Eco-friendly construction materials using gypsum and industrial wastes

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ABSTRACT: The sustainable construction greatly depends on the use of alternative products, such as industrial wastes. This paper reports the development of new composite materials based on gypsum incorporating granulated cork, a by-product of cork industry, cellulose fibres from waste paper and recycled used tyre fibres. The composite material developed is intended to be used as boards for non structural elements of construction, such as dry walls and ceilings. This research work studied the characteristics of the gypsum binder commercially available and its properties, as well as composite boards. In order to enhance the water resistance and mechanical properties of the composites several mineral additions were evaluated. Physical and mechanical properties of the developed boards were studied. Finally, fibre reinforced composites using waste materials were produced and analysed. Conditions and procedures of production were also studied using a pressure curing method in order to improve further the performance of the boards.

1 INTRODUCTION

The sustainable world's economic growth and people's life improvement greatly depend on the use of alternative products in the architecture and construction, such as industrial wastes. These materials conventionally have been referred to as "green materials".

Cork (bark of the plant Quercus Suber L), a substance largely produced in Portugal, is a material whose characteristics are of considerable interest for the construction industry. It is regarded as a strategic material with enormous potential due to its reduced density, elasticity, compressibility, waterproofing, vibration absorption, thermal and acoustic insulation efficiency (Gil 2005 & Hernández-Olivares, 1999).

Currently the world's annual paper consumption is in the order of 370 million tonnes (www.walesenvtrust.org.uk, 2007). Recycling of paper is generally considered to be the priority and best practicable environmental option. The cellulose is a self agglutinant material, when saturated and pressed link together its own particles. This material can provide a good binding agent for the used materials.

Tyres are produced at 250 million units each year in Europe (www.specialchem4polymers.com, 2004) and nowadays, there are recycling companies that proceed to shredding of used tyres, obtaining separated materials such as crumbed rubber particles, steel fibres and textile fibres from the tyre beads and reinforcement. The textile fibres have applications for use in insulation materials or as fibre reinforcing in concrete products (www.wastebook.org, 2007). In this research work the recycled used tyres textile fibres were used with the objective of providing reinforcement for gypsum composites.

The gypsum is a large used material in building construction by its diverse applications. However it is up till now a material with a lack of know-how, mainly at research level. The European production of extracted gypsum attained 21milions in 1996. The European industry has 220 factories that produce gypsum products and employ, direct or indirectly, more than 400 000 persons. In Portugal it have been produced about 500 000 ton of gypsum for each ear since 2000 (www.wastebook.org, 2007). The building sector consumes about 95% of total gypsum produced. It is calculated that about 80 to 90% of finishing interior work and partition walls in buildings are made of gypsum products, such as plaster and card gypsum. According to those thermal and acoustical properties, these products contribute significantly for the comfort of millions of persons. Having an extraordinary resistance to fire, the gypsum products contribute for the buildings security, particularly in public buildings.

One of the biggest deficiencies of gypsum as construction material is the low resistance to water. Although, actually, this aspect can be partially solved by adding to the gypsum some compounds based on silicones or other polymers, namely in gypsum card boards. This way, gypsum can be submitted to humid conditions, but even so do not permit utilization in external environments because of its low resistance to long direct contact with water.

The main purpose of this research work was to develop gypsum boards with enhanced mechanical and water resistance. To these boards were also incorporated wastes to turn them more lightweight and sustainable. It was intended to show that the manufactory of these boards for not structural construction elements is possible, for example, for internal and external coverings, dry walls and ceiling. For this, it was carried out the characterization and improvement of gypsum as construction material, turning it more resistant to water action. After, applications of this enhanced gypsum based material were studied focused on the mixture preparation, methods of casting and its corresponding physical performance.

2 MATERIALS

For this study four commercial available types of gypsum were selected: one plaster gypsum, recommended for manual application, one for projection, one for finishing and one escayola gypsum. According to the developed chemical analysis of these gypsums it was verified that the manual plaster and escayola gypsum presented a higher purity than the finishing plaster one by the higher calcium sulphate content (CaSO4). For this reason, these plasters were selected as the main materials for this research work. In terms of particle dimensions it was seen at laboratory tests (EN 13279-2, 2004) that the escayola gypsum have a bigger fineness. In terms of moisture content the tests (NP 319, 1963), shows that the plaster gypsum have a moisture of 1,05% and the escayola of 1,32%. It was also determined through tests (NP 318, 1963) the water/gypsum ratio necessary for a conventional plaster and the minimal gypsum content essential for hydration. The obtained water/gypsum ratio necessary for a conventional plaster was 0,52 and for the minimal hydratation reached 0,20.

