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Viability analysis of using cellulose pulp recycled from cement sacks in the production of compressed earth blocks

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Abstract

This study concerns the development and analysis of the Kraftterra composite – raw earth stabilized with disperse fibers made with kraft paper from recycled cement sacks – for the production of CEBs and mortar for masonry infill elements. Its main goal is to define the behavior of small walls (prisms) of Kraftterra in relation to diagonal compression. The tests show that the prisms produced with Kraftterra CEBs and mortar show excellent bond strength between block and mortar. All the prisms tested presented fissure lines very close to the normal load line and the fissures occurred in the blocks and in the mortar in similar manner, without separation between these elements. The mortar produced with Kraftterra results in strong bonds between blocks and produces homogeneous construction elements with uniform performance, that is, with high monolithicity.

1 Introduction

Every year, several tons of cement are used in the construction industry. After use, most of the cement sacks are disposed in nature without any treatment, creating an enormous negative environmental impact. In 2008, for instance, the production of cement in Brazil reached 59.9 million tons. From this production, 73% were sold in sacks, which is the equivalent of 37.3 million tons [1]. Considering each sack contains 50kg of the material, it can be estimated that in Brazil, in 2008 alone, 747.3 million sacks of cement were thrown away. This means a consumption of about 112 thousand tons of natural multilayer kraft paper for this use.

The fibers of the sacks of natural Kraft paper have excellent physical and mechanical properties. It is made according to the rigorous specifications demanded by the cement industry. It is a high strength cellulose sulfate of long fiber, which is mainly used in its pure form.

After the use of the cement, the sack, made of a material with such good physical and mechanical characteristics, is not reused by the paper recycling companies because it has been contaminated with cement. There is, however, great potential for its use in the production of new building components.

Rigassi [2] states that the addition of fibers to reinforce the earth is very common in traditional constructions with adobe blocks, but that this is in incompatible with the compression process of the CEBs, because it produces mixtures that are too elastic. The analysis with Kraftterra indicates the opposite. This article describes the process of production of Kraftterra, as well as the behavior of small walls (prisms) made with CEBs and mortar from Kraftterra in relation to diagonal compression.

2 Kraftterra production process

The first stage of the recycling process is the cleaning of the cement sacks, which are normally discarded with rests of the material in the bottom, particularly between the closing folds of the sack. This procedure is more necessary with sacks that have been exposed to excessive humidity or have had contact with water, which can mean the presence of small rocks of hardened cement or even large rigid plates in the bottom. This solid material can damage the recycling equipment. This stage requires care in the handling of the sacks to avoid contamination. It is necessary the use of security equipment such as gloves, glasses, masks, and adequate clothing.

After cleaning, the cement sacks are transformed into a cellulose pulp, which is basically the dispersion of the craft paper fibers. This dispersion is done through the immersion of the cement sacks in water and agitating until the separation of the fibers is complete. The addition of chemical products or heating of the water are not necessary.

To remove the excess water from the cellulose pulp, the use of a centrifuge is recommended. Then, the fibers must be dispersed. For this stage, the use of a waste grinder or a tree grinder, largely used in gardening, is recommended. After the dispersion, the process of mixing the Kraftterra can begin.

Figure 1: Agitator (left); centrifuge (center); and waste grinder (right).

The mixture of the new composite can be done with different tools and equipments such as a hoe, in manual processes, or even large soil mixers in mechanical and industrial processes.

With the use of concrete mixers, some measures must be taken to achieve a homogeneous mixture. In case a mixture rolls for a period longer than what is necessary for the homogenization of the composite, it starts to present clusters (Fig. 2). The more this happens in a mixture, the less homogeneous it will be, which could compromise the final performance of the building components.

Figure 2: Mixture of Kraftterra in a concrete mixer resulting in clusters

For the production of CEBs with Kraftterra, the correct order of putting materials in the mixture must be followed, because it affects the efficiency and homogeneity of the composite. It is also necessary a strict control to guarantee the adequate humidity within the mixture, once the humidity of the composite directly affects the final performance and the physical-mechanical properties of the building components and masonry infill elements.

First, one must put the disperse fibers. Then, a small portion of the earth previously mixed with cement should be added to cover the fibers uniformly with a thin layer, in order to avoid clusters. Slowly, all the earth previously mixed with cement must be added to the mixture, and the mixer should stay on until the mixture is homogenous. Then, water must be added slowly, until the ideal humidity for compacting is achieved. It is recommended to put the water in some type of pulverization or dispersion system, in order to avoid saturating the mixture in certain spots. With the homogeneous mixture, the composite is removed from the equipment and the process of compacting of the CEBs can begin.

