Innovative masonry blocks for partition walls

G. Vasconcelos¹, Elisa Poletti¹, P. Medeiros¹, Paulo Mendonça², P. Carvalho², S. Cunha¹ Aires Camões², P. Lourenço¹

¹ ISISE, Department of Civil Engineering, University of Minho, Guimarães, Portugal
e-mail: graca@civil.uminho.pt
² C-TAC, Department of Civil Engineering, University of Minho, Guimarães, Portugal

Key words: partition walls, blocks, composite materials, experimental validation

Abstract
This paper intends to propose a non structural system of partition walls with monolithic blocks based on a composite material resulting from an admixture of cork and textile fibers combined with a non cement binder, gypsum. These blocks consist of two half blocks which have to be connected during laying process. The developed blocks were first tested under compressive and flexural loading in order to derive their mechanical behaviour. Different curing conditions were applied to the blocks during their production in order to evaluate the effect on eth behaviour. The variables analyzed included curing temperature and period of curing, ambient humidity in which the blocks were prepared. This study aims at obtaining insight on the influence of these parameters on the mechanical behaviour of the blocks and at providing guidelines for their use in construction sites.

1 Introduction

Since the first civilizations man has shown a high demand to have a permanent shelter, which has progressively evolved to buildings as we know them today. The historical importance of masonry is mainly due to the fact that it constituted the main structure typology of the most common buildings. In particular masonry walls, considered to be the main structural elements assuring the global stability of masonry buildings can be built using discrete elements, consisting of stones or blocks, natural or artificial, connected together in a stable manner, with a combination of mortar joints. The walls can act also as non-structural elements as partition and enclosure in reinforced concrete buildings. Similarly to structural walls, they have to meet several functional requirements, namely the stability to self weight, eccentric vertical loads and out of plane horizontal loads, visual, acoustic, thermal as well as resistance to water. Currently masonry walls built with ceramic bricks with horizontal perforation with a thickness in a range between 7 and 15 cm, are the most used construction solution for partition walls. This system,
with a wide tradition, became the preferred solution due to its easiness of execution, flexibility and reduced cost. The construction of partition walls using this technique has to be carried out in different steps: (1) bricks humidification; (2) placing of first row; (3) placing of second row with connection to the first one through the application of a binding material, so that the vertical joints of two successive rows are not aligned; (4) placing of infrastructures. However, it should be stressed that lightweight solutions have been increasing in recent years.

The main objective of this study is the proposal of a green solution for partition walls based on blocks of a composite material that combines the use of granulated cork, textile fibers and gypsum. All raw materials are considered as sub-products of industries of cork, recycling tires and a thermoelectric power station. Thus, given the origin of the raw materials, a more efficient environmental performance compared to traditional solutions is sought for this product. In fact, nowadays only about 10% (in weight) of all that is extracted from the planet by industry is actually used in useful products, being the remaining considered waste. Therefore, a sustainable management of existing natural resources leading to a sustainable consumption is mandatory.

This article describes the solution for the blocks and for the constructive system, the details about the composite material, preliminary results on compressive mechanical properties of blocks and evaluation of the behaviour of the composite block for distinct load conditions based on a numerical simulation.

2 Constructive system

A new block has been developed for the execution of partition walls in new buildings, as well as in the rehabilitation of walls in existing buildings. The block consists of the assemblage of two symmetric halves. The half blocks can be used in rehabilitation works, see Fig. 1.

The block was designed so that vertical and horizontal holes are achieved (Fig. 1a and Fig. 1b). The block has an external and rectangular part with a constant thickness of 25mm and an internal part with variable thickness, constituted of concave and convex shapes. In the concave parts, the block has a thickness of 70mm and in the convex presents a thickness of about 25mm. The connection between blocks is made through a male-female system both in bed and head joints. It is intended that the vertical joints acts as dry masonry joints and a thin layer of gypsum mortar is added at the bed joints.

The major advantage of the block consists of the possibility of installing the infrastructures without the need of making holes after construction of the wall, avoiding the waste of materials and reduction of the cross section. For this, it is intended that the construction of the walls is phased according to the following steps: (1) the laying of half block up to a certain level in height; (2) installation of infrastructures and (3) connection of the other half block. The assemblage of the two half blocks is made through the perimeter of the inner face and the concave zones with appropriate adhesive material.

