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# EVALUATION OF PERFORMANCE UNDER FIRE OF COMPRESSED EARTH BLOCKS

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## ABSTRACT

In this paper are presented and discussed the main results of fire resistance tests on walls made of soil-cement and Kraftterra compressed earth blocks (CEB). Within this research it was intended to evaluate the fire resistance of walls made with CEB, with and without cellulose pulp incorporation deriving from recycling of cement sacks. Firstly, it is described the Kraftterra production processes and the fire resistance test campaign. Then, the performance of the blocks under analysis in terms of fire resistance is compared.

## INTRODUCTION

The fire risk in a dwelling may be high, as it may have several ignition causes (chemical, mechanical, thermal or even electrical). Also, catastrophic events, such as impact, explosions and earthquakes, are commonly associated to the occurrence of fires. These fires in buildings may have very severe consequences, as human life losses (Richardson, 2007), which has been justifying the society growing concern to this accidental action.

The application of Kraftterra blocks has rouse doubts regarding its fire resistance, limiting its application in practice. This study presents the results of fire resistance tests on walls made with soil-cement and Kraftterra compressed earth blocks – CEB. The purpose of this work was to assess and compare the fire resistance of walls made with CEB, with and without cellulose pulp incorporation, deriving from recycling of cement sacks.

According to Rigassi (Rigassi, 1985), adding fibres to reinforce the soil is very common in traditional adobe blocks' production but incompatible with the CEB compression process as they difficult the CEB production. The most effective method to improve the earth blocks is the compaction of the earth and/or its stabilization with additives (Yetgin et al., 2008). Fibre, cement, bitumen, lime or cow-dung can be used to stabilize the adobe (Ngowi, 1997). Natural fibers from bamboo, coconut husk and sisal (Ghavami et al., 1999) or artificial fibres like plastic or polystyrene fabrics (Binici et al., 2005) are examples of efficient stabilizers.

One possibility for the use of earth in construction is the Compressed Earth Block – CEB. The idea of compress the earth to improve the performance of adobe blocks is not new (Silveira et al., 2012). The first compressed earth bocks were produced with wood heavy rammer, a process which is still used nowadays in some regions of the world (Buson, 2007; Buson et al., 2010; 2009).

Currently, the composite more used for the production of CEBs is the soil-cement mixture. As the name itself express, it corresponds to a soil stabilized with cement, and normally the cement used is the Portland cement.

The new composite Kraftterra, studied in this work, has as main binder the Kraft fibres dispersed of the paper taken from recycling of cement bags. Other materials may also be used as supplementary stabilizing agents of Kraftterra, as for example, cement and lime. However, depending on the characteristics of the soil used in the mixture, these additional agents may be exempted.

## FIRE RESISTANCE

The European Standards EN 1363-1 (CEN, 1999a) and EN 1364-1 (CEN, 1999b) give details on the test procedures to evaluate the fire resistance of vertical non-load-bearing partition elements. The main properties to be evaluated in these tests are the ability of the construction element to maintain their integrity and thermal insulation.

The integrity refers to the ability of the partition element to prevent the passage of flames or hot gases between adjacent compartments. And, the thermal insulation refers to the property of the partition element to resist to the heat transmission, keeping the temperature increase, in the face not exposed to fire, within allowable limits.

It is considered that the test specimen guarantee the fire integrity when, during the test, the test specimen does not present openings which permit the passage of hot gases or flames lasting for more than 10 seconds, from the fire exposed face to the opposite face (not exposed).

It is considered that the test specimen is thermally insulated, while there is not an average temperature increase above 140°C on the unexposed face, and when the temperature increase is always lower than 180°C at any thermocouple of the same face (CEN, 1999a).

The EN 1363-1 (CEN, 1999a) adopts the ISO 834 fire curve (expression 2), which considers a constant value equal to 20ºC, and admits a variation of the initial temperature of 20°C ± 10°C.

$$T = 345\log_{10}(8t+1)+20 \tag{1}$$

This study was not performed on ideal temperature and pressure conditions, where six different specimens with dimensions 3.1x3.1m$^2$ each, where tested for 3 configurations (without plaster, with plaster in side exposed to fire and with plaster in both sides) and for the two materials. The construction of these six different specimens was not possible at once, due to Laboratory limitations in terms of number of available frames. The construction of the six specimens in different dates would induce major influences in its behaviour due to the differences in curing conditions of the specimens, associated to the different ages of construction. It was considered that the presented test set-up would be more informative for analysing the different behaviour.

