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Hydraulic-lime based concrete: Strength development using a pozzolanic addition and different curing conditions

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ABSTRACT

Concrete is a major worldwide building material, in which Portland cement is the usual binder. Taking into account environmental factors in cement production, especially concerning CO_2 emissions and energy consumption, this work aims at the development of concrete with a hydraulic-lime binder; in order to increase mechanical strength, pozzolanic materials were added. In this preliminary study, compositions with different percentages of hydraulic lime were tested and a pozzolanic material, a residue from expanded clay production, was used. Variations in percentage of pozzolan and conditioning were carried out. Concrete specimens were tested for mechanical strength at various ages and a pozzolanic index was determined in order to evaluate the influence of the pozzolanic material on attained mechanical strength. This paper presents the results of this testing campaign, concluding on the influence of pozzolanic additions and curing conditions on the strength development of this material.

1. Introduction

The protocol of Kyoto has created demanding goals in terms of decrease in greenhouse gas emissions. Furthermore, global warming and climate change effects felt throughout the world have created a growing concern on energy consumption and efforts towards the use of eco-friendly materials, with a lower environmental impact, are being undertaken. Cement industry generates around 5% of global CO_2 emissions, due to carbonate decomposition (about 50%), combustion of fuels in the kiln (about 40%). Electricity generation and transportation, ranking as the third largest carbon emitting industry in the EU [1,2]. It is estimated that each tonne of cement produces approximately 1 tonne of CO_2, mainly from the burning of fossil fuels and from the de-carbonation of limestone [1]. Although the cement industry is taking measures in order to ensure a reduction in greenhouse gas emissions, using alternative fuels or changing cement composition [3,4], this could be further achieved using substitute materials whenever possible. As a binder, Portland cement contributes towards high concrete strength, but other binders could be used in constructions with lower structural strength demands. Both air lime – together with pozzolanic additives – and hydraulic lime were used successfully for construction purposes throughout the ages, with an adequate performance and in some cases, a great durability.

Portugal has two cement production companies and high per capita cement consumption, partially due to investment in new-build versus rehabilitation. However, hydraulic lime (NHL5) is also produced, but there is no tradition in its use and it has been particularly applied in the still small market of building conservation practice. The use of hydraulic lime as a binder in concrete is a possibility, especially in applications where there is a need for a moderate versus high mechanical strength, although this characteristic may be enhanced by the use of pozzolanic materials, currently regarded as a valid possibility in an attempt to produce binders with lower CO_2 emissions. These materials are characterized by the ability to react with lime (calcium hydroxide) in the presence of water, forming calcium silicate hydrates.

Pozzolanic materials, of natural or artificial origin, must contain a high percentage of amorphous silica and a high specific surface in order to generate a pozzolanic reaction. Currently, the re-use of waste materials with pozzolanic properties is a growing reality as cementitious materials are widely applied and provide a suitable application possibility with evident advantages (mitigation of AAR, increase in mechanical strength, among others). Among these, products deriving from clay calcination, such as metakaolin, are starting to be applied in Portugal. The residue of expanded clay production used in this study is a similar product, resulting from clay calcinations at temperatures surrounding 1200 °C. Collected as a fine powder, or grinded, this material is a strong possibility for use in concrete and mortars. Added environmental value is given by the use of waste products or pozzolanic materials that create less environmental impacts, by lower calcinations temperatures and/or

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lower energy consumption, among others. The expanded clay residue used for this study derived from industrial waste.

2. Characterization of expanded clay residue

Obtained during the process of expanded clay production, this residue is a fine material with the same composition as expanded clay. It was characterized by X-ray diffraction (XRD), using a Philips X'Pert PW 3040/60 using Cu Kα radiation, with operational conditions of 30 mA and 50 kV, and speed registry 1°/2θ/min, with data acquisition by Philips X'Perta Data Collector v1.2., in terms of mineral composition and by X-ray fluorescence (XRF) using a Philips PW 1400 X-ray Fluorescence Spectrometer for the determination of chemical composition.

Expanded clay residue, ECR, is mainly composed of quartz (Q), spinel (SP), calcite (C) and feldspars (A, E). It has a small but evident band ranging from 20° to 30°, indicating the presence of amorphous material (Fig. 1). Silicates and aluminates are predominant in terms of chemical composition (Table 1) that also indicates the presence of iron, calcium and basic elements (sodium and potassium) in small quantities.