Figure 1: Geometry of the block: (a) half block; (b) whole block
3 Characterization of the composite material

The composite material results from the combination of FGD gypsum, re-granulated expanded cork, textile fibers and the setting time retarder, the citric acid. The FGD gypsum is a synthetic industrial by-product which comes from flue gas desulfurization of thermal power plants. It is chemically identical to conventional gypsum, provides more environmentally friendly applications and is highly available [4]. Cork (part of Quercus Suber L) is a material whose characteristics are of great interest for the construction industry. It is regarded as a strategic material of great potential due to its reduced density, elasticity, compressibility, resistance to water, good vibration absorption and a good efficiency in thermal and acoustic isolation [2,3]. In this work granulated cork was used in order to lighten the weight of the gypsum based composite and at the same time provide a better thermal and acoustic efficiency. Moreover, textile fibers obtained by recycling of used tires were also used in order to confer a greater resistance and ductility to the composite material. A setting time retarder (acid citric) had to be used so that hardening of composite material is compatible with the manufacture of the block. In fact, FGD gypsum reacts with water very quickly leading to the fast solidification of the mixture avoiding the maintenance of suitable workability to handle the fresh composite.

Aiming at obtaining the final composition of the composite material for the manufacture of the blocks, an experimental campaign was carried out aiming at obtaining the mechanical characterization of the produced compositions. Four distinct compositions were analyzed, see Table 1. As one of the solutions for the block envisages the use of an external pressed plate made only of gypsum, a pressed composition (P) was considered. Besides, three moulded compositions (M) resulting from the combination of FGD gypsum, textile fibers and cork were also studied. In these compositions the granulated cork was varied from 5, 7 and 9% (M5, M7 and M9) of the mass of gypsum.

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Typology</th>
<th>Water</th>
<th>Cork</th>
<th>Fibers</th>
<th>Retarder</th>
</tr>
</thead>
<tbody>
<tr>
<td>M5</td>
<td>moulded</td>
<td>80.0</td>
<td>5.0</td>
<td>3.0</td>
<td>0.05</td>
</tr>
<tr>
<td>M7</td>
<td>moulded</td>
<td>87.5</td>
<td>7.0</td>
<td>3.0</td>
<td>0.05</td>
</tr>
<tr>
<td>M9</td>
<td>moulded</td>
<td>93.75</td>
<td>9.0</td>
<td>3.0</td>
<td>0.05</td>
</tr>
<tr>
<td>P</td>
<td>pressed</td>
<td>22.5</td>
<td>-</td>
<td>-</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The experimental campaign was composed of compressive and flexural tests to obtain the compressive and flexural strength and the modulus of elasticity [5,6]. The pressed material has the highest density (1575 kg/m³) and the highest values of compressive and flexural strength and modulus of elasticity with 13.3 MPa, 1.47 MPa and 2196.9 MPa respectively. The mechanical behaviour of the moulded material is dependent on the percentage of granulated cork in the mixture. The density varied from 825 kg/m³ for composition M5 to 675 kg/m³ for M9, the modulus of elasticity ranged from 1899.6 MPa for M5 to 823.3 MPa for M9 and the compressive strength decreases from 3.1 MPa for M5 to 1.1 MPa for M9. The dependence of the flexural strength on the percentage of cork was not clear being the flexural strength of 0.58 MPa, 0.68MPa and 0.55MPa for M5, M7 and M9 respectively. The decrease of compressive strength with an increasing amount of cork appears to be approximately linear [5,6]. The global compressive and flexural behaviour of the pressed and moulded material is significantly different. The pressed material is considerably more resistant but presents a higher brittleness than the moulded material. In compression, the behaviour of the moulded material after the peak is defined by a slight resistance reduction for very high displacements, reflecting a much more ductile material. The difference in terms of modulus of elasticity between pressed and moulded material is lower being 15% higher than the moulded material.
4 Manufacture process of the block

Taking into account the type of finishing, two types of blocks were initially designed, namely a block completely moulded and a composite block with the nucleus made of the composite material connected to an external pressed plate. The existence of cork and fibers in the finishing layer proved to be inconvenient, due to the fact that it does not provide an aesthetically pleasing finishing.

