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Hemp-lime composite for buildings insulation: material properties and regulatory framework

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ABSTRACT

The increasing demand for indoor comfort in housing sector, together with the development of environmental awareness by people and societies, is leading to a rising need of new construction materials. Research and industries are then developing materials capable of meeting environmental and technical requirements: made from renewable sources; based on natural compounds to ensure healthy indoor environment and safe disposal; having good insulation properties, especially for energy saving. A material showing these features is the hemp-lime biocomposite, a natural-based mixture made of a lime binder matrix and shives aggregate, in different proportions. This paper wants to present an overview of the most interesting material properties for the building sector and a brief regulatory framework, in order to highlight the advantages that the use of this composite for building envelopes and internal partitions may provide.

KEYWORDS

bio-composite, biomasses, hemp-lime, energy efficiency, bio-insulation

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1. INTRODUCTION

It is well known that the ever increasing demand for indoor thermal comfort is driving the building sector to be one of the major energy consumers. One of the key factors to accomplish the reduction of energy consumptions is to boost up buildings thermal insulation systems, which allow to reduce heat and cold losses through the envelopes. As many traditional construction materials only have medium or poor insulating power, there is a growing interest for new building materials with better thermal insulation properties. Moreover, currently used materials mostly exploit non-renewable resources, have a non-sustainable fabrication process (e.g. emission of significant amounts of greenhouse gases and/or need of energivorous procedures), cannot be recycled at the end of their service life (e.g. they have to be disposed in landfills) or need high-energy-consuming techniques for recycling. For these reasons, and thanks to the development of individual and social environmental awareness, there is an increasing attention towards insulation materials made from biomasses (Galan-Marin et al., 2016). These bio-based materials have multiple environmental advantages, such as reduce the use of non-renewable resources, reducing pollution and energy uptake during the production phase, being recyclable after demolition. Furthermore, the spread of natural gas and LPG in place of biomasses as fuels in housing heating systems, has made available, especially in developing countries, huge amounts of biomass that need to find other applications (Liu et al., 2017). Among these bio-insulations, the composite made by mixing the woody core of the hemp plant with lime is attracting increasing interest in the building sector thanks to its interesting characteristics (Hussain et al., 2019).
This paper wants to provide an overview about the main properties of the hemp-lime composite and its advantages for the building industry. The paper also presents an outline of the European (and Italian) regulatory framework regulating the energy efficiency requirements in buildings. This is a preliminary work finalized to the assessment of the response of a building in which hemp-lime is used to increase thermal insulation.

2. REGULATORY FRAMEWORK

The regulation on construction components and building standards in European countries is driven by European Directives, which need to be transposed by Member States into national legislation to be effective. The policy requirements in the Directive are minimum obligations and Member States may introduce more severe measures.
The 2010/31/EU Energy Performance of Buildings Directive and the 2012/27/EU Energy Efficiency Directive are the EU's main legislative instruments promoting the improvement of the energy performance of buildings within the EU.
The 2010/31/EU Directive (transposed by Italy through Legge 90/2013) has resulted in positive change of trends in the energy performance of buildings. In fact, thanks to the transposition of the Directive introducing, in national building codes, novel energy efficiency requirements, new buildings consume only half as much as typical buildings from the 1980s.
The 2012/27/EU Directive (transposed by Italy through D.Lgs. 102/2014, in turn amended by D.Lgs. 141/2016) introduces measures to mandate energy efficiency improvements in all stages and sectors of the supply chain. It establishes a common framework for the promotion of energy efficiency within the EU, in order to meet its energy efficiency headline target of 20% by 2020, introduced by 2009/28/CE and 2009/29/CE Directives. This set of binding legislation, known as “Climate and Energy Package 2020”, aims to ensure that he EU meets its climate and energy targets for the year 2020:

- 20% cut in greenhouse gas emissions (from 1990 levels),
- 20% of EU energy from renewables,
- 20% improvement in energy efficiency.

In November 2016, the European Commission proposed an update to the 2010/31/EU Directive, which led to the publication of 2018/844/EU Directive on 19 June 2018, amending the previous one. This revision aims at accelerating the cost-effective renovation of existing buildings, with the vision of a decarbonised building stock by 2050, and promotes the use of smart technology in building systems, including automation. Member States will have to transpose the Directive's provisions into national law by 10 March 2020.

