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KRAFTTERRA COMPOSITE – PERFORMANCE ANALYSIS OF COMPRESSED EARTH BLOCKS WITH AND WITHOUT CELLULOSE PULP DERIVING FROM CEMENT SACKS RECYCLING

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Summary. *This study presents part of the results of an experimental campaign on the mechanical behaviour of Kraftterra composite. This research was developed as a framework of collaboration between the University of Brasilia, in Brazil, and the University of Aveiro, in Portugal. The objective of this study involves the development and the performance evaluation of compressed earthen blocks for the construction incorporating recycled cement sacks. Research's main goal is the hypothesis verification that the cellulose pulp that stem from cement sacks can be used to improve the characteristics, and particularly the mechanical properties, of the blocks with soil as raw material. This paper presents the Kraftterra mixture and production processes, as well as the performance analysis of compressed earth blocks – CEBs – produced with Kraftterra regarding the compressive strength.*

1 INTRODUCTION AND BACKGROUND

Tons of cement is used in civil construction in all countries of the world. The Cimento Organization [1], in Brazil, regularly publishes information regarding the world production of cement. They refer, for example, that based in information distributed by international cement associations (CEMBUREAU, the Representative Organisation of the Cement Industry in Europe; OFICIMEN, the Agrupación de Fabricantes de Cemento, in Spain; and, SNIC, the Sindicato Nacional da Indústria do Cimento, in Brazil), the world cement production was of 2,542 tons for the year of 2006.

In many countries, most of the cement sacks after used the cement are thrown out without any environmental treatment, causing an enormous negative environmental impact. However, as will be explained in this paper, the paper fibres of these sacks, Kraft paper, can be used for improving materials and reinforcing construction elements and components based on raw materials, diminishing the ecological impact with a proper recycling process.

The Kraft paper has excellent mechanical and physical properties. Its fabrication is oriented by strict specifications imposed by the cement industry and other users of multi-walled paper sacks. These specifications demand high strength long-fibre sulphate cellulose, which is mainly used in its pure form. For example, in Brazil the Kraft paper is made, mainly from bamboo, particularly from the *Bambusa vulgaris* specie [2]. After the cement is used, the Kraft paper sacks which have such good mechanical properties, normally, ends up not being accepted by the recycling industry, because the "contamination" with the cement. However, there is a great potential on its reuse for the production of new building composite material, namely the compressed earthen blocks.

The research presented in this paper attempts to seek for sustainable and efficient earthen block units for the production of construction components, recycling solid waste in civil construction industry. To make feasible and fruitful this recycling process, the application here developed and studied adopts the incorporation of cement sacks in the production of earthen blocks for earth architecture. Thus, the environmental impact caused by the actual trends in civil construction can be minimized, and in parallel new construction components and techniques are developed combining earth with Kraft paper, resulting in cheap, thermally and acoustically comfortable and safe constructions.

2 KRAFT PAPER RECYCLING AND KRAFTTERRA PRODUCTION PROCESSES

The production of the new composite material (see figure 1), called Kraftterra, initiates with the recycling process of cement sacks. At first, the long and entwined Kraft paper's fibres must be transformed into cellulose pulp. This process can be fulfilled throughout several techniques and with different tools and/or equipments. However, in the framework of the research in progress at FAU/UnB and DECivil/UA, it is foreseen for a method proposal of very low cost at all the phases of the recycling process and blocks production, aiming to attend the housing needs of low income population in the world. The use of a portable industrial mower is recommended.

After the transformation of the cement sacks into cellulose pulp, one should take out the exceeding water of the cellulose pulp. The use of a centrifuge machine is recommended.

The Kraft paper's fibres must be dispersed after the removal of the exceeding water from the pulp. This dispersion is necessary to facilitate the incorporation of the fibres into the soil during the Kraftterra mixture process and to result in a more homogeneous composite material, which if well raised, will have a positive impact in the performance of the construction components. As much efficient is the removal of the water excess from the pulp, the easier the fibres dispersal process will be. However, it should be avoided turn the pulp completely dry, which will complicate the fibres dispersion.