The used granulated cork is a by-product of a Portuguese industry containing diverse parts of cork with different particle sizes. The density is 384,5 kg/m^3 and the bulk density is 160,0 kg/m^3.

The cellulose fibres or paper pulp was made in the laboratory joining waste office paper, triturated in a mix machine, and water. The water content was the necessary for the mixture with gypsum.

The used tyre fibres are a material obtained by a recycling company of used tyres shredding. These fibres are generally composed by wires and cords (70% polyester, 15% nylon, 15% glass) and some rubber residues.

The water absorption tests were realized according to the Portuguese standard, NP 762, 1969. For developed mixtures cured under pressure it was added a mineral retarder to extend the time of curing.

3 METHODOLOGY AND RESULTS

3.1 *Incorporation of cellulose, granulated cork and tyre fibres on gypsum plasters*

It was produced four different plasters with a constant water/gypsum relation of 0,7 with the plaster for finishing. One was made without any addiction (mixture G), one with cellulose fibres (mixture G/Paper), one with granulated cork (mixture G/Cork) and the other with tyre fibres (mixture G/ Tyre fibres – see figure 1). These samples were tested for compressive strength at dry and saturated after immersion conditions (Comp Dry and Comp Moist), to evaluate the lost of resistance during water contact. Flexural (Flex) strength and water absorption by immersion were also tested. The samples were cured at room temperature until 7 days and maintained at 40ºC, to stabilize the moisture amount, and the immersion was realized until two hours at room temperature.

Figure 1 – Gypsum plasters with cellulose fibres, granulated cork and tyre fibres

Analysing the obtained results it can be seen that the cellulose fibres addiction slightly improves the flexural strength and maintains the compressive strength, even in dry or moisture conditions samples (see figure 2). However the additions of cork or tyre fibres decrease the compressive resistances. At flexural strength the tyre fibres have a similar behaviour to the cellulose. For both addictions more ductile behaviour was verified during the mechanical tests. Figure 3 shows a reduction of 15% of water absorption on reinforced mixtures with cork or paper. For other side, with the addition of tyre fibres it was verified a small increase of water absorption.

