The influence of ambient conditions into rammed earth compressive strength

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ABSTRACT: Nowadays, there are several research lines regarding how to improve rammed earth properties. Due to the lack of regulation for this material in Spain, the standard used as reference is related to fresh concrete. However, concrete and earth are completely different building materials. This paper presents the results obtained in earth samples that have been manufactured with the same percentage of initial water but they were hygroscopically stabilized at different relative humidities. Moreover, two types of rammed earth were studied using (1) lime water and (2) only water. The aim of this research is to evaluate how ambient conditions can influence compressive strength results of these two types of rammed earth.

1 INTRODUCTION

1.1 Justification

Traditionally, earth was used as building material for centuries in the Iberian Peninsula (Mileto et al. 2014). Lately, this practice was replaced by new and modern materials (as concrete, steel, clay bricks, etc.) and people began to consider earth buildings as a synonymous of poverty and low social status. However, most of the Iberian building heritage is constructed with earth that still need advances in research for conservation, rehabilitation and restoration.

From the construction point of view, one of the most relevant topics that arises earth constructions is its resistance. The maximum distributed load that can be withstood by an earth element depends on several factors as the constructive technique used, the properties of the material, the improvements made by the incorporation of stabilizers or additives, the method of preparation and compaction, among others. For this reason, compressive strength of earth elements with structural function must be known for both, rehabilitation and new structures purposes (Bestraten et al. 2012, Miccoli et al. 2014).

construction techniques (modified Proctor test uses compaction energy too high).

After the hygroscopic stabilization of the samples, the second step is to determine simple compressive strength (UNE 103400: 1993) and the real (initial and final) humidity of samples (UNE 103300: 1993).

2.3 Manufacture of samples

Once the particle size distribution and the optimum humidity were defined, 35 samples of rammed earth with the same composition and the same percentage of water (in vol.) were made (Fig. 1). The 35 samples were tested following the Standard Proctor test. This test is an easily reproducible method that guarantees the maximum density of the soil. Samples have cylindrical shape with dimensions of $\varnothing 101.5 \text{ mm} \times 116.0 \text{ mm}$ height.

Following this methodology, 20 rammed earth samples were made adding water and 15 samples adding lime water. The lime added into water corresponds to a calcium hydroxide with a concentration of 1.7 g/l. This concentration is remarkably lower than the concentration generally used to stabilize rammed earth with lime. Ranges of 5 to 8 wt% of lime in relation with the mass of earth are usually employed in stabilization. In our case the introduced lime corresponds to 0.02 wt% of the earth weight.

Immediately after the manufacturing of process of each sample, they were kept in the climatic chamber till the hygroscopic stability is achieved (Fig. 2).

Figure 1. Samples composition scheme. Left: only water, Right: lime water.

Figure 2. Rammed earth samples in the climatic chamber.

2.4 Hygroscopic stability

The ambient conditions where the samples were kept until their hygroscopic stabilization corresponds to an air temperature of $20 \pm 5^\circ\text{C}$ with 4 different relative humidities (RH):

- Environment "A": 30% RH
- Environment "B": 50% RH
- Environment "C": 85% RH
- Environment "D": 100% RH

In one hand, 5 samples produced with water were stabilised into each relative humidity (A: 30%, B: 50%, C: 85% and D: 100%). On the other hand, 5 samples produced adding lime water were stabilised in two environments (B: 50% and D: 100%).

The time that takes the stabilization of samples fluctuated according to the relative humidity of the environment where they are exposed. The hygroscopic stabilisation is considered to have finished once the weight variation is 0.1% or less.

Samples were made adding 7% of water (in vol.), obtaining an apparent average Proctor density of: $2.30 \pm 0.01 \text{ g/cm}^3$ for the samples made with water and $2.31 \pm 0.01 \text{ g/cm}^3$ for the samples made with lime water.

3 RESULTS

3.1 Earth characterization

The soil used for the experimentation corresponds to a clayey cohesive soil with medium plasticity.

