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Estimated and real durability of unfired clay bricks: Determining factors and representativeness of the laboratory tests

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HIGHLIGHTS

- Mechanical resistance depends on the type of the additive but not on the sand content.
- Capillarity absorption test is not appropriated to estimate earth based construction materials real durability.
- The total water absorbed test is suitable as earth based construction materials durability estimator.
- The freeze/thawing cycles test as it is defined in the Spanish Standards is not a good durability estimator.
- PC-8+GGBS additive obtained the best laboratory and real durability results.

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ABSTRACT

This paper presents an analysis of the representativeness of the main laboratory tests and the real durability of earth-based construction materials. For this study, a natural marl soil, mixed with different percentages of silica sand, was treated with portland cement, hydraulic lime, a mix of lime and ground granulated blastfurnace slag and other binder composed of a high magnesium oxide waste mixed with ground granulated blastfurnace slag. All the combinations were characterized based on the usual durability related laboratory tests as are: maximum density, unconfined compressive strength, wetting and drying, Swinburne accelerated erosion resistance, capillarity water absorption, total water absorption and freeze/thawing cycles. The results of these tests have been related to the real durability of the samples for eighteen months of outdoor exposure. They revealed the positive effect of sand adding in the materials durability and the great result of the binder based on magnesium oxide with ground granulated blastfurnace slag. It was also demonstrated the representativeness of the water absorption test as a durability indicator of earth based construction materials durability.

1. Introduction

Building construction with earth based construction materials (EBCM) is a worldwide technique from more than 9000 years ago, and currently is still used in most of the developing countries. These materials success are based on the easy availability of raw materials, their simplicity execution, their good thermal and acoustic properties and their economy [14,16].

In developed countries, this traditional construction system was virtually abandoned since the beginning of the 20th century in favor of more modern materials when, technological advances and economic capacity, generalized the use, for example, of concrete or fired bricks respectively. However, since the beginning of the 21st century, increasing interests on the recovery of EBCMs has been noticed also in developed countries. This is due, among other reasons, to their reduced carbon footprint, low embedded energy, the ability to be produced from wastes and by products, their good technical properties and their healthiness for the users of the buildings made of them [3,5,8,10–12,18,20]. Despite all these advantages, EBCMs have the drawback of high water affinity, which causes the resistant properties deterioration and could affect their durability [1,4,14,15,21]. These undesirable effects have been traditionally solved by using cementitious additives, by a high compacting energy, by the soil granulometry modification and by the isolation of these materials from the water. The use of

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cementitious additives, is an effective and economical way to improve the material engineering properties, due to the cementitious gels formation which develop a resistant matrix around the soil particles. This increases the treated soil density, improving contact between particles, thus increasing its mechanical properties [12,15]. In addition the cementitious additives used, improves the clay soils workability by decreasing their plasticity [19,7] and decreases the water movement capacity, improving its durability [2,9,13]. The use of a high energy compaction in manufacturing improves the contact between particles, increases the material density and reduces the size and number of pores. This improves the particle mechanical properties and contributes to make them less susceptible to the water effects [4].

Related to the granulometry modification convenience, an experts agreement hasn't been reached: many authors consider that the sand addition to soils with which these materials are made, allows to improve their properties since it increases the product density and decreases the amount and size of the mix pores, which could be an indirect indicator of good mechanical properties and durability. In this sense, different manuals and published studies recommend the use of different proportions sand to clay. For example, Muntohar [12] stated the optimum proportion soil to sand was 70 to 30% to get the higher compressive strength, higher density and lower permeability in a stabilized soil. Ciancio and Walker [3] tested ten soil mixes for the stabilized with cement and not stabilized rammed earth construction. In these mixes the clay and sand contents were 5–40% and 20–60% respectively. They found that six of the mixes were adequate for this purpose based on unconfined compressive strength, accelerated and drying shrinkage tests. The four mixes were not suitable were those with the highest clay content. On the other hand, some authors working with pure clay soils achieved materials with high mechanical properties and durability. Oti et al. [14] and Oti and Kinuthia [17] stabilized pure Lower Oxford Clay soils with Portland cement and lime plus Ground Granulated Blastfurnace Slag (GGBS). They obtained unconfined compressive strength values above 5 MPa and a highest weight loss at the end of 100 freezing-thawing cycles of 1.9%. This shows the complexity of the interpretation of the effect of the sand to clay content in the stabilization of a soil, and the difficulty of results extrapolation from one study to another. Anyway, it has been stated that sand addition allows a better soil workability and the swelling and shrinkage reduction when very plastic soils are used [3]. Finally, in EBCMs manufacturing it is important to consider the possibility to use products such as plasters or water repellents that avoid, together with the proper selection of the type and amount of cementious additive, compaction energy and the soil particle size, the water to enter in the material.