Expanded clay residue is a very fine material, with a specific surface of 9100 cm^2/g and it was sieved in order to ensure a maximum particle size of 75 μm, enhancing pozzolanic reactivity. This characteristic was measured following NP EN 196-5: Methods of testing cement. Pozzolanicity test for pozzolanic cement. Although this testing procedure is intended for application to pozzolanic cements, it has proven adequate for the measurement of the pozzolanic reactivity of pozzolanic materials as it measures $Ca(OH)_2$ consumption in a solution with a standard quantity of cement and pozzolan. When applied to the expanded clay residue, this testing procedure classified the material as an active pozzolan.

3. Materials and methodology

3.1. Materials

All the materials used in this study were commonly available in the central region of Portugal. The binder used was hydraulic lime (NHL5) that is currently the only hydraulic lime produced in Portugal. Additionally, its compressive strength of 5 MPa at the age of 28 days is sufficient to be improved by the addition of a pozzolan, allowing the achievement of concrete with strength in the range 15–20 MPa at age 90 days. Concrete with this strength could be used in low demanding structural applications such as urban equipment, cycling roads, blocks, among others.

Aggregates used in this study were natural siliceous sand and calcareous coarse aggregate. Coarse aggregates were divided into two groups; one in the range 5–10 mm (CA1) and the other in the range 10–25 mm (CA2).

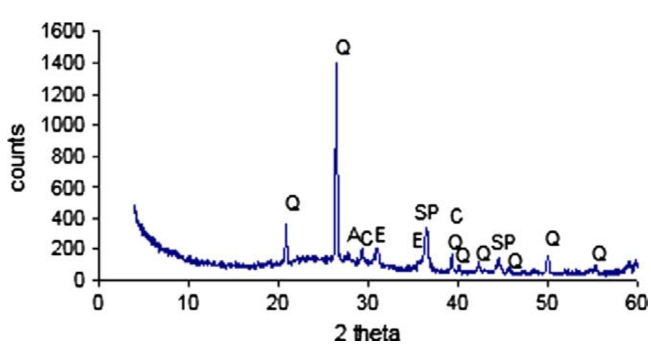

Fig. 1. XRD of expanded clay residue.

3.2. Concrete composition

Concrete composition was studied using a modified Faury method that takes into account the differences between cement (that served as basis of the method) and hydraulic lime. Aggregates were used in a saturated condition. The water/cement ratio was 0.45. Hydraulic lime was replaced by 20% (composition M2) and 30% (composition M3) of expanded clay residue, by weight. Grading of aggregates is presented in Fig. 2 that also shows the resulting final grading curve. The final mix proportions for all types of studied eco-concrete are shown in Table 2 including hydraulic-lime percentage in the binder (p).

3.3. Methodology

The developed experimental program was designed to assess the effect of ECR addition to hydraulic-lime concrete and its behaviour under different curing conditions. Three different curing conditions at atmospheric pressure were used where the relative humidity, RH, of the environment was changed. Concrete specimens were cured immersed in water, at 95% RH and at 65% RH. The temperature was kept constant at 20 °C.

Fresh properties of concrete such as density and workability were measured. Workability of fresh concrete was measured using

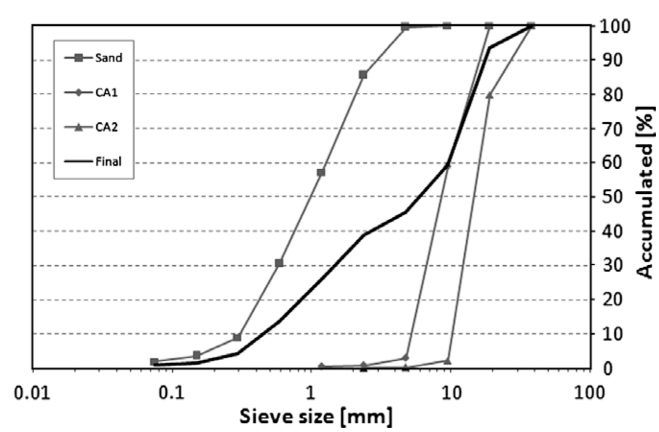

Fig. 2. Aggregate grading curves.

Table 2
Mixture composition including hydraulic-lime percentage in the binder (p)

Name	Constituents (kg/m^3)						p (%)
	CA1	CA2	Sand	NHL5	ECR	Water	
M0	619	455	321	550	–	247.5	100
M2	619	455	321	440	110	247.5	80
M3	619	455	321	385	165	247.5	70

Table 1
Chemical composition of expanded clay residue

Oxides	CaO	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	TiO_2	P_2O_5	MnO	LOI
Percentage in weight	3.92	56.52	19.50	8.05	4.58	3.97	0.33	0.95	0.18	0.14	0.70