NEW ECO-FRIENDLY HYBRID COMPOSITE MATERIALS FOR CIVIL CONSTRUCTION

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ABSTRACT

This paper concerns the development of new hybrid composite materials using granulated cork, a by-product of cork industry, cellulose pulp, from recycling of paper residues, and hemp fibres. The binder used is either cellulose pulp or lime-pozzolan mixture. Such materials may be used as composite boards and mortars for non structural elements of construction, such as dry walls and ceiling or floor levelling and filling. The possibility of using these composites in conjugation with light structural supports has been studied. The paper will present the properties and the manufacturing methods used to produce the above mentioned promising eco-friendly composites that can unfold ways of using industrial wastes as new construction materials with excellent inherent thermal and acoustic properties.

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 conventionally called "green materials". The granulated cork, a by-product of cork industry, the cellulose pulp, obtained from paper residues recycling and the hemp fibres are obvious materials to be used for this purpose.

These materials are able to be used as composite boards and mortars for non structural elements of construction, such as dry walls and ceiling or floor levelling and filling. Cork, which is a substance largely produced in Portugal, combines a reduced density and high elastic, compressive, impermeable and thermal properties with excellent acoustic insulation and dumping absorption characteristics [1, 2]. Natural hemp fibres, *cannabis sativa L*, being devoid of any psychotropic substances, can be used as reinforcement with mechanical proprieties similar to jute staple, sisal, flax and coconut fibres. These fibres may compete with synthetic ones in respect to chemical, physical and mechanical properties, especially in tensile strength, thermal and acoustic insulation and bactericidal characteristics [3, 4].

Cellulose pulp or lime-pozzolan mixtures were used as binders of the new hybrid composite materials developed in this research work. An optimal metakaolin and lime content was achieved to produce the binder for the developed composites. The final mixture was used to produce hemp fibres reinforced lightweight composite block and plates that were tested revealing to have promising properties.

Composites made from paper pulp and granulated cork, incorporating small amounts of polymeric binders and mineral additives, were also submitted to tests to determine their physical and mechanical properties. Sandwich panels made by combining these composites with light structural honeycombs were also studied.

The obtained results show that these promising eco-friendly composites can be easily manufactured with excellent thermal and acoustic properties.

2. RESULTS & DISCUSSION

2.1 Optimum metakaolin/lime content in the new composite binder

To determine the optimum metakaolin and lime content for the new composite binder, metakoalin-lime mixtures produced using different metakaolin/lime percentages were submitted to compression tests at different curing times. The best results were achieved with 75% of metakaolin and 25% of lime (see Fig. 1).

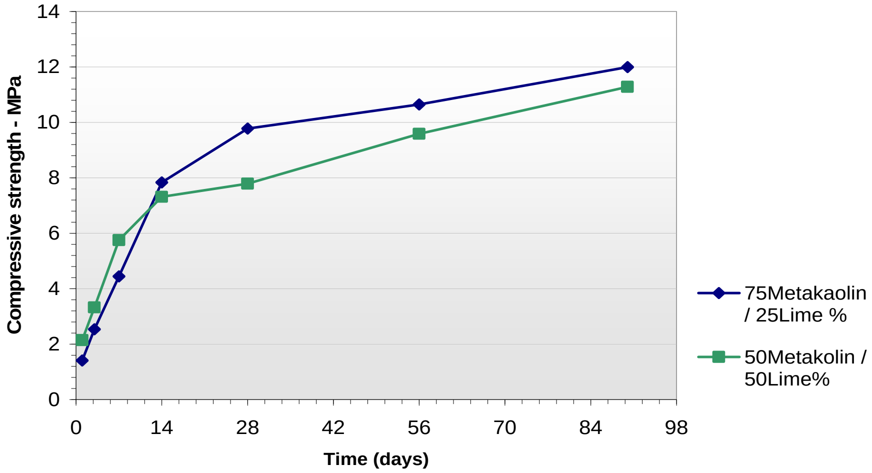


Figure 1. Compressive strength of mortars using different metakolin/lime contents

The influence of curing temperature on the pozzolan mortars was also investigated and the obtained results have shown that warmer environments are more suitable, such as in the summer season. In fact, a decreasing in the hardening rate was observed when lower temperatures occurred in the initial 42 days of the curing process. A consolidation of mortars applied in cold winter days can become difficult [5].