The CEBs were produced with 6% of cement (in mass), 6% of disperse fibers (in mass) and enough water content for each composite to reach optimum compacting humidity levels.

3 Prototypes description and test campaign

3.1 Compressed earth blocks - CEBs

For the production of the CEBs, a manual press TERSTARAM made by Apppro-Techno was used (Fig. 3). This press produces two solid flat CEBs at a time, with the following dimensions: 22cm x 11cm x 5,5cm. It has a system of adjusting the height and volume of the form with metallic bars below the lever arm responsible for lifting the bottom of the form.

Figure 3: Press TERSTARAM. Detail of the height adjust system of the form (right).

After pressing, the CEBs were cured in a place with controlled ventilation and no direct sunlight. For the standardizing of the cure conditions and not favoring or detriment of the CEBs from Kraftterra or soil-cement, all the CEBs were cured identically and to prevent loss of humidity, that is, through only the environmental conditions of the laboratory, without any humidifying process. There was no record of fissures or other pathologies on the CEBs due to the cure process neither in the Kraftterra blocks nor in the soil-cement blocks. The soil used for the production of the CEBs had 84,5% of sand and 15,5% of fine fraction (7,3% of silt and 8,2% of clay). This soil is from a region next to Aveiro, Portugal.

3.2 Production process of masonry infill elements

The choice was made to make the mortar with the same soil and same composition of the CEBs, that is, Kraftterra. The consistency of the mortar demands quantities and proportions of water in the mixture much higher to those of the CEBs. However, the higher the humidity in the mixture is in relation to the optimum values of humidity, the worse the final performance and physical and mechanical characteristics of the composite. Therefore, the amount of stabilizers in the mortar was increased in order to guarantee that all the infill elements had uniform behavior and performance. The mortar has 12% of cement in mass.

To guarantee a good unity between blocks and mortar, one must prevent the CEBs from absorbing the water from the mortar too quickly. Thus, the blocks must be wet immediately before laying. It is recommended submerging the CEBs in water for a few seconds. The excess water on the blocks can be removed with a sponge.

The difference between the bricklaying process with mortar from Kraftterra and that from soil-cement is due to the presence or not of fibers in the mixture, which creates difficulties in the use of mason's trowels and finishing trowels. When removing the excessive Kraftterra mortar after laying the CEBs, the use of a mason's trowel removes more material than necessary leaving empty spaces between blocks, which could compromise the final performance of the subsystem and result in an unappealing finish in the case of walls with facing CEBs. To solve this problem, the elements were laid without a mason's trowels. With only waterproof gloves, it was possible to lay the bricks without difficulty, with less waste of materials and without consuming more time. The gloves are recommended for the composites that contain cement. For the Kraftterra mixtures that have no cement, this process can be done by bare hands.

The prisms were cured in the laboratory in regular environmental conditions, without direct sunlight or artificial ventilation. No humidifying process was used during the cure period.

3.3 Diagonal compression strength test - walls

The prisms tested in diagonal compression were made with five courses, each with one CEB and a half, and joints with approximately 15mm, which resulted in square prisms with average dimensions of 34,5 x 34,5 cm and 10,6cm in thickness.

The test was performed according to the RILEM recommendations [3] and ASTM standards [4]. This test was done in the following way: a square masonry panel is submitted to a compressive force, applied in two opposite corners along a diagonal, until its rupture. The shear force is deduced from the diagonal compressive force based in a theoretical distribution of normal and shear stress for a continuous, homogeneous and elastic amount of material.

To measure the deformities resulting from the tests, a fixation and support system was developed for the placement of strain gauges through the use of parabold anchor bolts. This device allows an aluminum bar of circular section to be placed onto two points, in one of which the movement of the bar is free. On this bar a strain gauge is fixed and the measurement of the deformities can be done using as base the top of one of the anchor bolts, as in Figure 4.