For the manufacture of the moulded paste in first phase water and setting time retarder are blended through a suitable automatic mixer during 15s. After this the FGD gypsum is added, being blended for 30s. Finally, the cork and the fibers are added, blending them for 1min and 30s, so as to guarantee a homogenous paste. After preparing the mixture, it is placed in the mould (Fig. 2a). The pressed plate was produced using a hydraulic machine. The mixture (FGD gypsum, water and setting time retarder) is spread in a metallic mould after which a load of about 900kN, corresponding to 5.0MPa, is applied. If a composite block is intended to be manufactured, the pressed plate is connected to the moulded material as shown in Fig. 2b. If a total moulded block is required, the finishing surface can be obtained by placing a moulded paste consisting of FGD gypsum, water and citric acid above the composite material. The final finishing of the blocks, both in composite and moulded blocks is approximately the same.

Comparing the manufacture procedure of the two types of blocks, the completely moulded block is lighter, of faster execution and uses less equipment, having lower energy consumption, resulting thus in a more sustainable and economical solution.

5 Preliminary mechanical validation of the block

5.1 Experimental characterization of the block

Compressive tests were made in completely moulded blocks and in blocks with the pressed plate for the composition M7.

The tongued parts were removed from the blocks and edges of the blocks rectified so that adequate alignment of the vertical forces could be achieved. The two halves of the block were glued using an epoxy resin, applied on the perimeter and in the concave zones, in the same way as the blocks are intended to be connected in construction. Subsequently, a new rectification of the edges was done so as to ensure more accuracy in the execution of the tests. The tests were carried out under displacement control, in order to be able to acquire the post-peak behaviour. The load velocity was of 4.2kN/s, in accordance to the European standard 772-1:2000. A thick steel plate was placed at the top of the block to ensure uniform distribution of vertical load. Two vertical LVDTs were placed in the opposite sides.
of the block from which the average vertical displacement was calculated. A general view of the test setup can be viewed in Fig. 4.

![Test setup used for the uniaxial compression tests of the blocks](image)

The results obtained for the tests performed on completely moulded blocks and blocks with the pressed plate are presented in Fig. 5a, in which the stress-strain diagrams are shown. The strains were calculated based in the measured displacements and the stresses were calculated taking the gross area of the blocks.

![Stress-strain diagrams obtained in uniaxial compression tests](image)

The block with the pressed plate has a higher compressive strength, approximately 57% higher than the compressive strength of moulded block, but a more fragile behaviour, as after reaching the maximum strength a relatively marked reduction on strength takes place. The completely moulded block has much more ductile behaviour being the post-peak regime characterized by a smooth and progressive softening.

In order to verify the influence of different curing processes, compressive tests were carried out on blocks cured in a laboratory environment (about 20ºC) and in the oven (about 40ºC), after 14 and 21 days of curing (Fig. 5b). It appeared that the compressive strength of the blocks is influenced by curing conditions and time curing. The tests carried out on the blocks after 21 days of curing in the lab show an increase of 77% in compressive strength when compared to those performed on the same blocks after 14 days. Concerning the blocks cured in the oven, the tests done after 21 days point out an increase in compressive strength of 16% compared to the blocks tested after 14 days.

Comparing directly the tests performed at 14 days an increase of 122% of the compressive strength is observed in the blocks cured in the oven, relatively to those cured in the lab. However, this difference
tends to attenuate in time, as it can be noticed that for the tests performed at 21 days, the increase in the compressive strength of the elements cured in the oven is only of 45% compared to the blocks cured in the lab. With lab curing conditions, the cracking of the block occurs for levels close to the maximum load, whereas with the cure in the oven the cracking appears at early stages of loading.

