A PRELIMINARY STUDY OF PHYSICAL AND MECHANICAL PROPERTIES OF SUSTAINABLE HEMP FIBERS BASED COMPOSITE MATERIALS FOR BUILDING INSULATED WALLS

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Abstract

This work investigates the possibility of preparing new eco-sustainable hemp based composite materials by means of an agro-industrial production chain set up. The physical, mechanical and microstructural properties of the hemp composite materials were investigated. Moreover, thermal insulating conductivity measurements were performed, to assess the highly insulating characteristics of the composites. Correlations between the investigated properties were made.

The results show the effectiveness of a correct mix-design in improving the physical, mechanical and microstructural properties of the composites. Materials exhibit a good combination of thermal insulation, weight and mechanical strength.

1 Introduction

Sustainability represents a primary issue for construction industry. New materials and technological solutions with low environmental impact are widely proposed and investigated to meet sustainability requirements [1-5]. Natural fibers represent one of the most studied materials [6-8]. The development of a hemp production chain offers highly interesting features and potentialities for both products and processes innovation [9-13]. The key point of this development is the exploitation of all products in the production chain. Hemp can be considered an environment friendly crop, as well as an ideal type for crop rotation in sustainable and agricultural systems.

This work investigates the possibility of preparing new eco-sustainable hemp based composite materials by means of an agro-industrial production chain set up. The production process, from the hemp sowing up to the materials production, was studied and developed. The main aim of this work is the use optimization of renewable sources throw preparation and characterization of hemp composite materials with high technological performances (good mechanical properties, low density and good thermal insulation). Great care was taken in the study of the most appropriate mix design and in the samples preparation, to improve the durability of the composite material. In particular, two different types of both matrix and fiber dimensions were studied.

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2 Experimental part

2.1 Materials

2.1.1 Binders

Two different types of binders were used in the samples preparation, to investigate their behavior with the fiber: (*i*) binder *R*, a natural extremely reactive hydraulic admixture and (*ii*) binder *M*, based on a mineral oxide.

2.1.2 Fibers

As to hemp fibers, integral "chips" were used. Hemp represents a renewable resource: it is produced in agriculture in only 3.5 months. A production of dry biomass is at least 4 ÷ 5 times that produced by a forest of equal extension in a year.

In particular, both coarse (named *C*, Fig.1*a*) and thin (named *T*, Fig.1*b*) chips were used. Moreover, the *T* type was obtained from *C* type by a suitable cutting machine: the fragmented fibers were about 3 ÷ 4 mm in diameter and 10 mm in length.

(*a*) (*b*)

Figure 1. Hemp fibers: coarse (*a*) and thin (*b*) chips.

2.2 Samples

Two types of composites were investigated: specimens with binder *R* and thin chips (RT-samples, Fig.2*a*) and specimens with binder *M* and coarse chips (*MC*-samples, Fig.2*b*).

A suitable treatment of the fiber prior to batching was studied and set up.

Hemp based composite specimens with binder *R* and thin chips were prepared at room temperature according to the following steps:

- addition of the water amount necessary for hemp saturation;
- pouring of the binder previously added with a set-retardant (2 wt. % on the binder amount);
- addition of further water amount necessary for the binder hydration;
- compression moulding of the prepared admixture under a pressure of 5 MPa for about 20 minutes.

Specimens with binder *M* and coarse chips were prepared according to the following procedure:

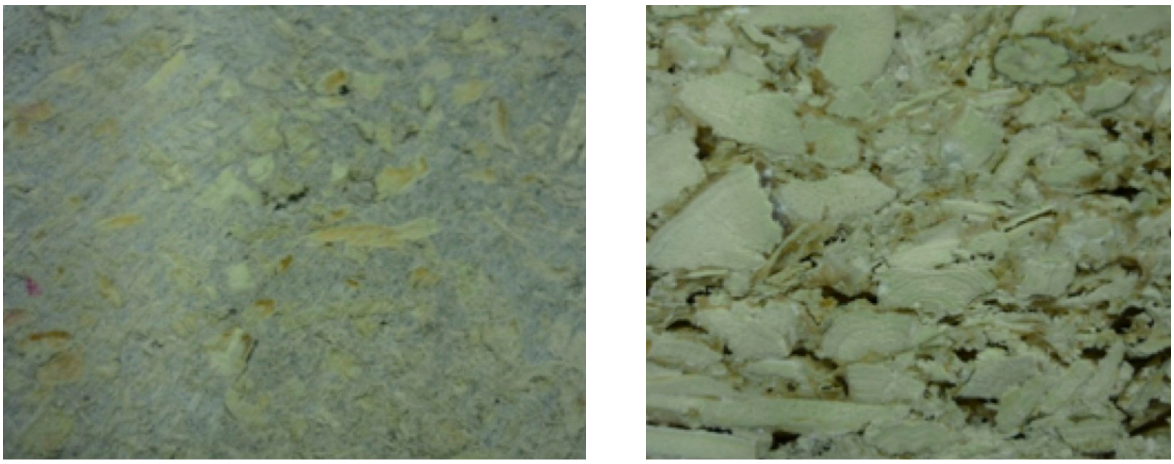
- addition of a suitable additive, necessary for hemp saturation;

- pouring of the binder previously added with a water-resistant admixture (1 wt. % on the binder amount);
- addition of further liquid additive, necessary for the binder reaction;
- microwave treatment for 4 minutes;
- compression molding of the prepared admixture under a pressure of 5 MPa for about 20 minutes.

The hemp based composites mixtures investigated are reported in Table 1.
Three series of RT samples were prepared with binder amount ranging from 47 to 55 wt. % and accordingly decreasing thin fibers content (from 12 to 9 wt. %). The first water addition wt. % is equal to the fiber wt.%.
Moreover, two different series of MC samples were prepared with binder amount ranging from 19 to 25 wt. % and decreasing coarse fiber content (from 31 to 25 wt %). The first additive addition wt. % corresponds to the fiber wt.%.
For each hemp based formulation, at least 10 panels of 560 x 380 x 50 mm were prepared and cured for 28 days at 20 °C and 50 % R.H.. Specimens of the proper dimensions for physical and mechanical tests were cut from the panels (Fig.2).

Samples	**Binder type**	**Fiber type**	**Fiber [wt. %]**	**1st H_2O addition [wt. %]**	**1st additive addition [wt. %]**	**Binder [wt. %]**	**2nd H_2O addition [wt. %]**	**2nd additive addition [wt. %]**
RT-1	*R*	T	12	12	0	47	29	0
RT-2	*R*	T	10	10	0	51	28	0
RT-3	*R*	T	9	9	0	55	27	0
MC-1	M	C	31	0	31	19	0	19
MC-2	M	C	25	0	25	25	0	25

Table 1. Mix proportions of the hemp based composites.



(*a*) (*b*)

Figure 2. Hemp based composite samples: external surface of RT-3 (*a*) and MC-2 (*b*).

2.3 Samples characterization

Bulk density (ρ_B) and water absorption measurements (WA) at room temperature were determined on samples of 50 x 50 x 50 mm, according to UNI EN 1602 [14] and UNI EN 13775 [15] Standards, respectively. At least 5 tests were performed on each material.

Compression strength (σ_c) and three-point flexural strength (σ_f) were determined by means of a 100 kN Amsler Wolpert testing machine, according to UNI EN 826 [16] and UNI EN 12089 [17] Standards. In particular, σ_c values were determined on samples of 50 x 50 x 50 mm (at least 5 measurements for each mix were performed). The σ_f values were determined on samples of 260 x 120 x 50 mm (at least 8 measurements for each mix were made).
To investigate the effect of the different binders on hemp fibers, as well as any possible difference in the mixes with coarse and fine chips, microstructural observations were carried out on undisturbed fracture surfaces. Optical (Wild 3M Heerbrugg stereoscope) and scanning electron microscope (Philips XL20 SEM) were used.
Thermal conductivity measurements were made at 35°C on hemp based composite panels of 500 x 500 x 30 mm, according to ISO 10456 [18]; two measurements were performed for each mix.