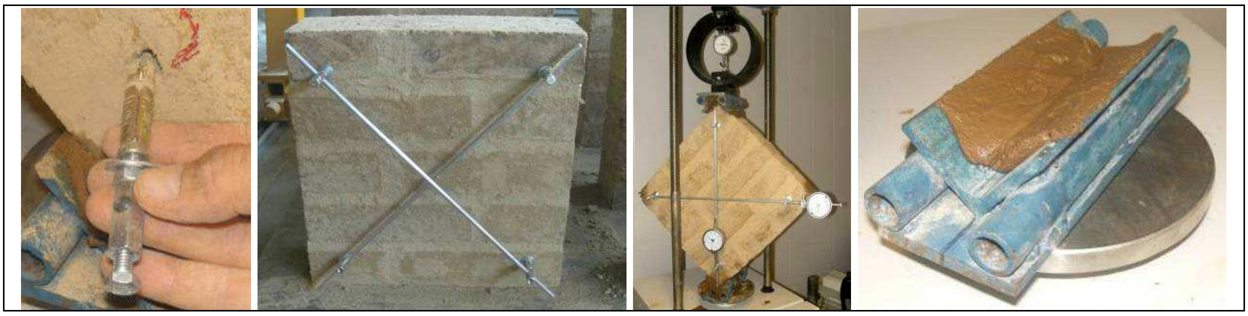

Figure 4: Fixation system for the bars and supports for the strain gauges in the prisms.

Holes were made with an electric drill in certain points for the insertion of parabolts. The drills had the same diameter as the anchor bolts, which allowed for a perfect fit, without no need for additional adhesive materials and without damaging the prisms.

To place and align the prisms in the compression equipment, two metallic supports with corners were used. To improve distribution of the loads, it was used a thin layer of mortar in plastic consistency made with water and a fine fraction of the earth used in the prisms (Figure 5, right).

Pereira [5] states that from the stress-strain curves obtained through diagonal compression tests, it is possible to estimate the shear stress and the transverse tensile modulus of each prism. The shear stress (Ss) is calculated for each prism having as a base the expression (1):

$$S_s = \frac{0{,}707 \cdot P}{A_n} \tag{1}$$

Where P represents the rupture force and An the actual cross-sectional area, the latter being determined by the expression (2):

$$A_n = \frac{l + h}{2} \cdot t \cdot n \tag{2}$$

Where 1 and h represent the width and height of the prism, t its thickness and n the fraction of the solid area of the prism (in this case, n equals 1 because the CEBs used in the prisms were solid, flat and without frogs).

The shear strain (γ) is obtained through the expression (3) and the transverse tensile modulus (G) is the quotient of the shear stress (Ss) by the shear strength (γ), as in (4).

$$\gamma = \frac{\Delta V + \Delta H}{g} \tag{3}$$

Where ΔV represents the vertical shortening, ΔH the horizontal expansion, and g the relative distance between the vertical points which is assumed to be equal to the relative horizontal distance.

$$G = \frac{S_s}{\gamma} \tag{4}$$

The results of the diagonal compression tests are represented by two curves: one with the vertical force against the vertical strain (left); and the other with the horizontal strain (right) as shown schematically in Figure 5. The deformations correspond to the averages of each sign in the associated direction.

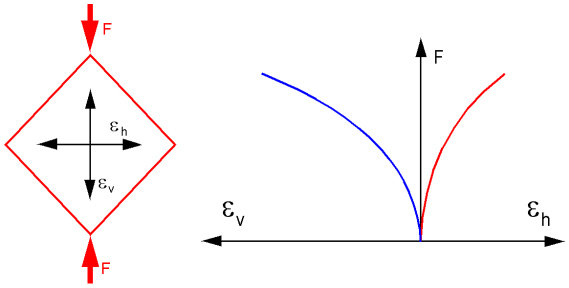

Figure 5: Generic scheme of the diagonal compression tests on walls, source [6].

Six prisms were made with Kraftterra CEBs and mortars for the diagonal compression strength tests. One of them went initially through accelerated aging cycles.

3.4 Accelerated aging cycles

To execute the accelerated aging cycles the Brazilian standard NBR 13554 [7] was used as reference. These cycles of wetting and drying are meant to simulate the impact of the weather in the durability of the construction elements. This is done in order to accelerate pathogenic processes and maximize the action of environmental factors of degradation of the CEBs, such as: high oscillation in humidity and temperature; and the use of extreme conditions in both environmental situations. Durability refers to the action of the water in successive cycles of humidifying and drying with high oscillation in temperature. The immersion of the prisms in water associated with large thermal oscillation provokes volumetric variations with the possibility of rupture of bonds between particles resulting in progressive degradation, where fissures, wear, or disintegration of part of the building components might occur.

The NBR 13554 [7] defines the procedures and describes the cycles of wetting and drying of the durability test. There are 6 consecutive 5 hour cycles of immersion in water in room temperature and 42 hours in a stove at 71 ºC. It is also recommended a brushing procedure to evaluate and define the loss of mass, which was discarded because the prisms would later be used in comparative performance analysis for diagonal compression, and the wear provoked by brushing could cause distortions and mistakes in the results. Therefore, the duration of the humid cycle was adjusted to 6 hours, which allowed the total time of each cycle to remain 48 hours.