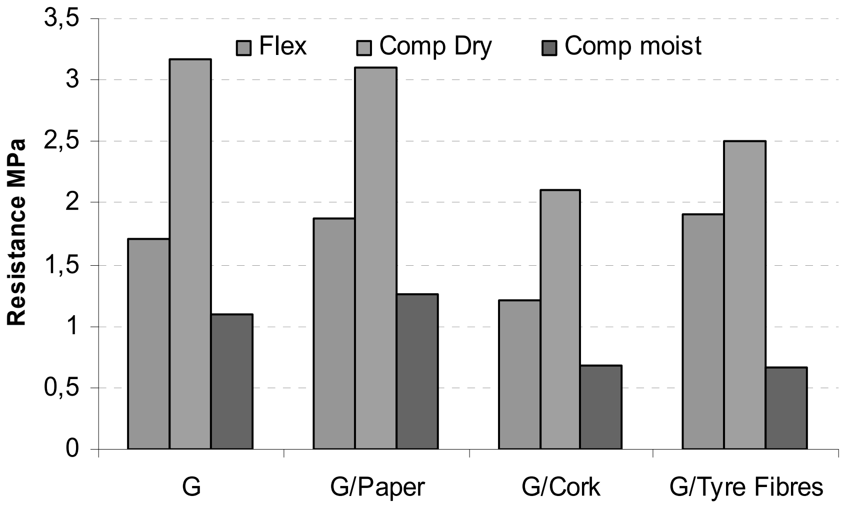

Figure 2 – Compare of plasters with paper, cork and tyre fibres

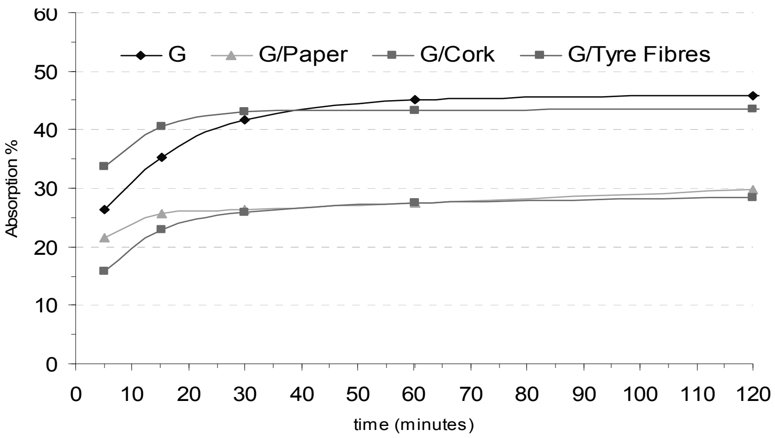

Figure 3 – Absorption of gypsum plasters

3.2 *Reducing water absorption by pressure curing*

A tested method for reducing the water absorption was by pressure curing of the gypsum based mixture. With this procedure it was possible to minimize the voids content and enables a reduction in the amount of water necessary to the mixture. This way, one can produce a much more compact mixture and, consequently, enhance significantly its performance. In this stage it was prepared a low consistence mixture joining plaster gypsum to only 20% of water (in mass). That corresponds to the minimal experimental determined value needed for hydration. Using a manual hydraulic press cylindrical samples were produced under a pressure of about 40,0 Psi (275,8 kPa). These samples were made at two different temperatures (room temperature, 25ºC, and 50ºC) and both were maintained after casting at room temperature until 7 days. For the tests the samples were maintained at 40ºC to stabilize the moisture content. After this the samples were submitted to compressive and water absorption tests by immersion until 2 hours. The saturated samples were also submitted to compressive tests.

Observing figure 4 one can compare the compressive strength results obtained in these pressed gypsum based mixtures made with the others selected plasters available on Portuguese market. As one can see a considerable increase on the compressive strength on the dry samples of pressed gypsum (legend on graphics as Press25º and Press50º), mainly at 50ºC, was attained. On the other way, the moist samples show a small increase in compressive strength.

In figure 5 it is possible to observe the water absorption test results obtained on pressed and un-pressed samples (pressed gypsum, plaster and commercial card gypsum board commercial designated as water resistant WR and in figure 5 as card gypsum WR). These results demonstrated the greatly favourable effect of pressed curing, responsible for a decrease in water absorption of about 40%. Comparing the pressed gypsum with the commercial available card gypsum tested, the pressed one maintains the values and the absorption of card gypsum continue to increase along the time.

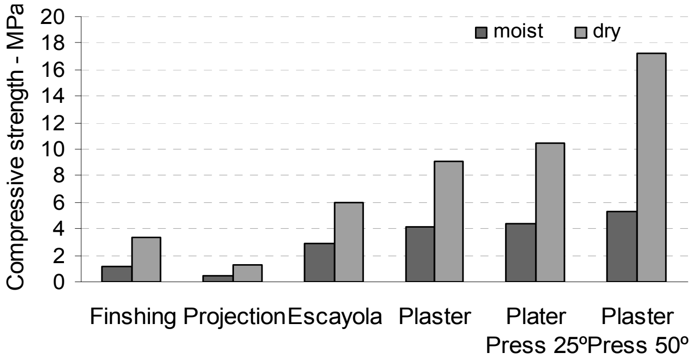

Figure 4 – Compare of plasters /pressed gypsum

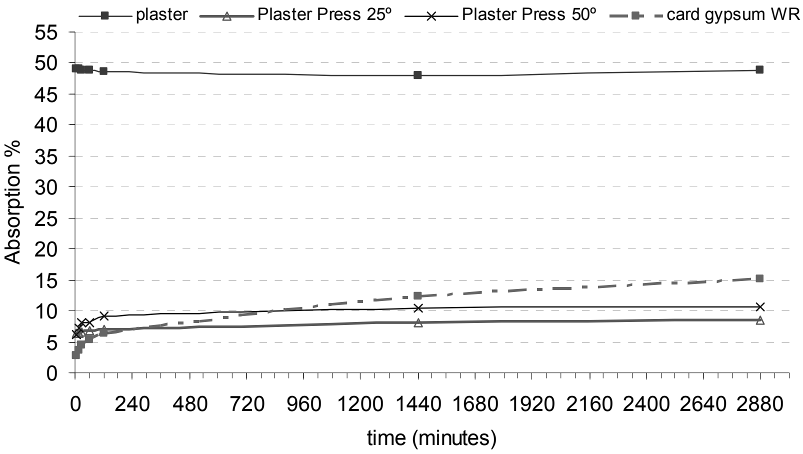

Figure 5 – Compare of pressed/plaster/card board gypsums

3.3 *Incorporation of cellulose, granulated cork and tyre fibres on pressed gypsum boards*

Once the pressure curing reveals to be very promising, it was adopted to the producing of gypsum boards. For the development of these boards it was necessary, at a first stage, to make them without any addiction to obtain the better process of manufacture and to achieve the adequate cohesion and finish. These boards were prepared with a metallic mould of 200x200 mm^2, filled with the fresh mixture made with a water/gypsum ratio of 0,20 and incorporating 0,3% (of gypsum mass) of mineral retarder. The boards were submitted to a pressure of 87,0 Psi (600,0 kPa) during 10 minutes. The boards were removed from the mould at the day after the casting and conserved subjected to 40ºC for curing and drying during 7 days. These have the designation P0 in Table 1 and figure 6.

