Sugar components as a natural reinforcement of earth based construction materials

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ABSTRACT: An important part of the world's population, approximately 3 billion people, on six continents, lives or works in buildings constructed of earth based materials. A research work developed in the Trás-os-Montes e Alto Douro University (UTAD) and focused on the biomimetic study of the *Andorinha-dos-beirais* bird nest concluded that there is a strong possibility that this bird adds a significant amount of glucose type sugar into the clay material during the building process of its nest. Results from the numerical model of the nest indicated that this natural structural system works mainly in compression, which is in line with inherent properties of earth based materials, with reduced tensile and shear capacity. Experimental tests have shown that an agglutination phenomenon may occur resulting from the building process adopted by the *Andorinha-dos-beirais* bird. Based on these conclusions, this research work intends to analyse the influence of the glucose sugar type addition into the nest structural performance. In this context, compression tests were done varying the liquid phase, sugar percentage and curing period. Experimental results can be used to sustain the use of this technique in the context of earth buildings construction and can contribute for the future proposal and development of new raw building composite materials.

1 INTRODUCTION

The search for sustainable building materials and solutions which have associated a reduced amount of CO_2 emissions and energy consumption and, consequently, are environmental friendly is extremely important in what regards the building industry contribution for climate change issues (Murta et al, 2009[1]; Murta et al, 2009[2]).

Half of the world's population approximately, 3 billion people on six continents, lives in buildings made from earth (www.eartharchitecture.org/). In the third world countries almost half of the existing buildings are made of earth (Minke, 2005). Earth construction represents an important worldwide heritage, reflecting the existing cultural diversity of the humanity (Carvalho et al, 2008). Examples of ancient earth constructions are: the China Wall (2000 B.C.) (www.greatwallchina.info) and the Arge Bam city in Iran (500 B.C.) (www.flickr.com/photos/negaheno/). This impressive earth heritage also reveal that earth construction can have a very sustained durability. At the same time, cutting edge modern earth constructions, such as: the Adobe Repository for Buda Statue in Japan (2001 A.D.) (www.eartharchitecture.org/) and the Desert Cultural Centre in Canada (2006 A.D.) (www.canadianarchitect.com/), prove that earth based building materials are nowadays in increasing demand. Earth has been used in recent years in the construction of dams in many countries (Zhang et al, 2008).

Redefining educational curricula to address sustainability issues is something that must occur at all levels of formal education (Tamoutseli, 2008), particularly in what regards the construction mega-sector. Earth based building materials are sustainable, in one hand because earth is natural, recyclable and abundant anywhere in the world, and in the other hand because the

techniques used to manufacture these materials are usually simple, requiring an unexpressive amount of energy consumption and also having an unexpressive amount of CO_2 emissions associated. The building materials and the building techniques related to earth construction have been developed continuously. As example, can be stated the emerging *quincha metálica* technique (Cortés, 2009) which replaces a traditional timber internal structural system by a metallic structure, keeping the traditional earth plaster covering of the wall system.

The most popular traditional Portuguese building techniques that use raw earth as a building material are *taipa*, *adobe* and *tabique*.

The main objective of this research work is to study the influence of sugar addition on the earth, as a natural reinforcement, in the performance enhancement of earth based construction materials and products. Therefore, contributing for the development of a new sustainable building technique. The sugar component can be obtained from several plants and fruits, that if adequately planned do not interfere with the world food supply.

2 BACKGROUND

A biomimetic study of the *andorinha-dos-beirais* bird nest (Silva et al, 2009[1]; Silva et al, 2009[2]) has concluded that there is a strong possibility that this bird adds a certain amount of glucose into the clay material during the building process of the nest. This component may change the properties of the earth-based material, increasing the performance of this raw material. This study included: the identification of the elementary chemical and mineralogical compositions of the material samples by the scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) and by the X-ray diffraction analysis, respectively; the identification/characterization of the organic composition by using the colorimetric method, for which the protein components were detected by the biuret method and the polysaccharides/sugars components by the total sugar method. The type of polysaccharides/sugars identification and their amount quantification was done by the anion-exchange chromatography method.

3 LABORATORY RESEARCH DESIGN

The aim of the laboratory program related to this research work was to understand the potential effect of sugar on the compression strength capacity of a clayey soil. The reason for choosing a clay for this experiment was based on previous research (Silva et al, 2009[2]) which reports that clay is the main material used by the bird for its nest building.

This probably is related not only with the fact that its smaller particle size, when compared to sand particles, makes it easier to be carried during nest construction, but also due to the more stable chemical composition of sand particles, making it immune to combinations with sugar components. A very common type of clay used in soil related laboratory research was used – *china* clay.