Although there is no consensus in this regard, the relationship density-resistance-durability is often considered for the composition design and the selection of the EBCMs manufacturing parameters. This is why the technical characterization of these materials is based on tests of mechanical strength and water related properties, from which their durability is estimated. This way of durability estimation, commonly used in conventional building materials, has shown to be unreliable in the EBCM case, underestimating it many times, when compared with these materials real durability [6].

This work, aimed at an audience both scientific and technical, presents an experimental study which analyzes systematically the effect of main EBCMs manufacturing parameters affecting the durability, comparing the laboratory results with those which have been obtained under outside use conditions to establish the reliability of different laboratory tests to predict the real durability of an EBCM.

2. Materials

2.1. Soil

The soil used in this study was a sample of grey marl from the region of Pamplona, Northern Spain. This is a soft gray-colored rock, without defined stratification. Marl is a low load-bearing capacity soil, which greatly limits its use as construction material. In order to carry out this experiment, one tonne of natural marl was extracted, and after homogenization of the sample, it was crushed to a maximum particle size of 2 mm. The sample was characterized by determining its Atterberg limits following standards UNE 7378 and 103103, obtaining LL = 25.72% and PL = 18.05. Based on Casagrande Classification, this soil belongs to class CL, low-plasticity clayey silts. Chemical XRD analysis of this sample gave a mineralogical composition of 51% calcite, 20% illite, 15% quartz, 5% kaolinite, 5% attapulgite and 4% ankerite.

2.2. Sand

In this study a commercial silicon sand for mortars was used. This sand was obtained from the crushing of siliceous natural rocks. Fig. 1 shows the its grading curve.

2.3. Portland cement (PC)

Portland cement used in this study was manufactured in accordance with the European Standard EN 197–1, marketed under the trade name of CEM II B-M VL 52.5 N. Table 1 shows its composition as well as the other additives considered in this experiment, expressed as their most important oxides, based on XRF analysis.

2.4. Limes

Two different types of lime were used in this study: A Natural Hydraulic Lime (NHL-5), obtained from burned non-pure limestone and manufactured in accordance with the European Standard EN 459–1. This Lime has hydraulic properties due to the presence of Aluminum and Silicon oxides as well as Calcium oxide. Also a calcareous hydrated lime (CL-90-S) was used in the study, obtained from burned pure limestone and manufactured in accordance with the European Standard EN 459–1.

2.5. PC-8

This material is a byproduct rich in Mg, obtained during the calcined magnesite production by means of the calcination of natural $MgCO_3$ rocks up to 1100 °C. This process is carried out in a rotatory

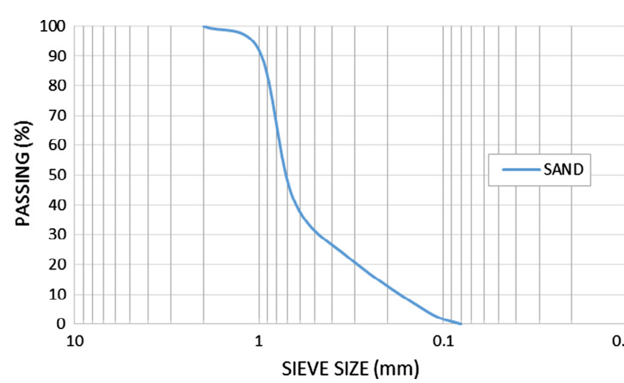

Fig. 1. Granulometric curve of the used sand.