2.2 Hemp lightweight concrete

2.2.1 Hempcrete blocks

After studies carried out on the effect of different mineral additives, three different compositions were used to produce hemp fibre reinforced composite concrete (hempcrete) blocks. A metakaolin/lime mixture, using the optimum proportion defined in the previous paragraph (75/25), was used as binder in the produced hempcretes.

Table 1 shows the used composition of concretes [6]. Figure 2 depicts the typical aspect that the fabricated hempcretes presented before and after curing. Two mineral additives were also introduced in the compositions.

It is noted that during compaction fibres become mostly oriented in one direction.

Samples of the three different made hempcretes were submitted to compression tests in the direction parallel to hemp fibres, which mechanically can be considered as the most unfavourable direction.

As Figures 3, a) and b) show, all the manufactured hempcretes demonstrated to have a ductile failure. Up to Figure 4 shows that after achieving a critical strength samples continued to deform at constant stress.

Table 1. Composition of the produced hempcrete blocks

Composition	Sample reference		
	B6	**B7**	**B8**
Hemp hurds (fibres) (5-15mm length, thickness>2mm)	24%	29%	34%
Waste paper in pulp (paper mass)	10%	5%	-
Metakaolin	53%	53%	53%
Lime	13%	13%	13%
Additive 1	2% of lime	2% of lime	2% of lime
Additive 2	2% of lime	2% of lime	2% of lime
Water ratio in paper pulp	86% of paper	86% of paper	-
Water/Binder ratio	1	1	1

a) before curing

b) after curing

Figure 2. Hempcrete block samples with 0.05x0.05x0.05 (m), before and after curing

a) at the initial rupture

b) after the initial rupture

Figure 3. Compressive behaviour of the hempcretes

Considering that these developed lightweight composite concretes, as other existing hempcretes [1, 4], are non-structural materials intended to be used in combination with structural elements, such observed ductile behaviour may be attractive as it enhances the accommodation and adjustment between structural and non-structural elements. This improves the absorption of small displacements and dumping, which always occur in houses and buildings.

As can be seen in Figure 4, higher compressive strengths were obtained when paper pulp was used in the hempcretes composition (samples B6 and B7). Furthermore, all compositions have shown to have a satisfactory compressive strength for the foreseen non-structural applications. The final average compressive strength obtained, 0.6 MPa, was similar to that observed by other European research centres [4, 7].

The experimental results do not indicate a continuous increase in strength with curing time. The reason for this behaviour is not clear at this time.

Normally, compressive strengths of this order are considered adequate for non-structural lightweight concretes. Thus, the mechanical behaviour observed indicates that this material may be used in many applications where conventional mixtures are being used. These eco-efficient hemp/lime mixtures can substitute other raw materials that have high CO_2 emissions.