The global energy performance of buildings can be improved working on two factors:

- dwelling installations and facilities (i.e. electric and heating/cooling systems),
- building components and materials.

Regarding the materials, a key practice to achieve the goal, is to use, in the building design, innovative and/or traditional materials that minimize environmental impact during their entire life cycle (e.g. low consumption of primary energy and water, low emission of CO2 and other polluting substances, all evaluated in the production, use and disposal phases). With 2009/125/EC Directive (transposed by Italy through D.Lgs 15/2011), also known as "Ecodesign Directive", the European Union extends the application of 2005/32/CE Directive, issued for energy-using products, to energy-related products (e.g. windows, insulation materials, etc.). The ultimate scope of this Directive is to set mandatory ecological requirements, forcing the products' manufacturers to reduce their energy consumption and other negative environmental impacts such as use of resources, energy and water, polluting emissions, waste issues and recyclability. Being the 2009/125/EC a framework directive, it does not directly establish minimum ecological requirements, which are instead set through specific implementing measures. Manufacturers who are willing to market products covered by an implementing measure in the EU area have to ensure that they conform to the energy and environmental standards set out by the measure.

In order to make it easier for building designers the evaluation of sustainability and energy efficiency of constructions, voluntary certification programs have been developed in many world countries. In United States for example, the U.S. Green Building Council issued the LEED (Leadership in Energy and Environmental Design) protocol. It provides a set of standards ratings to assess environmental sustainability and performance of buildings, or parts of them. When a building obtains the LEED certification, means that it is considered environmentally friendly and a healthy place to live and work, with certain economic and environmental benefits. This protocol is now used by over 100 country around the world. Other protocols are VInCES (Valutazione Integrata del Ciclo di vita per l'Edilizia Sostenibile – Italy), HQE (Haute Qualitè Environnementale – France), SBTool (Sustainable Building Tool, previously known as GBTool - Green Building Tool), DGNB (Deutsche Gesellschaft Für Nachhaltiges Bauen - Germany), BREEAM (BRE Environmental Assessment Method - UK), CASBEE (Comprehensive Assessment System For Building Environmental Efficiency - Japan), ITACA protocol (Italy). The last one is a popular rating system for buildings, useful in setting clear and measurable objectives in public initiatives to encourage the sustainability of buildings. The evaluation is based on sheets, assigning a performance score to each building component by means of objective indicators (UNI/PdR 13.0:2015).

Using the hemp-lime composite allows to obtain better score in ITACA certification compared to other classic building materials (e.g. concrete blocks). As an example, in the following are reported some of the criteria for which is possible to improve the score:

- Materials from renewable sources
- Local materials (some places)
- Recyclable or reusable materials
- Biosustainable materials (some places)
- Building envelope thermal transmittance
- Building thermal inertia
- Air temperature and relative humidity in mechanically heated and cooled environments
- Air temperature in summer season
- Acoustic quality of the building
- Retention of building envelope performance.

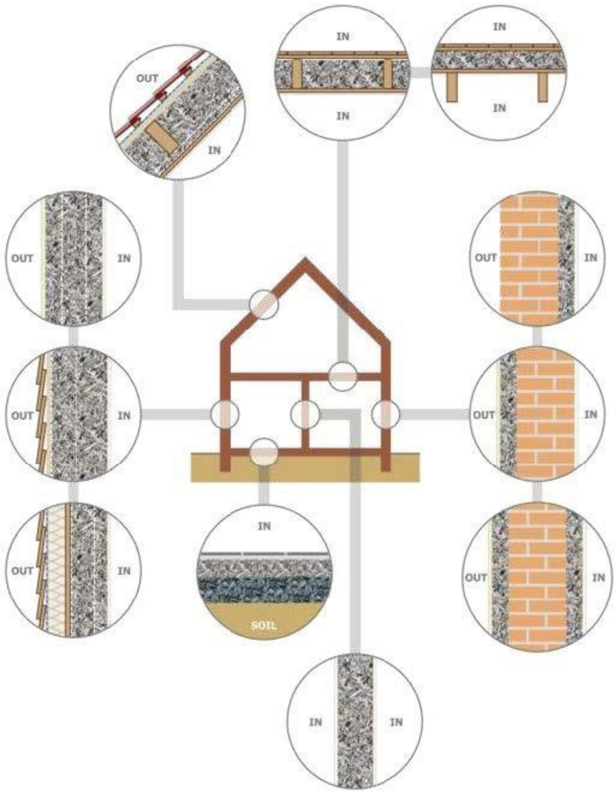


Figure 1
Uses of hemp-lime composite in buildings (edilportale.it)