## EXPERIMENTAL TEST SET-UP

For the construction of the wall were adopted vertical and horizontal joints with a thickness of about 1.5 cm. To perform the fire resistance test, it was constructed the CEBs wall infilled in a surrounding reinforced concrete frame, with dimensions 3.10m x 3.10m, that constitutes the oven cover.

A single test to characterize the fire resistance of Kraftterra and traditional CEB masonry was carried out, for different plastering conditions. Comparative analyses were performed between wall panels constructed with soil-cement blocks and with Kraftterra blocks, as well as for different plastering conditions. To that end, the wall was constructed in two different phases, corresponding to two distinct horizontal bands, namely the bottom half-height wall with traditional soil-cement CEBs and soil-cement mortar in the joints, and the top half-height with Kraftterra in the CEBs and mortar.

In order to experimentally assess different plastering conditions commonly adopted in buildings' construction practice with CEBs, the wall was divided into three vertical strips, 1 m wide each, to produce three different plastering configurations for each type of wall (soil-cement and Kraftterra). Figure 1 shows the two faces of the wall before testing. The nomenclature adopted for each wall panel is presented in Figure 2. The central strip was not plastered on both sides (P2 and P5 for panels with Kraftterra and soil-cement blocks, respectively). One lateral strip was plastered only on the face exposed to fire (P1 and P4 for panels with Kraftterra and soil-cement blocks, respectively). The other lateral strip was plastered in both sides of the wall (P3 and P6 for panels with Kraftterra and soil-cement blocks, respectively). Thus, six different panels were studied. For the plaster, it was adopted the same composition in all panels, namely a soil-cement mortar, with the same soil used in the production of the CEBs and 12% of cement (in mass). The average thickness of the plaster was 2.0 cm, which results in a wall with a total thickness of 15 cm (for the panels plastered on both faces). Before plastering, the wall was previously wet to prevent rapidly water absorption from the mortars, and to minimize the shrinkage.

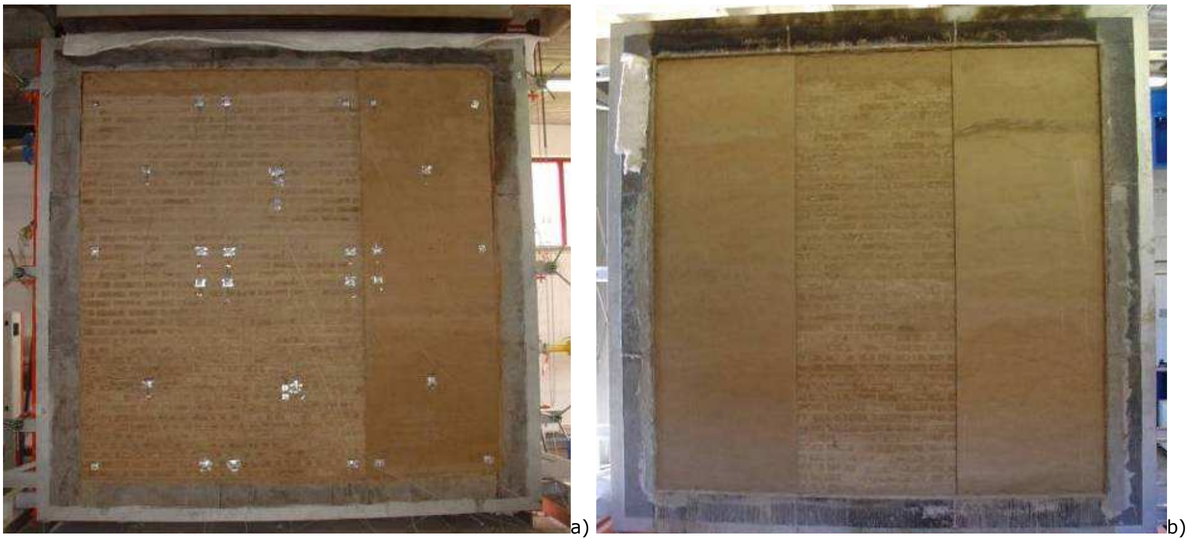

Fig. 1 a) External face and b) inner surface of the constructed wall, infilled in a reinforced concrete frame mounted to test for fire resistance at the LERF laboratory.

