Eco-concrete: preliminary studies for concretes based on hydraulic lime

A. Velosa[1] & P. Cachim[2]
[1]*Department of Civil Engineering, University of Aveiro, Portugal*
[2]*LABEST & Department of Civil Engineering, University of Aveiro, Portugal*

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. Furhermore, in order to increase mechanical strength, particularly at early ages, 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, water/cement ratio and conditioning were carried out. Concrete specimens were tested for mechanical strength at various ages. This paper presents the results of this initial testing campaign, concluding on the feasibility of the use of hydraulic lime for concrete production and potential applications, as well as the influence of curing conditions on the strength development of this material.

1 INTRODUCTION

Cement industry is one of the most pollutant industrial sectors worldwide, ranking as the third largest carbon emitting industry in the EU (Rehan, 2005, Szábó, 2006). It is estimated that each tonne of cement produces approximately one tonne of CO_2, mainly from the burning of fossil fuels and from the de-carbonation of limestone (Rehan, 2005) Due to the Kyoto protocol and growing environmental awareness, various measures concerning reduction in CO_2 emission are under study, ranging form process improvement, use of different raw-materials and alternative fuels (Gäbel, 2005, Rehan, 2005, Szábó, 2006). A valid possibility is the use of pozzolanic materials (Gartner, 2004) either with the traditional cement binder or with other binders such as air lime or hydraulic lime, which are themselves less pollutant than cement. These materials have been used in structural concrete since Roman times, attaining great durability, evident in buildings such as the Pantheon in Rome.

Pozzolanic materials are characterized by the ability to react with lime (calcium hydroxide) in the presence of water, forming calcium silicate hydrates. These materials, of natural or artificial origin, must contain a high percentage of amorphous silica and a high specific surface in order to generate a pozolanic reaction. Currently, the re-use of waste materials with pozolanic 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). Amongst these, products deriving from clay calcination, such as metakaolin, are starting to e applied in Portugal. The residue of expanded clay production used in this study is a similar product, resulting from clay calcinations at temperatures surrounding 1200ºC. Collected as a fine powder, or grinded, this material is a strong possibility for use in concrete ad mortars.

Portland cement is the usual binder for concretes, due to its deeply studied performance and achieved resistance. However, high resistance concrete is unnecessary for some applications and in this field other, less pollutant binders, such as hydraulic lime may be used. Hydraulic lime production decreases CO_2 emissions in 82% compared with cement production (Portland Cement Association). In order to increase mechanical resistance of hydraulic lime concretes, pozzolanic additives may be used.

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) in terms of mineral composition and by X-Ray Fluorescence (XRF) for the determination of chemical composition.

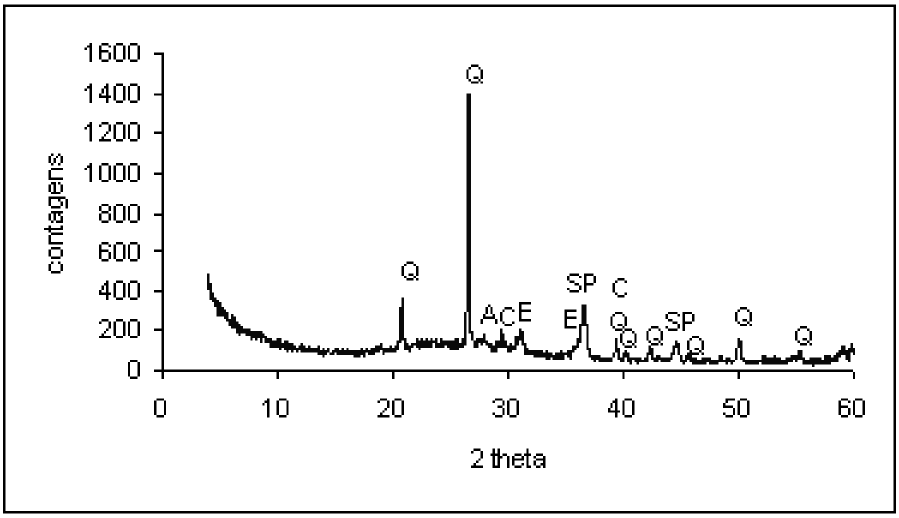

Figure 1 – XRD of expanded clay residue.

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 20º to 30º, indicating the presence of amorphous material (Figure 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).

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	L.O.I.
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

3 METHODOLOGY

Aggregates used in this study were natural sand and calcareous coarse aggregate. Hydraulic lime was NHL 5.

Table 2. Mixture composition.