The sugar added in the mixtures was current commercial sugar type. The use of a common type of sugar is economically justified, since its low cost will allow the use at a large scale for earth construction. Sugar crystals are orderly arrangements of sucrose molecules, which in turn are composed of carbon, hydrogen and oxygen (French et al, 2004). When the sugar is added to water, it goes into solution, but only up to a certain amount of sugar can be added to the solution for a given temperature. Sucrose can also be seen as a combination of two simpler sugars: fructose and glucose. Hydrolyze of sucrose in neutral environment (pH = 7) will result in the separation of these two components [1]:

$$C_{12}H_{22}O_{11} + H_2O \Rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$$
$$\text{(sucrose) + (water) => (glucose) + (fructose)} \qquad [1]$$

While hydrolyze in acid environment (pH < 7) will result in two molecules of glucose, [2]:

$$C_{12}H_{22}O_{11} + H_2O \Rightarrow 2\ C_6H_{12}O_6$$
$$\text{(sucrose) + (water) => 2 (glucose)} \qquad [2]$$

Since rain has a pH between 5.6 and 5.7 in non-polluted atmosphere, it is fair to consider that hydrolyze during nest construction will take place in acid environment, meaning that glucose is the component responsible for the reaction. Samples with 0%, 2%, 6% and 10% sugar in weight of the total mixture were prepared (Table 1).

After consideration regarding the percentages of each component in the mixtures – specifically soil, sugar and water – it was decided to keep the water / (soil + sugar) at a constant value of 15%. The 15% value was obtained after some trial mixtures, intended precisely to estimate the water needed for mixture homogenization.

The other possibility considered and tested was to keep the water / soil ratio at a constant value when sugar percentage was modified, but it was declined since the variation in sugar would also modify significantly the viscosity of the solution.

The small increase in water / soil ratio of 1.9% between the 2% and 10% sugar content (Table 1) was necessary to compensate for the increase in the liquid phase viscosity. Otherwise the mixing process was significantly ineffective, making practically impossible to achieve an acceptable level of homogeneity.

The clay was previously dried for 48 hours before the mixing, to guarantee that the only water present in the mixture was the intended. The liquid and plastic limits of the used clay are 33.2% and 20.3% respectively, resulting in a plasticity index of 13%.

Sample size and shape was a 3 x 4.5 cm cylinder, to be tested for unconfined compression after 7, 14 and 28 days curing inside the molds. These curing periods were later altered, and a single curing period was used. This was due to the fact that the samples did not gain enough cohesion to be removed from the molds at the intended periods.

After the 28 days curing period passed without significant improvement in sample hardness, it was decided to leave the samples in the oven at 50ºC for 48 hours. The increase in temperature accelerated the hardening process, allowing the testing of the samples after 30 days curing.

Table 1. Mixture composition (in weight) for each sugar content.

	Sugar content			
	0%	2%	6%	10%
Soil	85%	83%	79%	75%
Water	15%	15%	15%	15%
Water / soil ratio	0.176	0.181	0.190	0.200
Sugar / water ratio	0	0.133	0.400	0.667
Sugar / soil ratio	0	0.024	0.076	0.133

Three samples, from one batch, were tested to produce a single result. The molds were filled and weighted to guarantee minimal variations in density between the three samples (Figure 1). Overall there was only a slight change in density, even with the variation in sugar content (Table 2).

a) clay b) water c) mixing d) filling e) weighting

Figure 1 – Fabrication of the samples.

Table 2. Average sample's weight for each sugar content.

Sugar content	0%	2%	6%	10%
Average weight	58.84 g	58.72 g	58.40 g	59.04 g

The unconfined compressive tests (UCS) were performed in the Materials and Soil Laboratory of University of Trás-os-Montes e Alto Douro (UTAD) using a 5 kN capacity hydraulic testing machine, at a strain rate of 0.30 mm/minute, Figure 2.

Figure 2: Compression test equipment.

4 RESULTS AND ANALYSIS

After being removed from the molds the samples revealed some voids in the volume (Figure 3), which increased with sugar content. This was particularly unexpected since the weight of the samples prior curing was similar (Section 3). Cracks (Figure 3, detail I), missing mass (Figure 3, detail II) and irregular top surfaces (Figure 3, detail III) were the main defects presented.

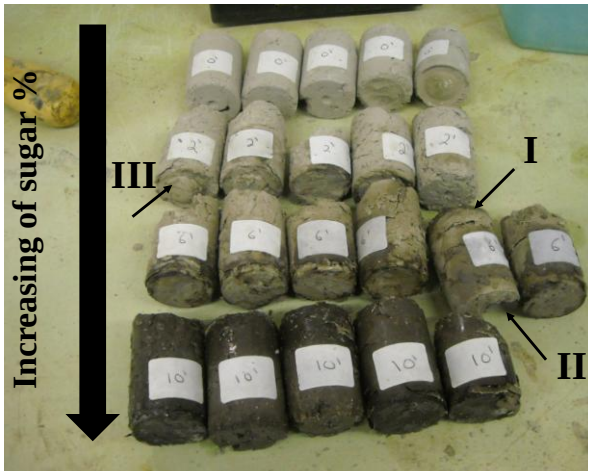

Figure 3. Samples prior to UCS testing.

Some samples were so badly altered in shape that they could not be tested. This was due to deficiencies of the molding process, resulting from the high plasticity of the mixtures with sugar.