## TEST MONITORING AND GLOBAL BEHAVIOUR OF THE TESTED SPECIMENS

The test was conducted at two distinct stages (heating and cooling) with the total duration of 6 hours and 54 minutes. Figure 2 presents the external thermocouples position on the test specimen in each panel and the considered points for lateral displacement measuring. It can also be observed in this figure the position of the internal thermocouples used to measure temperature evolution within the wall for panels P2 and P5.

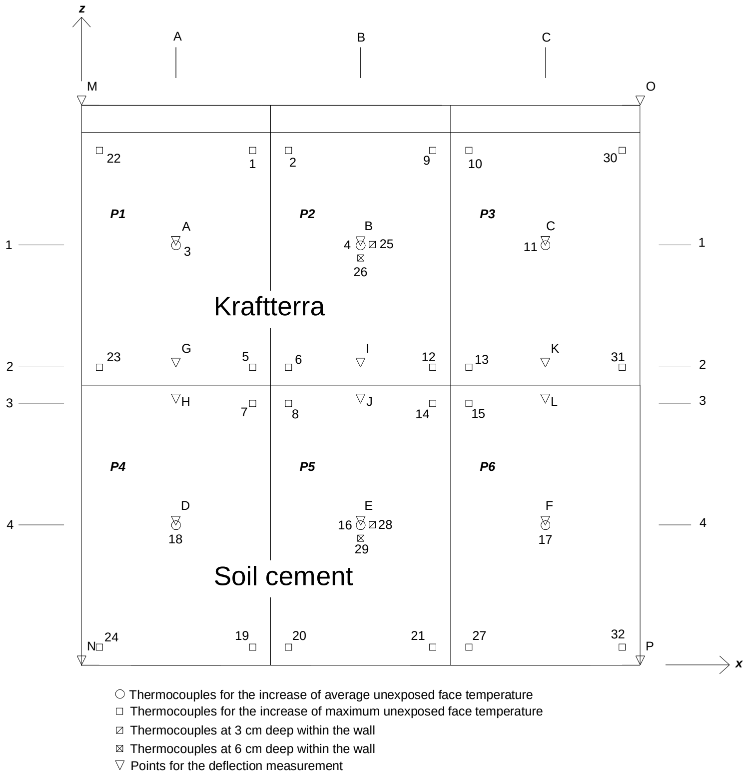

Fig. 2 Test instrumentation set-up, thermocouples and points where displacements were measured.

A neutral pressure plane was imposed at 500 mm of the floor level.

During the first 2 hours of the test, the average temperature of the furnace thermocouples followed the fire curve ISO834 temperature evolution.

After the first 2 hours of the test, the furnace was turned off, but all connected external thermocouples were kept on to measure the temperature evolution during the cooling phase.

It should be noticed also that: during heating it was observed humidity in different cracks, caused by water evaporation within the blocks and subsequent condensation on the plastered surface non-exposed directly to fire (Figure 3); and, after 1 hour and 53 minutes from the beginning of the test, it was observed the occurrence of a vertical fissure in the face non-exposed to fire, initialized in the middle of panel P2, as shown in Figure 3. It is noteworthy that the wall integrity was not at risk, and no hot gases or flames passed through the test specimen.

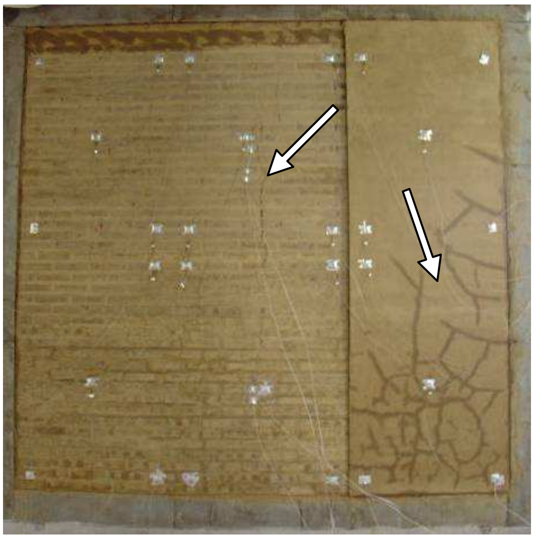

Fig. 3 Vertical crack at the centre of the non-exposed to fire face. Appearance of humidity in cracks caused by water evaporation inside the wall.

