06 mm [22].

In addition to this, Schackow et al. [12] have concluded that the reaction between the amorphous compounds of brick powder, such as silica and alumina, with calcium hydroxide generates silicate/aluminate hydrates similar to those produced in the cement hydration. Furthermore, according to the abovementioned work of Schackow et al. [12], another factor that could have an influence in the good performance of cement binders with brick powder, would be the filler effect of this addition, because it would occupy the pre-existing voids present in the pore network of the materials, reducing in this way their pore sizes.

On the other hand, the study of the microstructure of cement-based materials is important, because it is related to their mechanical and durability-related properties [23]. Among the different techniques for characterising the microstructure, the novel non-destructive impedance spectroscopy has recently experienced a great development, becoming popular for the study of different cement-based materials, such as those prepared using slag and fly ash cements [24,25], as well as exposed to aggressive [26,27] or non-optimum environments [28]. Nevertheless, the impedance spectroscopy technique has never been used for studying the evolution of the microstructure of cement mortars which incorporate waste brick powder.

Other uses of this waste have been as aggregate in hydraulic lime mortars [29] or colouring additive for plaster [30], with no structural intention.

Therefore, the main objective of this research is to study the influence in the long-term (until 400 days) of the addition of waste brick powder in the microstructure, durability and mechanical properties of mortars which incorporate up to 20% of this addition as a clinker replacement. As a reference, mortars made using ordinary Portland cement without additions were also studied. The non-destructive impedance spectroscopy technique and mercury intrusion porosimetry (as contrast technique) were used in order to characterise the microstructure of the specimens, and its time evolution. Moreover, differential thermal analysis of the mortars was also performed, in order to check the pozzolanic activity of the waste. Durability-related parameters, the effective porosity, the capillary suction coefficient, the steady-state diffusion coefficient obtained from saturated sample's resistivity and the non-steady state chloride migration coefficient were analysed, to ensure that the addition of the brick powder will not worsen these properties. Finally, for checking the mechanical behaviour of the mortars, their flexural and compressive strengths were also obtained.

2. Materials and methods

2.1. Waste brick powder characterisation

Waste brick powder was obtained from industrial brick residuals from demolition debris. Particles under 75 μm were selected after grinding and sieving the brick powder. The results of the chemical and physical analysis are shown in Table 1.

Table 1
Physical and chemical properties of waste brick powder.

Composition	Brick powder
SiO_2	41.47%
Al_2O_3	39.05%
CaO	0.63%
Fe_2O_3	12.73%
SO_3	1.59%
MgO	–
Na_2O	–
K_2O	2.81%
TiO_2	1.03%
CuO	0.70%
Density	2660 kg/m^3
Blaine surface area	6485 m^2/kg

Blaine values specified in Table 1 were obtained following the ASTM C204 specifications [31]. The values show that bricks powder presented higher specific surface than cement, agreeing with previous studies [9].

The mineralogical study of the brick powder on dry powder was carried out using XRD. The inorganic crystalline phases identified in the XRD patterns (Fig. 1) were silica (sand used to adjust the plasticity of the brick green mixture), illite (main mineralogical constituent of the clay used in brick manufacture), and hematite (used to reduce the firing temperature and favour the formation of liquid phases).

In Fig. 2 SEM observation is reported, showing that waste brick powder consisted of morphologically irregular particles, whilst the elemental analysis (see Fig. 3) was substantially consistent with the XRD analysis. Finally, the particle size distribution of the waste brick powder used is shown in Fig. 4.

2.2. Sample preparation

Three types of cement mortars were studied in this work. The first one was prepared using a commercial ordinary Portland cement, designated CEM I 42.5 R (CEM I hereafter), according to the Spanish and European standard UNE-EN 197-1 [32]. Moreover, two blended cements, which incorporate waste brick powder, were used. Both blended cements were made with an ordinary Portland cement, CEM I 42.5 R [32], which was replaced by 10% and 20% of brick powder. They will be referred as BP10 and BP20 respectively from now on. The water to cement ratio was 0.5 for all the mortars, and the aggregate to cement ratio was 3:1. Aggregates used were siliceous, with the granulometry according the prescriptions of the standard UNE-EN 196-1

Two kinds of specimens were prepared. The first type consisted of cylindrical specimens of 10 cm diameter and 15 cm height, and the second one consisted of prismatic samples with dimensions 4 cm × 4 cm × 16 cm [33]. Both kinds of samples were maintained in 95% relative humidity (RH) chamber and 20 °C for the first 24 h. After that, they were de-moulded and the 10 cm-diameter and 15 cm-height cylindrical samples were cut to obtain different cylinders of 1 cm and 5 cm thickness. Finally, all the samples were kept under an optimum laboratory condition (20 °C and 100% RH) until the testing ages.

2.3. Mercury intrusion porosimetry

The classical mercury intrusion was used in order to study the microstructure of the mortars, in spite of its drawbacks [34,35]. The tests were performed with a porosimeter model Poremaster-60 GT from Quantachrome Instruments. Before the test, samples were oven dried for 48 h at 50 °C. Total porosity, pore size