The production of the new composite material Kraftterra follows the traditional mixture sequence on the production of these elements. At first, it should be putted the dispersed fibres in the mixing device and initiate its rotation. Then, a small amount of soil already mixed with cement is added, so that it homogeneously covers up the dispersed fibres with a thin soil layer. Slowly it should be added the soil-cement to the mixture and let it blend until it becomes an homogeneous material. After this phase, it should be added water until the material reaches the ideal compactation humidity.

During the pouring of the earth into the mixture, it should be avoided the production of dust by the blending equipment. In the case it occurs, is because the mixture used is too dry, which difficult the incorporation of the fibres into the soil.

In this project is studied the use of Kraftterra in the production of compressed earth blocks (CEBs). The major difference between the CEBs and the traditional adobe blocks is basically its plasticity. In fact, to produce traditional adobe blocks it is required for a mixture with a higher plasticity, with 50-60% of water content in weight, while for the production of compressed blocks the ideal mixture is much dried, with water content around 10-20%. For the compressed blocks, as much clayed are the soils higher is the water content that have to be added to obtain the optimal compactation level.

Figure 1: Kraftterra blocks production: cement bags cutting; fibres dispersion; mixture with soil-cement; compressed blocks.

3 TESTING CAMPAIGN: MATERIALS USED AND MANUFACTURE OF BLOCKS

For the study developed, were produced samples of Kraftterra and of Soil-cement blocks. The soil used was collected in Aveiro district region, in Portugal. From the granulometric analysis, it was verified that the soil used contains 15% of silt and clay (< 0.075μm). For the samples production, the natural soil was sieved with a sieve of 4.76μm apertures, and the retained material was discarded.

Ordinary Portland cement (32.5N) was used throughout in the mixture for soil stabilisation. For each modified (Kraftterra) soil mixture, cement was added in the volume dry proportion of 1:16 (cement:soil), or in the mass proportion of 6%. Other authors working on the field of earth construction refers that for mixtures with more than 10% cement content, the stabilisation generally becomes uneconomical [3]. Also, they refer that blocks containing less than 5% cement content are often too friable for easy handling. In Brazil, it is commonly adopted in the production of CEBs a cement proportion of 1:8 or 12%.

In this comparative study, it is intended evaluate the mechanical performance of the Kafterra CEBs, comparatively to the Soil-cement CEBs. It was adopted for the Soil-cement specimens 6% of cement content in weight, and for the Kraftterra specimens 6% of cement and 6% of Kraft paper.

For the cement sacks recycling process and for the mixture (Kraftterra or Soil-cement) production it was used water at the ambient temperature, potable, without impurities. The cement sacks, previously to dispersion of their fibres, were cleaned from all the cement in its interior.

The mixtures for the CEBs production were prepared in a concrete mixer, following the sequences: for the production of Kafterra (Kraft fibres dispersed > soil+cement > water); and, for the production of Soil-cement (soil > cement > water). The time adopted for each mixture was defined in order to guarantee homogeneity of the products.

The procedures for the moulding and curing of the compressed earth blocks were done according to the recommendations described in the Brazilian standard NBR 12024 [4]. The test units were moulded in small Proctor cylinders (diameter of 100mm and height of 127mm), being produced in three layers, being each layer socket with 26 beats.

After 7 days curing, compressive strength tests on the Kraftterra and Soil-cement specimens, based on the procedure described in the NBR 12025 [5], were done. Some adjustments were made, as recommended by Pitta and Nascimento [6], namely in what regards the emersion of the samples in water before testing.

4 PERFORMANCE IN COMPRESSION TESTS OF THE CEBS

From the vast testing campaign it was confirmed that the water humidity highly influences the mechanical behaviour. In fact, small differences in terms of water content adopted in the mixture can origin huge differences regarding the performance of the CEB samples.