As the same way, the boards with granulated cork and/or cellulose fibres or paper pulp were prepared following the same methodology of mix, casting, pressure and curing conditions (P1a until P4b). Six mixtures were prepared: two introducing granulated cork (2,5 % and 5 % of the mass of gypsum), two with paper pulp (3 % of the mass of gypsum) and the referred cork content (see Table 1); two with tyre fibres (2,5 % of the mass of gypsum) and the cork content; and other two mixtures with tyre fibres and paper pulp (2,5 % of the mass of gypsum and 3% of paper) and the cork content.

Table 1 – Material Percentages of boards (in mass of gypsum)

Board	Cork %	Paper %	Tyre %	Kg/m3
P0	–	–	–	1531,863
P1a	2,5	–	–	1460,39
P1b	5,0	–	–	1269,36
P2a	2,5	3,0	–	1168,939
P2b	5,0	3,0	–	1321,123
P3a	2,5	–	2,5	1281,439
P3b	5,0	–	2,5	996,0474
P4a	2,5	3,0	2,5	1311,23
P4b	5,0	3,0	2,5	1198,939

The next figures show the final appearance of the developed boards and the texture correspondent at near the real scale (see figures 6 to 8). Figure 6 show the simple board and incorporation of granulated cork and tyre fibres, figure 7 shows the incorporation of granulated cork and paper pulp in pressed gypsum-based boards.

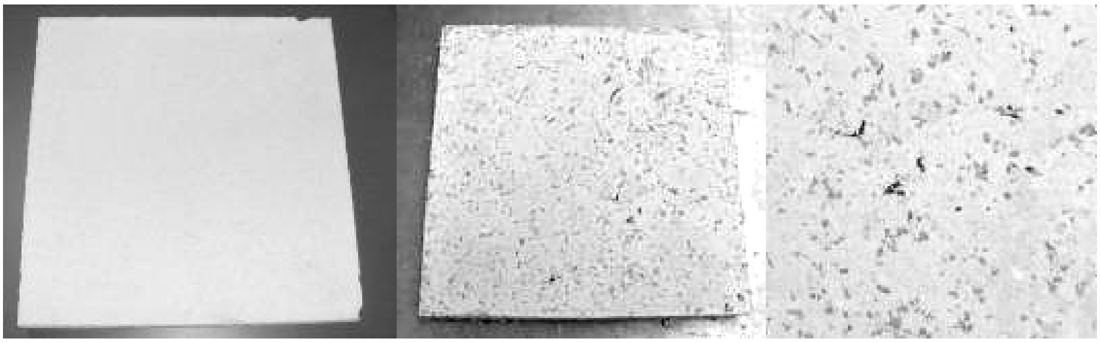

Figure 6 – Board of pressed gypsum P0 and board with cork and tyre fibres P4a and is texture

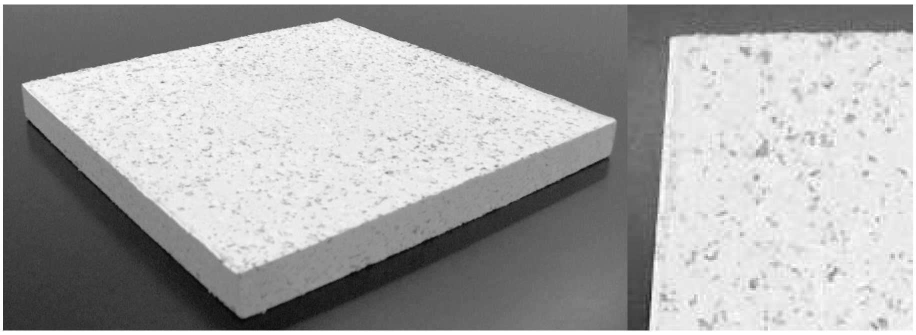

Figure 7 and 8 – Board of pressed gypsum with paper and cork and is texture P2a

These boards were submitted to flexural tests at 7 days of curing to evaluate their mechanical behaviour. By observing figure 8 it is possible to conclude that the mixtures flexural strength diminish with an increase of incorporated waste content, either for cork granules, paper and tyre fibres. Although, the paper fibre reinforcement on the mixture made with the greater cork content (P2b) reduces significantly the difference of resistances, showing the same behaviour in the paper reinforcement with the tyre fibres (P4a and P4b). This happened because the cellulose fibres behaved as a link between cork and gypsum turning the material more compact. The two materials work together as an adequate complement turning the boards more ductile than P0 (see figure 9).