Name	Constituents [kg/m^3]					
	Agg. 10-25	Agg. 5-10	Sand	NHL 5	ECR	Water
M0	381.5	945.6	67.3	550	-	247.5
M2		945.6	67.3	440	110	247.5
M3		945.6	67.3	385	165	247.5

The developed experimental program was designed to assess the effect of the addition of expanded clay residue on the mechanical strength of hydraulic lime concrete. Hydraulic lime was replaced by 20 and 30 % of expanded clay residue, by weight. The results were compared with a reference mixture containing only hydraulic lime. Table 2 summarises the three different compositions. Water/cement ratio was 0.45. Different curing conditions were used where the relative humidity, RH, of the environment was changed. Concrete specimens were cured immersed in water, at 90 % RH and at 60 % RH. The temperature was kept constant at 20 ºC.

Compressive tests on 15 cm cubes were performed at 7, 28 and 90 days according NP EN 12390-3:2003 standard. Additionally, workability of fresh concrete was measured using the slump test (NP EN 12350-2:2002).

4 RESULTS AND DISCUSSION

Slump results are all in the range 0.5 to 1.5 cm that indicates a rather small workability of concrete. Since the aim of this study was the investigation of the effect of expanded clay residue and of curing conditions, this lack of workability wasn't considered a very important issue at this stage. Nevertheless, this is an important aspect that must be accounted for in the subsequent development of the study that can probably be solved by addition of a plasticizer.

The effect of the curing conditions on the compressive strength of limecrete can be observed in Figures 2 to 3. It is apparent from the figures that reference limecrete, mixture M0, has higher strength if cured at normal conditions (20 ºC and 60 % RH) than in a saturated environment.

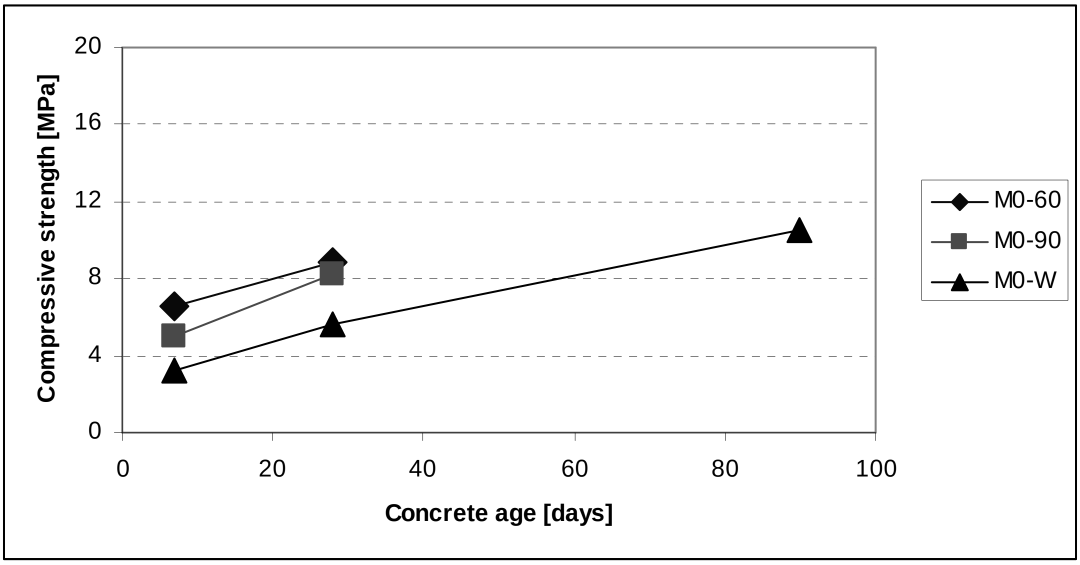

Figure 2. Compressive strength in different curing conditions for mixture M0.

The presence of expanded clay residue (Figures 3 and 4) reverses the situation. For mixture M3 the effect of curing conditions is quite apparent, especially between 28 and 90 days, where a 60 % increase in strength can be observed if specimens are cured in a saturated environment. The results observed for mixture M2 show transition behaviour between mixtures M0 and M3, as can be easily seen in Figure 5. Thus, it seems clear that when expanded clay residue is used, curing in saturated conditions is better.