3 Results and discussion

Table 2 shows the physical and mechanical properties (ρ_B, WA, σ_c and σ_f) of the hemp based composite samples after 28 days of curing. As can be observed, an increase in the binder amount (both *R* and *M* type) leads to an increase of bulk density, a decrease in the water absorption values, as well as in increase in both compressive and flexural strength values. Moreover, hemp based composite materials with binder *R* exhibited the highest ρ_B values and, correspondently, the lowest WA values. The RT-series showed the highest values of compressive strength; this result is in agreement with the values of the physical properties (the highest ρ_B and the lowest WA).
On the contrary, the MC-2 specimen containing binder *M* and coarse chips showed the highest σ_f values. This can be ascribed to its microstructure, where large chips act as further bridges, hindering the propagation of cracks in the region of the material subjected to tensile stress.

Samples	**ρ_B [Kg/m^3]**	**WA [%]**	**σ_c [MPa]**	**σ_f [MPa]**
RT-1	1080	51.4	5.1	1.4
RT-2	1190	43.2	5.4	1.8
RT-3	1260	38.9	5.5	2.1
MC-1	550	82.9	1.1	1.9
MC-2	620	69.2	1.9	3.5

Table 2. Physico-mechanical properties of the investigated hemp based composite samples.

Optical and SEM observations of the undisturbed fracture surfaces of the samples showed the fibers well covered by the binder (Fig.3); this indicates a good adhesion between matrix and fibers. Moreover, as expected, the RT samples showed a more compact microstructure in comparison with the MC samples; this is in accordance with the results of the physical and mechanical properties (Table 2).
Finally, Table 3 compares the thermal conductivity (λ) of RT-1 and MC-2 composite panels (Fig.4). As can been observed, MC-2 panel showed the lowest λ, as well as the lowest bulk density values.
The previously described results show that hemp composites materials with good performances (i.e., combination of microstructural, physical, mechanical and thermal properties) can be obtained, if a proper mix design is used.

Investigation is still in progress: tests are mainly addressed to further lowering the thermal conductivity of the panels. This will allow the use of these materials as wall for low-cost eco-sustainable buildings. As example, Fig.5 shows a prototype of a hemp based composite wall.

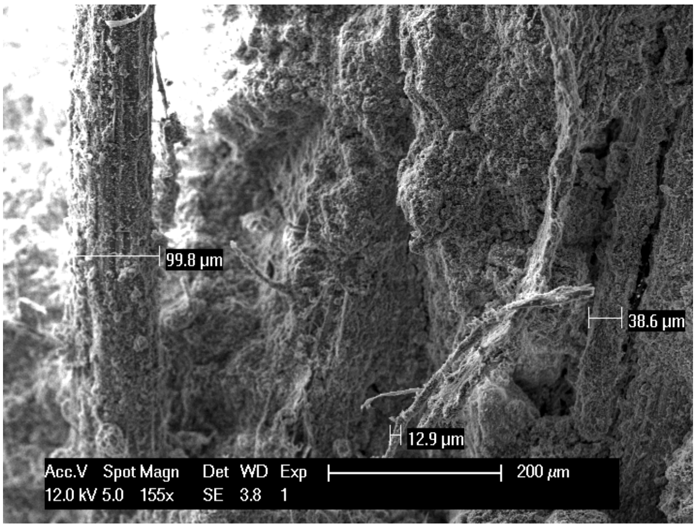


Figure 3. Fracture surface of RT-1 hemp based composite sample.

Figure 4. Hemp based panels for thermal conductivity tests: RT-1 (on the left) and MC-2 (on the right).

Samples	ρ_B [Kg/m^3]	Thermal conductivity [W/mK]
RT-1	1080	0.139
MC-2	620	0.087

Table 3. Thermal conductivity of hemp based composite panels.

4 Conclusions

- The investigated composite materials exhibit a good combination of thermal insulation, density, mechanical strength and cost.
- The results show how a proper mix-design can improve the overall performances of the composites.

- The studied hemp based panels can be profitably used as thermal insulating wall for fully ecological and eco-sustainable building construction. Further investigation is in progress, mainly addressed to obtain materials with better (i.e., lower) thermal conductivity.

(*a*) (*b*)

Figure 5. A prototype of a hemp based composite wall: external surface (*a*) and horizontal section (*b*).

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