6 Numerical analysis of the block

A numerical analysis was performed in order to compare the results with those obtained experimentally. The analyses were run using the software DIANA. A 3D model of the block was built using isoparametric solid wedge and brick elements (CTP45 and CHX60), both based on quadratic interpolation [7]. As the model resulted particularly heavy from a computational effort point of view, only half of the block was considered positioning the symmetry boundary conditions on all of the perimeter of the inner part and on top of the concave parts, as they’ll be connected in the partition walls. A linear elastic analysis was performed assuming the elastic material properties obtained experimentally for the moulded composition M7 [5,6]. The block was completely fixed at the bottom and on the top surface a uniform pressure was applied to simulate the vertical compressive load. For this linear phase, the stress distributions were analyzed in order to compare them with what was observed experimentally. The adoption of the half block was also considered to analyze its behaviour when used alone, for example for covering purposes.

It is important to emphasize how these results are only preliminary, as the experimental and numerical campaigns are still under progress, but they nonetheless show how the proposed block should behave. Considering the principal stresses distribution (Fig. 6), the compressive and tensile stresses paths can be observed and the potential cracking zones localized. Fig. 6a shows the maximum principal stresses. The external plate cracks are expected in the thinner part of the block due to higher tensile stress concentrations, which appeared to confirm the results obtained in the experimental tests on blocks (Fig. 7). The stress distribution shows that the loading path follows mainly the external plates with constant thickness being the role of the concave parts for resisting both to tension and compression almost marginal. Fig. 7 shows the experimental failure mode for the block cured in the lab for 14 days. It can be ascertained how the cracks appear in the thinner and weaker part of the block both internally and externally.

Figure 6: Maximum (a) and minimum (b) principal stresses for half block with symmetry conditions.

Subsequently, only half block without symmetry boundary conditions was considered, a situation which occurs when the block is used to cover an existing wall just for finishing purposes and is therefore subjected only to its self weight, or also to simulate the placement of the walls, as described above. For this block, an analysis for a wall was performed to see if the block is able to resist to the self weight of the whole wall. The wall studied was constituted of 9 blocks, for a total height of 2.7m.
Firstly, only the bottom block was considered applying on top a distributed load corresponding to the 8 blocks on top of it, so as to have a lighter model for the future non linear analyses. The load was applied both uniformly and with a trapezoidal distribution similar to the one given by the reaction forces of one half block subjected to its self weight. The comparison between the two models is reported in Fig. 8. The model in Fig. 8b represents better the real behaviour of the whole wall as it considers the real distribution of the weight of the blocks above the bottom one, whilst with the uniformly distributed load eccentricities are generated. In any case the compressive stresses at the base are considerably low and much lower than the compressive strength of the blocks obtained in the experimental campaign.

Secondly, the model with the whole wall was analyzed (Fig. 9). As the half blocks will only have a covering purpose, no additional loads were applied, only the self weight. The results are similar to those of the model represented in Fig. 8b. Slightly higher values were achieved for the model which considered only the bottom half block (Fig. 8b), both in terms of stresses (13.8% of difference) and of displacements (8.4% and 13.3% of difference for horizontal and vertical displacement respectively).
This is probably due to the fact that the boundary conditions for the two models are different, as the bottom block in the latter model is constrained on top, contrarily to the former one. It appears that the bottom block is able to bear the load of the blocks above, as the ultimate compressive strength is not yet reached, achieving only 1/10 of the compressive strength.

7 Conclusions

Based on the experimental results obtained, it can be concluded that the use of a mixture which incorporates FGD gypsum, granulated cork and textile fibers is suitable for the execution of blocks to be used in masonry constructions, provided they are seen as products with non structural purposes. The obtained results allow to identify a more ductile behaviour for the completely moulded blocks, as well as a reduction of compressive strength of 36% compared to the blocks with the pressed plate. Moreover, it was noticed a great influence of the curing processes on compressive strength. The blocks cured in the oven have a more brittle behaviour and compressive strengths greater than those cured in the laboratory of 122%, whereas there is a slight increase on strength in time for both curing environments. From the preliminary numerical analyses, the experimental results and the numerical ones seem to be in accordance and moreover it appears that the half block is able to bear the self weight of a covering wall.

Acknowledgements

The authors thank to Portuguese Agency on Innovation by financing the research Project SipdECO – developing innovative solutions for eco-efficient partition walls and to the companies Sofalca Lda, Pegop S.A., And Biosafe S.A.

Reference