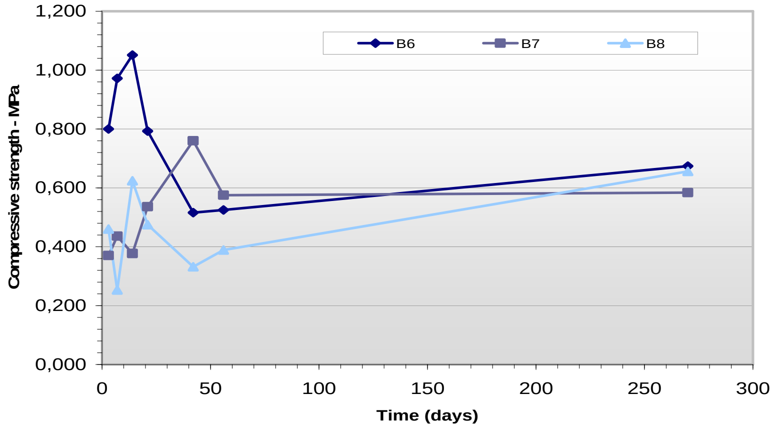


Figure 4. Variation of the compressive strength until 270 days

The developed hempcretes were also submitted to water absorption tests to evaluate the resistance to water and moisture. The results obtained are shown in Figure 5. To improve the hempcretes water absorption, three products were added to B6 composition to obtain the products designated as B6 waterproof, B6 PVA, B6 varnish and B6 oil in Figure 5. They correspond, respectively, to additions of a chemical product (Q2 Isolit Cer S supplied by Quimidois company), a Polyvinyl Acetate (PVA) based glue solution, a colourless and shining synthetic varnish (usually used in outside wood) and a linseed oil (similar to the hemp oil).

The product referred in Figure 5, as B8 (compact) correspond to hempcrete compacted mechanically.

As may be seen in Figure 5, the use of paper pulp leads to higher water absorption,values that can reach about 100% or more. However, this limitation can be significantly reduced through the addition of an adequate waterproofing product. The painting of Q2 Isolit Cer S reduced the water absorption percentage for a value of approximately 3.34 % at the end of four curing days. Samples with higher compaction effort showed lower absorption (compare B8 compact with B8).

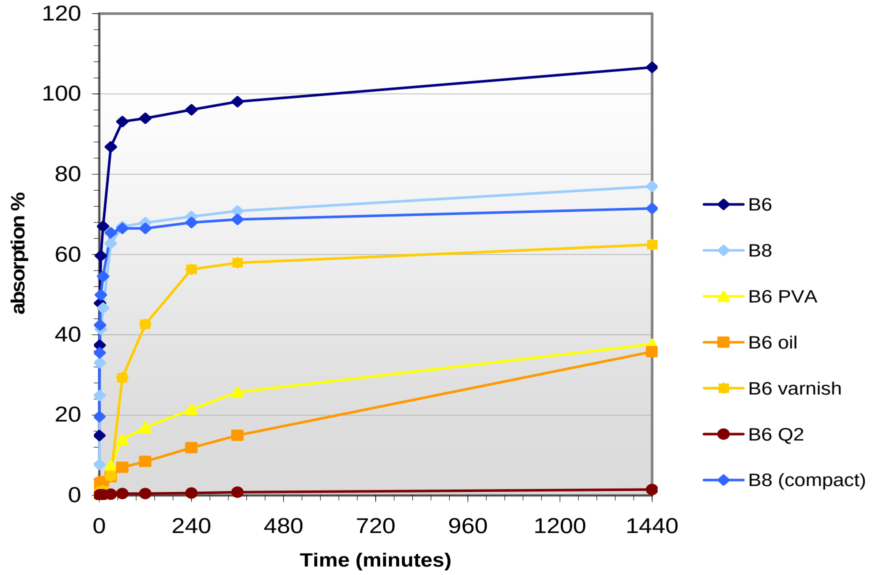


Figure 5. Water absorption percentage against time (24h)

2.2.2 Hempcrete plates

Mechanical compaction was used to manufacture hempcrete board using the compositions referred in Table 1. These boards may be employed in many applications, such as walls or pavements.

Figure 6 presents the final aspect and the texture of the manufactured hempcrete plates.

a) final hempcrete plate

b) hempcrete plate's texture

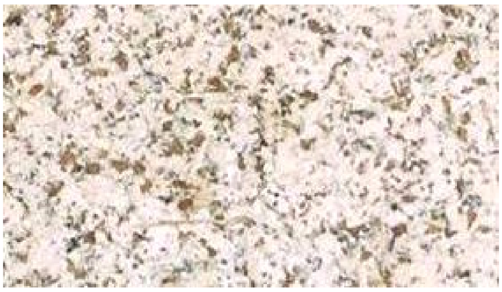
Figure 6. Hempcrete plates manufactured by mechanical compaction

In these plates the hemp fibres are dispersed in all directions, which improve the material mechanical performance. As observed with hempcrete blocks, the compacted plates have proven to show a similar ductile behaviour when submitted to compressive tests [8].