For the definition of the water content, for each material, it were made several compactation test trials and it was adopted the value of water content corresponding to the best mechanical performance. With this procedure it was possible to reach the optimum compactation humidity, and the corresponding water content in the mixture, so as to reach the better performance regarding the compressive strength.

In figure 2 are presented the results of the compression tests, in terms of stress-strain curves, for the two materials studied, the Kraftterra (left) and the Soil-cement (right). As can be observed in figure 2, for each specimen, was also recorded the corresponding humidity level of the mixture.

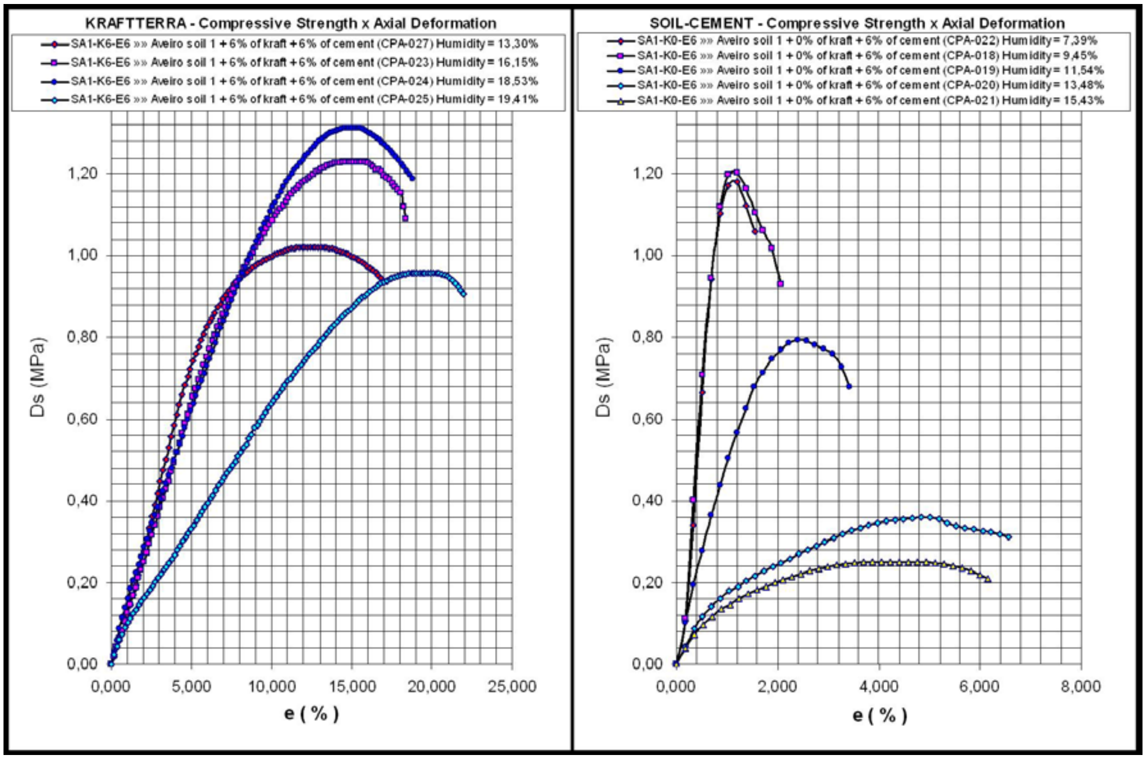

Figure 2: Stress-strain curves resulting from the compression tests on Kraftterra samples (left) and Soil-cement samples (right).

The first important conclusion is that the Kraftterra samples reached higher compressive strength than the Soil-cement samples. For all the comparative tests, the performance of the Kraftterra was better than the corresponding for the Soil-cement samples.