This setback casts some doubts on the final strength results obtained, since the exact cross section area of the samples could not be determined, hence the area of a circle with a 3 cm diameter was considered. The samples were weighted prior to being tested, and the results were compared with the samples' weight determined at the very start of the curing process (Figure 4). It is clear that there was a decrease in density, most probably from the loss of water. Furthermore, these results also express that the adopted molding process was not the most convenient since there is no tendency in the results.

The results with the unconfined compression tests are shown in Figure 5. The fact that the compressive strength was higher for the samples with no sugar probably reflects the better conditions in which these samples were extracted from the mold. Meanwhile, there is also no tendency in these results due to the reasons mentioned above.

The fact that a higher temperature was used for the two last days of curing could also have some influence not only on the final shape of the samples but also on the compressive strength

levels. To address this situation lower percentages of sugar should be tested in order to improve the curing process and avoid the need to increase temperature.

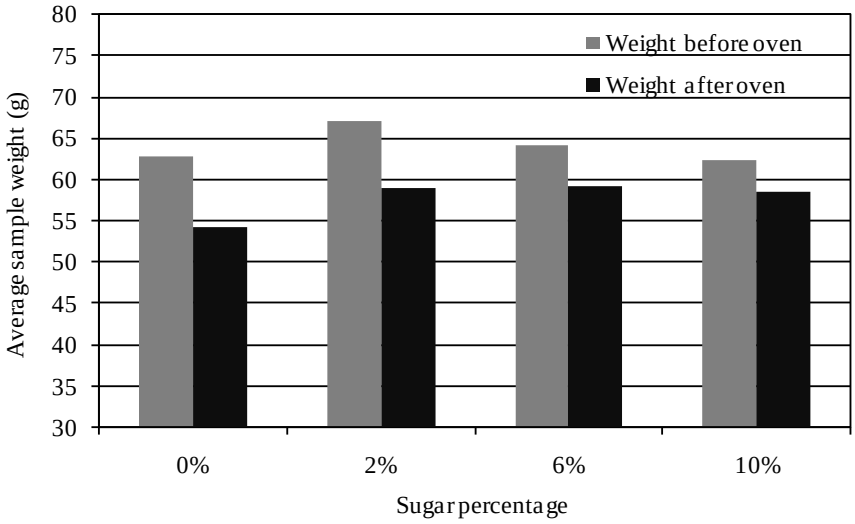

Figure 4. Average weight of the samples before and after oven.

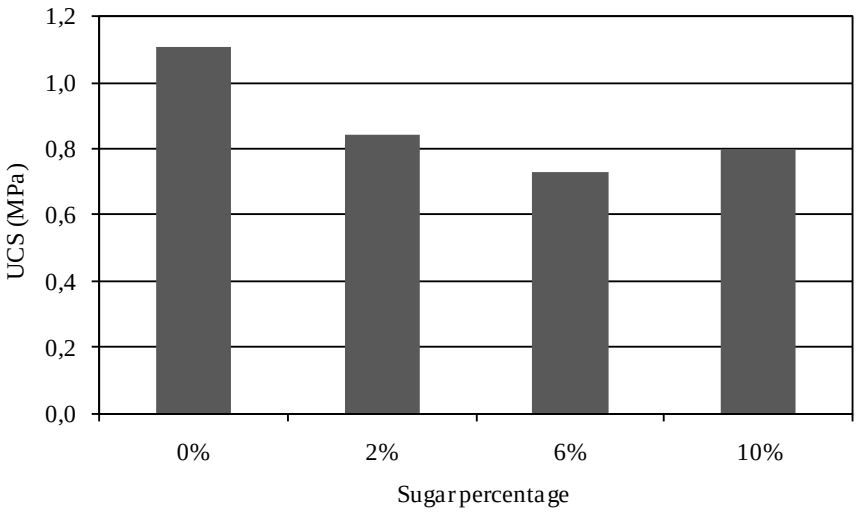

Figure 5. Unconfined compressive strength (UCS).

5 MAIN CONCLUSIONS

The work here presented was the first step in a thorough research program which is being held at UTAD University. Therefore, the options taken regarding the sample preparation and curing could not be based on any previous research ever reported. The conditions of the samples before testing revealed that some changes regarding their preparation are needed:

- Maximum sugar content should be lower. This will allow the mixtures to be prepared with the same water content (as referred in Section 3), which in turn will allow the use of just the necessary water for homogenization.
- Greater care is needed when filling the molds. A higher frequency table should prevent the samples from forming significant air voids in its volume, this way achieving uniform samples, which will influence both weight and strength results.
- The samples need to be removed from the molds for curing, so that its condition can be controlled.

- In future tests curing in the oven should be avoided, since it might had some influence on final shape and strength of the samples.

These proposed changes in the testing process are already being put in practice and new developments should help prove the suitability of this technique for earth construction. Chemical and SEM/EDS analysis were also designed to help understand the reactions behind the expected soil improvement.

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