Not Conventional Materials for a Sustainable Construction: A Bio-construction System Reinforced with Cellulose Fibres

Rute Eires [1], Said Jalali [2]

[1, 2] Departament of Civil Engineering, University of Minho, 4800-058 Guimarães, Portugal

[1]rute@civil.uminho.pt, [2] said@civil.uminho.pt

Keywords: Construction Technology; Unconventional Materials; Sustainable Construction, Industrial Hemp; Paper Residue; Natural Fibres.

Abstract. The aim of this research was to determine the main characteristics and relative performance, in comparison to conventional masonry, of a composed hempcrete or hemp-concrete. The material under investigation was made of hemp cellulose and waste paper pulp from paper waste, with a composed binder of metakaolin and lime, without cement addition. This made for lighter concrete with superior characteristics to those of traditional concrete, in that it allowed for manufacturing of blocks and boards, and so the development of a prefabrication system. The main characteristics of this composed *hempcrete or hemp-concrete* were therefore studied, and its relative performance evaluated both in terms of thermal and acoustic insulation, and in terms of mechanical strength.

Fig. 1 - Concrete with Cellulose of Industrial Hemp (hemp hurds) – University of Minho

Introduction

Industrial hemp, *cannabis sativa L*, is an extraordinary non-toxic and non-narcotic plant (it has extremely low contents of psychoactive compounds, below 0.2% THC on the basis of dry matter), and has been used for a wide variety of applications for thousands of years. In ancient times people would add hemp hurds and fibres to their clay building bricks to make them stronger and more durable. The hemp hurds were extracted from hemp plants through a dry process, without the use of chemicals or the need for rotting, leaving an interior core with a high percentage of cellulose fibres.

Fig. 2 - Industrial hemp hurds

The industrial hemp thus presents itself as an environmentally favourable, quickly renewable resource, with low levels of embodied energy and high silica percentages in its composition. In Europe, hemp hurds and fibres are increasingly being used in construction, in applications such as thermal insulation, composites replacing fibreglass based materials, concrete and the rehabilitation of old buildings. Despite their higher cost relative to traditional material, their ease of handling, low environmental life cycle impact and superior moisture diffusion and sound proofing properties are hemp hurds and fibres a new sustainable path in many European countries.

[1] Architect, Post-graduated in Materials and Rehabilitation of Construction
[2] Associate Professor

Hemp Construction. Structural concrete based on cellulosed hemp fibres or hurds is not currently manufactured. Yet such hemp based concrete, activated by alkaline hydrated lime, makes for a much lighter material than the conventional, with excellent insulating thermal and acoustic properties, permeable to water vapour without the occurrence of superficial condensations, fire-extinguishing, resistant to bacteria and insects, and protective of wooden structures.
This type of concrete can be produced through a variety of methods: concrete with pulp paper, boards of paper pulp with gypsum or fly ashes, or still composites of paper pulp with hemp, mainly used for design pieces. None of these materials, however, can totally fulfil the functional and economic requirements of current constructions. This is due not only to extended curing times, reduced in some cases by the addition of cement, but also to the need for better compaction and more workmanship.

Experimental Work

The new construction system proposed aims to fulfil as many market needs as possible, thus appealing to as large a share of that market as possible. The technologies applied both create novel combinations of raw materials typically put to alternative uses, and incorporate completely new components, such as waste paper pulp, lime and metakaolin. A summarised comparison between this component reformulation and conventional concrete can be found in Table 1.

Aggregate	Sand	Cement	
⇩	⇩	⇩	
Hemp Cellulose	**Waste Paper Pulp**	**Lime**	**Metakaolin**
Low embodied energy (1.15kw/m3)	Waste utilization - Recycling	Soft increasing of mechanical strength	Cement substitution – less carbon production.
Natural material – renewable		More faster drying material	
Bacterial and insects resistance	Reduced costs	Reduced costs	Reduced costs
Increasing of mechanical strength by cellulose fibres	Increasing of mechanical strength– by mortar consistency	Fire resistance	Fire resistance
Reduced permeability to water – water absorption control	Better water absorption control	Fire resistance	Fire resistance
	Cracks reduction		

Table 1. Components reformulation

Compositions and Materials. The dosages of each of the components of the new material were adjusted in order for it to acquire the desired characteristics. As a first step, the optimal proportion of lime was fixed in metakaolin mortar: the metakaolin and water components and lime were both compressed in small test specimens, cured at constant room temperature and humidity (Fig. 3). This same method was then used to study the effect of a number of mineral additives on strength at young ages; and in a second stage, percentages of waste paper pulp and hemp hurd were used for the best mortar obtained previously, and their effects analysed (Table 2). Samples of each of the three materials were obtained and tested for compressive strength at different ages.

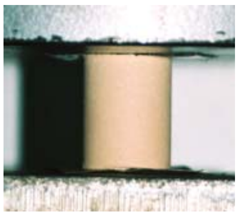

Fig. 3 - Metakaolin-lime mix.