3. MATERIAL PROPERTIES

Hemp-lime composite is a natural based material, made of a lime binder matrix and shives aggregate, added in different proportions. It is getting more and more used in building industry in different forms (panels, blocks, sprinkled, etc.) as a component for envelopes and internal partitions (figures 1 -5).
Its spreading is because it represents an effective solution to achieve energy savings and guarantee indoor comfort and healthy environments. Most interesting properties are described and discussed in the following.

3.1 BREATHABILITY AND HEALTHINESS

The use of a breathable material allows to avoid, or at least mitigate, the development of humidity in building envelopes. Traditional techniques involving insulating materials, such as glass or mineral wool and polyurethane, require the installation of a vapour barrier in the inner part of the wall to avoid condensation and ensure comfort for the inhabitants. However, this increases the possibility of condensation forming inside the wall in cases of humidity peaks, in addition to the deterioration of the walls and the formation of mould, particularly when water vapour moves towards the inside, as it usually happens in summer season. For this reason, using a breathable material for the building envelope is extremely important (Busbridge & Rhydwen, 2010).
The breathability of a material depends on its hygroscopicity, that is the ability to absorb or release the water vapour in the surrounding environment according to changes in air relative humidity. Since air moisture content is highly variable in buildings (with peaks exceeding the limit of 70%, especially in kitchens and bathrooms), it is important that the inner surfaces (walls, slabs and floors) have the ability to absorb moisture from environment and return it later. The hemp-lime composite is a breathable material, as it has a good hygrometric behaviour due to the structure of hemp, made of microscopic cavities, which enables the material to have an absorption capacity up to 5 times its weight. This hygroscopic nature makes the hemp-lime mix a humidity regulator, capable of absorbing the excess moisture and releasing it when necessary (Ronchetti, 2007). Its water vapour transmission rate is in fact quite high, which allows reducing condensation phenomena. Furthermore, being the hemp-lime a bio-based material, it does not release volatile organic emissions (formaldehyde, CO, NO_2, benzene and naphthalene), unlike synthetic insulators and products containing adhesives, whose presence in indoor environments may be dangerous (Bevan & Woolley, 2008).

Figure 2
Hemp-lime bricks (isohemp.com) and insulation panels (diasen.com)

3.2 THERMAL PROPERTIES

The hemp shavings structure, rich in microscopic cavities, also trigger continuous micro-condensation and micro-evaporation mechanisms, which block the heat transfer through the building envelopes. The significant mass (density (ρ) = 250-500 kg/m3) allows accumulating heat and releasing it slowly, similarly to what happens in stonewall houses (i.e. cool rooms in summer and warm in winter).
Several studies have been carried out to measure hemp-lime thermal parameters. For example, Walker & Pavia (2014) found that the thermal transmittance [U] of a 300 mm thick hemp-lime wall is between 0.3 and 0.7 W/m2K, and this value increases with density. Similar results were obtained by Cerezo (2005), who defined an empiric relationship between density and thermal conductivity (K):

$$K = 0{,}0002\ \rho + 0{,}0194 \qquad (1)$$

Figure 6 shows that the experimental values of thermal conductivity found by Walker & Pavia are consistent with Cerezo's empirical relation. The homogeneous nature of the material also allows reducing thermal transmission at the nodes, avoiding the formation of thermal bridges (Ronchetti, 2007).
Daly et al. (2012) compared the performance of a typical external corner junction for three different technological solutions: a traditional concrete block wall (a), a hemp-lime blocks wall (b) and a hemp-lime wall with rigid wooden frame (c). The results of their study show that using the hemp-lime biocomposite can reduce the linear thermal transmittance (ψ) up to 26% (ψ = 0.088 W/mK for (a), 0.083 W/mK for (b) and 0.065 W/mK for (c)).