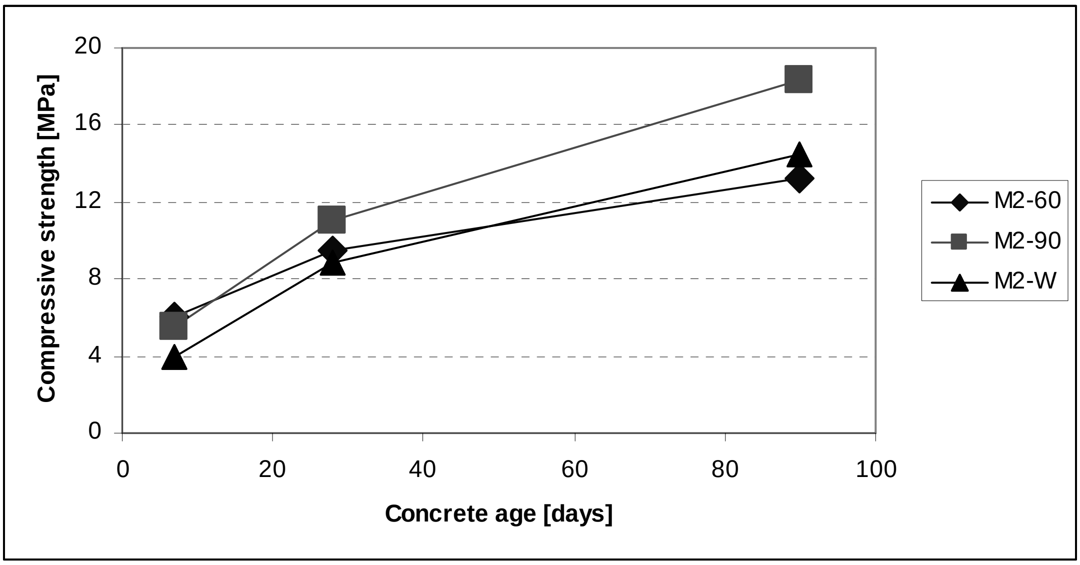

Figure 4. Compressive strength at different curing conditions for mixture M3.

The addition of expanded clay residue only has a beneficial effect on strength at 90 days and in saturated curing conditions or under water.

Figure 5 shows results of mortars cured in different curing conditions at age 28 days. Although this is too early to asses the influence of the addition of pozzolans, the behaviour of hydraulic lime concrete with expanded clay residue is slightly improved in saturated conditions or under water.

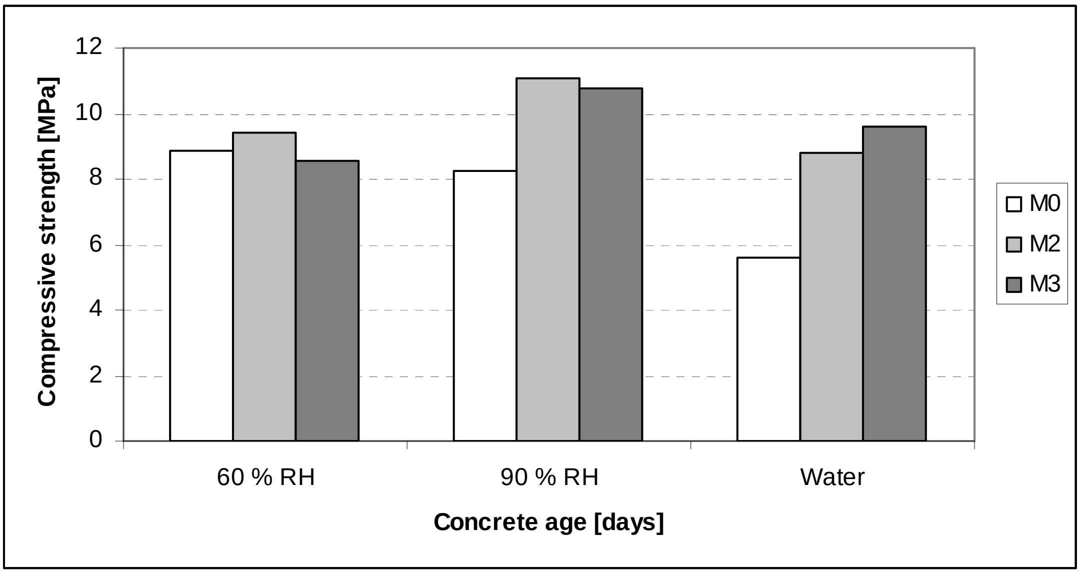

Figure 5. Compressive strength at 28 days.

These results show that the influence of curing conditions at early ages is small but becomes evident at age 90 days. Additionally, concretes with expanded clay residue perform better in saturated curing conditions or under water. This may be explained by water demand of the pozzolanic reaction, which is slower than hydraulic reaction but will only take place in the presence of available water. This slower reaction will only produce visible results at later ages, accounting for the differences between results of concretes stored in saturated conditions or under water at age 90 days.

5 CONCLUSIONS

Expanded clay residue is a suitable material for application in concrete with hydraulic lime binder as a pozzolanic addition. A substitution of hydraulic lime by 20% and 30% expanded clay residue produced increased compressive strength at adequate curing conditions, especially in the latter case.

As results indicate, curing conditions produce significant changes in mechanical strength, but not at early ages, due to the development of chemical reactions in time. Daily variations of environmental conditions, reaching peaks of over 90% relative humidity, favour pozzolanic reaction and the addition of pozzolans to hydraulic lime.

The use of these materials contributes towards the production of sustainable concrete. However, these are preliminary studies and further studies need to be conducted towards the improvement of workability (using less water and introducing plasticizer) and characterisation of hydraulic lime with pozzolan behaviour at latter ages, aiming towards definition of usage possibilities in construction.

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