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Thermal and structural properties of a hemp–lime biocomposite

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HIGHLIGHTS

- We examined different mixture of hemp and lime in order to produce a light concrete.
- Both thermal and structural properties have been investigated.
- We set an experimental protocol to make samples and measurements reproducible.

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ABSTRACT

The need to reduce greenhouse gases emission produced by the building sector leads to the research of renewable and less impacting materials that can replace traditional ones.

This subject has encouraged new researches on biocomposite concretes with the aim to exploit renewable resources like vegetal fibres intended as materials whose production processes are generally characterized by low costs and energy demand. This biocomposite is obviously much lighter than concrete and, therefore, can be suitably used in such cases where a structure cannot be overloaded, for instance in the realization of a green covering on top of a preexistent building.

In this work, a first analysis of the thermal and structural behaviour of a biocomposite concrete, constituted by a mineral matrix (lime) with the addition of vegetal fibres (hemp), has been carried out, with particular attention to the amount of fibres and its granulometry in the mixture. The drying process contemplate a permanence of the material in a thermostatic chamber.

The analysis carried out shows that hemp can be used both for the realization of insulation panel (hemp fibres alone) and as a construction material (hemp bast and concrete mix). This biocomposite has shown good insulation properties and some mechanical resistance. However, the results show that further analyses should be carried out on the drying process of the material, as it can greatly influences thermal and mechanical properties.

1. Introduction

Worldwide reduction policies of the pressure exerted by the building sector on the environment are leading toward the construction of eco-compatible buildings [1], that is buildings characterized by low environmental impact and ensuring health conditions to inhabitants [2]. This effort is particularly evident in the search for new technical standards, capable of providing criteria in terms both of energy and environmental performances of buildings [3,4]. In the bioecological conscious planning, a particular attention has to be devoted to the utilization of low environmental impact materials, that is materials not releasing toxic substances in the environment, presenting good thermo-physical properties and low energy content [5].

In this regard, natural materials seem to have all the above mentioned properties and they will probably represent a viable option to currently used building materials in a few years, both for the possibility to find them near the utilization sites and for their higher environmental compatibility with respect to more sophisticated materials that can undergo chemical alterations or high energy demanding processes.

Many researchers have approached the study of natural materials, especially investigating their thermal insulating properties. The most studied materials are jute [6–8], cork [9], corn cob [10,11], hay [12], sugarcane [12,13], wood wool and rock wool [14], cellulose loose-fill [15], flax [6,16–19], straw bales [20–22], coconut [23–26] and hemp [6,17–19,27–31].

Beyond high environmental performances, a good natural material should also respect traditional quality criteria, like

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Table 1
Density and thermal conductivity values of some natural materials.

Fibre raw material	Bulk density (kg/m^3)	Thermal conductivity λ (W/mK)
Cork [9]	120–180	0.045
Corn cob panels [10]		0.139
Sugarcane [12]	100–125	0.0469–0.0496
Stone wool [14]		0.039
Cellulose loose-fill [15]		0.05
Flax [19]	5–50	0.038–0.075
Cellulose (recycled paper) [19]	30	0.041
Hemp [19][a]	20–45	0.040–0.060
Straw bales [20]	102.6	0.067
Coconut [26]	85	0.058

[a] Measured value by present authors of the raw material: 25 kg/m^3.

transpirability, hygroscopicity, fire resistance, moulds and fungi resistance, odourless, lack of radioactivity and dangerous substances, electrical neutrality and recyclability [32,33].

Another aspect that has to be taken into account about the utilization of natural materials in buildings is the change of some of their properties, according to the considered material [34], depending on the zone of provenience, harvest time, extraction methods, attacks from alkaline and biological substances, deterioration due to high temperatures or humidity (natural fibres are generally hydrophilic) [6].

In Table 1, density and thermal conductivity values of some natural materials are reported.

In the present work, some analyses carried out on the thermal and physic characteristics of hemp are shown [35,36]. Hemp is a plant that can be perfectly cultivated in regions like Sicily (Italy) thanks to its climate. Furthermore, the *Regione Siciliana* [37] has proposed a plan to promote a supply chain that could invest different sectors, starting from the agricultural one. In fact, hemp could be conveniently used in abandoned fields, to recover field polluted by plant protection products, to produce energy from biomass or combustible oils from seeds, and in the building sector to produce insulating panels or lime–hemp concrete. In particular, for the production of lime–hemp concrete only the shives are used, while the fibres, that are the most valuable part of the plant, can be used for other aims.

2. Hemp: characteristics and possible uses

The term hemp is used for the strain of the plant *Cannabis Sativa*, an annual crop with a high (until 4 m) and thin stalk, with the apical part covered with foliage [38]. Hemp is characterized by very good thermo-acoustic properties and its transpirability and hygroscopicity makes it a good regulator of the indoor moisture content [29]. Furthermore, as it does not contain proteins, it is unlikely attacked by insects and moths.

In the building sector, hemp is used for the realization of construction panels for interspaces in wooden structures, internal walls coating, ventilated coverings, internal partition walls, false ceilings and floors. Such panels are characterized by a very low specific weight and a high tensile, compressive and flexural strength. Hemp can also be used as plaster for outside walls or as insulating substrate in green coverings. Finally, by means of specific working processes, a fireproof material can be obtained [34,35].

Hemp does not contain harmful substances nor is dangerous for health both in production and laying phases.

Hemp has to be processed before its utilization. In summer, plants are cut and dried in the sun for two weeks; then they are swingled for separating the bast (that is fibres located in the outer stalk) from shive, that is the wooden inner part (Fig. 1).

3. Experimental phase: the laboratory

Hemp has been characterized in the Natural Materials Laboratory located in the Dipartimento dell'Energia of the Università degli Studi di Palermo, Italy. Tests have been carried out both on hemp alone and a biocomposite material. In the first analysis, only the bast has been used to make samples for the calculation of the thermal conductivity of the material, while in the second one the wooden part, the shives, have been mixed with inorganic bindings and then both thermal and mechanic tests have been carried out.

In the following, a list of the main equipments used is reported:

- custom moulds (composed by a tile as bottom and wooden boards as side walls);
- cylindrical moulds;
- cutting mill Retsch™ SM 100 Comfort;
- electronic balance RADWAG™ WLC 30/C1/K;
- mortar mixer Matest™ E095;
- thermostatic chamber ACS™ Inter Continental;
- heat flow meter LaserComp™ FOX 314;
- universal testing machine Zwick Roell™ Z600.

4. Hemp bast panels

The first tests have been performed on the hemp fibres, said bast. The EN 12664 standard [39], that specifies principles and process to test thermal conductivity by means of heat flow meters, has been carefully followed utilizing the equipments present in our laboratory, so disregarding some parameters, mainly concerning the geometric characteristics of samples like faces parallelism and roughness. However, a particular attention in making samples has been devoted to such aspects in order to minimize them as much as possible.

Between the different aims of such analysis, we single out:

- observing the behaviour of bast coming into contact with water;
- assessing bast characteristics after its processing, particularly as far as rigidity and compressibility are concerned;

Fig. 1. Hemp fibres, said bast (left) and wooden part, said shive (right).