4 Prototypes description and test campaign

Table 1 contains information on the six prisms tested in diagonal compression and their respective values of shear stress (Ss) and transverse tensile modulus (G). The prism “EA” went through accelerated aging cycles as described above.

The average value of the shear stress reached during diagonal compression tests (0,566MPa) is very close to 1/10 of the average value of the ultimate simple compressive stress (5,66MPa). This behavior was already mentioned by Varum et al [8] when working with adobe walls.

Table 1: Diagonal compression tests, shear stress (Ss) and transverse tensile modulus (G)

	P (kN)	l (mm)	h (mm)	t (mm)	n	A_n (mm^2)	S_s (MPa)	ΔV (mm)	ΔH (mm)	g (mm)	γ	G (MPa)
PK1	32,93	345	345	106	1	36570	0,636	1,20	0,70	358	0,0053	119,97
PK2	27,02	345	345	106	1	36570	0,522	2,40	0,50	358	0,0081	64,49
PK3	33,35	343	345	106	1	36464	0,646	3,60	1,69	358	0,0147	43,77
PK4	28,92	344	343	106	1	36411	0,561	1,40	3,00	356	0,0123	45,44
PK5	26,17	345	344	106	1	36517	0,506	1,80	0,50	357	0,0064	78,67
EA	27,23	347	348	106	1	36835	0,522	4,20	1,99	360	0,0171	30,40

Through the stress/strain graph it is possible to see that the prism that went through accelerated aging cycles had a comparatively inferior performance, with a decrease in the ability to withstand diagonal compression and more vertical and horizontal strain. In the graph of Figure 6, values up to the breaking strength were recorded.

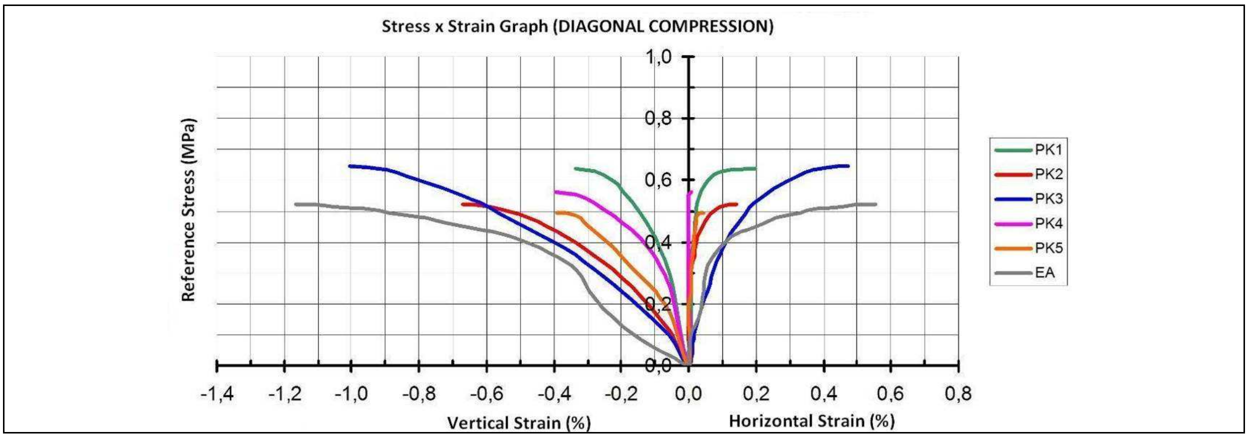

Figure 6: Diagonal compression, graph Stress (Ss) x Vertical and horizontal strains

The diagonal compression strength tests show that the prisms produced with Kraftterra CEBs and mortar have excellent bond strength between block and mortar. The monolithicity of the prisms can be proved visually by their aspect at the end of the diagonal compression tests. It is important to highlight that the tests were interrupted after the pointer returned in 10% from the maximum value reached. All the prisms present fissure lines very close to the normal load line and the fissures occurred in the blocks and in the mortar in a similar manner and without separation between them (Figure 7).

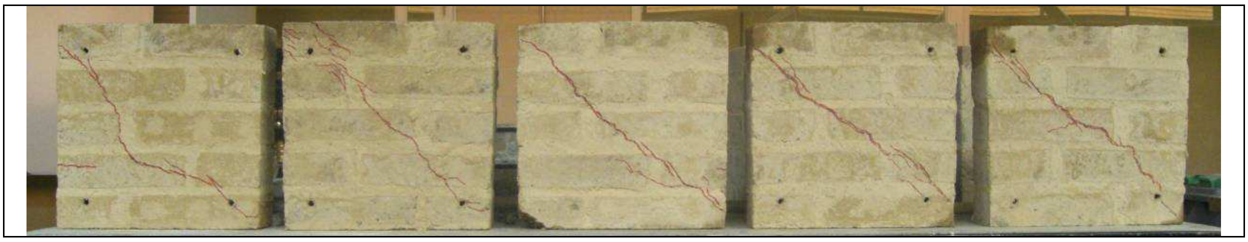

Figure 7: Prisms at the end of the diagonal compression tests. The fissure lines were highlighted.