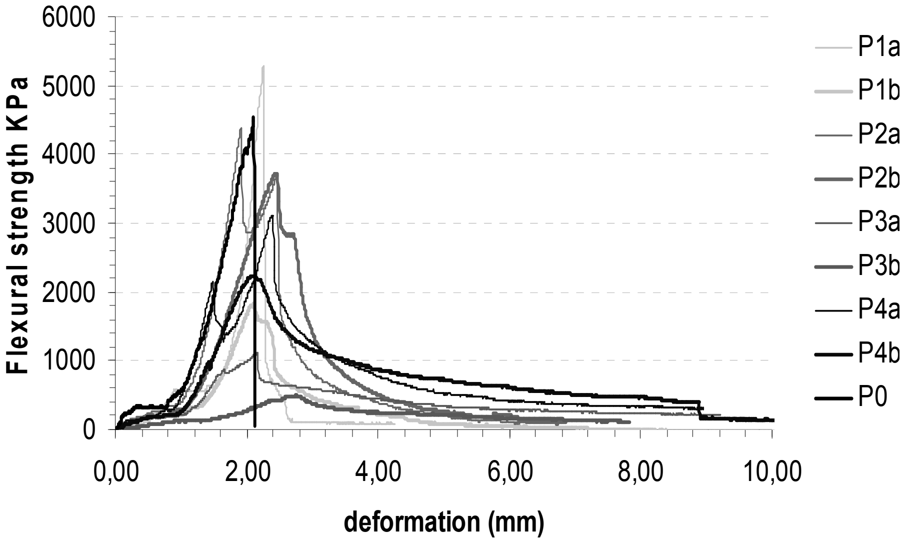

Figure 8 – Flexural behaviour of pressed gypsum

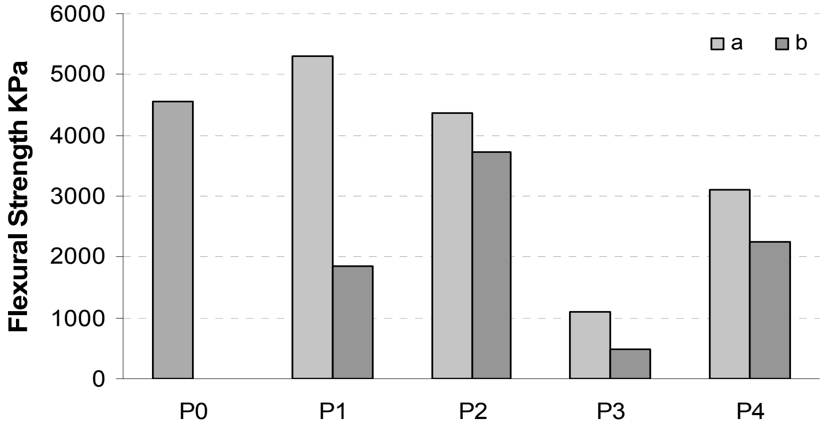

Figure 9 – gypsum/cork and cork/paper

4 CONCLUSIONS

According to the obtained results in the tested boards one can conclude that the incorporation of granulated cork or tyre fibres on plaster gypsum and pressed gypsum seems to be possible but reduces their mechanical performance. However these disadvantages can be compensated when compared with sustainable profit, density reduction and improvement of the conventional gypsum board in terms of thermal and acoustical behaviour (properties to be tested with the continuity of this research work).

This research work shows that it is possible to reduce significantly the water absorption by immersion, permitting an external application of these gypsum boards.

The addition of cellulose fibres can improve the flexural behaviour allowing higher cork contents with less reduction on resistances. Furthermore, this addition offers a better cohesion and finishing appearance when applied on pressed gypsum boards.

As well, it was verified the possibility of manufacture non structural construction elements, for example, internal and external coverings, dry walls or ceiling. These are new applications for the waste materials mentioned, turning the boards more environmental friendly, and promoting a new possibility for use gypsum in the external environments.

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