2.3- Granulated cork and paper pulp composite plates

Several composite plates were manufactured using different paper pulp and granulated cork contents. An additive and hemp fibres (2cm length) were incorporated to improve the mechanical strength, the water absorption performance and the fire resistance. Gypsum was used as binder. The typical aspect of the manufactured plates may be seen in Figure 7.

a) plate's general aspect



b) plate's texture

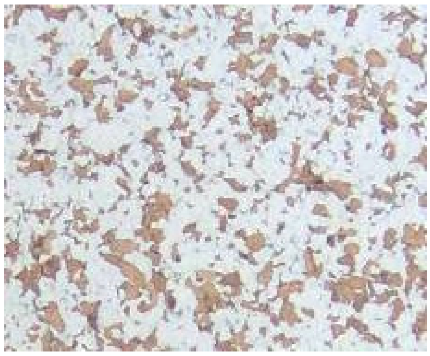
Figure 7. Paper pulp and cork plates reinforced with hemp fibres

In these plates a different curing methodology was used. After casting, plates were subjected simultaneously to compression and thermal curing.

The process was optimised in order to minimise the energy and time consumption. The best results were obtained using a compaction force of 15kN and a thermal curing temperature of 110 ºC during 3 h or, alternatively, at room temperature during 3 days.

This procedure allowed to obtain plates with satisfactory cohesion and with a completely smooth texture. Figure 8 shows a typical granulate cork and paper pulp plate manufactured in these conditions.

a) final typical aspect



b) plate's texture

Figure 8. Plate made from granulated cork and paper pulp after curing.

The plates showed to be fragile in flexion and the obtained average flexural strength was 400KPa.

It is usual to use a compression/decompression test to evaluate the mechanical behaviour of specimens containing cork particles.

During this test the material did not suffer significant changes under compression up to 4% of deformation and recovered 28% of the deformation during decompression phase.

The manufactured plate samples were also subjected to water absorption tests. The tests revealed that the original material presented high water absorption (about 160%). Thus, the same mentioned waterproof products were used. The application of these waterproof products reduced significantly the water absorption effect. The results were reduced to 50% with linseed oil, 80% with varnish and 100% with PVA.

Three tests were used to determine the coefficient of thermal conductivity on plates with dimensions 50x50x4cm. An average coefficient of conductivity λ_{10}=0,084W/mºC was obtained. By comparing this coefficient with those of other materials used for similar applications, one may conclude that the developed board has a good thermal conductivity (see Table 2).

Table 2. Thermal conductivity of different materials used in construction

Materials	**Thermal Conductivity** (W/mºC)
Gypsum/Paper pulp	0,36
Gypsum Card	0,18
Hempcrete with lime	0,13-0,19
Developed Composite – Paper pulp/cork	0, 084
Composite of expanded cork	0,036-0,40
Cork	0,045
Rock wool	0,045
Hemp fiber isolation	0,040
Polystyrene	0, 03

In order to improve the flexural performance of the developed board, the material was combined with commercials available recycled paper and polypropylene (PP) honeycombs to form sandwich panels (see Figure 9). Such sandwich panels, having rigid or flexible polymeric honeycombs, are used to increase the flexural behaviour of structural elements. The use of sandwich board could allow panels to be used in applications, such as, dry walls and ceiling.

It is seen that the presence of water in the paper honeycomb structure affects significantly the stiffness and strength of the panels. Thus, the panels made by combining the cork/paper pulp plates with the honeycomb polypropylene presented not only better mechanical results but also higher consistency and appearance. As Figure 9 shows, the polymeric structure is adequate for the mechanical compaction process used.