Sabbatini [9] affirms that the monolithicity of the wall and the strength to volumetric strain, eccentric loads and orthogonal forces in relation to the wall - which are the result of the combination of tensile and shear strength - all depend on the bond strength between block and mortar as well as in the superficial area of contact between them.

This author also states that bond strength is not a property intrinsic to the mortar. It depends on the nature and characteristics of the base, meaning that there is an interrelated action between base and mortar creating an interface. In the ability of that interface to absorb tangential stress (shear stress) and normal stress (tension) without rupturing, depend the monolithicity of the wall and the strength of the masonry to withstand volumetric strains such as hydraulic retraction, thermal expansion, perpendicular, eccentric, and orthogonal loads, and tangential loads to the wall such as wind loads, execution eccentricity, tremors, etc.

Even after the final diagonal compression strength tests, the prisms still presented enough bond strength to avoid separation when lifted by only one side (Fig. 8, left).

Although the prisms that went through the process of accelerated aging had an inferior performance to the rest, their appearance and behavior at the end of the simple compressive strength test were similar to those that did not go through these cycles. This means that the rupture occurred following the normal load line and passed through the blocks as well as the mortar (Fig. 8, right). However, it is possible to see several rupture lines, differently from the other prisms where the rupture lines were clear and practically continuous.

Figure 8: Prisms when lifted show bond strength in the rupture area (left), and Kraftterra prism that went through accelerated aging cycles - appearance after the test (right).

The presence of these rupture lines shows that the accelerated aging cycles decreased the strength of the prism to shear forces and stress. However, the ability to withstand these forces remains even after the rupture by diagonal compression.

5 Final Conclusions

The use of disperse Kraft paper fibers from recycled cement sacks shows by itself the environmental concern of the proposed theme. However, the possibility of using such an abundant residue in our society must not be seen as the only contribution of this work, taking into account that this use also results in a significant improvement in some of the physical and mechanical properties of the final development of the building components (CEBs) and construction elements (walls).

The inclusion of Kraft paper disperse fibers from recycled cement sacks in CEBs and mortars allows for a large increase in the walls' ability to withstand diagonal compression, even after the breaking strength. Furthermore, the mortar made with Kraftterra results in strong connections between blocks and produces homogeneous building elements with uniform performances and high monolithicity.

Reference

[1] SNIC, Sindicato Nacional da Indústria do Cimento: *Relatório Anual 2007-8*. Disponível em http://www.snic.org.br/25set1024/relat_2007-8.html (04/2010)

[2] RIGASSI, V.: *Compressed earth blocks – manual of production*. CRATerre-EAG, vol.1, GATE/GTZ/BASIN, ISBN 3-528-02079-2, Alemanha, 1985.

[3] RILEM: *Technical recommendations for the testing and use of construction materials*. International Union of testing and Research Laboratories for Materials and Structures, 1992.

[4] ASTM: *Standard test method for diagonal tension (shear) in masonry assemblages - E 519-81* (reapproved 1993) - ASTM Standards on Masonry, 03-315097-60, 1997.

[5] PEREIRA, H. C.: *Caracterização do comportamento estrutural de construções em adobe*. Dissertação. Departamento de Engenharia Civil da Universidade de Aveiro. Portugal, 2008.

[6] VARUM, H.: *Seismic assessment, strengthening and repair of existing buildings*. Tese de doutorado apresentada no Departamento de Engenharia Civil, Universidade de Aveiro, 2003.

[7] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – ABNT: *NBR 13554 – Solo-cimento, ensaio de durabilidade por molhagem e secagem*. Rio de Janeiro, 1996.

[8] VARUM, H.; Costa, A.; Pereira, H.; Almeida, J.: Comportamento estrutural de elementos resistentes em alvenaria de adobe. In *Anais do TerraBrasil 2006 - I Seminário Arquitetura e Construção com Terra no Brasil e IV Seminário Arquitectura de Terra em Portugal*, Brasil, 2006.

[9] SABBATINI, F. H.: *O processo construtivo de edifícios de alvenaria estrutural sílico calcária*. Dissertação apresentada à Engenharia Civil da EPUSP. São Paulo,1984.