The crack run vertically along the centre of the wall (panels P2 and P5), being better visualized on the face directly exposed to fire (see Figure 4). On the exposed face the detachment of plaster was observed in some locations.

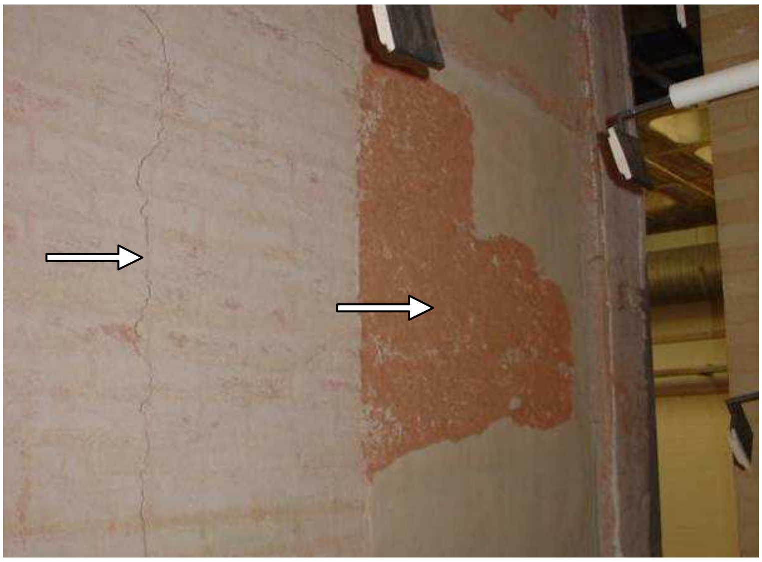

Fig. 4 Vertical crack in the centre of the wall face directly exposed to fire. Detail of plaster detachments.

## TEST RESULTS AND COMPARISON

The graph of Figure 5 illustrates the furnace temperature evolution, corresponding to the ISO834 curve up to 120 minutes. After 120 minutes the furnace was turned off, in order to reproduce the cooling phase of a natural fire. It was decided not to account with the ignition phase of real fires (Manzello, 2005), to be possible to determine the fire resistance time as prescribed in fire resistance test standards (CEN, 1999a).

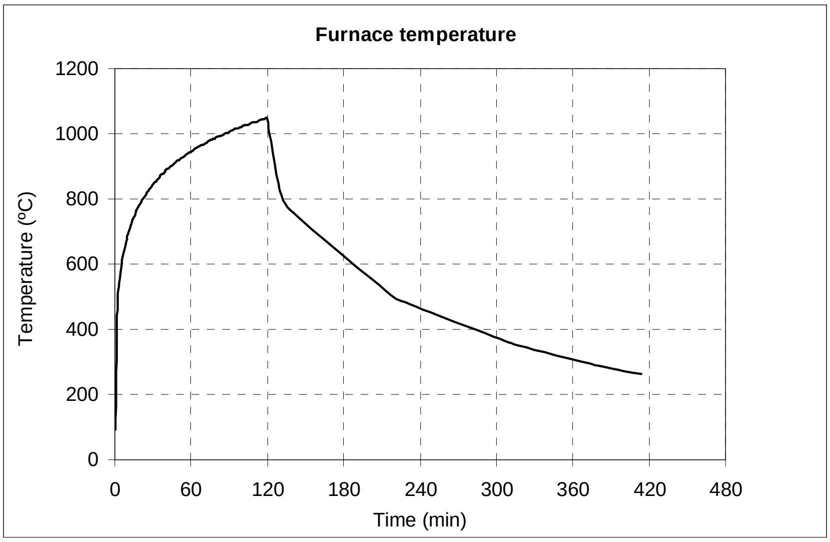

Fig. 5 Furnace temperature evolution.