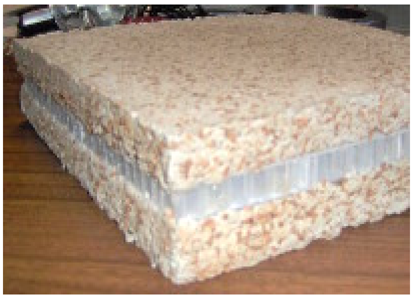


Figure 9. Sandwich panel made from a paper pulp/cork plate and PP honeycomb

Figure 10 depicts the results of the flexural tests for evaluating the mechanical behaviour of the sandwich panels. As it can be seen, the better performance was obtained for the combination of the base composite plate with a polypropylene honeycomb. By comparing the results with those obtained for other materials used in dry walls, covering and ceiling, the obtained strengths were similar than those obtained on gypsum card panels.

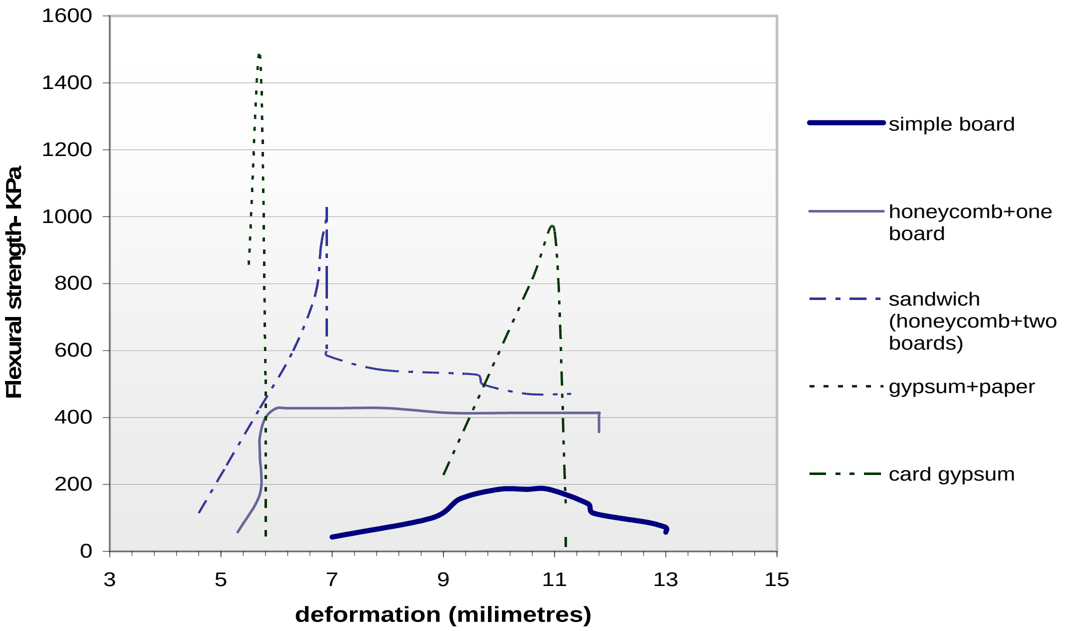


Figure 10. Flexural behaviour of different materials

The thermal coefficient of conductivity was also determined for the produced honeycomb sandwich panels. It was noted that the obtained value (λ_{10} = 0.085 W/mºC) was similar than the one determined in the initial pulp/cork panel.

3. CONCLUSIONS

The best binder for the eco-efficient composites developed in this research work was a mixture of 75% metakaolin and 25% lime.

It was found that higher curing temperatures increased the rate of strength gain of this binder.

The developed lightweight hempcretes blocks showed a ductile behaviour which may be considered compatible to the majority of the non-structural possible applications. The granulated cork/paper pulp composites have also proven to have adequate properties for several non-structural applications, such as, coverings walls, dry walls and ceiling. Furthermore, the sandwich panels made from the combination of the cork/paper pulp composites with polypropylene honeycombs have shown to improve significantly the flexural behaviour of the developed eco-friendly materials.

Furthermore, the developed composites have good thermal insulation characteristics and can be produced to have low water absorption.

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