The soil contains 28% of clay and silt (particle size less than 0.063 mm) with a liquid limit of 36% and a plastic limit of 24%. In addition, a comparative study has been carried out in order to test the plastic behaviour of the clays in relation to the type of water added (water or lime water). Figure 4 shows the variation that occurs when we replace the kneading water with lime water.

The plasticity index of clays mixed with water is 11.94. However, this value strongly decreases when adding lime water (1.92). This variation will condition the water required by the samples produced using lime water, which will be higher so as to achieve plastic workability.

Figure 3. Particle size distribution.

Figure 4. Variation of clay plasticity.

Figure 5. Compressive strength test.

3.2 Compressive strength test

After the hygroscopic stabilisation, standardised compressive strength tests were performed (UNE 103400: 1993) (Fig. 5).

Figure 6 shows the results obtained in all samples tested and Figure 7 compares the average values of the samples (made with only water and lime water, under each relative humidity) as well as the final average densities. It can be seen that behaviours can be classified in three different zones as follows:

Zone A corresponds to the values obtained in samples made with water and stabilised in 30% RH and 50% RH. The average compressive strength is $1.43 \pm 0.3 \text{ N/mm}^2$. The apparent average density of samples once stabilized in both RH is lower ($2.15 \pm 0.1 \text{ g/cm}^3$) and has decreased by $7 \pm 1\%$ if results are compared with Proctor density results ($2.30 \pm 0.01 \text{ g/cm}^3$).

Zone B corresponds to the values obtained in samples made with water and stabilised in 85% RH, and samples made with lime water and stabilized in 50% RH. It can be noticed that the values of compressive strength obtained are $0.78 \pm 0.05 \text{ N/mm}^2$, that means that compressive strength is halved if results are compared to Zone A. The density of these specimens ($2.17 \pm 0.01 \text{ g/cm}^3$) are very close to the densities obtained in Zone A samples, but still lower than the specimens themselves before being tested.

Figure 6. Stress vs strain of all samples.

Figure 7. Average stress vs strain of samples.

Zone C corresponds to the values obtained in samples stabilized in the environment at 100% RH, for both water and lime water types. Compressive strength value obtained is $0.1 \pm 0.1 \text{ N/mm}^2$. Compressive strength of samples in zone C is reduced to 1/12 of compressive strength obtained in water samples stabilised in 35% and 50% RH. Apparent average density of samples in zone C is very close to density proctor ($2.29 \pm 0.02 \text{ g/cm}^3$).

4 CONCLUSIONS

Results clearly showed a direct relation between the environmental conditions (relative humidity) where the samples were cured and their compressive strength. Moreover, apparent density was also affected by environmental conditions if results are compared to the initial Proctor apparent density. This parameter control is not new in building materials. For example, standards of wood, plasters and even natural stone takes into account this parameter during the manufacturing process of samples (UNE-EN 408: 2003, UNE-EN 14146: 2004 and UNE-EN 102042: 2013).

For this reason, authors consider extremely important to let know the initial humidity content of samples and also the relative humidity of the environment where samples are placed during the curing process. These two parameters will condition the final values of apparent density due to the hygroscopic behaviour of earth and, therefore, compressive strength.

Compressive strength results of the same sample composition vary more than 900% between dry environment (35 to 50% RH) and very humid environment (100% RH). Variation between 200% and 400% were observed between dry environment and humid environment (85% RH). Therefore, authors highly recommend relative humidities below 50% so as to hygroscopically stabilise rammed earth samples and also to achieve the best compressive strength results.

It is also important to remark that when relative humidity is close to 100%, compressive strength strongly decreases (between 0.4–0.5 N/mm²), therefore, this materials will be not able to be used as a building material.

Finally, authors have been able to verify that the behaviour of water samples and lime water samples is very different although they were placed in the same environmental conditions: lime water earth samples achieved lower compressive strength values than water earth samples when they were stabilized in high relative humidity conditions.

Samples made with lime water (pH 12) archived lower values of compressive strength than samples prepared with water (pH 7). This can be explained by the reduction in the plasticity index of the clay fraction induced by the alkaline pH. In these conditions the clay acts as a mud. The amount of lime used in this work is 4000 times lower than the lime used to stabilize rammed earth.

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