According to the behaviour criteria proposed at the EN 1363-1 (CEN, 1999a), the insulation is defined by the time in minutes during which the wall is still maintaining its partition function, without developing high temperatures in the unexposed surface. This is evaluated by limiting the increase in the average temperature to 140°C, or limiting the increase of temperature at any point to 180°C.

The global behaviour of the wall was excellent. At any point, the temperature in the external surface increased more than 80°C, until the furnace was turned off (120 minutes after starting the test). This demonstrates that CEBs walls have an adequate performance on fire, considering the performance criteria exposed before. After the 120 minutes, it was also characterized the wall behaviour at the cooling phase.

As presented in Figure 2, the thermocouples t25 and t26 were implemented to measure the temperature evolution for different depths of the Kraftterra (panel P2), and the thermocouple t29 (t28 thermocouple was damaged during the test) for the soil cement (panel P5). Figure 6a) presents the temperature evolution at these thermocouples and for the correspondent unexposed surface thermocouples (t4 for panel P2, and t16 for panel P5). The maximum temperature recorded in the interior of panel P2 (with the thermocouple t26) is about 75ºC inferior to the corresponding for panel P5 (t29).

Although the maximum furnace temperature is achieved at 120 minutes, the wall temperature continues to increase afterwards due to the heat transfer process.

From the graph in Figure 6a), it is also possible to observe the differences along the wall thickness of the conclusion of the water vaporization phase. This vaporization process decelerates the temperature evolution in the unexposed to fire surface. It can be observed that in both panels the heating in the unexposed surface is faster and the cooling is slower when compared with the corresponding evolution inside the blocks. For the Kraftterra blocks the vaporization occurs at 120 minutes in the unexposed to fire surface, being not so pronounced the temperature increase.

The average temperature increases for the six panels was compared with the limit of 140ºC. In this comparison, for each panel, it is considered only the thermocouple located in the panel centre. Figure 6b) presents the average temperature evolution for the six panels. The temperature increase limit (140ºC) is not reached in any panel during the first 120 minutes of the test performed following the ISO fire curve.

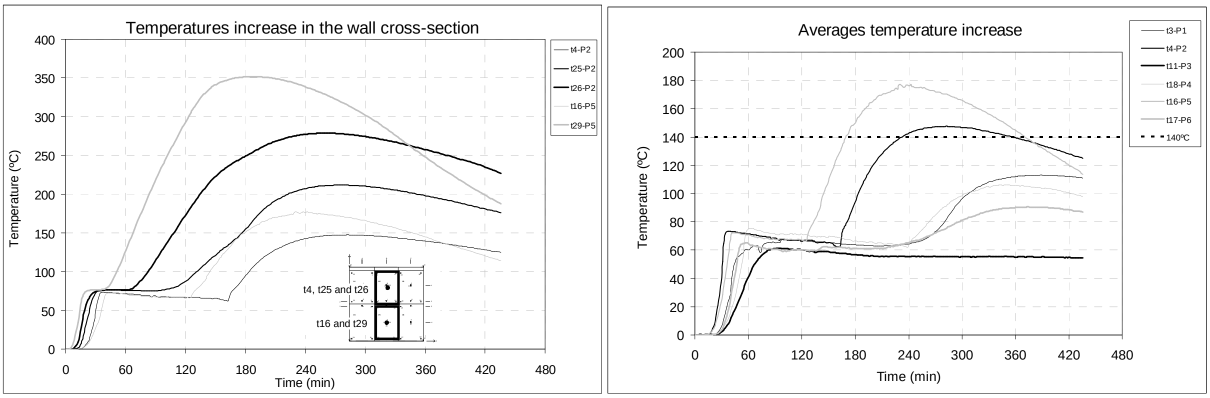

Fig. 6 a) Temperature evolution throughout the wall cross-section; b) Average temperature increase in the unexposed surface of the six panels.

Graphs in Figure 7 show the temperature evolution recorded in each thermocouple, for panels 2 and 5.