Another interest conclusion taken form this comparative analysis is related with the humidity level. As known, for the Soil-cement material the optimum humidity for workability does not conducts to the highest mechanical performance. But, with these test results, it was verified that for the Kraftterra material the optimum humidity for workability concerns was extremely close to the humidity corresponding to maximum mechanical performance. This fact is a great advantage for the use of Kraftterra material. In fact, good mechanical behaviour can be obtained with ideal workability conditions, contributing for the production of mixtures more homogeneous after the mixing process, and also to a better and easier incorporation of Kraft fibres into the soil.

Regarding the global response curve, in terms of stress-strain, for the two materials studied, it was observed a much larger deformation capacity of Kraftterra specimens, for the peak strength. In fact, the Kraftterra material presents its maximum strength for a deformation level of about 15%, and the Soil-cement material between 2% (for specimens with higher strength) and 4% (for lower strength). Regarding the deformation capacity, it was observed, as expected, that the Soil-cement specimens have a fragile response, while the Kraftterra specimens presents a response with a much high ductility level, i.e. after reaching its maximum strength the Kraftterra support the compression load even for larger deformation demands. It is underlined that each compression test was stopped when the strength drops of about 10% of the corresponding maximum compression strength value.

In figure 3 are presented the typical rupture mechanisms in compression for the two materials.

Figure 3: Kraftterra (left) and Soil-cement (right) samples after compression tests.

For the two materials studied, it was verified a clear tendency of larger ductility capacity for the specimens with higher humidity of compactation, as can be observed in the collapse mechanisms presented in figure 4. In fact, the two specimens of Kraftterra with same mixture were tested for the same age (28 days), but they were produced with different levels of humidity contents, namely 21% (left) and 13% (right). After compression testing they reached maximum deformations of about 15% and 8.5%, respectively.

Figure 4: Kraftterra samples after compression tests for different compactation humidity contents: 21% (left) and 13% (right).

Jiménez [7] in his work related to the incorporation of vegetal saps to reduce the water absorption of CEBs, quoting Minke [8], affirm that "the compressive and tensile strength can be improved by adding starch or cellulose, but that these additives reduces the cohesion and increases the shrinkage levels, which is an disadvantage". Other authors Bouhicha *et al.* [9], have also developed a study on the influence of straw fibres inclusion in the performance of composite soil-straw material. Four different soils were tested and used to manufacture soil specimens with straw reinforcement at different reinforcement/soil ratios and fibres lengths. The results of their tests proved the positive effects of adding straw in decreasing shrinkage, reducing the curing time and enhancing compressive strength if an optimal reinforcement ratio is used. In their study, the flexural and shear strengths were also increased and a more ductile behaviour and failure was obtained for the reinforced specimens.

All the tests made till now with the Kraftterra material indicates that the inclusion of Kraft fibres does not prejudices the cohesion, neither increases the shrinkage. In contrary, Kraft fibres improve the behaviour of the material for these two properties and also the mechanical properties.

5 CONCLUSIONS AND FINAL COMMENTS

The comparative experimental analysis conducted indicates that the performance of the new composite material, Kraftterra, regarding compressive strength, showed the high potential of this material to be incorporated in the production of CEBs. Besides the important ecological and environmental concerns related to the recycling of solid waste produced by the civil construction industry, the new composite material allows a cost reduction of Soil-cement blocks. In fact, it can be reduced to less than half the cement quantity in traditional Soil-cement blocks, if Kraft paper is incorporated.

The fabrication process of the Kraftterra blocks shows itself to be economically viable for the production of low cost constructions, to attend low income population. With lower costs associated to the blocks production process, naturally, it is underlined the advantages of using local and ecological friendly materials in construction. The block production process also can integrate the own residues.

Many other aspects and properties related to this new composite material still have to be studied and analyzed, so that the material's performance can be defined with more accuracy and confidence. However, as was already stated, are already evident the advantages and potentialities of including Kraft fibres form recycling on the production of compressed earth blocks.

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