Figure 3
Insulation using hempcrete blocks for a half-timbered farmhouse (isohemp.com)

Figure 4
Floor isolation with hempcrete blocks and no adhesive agent in a detached house (isohemp.com)

Figure 5
Acoustic interior insulation with hempcrete blocks for a school renovation (isohemp.com)

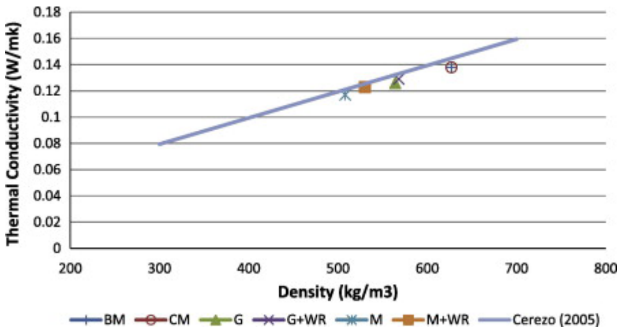


Figure 6
Relation between thermal conductivity and density. Experimental points are obtained by [Walker&Pavia] using different type of matrices (BM = builder's mix; CM = commercial mix; G = ground granulated blast furnace slag (GGBS); G+WR = GGBS with water retainer; M = metakaolin binder (MK); M+WR = MK with water retain). The blue relationship is Cerezo's curve for hemp-lime composites (Walker & Pavia, 2014)

3.3 SOUNDPROOFING

A key factor to achieve optimal indoor comfort is the soundproofing of walls and floors from both external noise (e.g. traffic, construction sites, railways, etc.) and internal noise (e.g. footfall, reverberation form other housing units or other rooms in the same house, etc.). The sound reduction index (RIw) is used to measure the ability of a certain structure (such as walls, windows, doors, etc.) to reduce the noise. The minimum value of this parameter is fixed by national laws.
Figure 7 shows the sound insulation requirements for building elements in 24 European countries. In the previously cited study, Daly et al. also evaluated the soundproofing power of a hemp-lime wall with a thickness between 300 and 400 mm, finding that it is about 57Db. This value meets even the highest standard of 55Db adopted in seven European countries (figure 2). This soundproofing feature is due to the high porosity of the hemp-lime biocomposite, which is able to absorb up to 80% of the acoustic energy incident on it.

3.4 FIRE-RESISTANCE RATING

Several studies have tested fire resistance of the hemp-lime composite, showing that the "stony" nature of the material makes it fire-resistant with no need for treatment with flame-retardant chemicals. The material is classified as "flame resistant" and it does not release toxic or flammable fumes.
The Building Research Establishment (2009) carried out a fire resistance test on a 3m x 3m Tradical® Hemcrete® non-rendered or plastered wall, in accordance with BS EN 1365-1:1999. The structure exposed to fire resisted for 73 minutes in respect to integrity, insulation, and load bearing capacity.

3.5 LOAD-BEARING PROPERTIES

Hemp-lime bricks are not made for load-bearing applications. However, when used with a rigid frame (often wooden in new buildings) they actually constitute the insulating infill wall. Hence, it may be useful to know their load-bearing capacity and strength development time. This is important to understand when the wet conglomerate can sustain its own weight, allowing the removal of formworks without collapsing the material. This way it is possible to avoid damaging the bricks being pressed by load stress, and preserve their porosity, guaranteeing good performances.
Benfratello et al. (2013) found that the typical

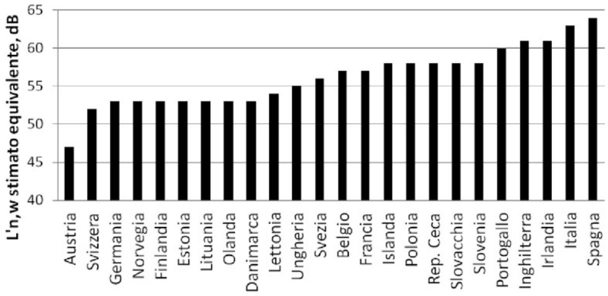


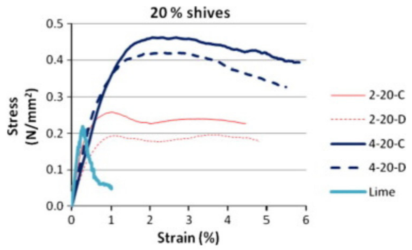
Figure 7
Sound insulation requirements for building elements in European countries (Campolongo et al., 2011)

compressive strength for a mixture with 20% shives is in the range of 0.20 to 0.47 MPa, depending on the density of the mixture and the type of binder used. Clearly, it increases with curing age (figure 8).
Murphy et al. (2010) examined flexural strength, finding that it is between 0.08 and 0.14 MPa, depending on the binder type and the hemp:binder:water ratio (figure 9).