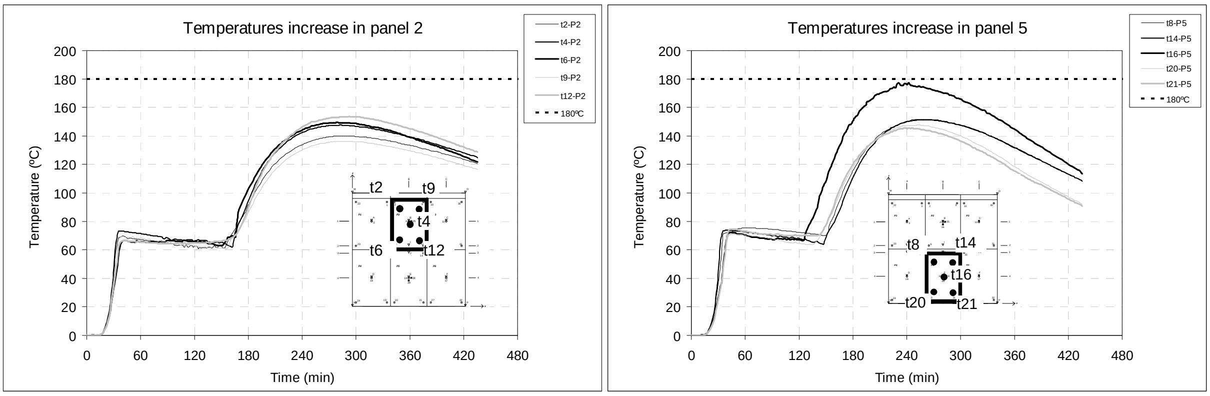

Fig. 7 Temperature increase evolutions in the thermocouples of a) panel P2, Kraftterra blocks without plaster; b) panel P5, Soil-cement blocks without plaster.

Analyzing individually the results for each panel, it is concluded that the Kraftterra CEBs present slightly better performance than soil-cement BTCs, especially in the situations without plaster and with plaster on both sides. However, it is also clear that, in general terms, both types of blocks showed similar performance, being the major difference the lower heat transfer showed by the walls with Kraftterra blocks. In fact, as it can be observed in the graphs of the previous figures, after switching off the furnace, lower values of temperature were recorded for panels with Kraftterra blocks. This difference is more pronounced when comparing the two panels without plaster (P2 and P5).

The recorded plateau temperature on all thermocouples, between 60°C and 80°C of temperature variation, was induced by the material moisture. The total moisture evaporation occurred in the cooling phase, where it was possible to observe rising temperatures, mainly in the panels without plaster.

It can also be concluded that the plaster had a positive effect on the fire resistance. Separation between the plaster and the wall was observed in both surfaces, the exposed and the unexposed to fire, which have induced the emergence of air flow zones, not favouring the temperatures increase.

Cooling phases in fire scenarios are gaining increasing importance in the design for fire safety. In fact, the test results showed that the cooling phase is strongly related to the delay of the temperatures increase (see in Figure 6a) the temperature recorded in thermocouples T29 and T26). Although it can be observed that the maximum temperatures were achieved on the cooling phase, after more or less 240 minutes in the panels with no plaster and 340 minutes in the panels with plaster on one side only. The results show that these temperatures increase never reached 180ºC, the prescribed limit for the ISO curve and not directly applicable for this phase.

## FINAL COMMENTS

From the fire resistance test performed, it is concluded that the inclusion of Kraft paper fibres, from the recycling of cement bags, in the production of CEBs resulted in panel elements with adequate performance and fire resistance. The test results confirm that the walls with Kraftterra CEBs, with or without plaster, can be used as partition walls.

As referred, all the walls analyzed with CEBs of soil-cement and Kraftterra showed adequate performance and fire resistance. For all the panels, the stability was guaranteed and the different compositions guarantee the wall integrity until the conclusion of the ISO fire test (120 minutes duration), and prevented the flames, smoke and hot gases passage. In what regards the thermal insulation, the wall with Kraftterra CEBs showed a better performance.

It is noteworthy the fact that for all walls (made with soil-cement and Kraftterra CEB blocks) the temperature rise on the external face was far below from the values recommended in the standards. The performance of the studied walls, made with Compressed Earth Blocks, was comparatively higher than that required for other types of partition masonry walls.

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