	Mix 1		Mix 2		Mix 3	
Composition		Kg/m3		Kg/m3		Kg/m3
Hemp Hurds (5-15mm, esp.>2mm)	1,000	114,286	1,000	114,286	1,000	114,286
Waste Paper Pulp (dry)	0,420	56,000	0,187	21,333	-	-
Water at Pulp	2,580	295,030	1,146	131,048		
Metakaolin	2,250	257,143	2,250	257,143	2,250	257,143
Lime	0,562	64,286	0,563	64,286	0,563	64,286
additive 1	0,001	1,286	0,001	1,285714	0,001	1,286
additive 2	0,001	1,286	0,001	1,285714	0,001	1,286
Water	2,800	320,000	2,800	320	3,710	320,000

Table 2. Materials used for different mixes studied

Results and Discussions

Physical Characteristics and Compressive Strength. The *hempcrete* obtained, like traditional concrete, needs to undergo a compaction process. The composite material takes one to two weeks to cure, and its strength increases progressively as it cures, due to the reactions that take place. Because this process requires more time compared to conventional concrete the latter reaches higher strengths more quickly.

Fig. 4 – Concrete with hemp hurds, metakaolin, lime and waste paper pulp.

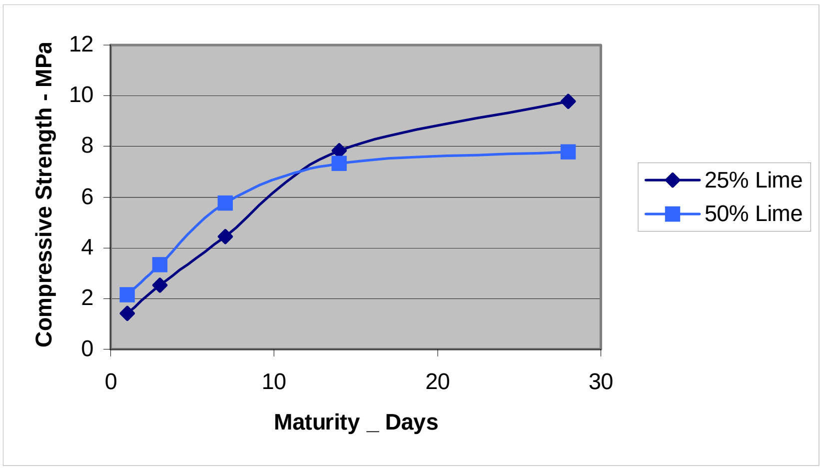

Fig. 5 – Lime stabilization

The compressive strength tests allowed for the possibility of minimizing lime incorporation to be checked. The results indicate that the best combination is of 25% lime and 75% metakaolin (Fig. 5). The second experiment further corroborated the strong potential in additive incorporation.

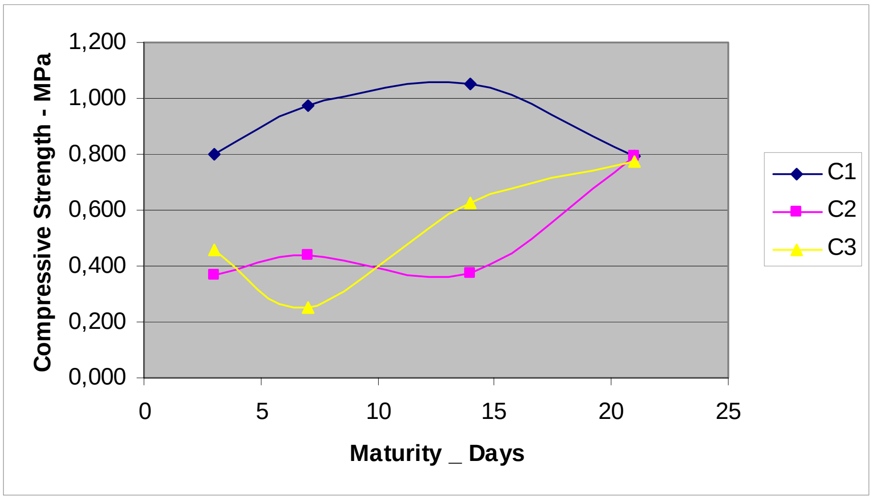

Fig. 6. Compressive Strengths

The compositions with hemp hurds showed good structural strength, with results similar to the strength levels of traditional *hempcrete* studied in previous researches at European centres, such as the Building Research Establishment, BRE. Failure at compressive strength tests followed the same pattern as other researchers had reported (Fig. 6). The fact that this material has continuous deformation, even when tested at perpendicular direction to direction of compaction, is a characteristic of any kind of *hempcrete* (Fig. 7).

Fig. 7 – Resistance behaviour

Conclusions

The mechanical performances indicate that using metakaolin instead of cement with a small percentage of lime can produce equivalent or even better results, than the usual mixes of lime-hemp or cement-hemp. The results also indicate that a small percentage of waste paper pulp produces an increase in strength.

Future research thus needs to evaluate further the characteristics of this material, such as acoustic, thermal and water resistances. In any case, this new composite material promises to contribute to more environmental constructions and enhance sustainability in building materials.

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