3.6 ADDITIONAL PROPERTIES

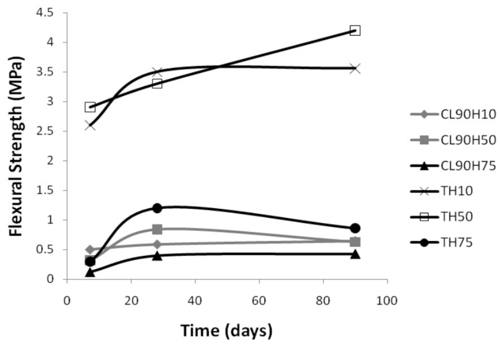
Besides the features described so far, the hemp-lime biocomposite also has other interesting characteristics; main ones are reported in the following.

- Protection against infestations: contrary to popular belief, the hemp-lime mixture is not attractive to rodents, mainly because when hemp is put together with lime, mineralization reactions are triggered. Lime has been widely used through history for its ability to preserve natural fibres, protect them against all kind of infestations and resist the formation of mould and bacteria.
- Recyclability: At the end of its useful life, the hemp-lime biocomposite is totally reusable or recyclable: all end products, resulting from both demolitions and cutting, can be easily crumbled and re-mixed adding water and lime in a cement mixer to create screed bases, bedding mortars and plasters and insulating material for cavities. Single compounds are also biodegradable themselves, hence, whether disposed, the material decomposes naturally with a very low environmental impact, being free from toxic and synthetic substances. Another way to reuse the material and its scraps is to grind it and spread it on agricultural fields to increase the pH of soil (as a fertilizer).
- Toxicity: The toxicity of hemp-lime conglomerate, during both the production and installation phase, is limited to powders production. These powders are photochemical oxidants, able to irritate the respiratory tracts. The hemp-lime final product instead, is a natural material with no (or very little) toxicity and low gas emissions, which makes safer also the demolition process.



Sample ID	Dimensions (height/diameter) [mm/mm]	Density [kg/m³]	Young modulus [N/mm²]	Ultimate strength [N/mm²]	Strain [%]
2-20-C	99/99	604	64.1	0.259	1.01
2-20-D	98/99	610	34.9	0.194	1.09
4-20-C	97/97	607	40	0.462	2.34
4-20-D	97/97	614	49.3	0.419	2.75
Lime	99/95	955	-	0.219	0.28

Figure 8
Results of compression test on cylindrical hemp-lime specimens (Benfratello et al., 2013)



Mix Name	Binder	Hemp:Binder:Water By Volume	Application % volume
CL90H75	CL90	1:0.33:3.3	Non-load bearing wall 75% hemp 25% binder
CL90H50	CL90	1:1:3.3	Floor 50% hemp 50% binder
CL90H10	CL90	1:9:22.2	Plastering 10% hemp 90% binder
TH75	Commercial Binder	1:0.33:3.3	Non-load bearing wall 75% hemp 25% binder
TH50	Commercial Binder	1:1:3.3	Floor 50% hemp 50% binder
TH10	Commercial Binder	1:9:22.2	Plastering 10% hemp 90% binder

Figure 9
Results of flexural test on prismatic hemp-lime specimens (Murphy et al., 2010)

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

Bio-insulations made from renewable resources are currently receiving an increasing attention since they have proven to be a very interesting material for building envelopes as well as for internal partitions. Hemp-lime mix is a fully biodegradable biocomposite that offers many technical advantages, other than environmental, such as being sustainable, toxic-free and meeting the possible future ecological demands of legislation. In this paper, main material properties are analysed, finding that the composite provides good insulation, breathability and humidity control, fire and frost resistance, insect and rodents proofing, versatility. The paper also describes the role of the material in the regulation in force, highlighting the advantages coming from its use.

Then, hemp-lime can be considered a promising thermal insulation for buildings, although more work is needed in order to fully understand and exploit the material's potentials. Future research step will focus on the evaluation of the variation in thermal performance of a traditional building in which, keeping unchanged all other characteristics (e.g. roofing, electric and heating systems, etc.), existing hydraulic lime plasters are removed and substituted with hemp-lime-hemp plaster.

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