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Use of agro-wastes in building materials in the Mediterranean area: a review

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Abstract

In the recent years, the environmental issues i.e. pollution and energy consumption foment an increasing interest and the resulting regulations led the construction field to focusing on the thermal insulation. The insulation materials commonly used in building constructions are mainly realized using non-renewable materials and this provoke problems in reusing or recycling the products at the end of their lives. Moreover, the production of these materials often requires high-energy consumptions. The development and the application of bio-based insulation materials can contribute to minimize the environmental impacts of buildings reducing the energy demand both during the construction and the use. For this reason, these kinds of materials are developing very fast, although they are still at a very early stage. Among the biomasses used, the agro-residues can have an interesting role because their use allows the revaluation of agricultural wastes, whose disposal is another serious issue. This work aims to report a state of the art of some building insulation products available in the Mediterranean context made of agro-wastes such as cereal straw, hemp and olive waste.

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Keywords: energy consumption, waste, fibers, hygrothermal properties

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1. Introduction

The European Commission [1] estimates that Italian buildings consume about 30% of the global energy and produce about 15% of the CO_2 emissions. The improvement of the thermal performances of existing and new buildings can contribute to reduce the heating and cooling demands in order to get energy savings.

On one side, the interest on building materials with vegetable fibers has raised in the last years also due to the world economic crisis that causes the overturning of the current thought.

On the other side, the social progress and the global development have led to increase the people's demands on indoor air quality, reducing meanwhile the energy consumption [2].

Liu et al. [3] assert that depending on the raw materials the common insulations can be classified into four categories: (1) from rocks and slags, such as rock-wool, glass-wool, expanded perlite, glass beads, vermiculite, cinder, ceramic products, etc.; (2) from petrochemical and coal chemical intermediate products, such as Polystyrene, Polyurethane, Polyethylene, etc.; (3) from plants, including agricultural waste, forestry waste and industrial plants fiber waste, such as straws, rice husk, waste papers, wood shavings, cotton, corn crops, etc.; (4) from metals, such as metal reflection film, hard metal visor, radiation plate, etc. These latter applications are still limited because they can only be applied in roofs and they are much more expensive than other thermal insulation materials.

Asrubali et al. [4] describe the state of art of the sustainable building materials taking into account the unconventional materials and dividing them in two classes: natural and recycled.

It should be note that commonly used materials, such as mineral wool and plastics can cause environmental issues due to the use of non-renewable materials, and to the disposal phases at the end of their lives.

Thus, one of the preferred way to realize insulating materials is using natural raw materials and reusing local agro-waste for producing panels, plaster, blocks suitable for the passive houses[5- 10].

The introduction of the concept of "sustainability" in the building sector gradually led to the production of insulation products made of natural or recycled materials; some of them are already present in the market while others are still at an early stage of production or study [4]. However, it must be considered the solving problem of the disposal of agro-wastes. Crop residues represent more than half of the world's agricultural phytomass [9]. Such residues are generally left and burned in the fields. Lozano et al. [9] have shown the use of the residues for producing energy and biomass.

Liu at al. [3] show the potential use of the agricultural waste in the building field: solid boards/panels (including block types), raw biomasses, multi-layers (including sandwich types), filled loosen/foaming types, particles, slurry types, coil, etc. Bories et al [10] examining the use of the biomass for the fired bricks demonstrate the significant enhancement of the thermal properties.

However, according to Kymäläinen et al. [11] bast fibers as a natural resource have a risk for microbial and other contaminants, and their quality should be monitored regularly.

Careful procedures during harvesting, processing, manufacturing, building are required in order to avoid the risk of negative effects (i.e. molding) caused by moisture and free water. Furthermore, the development of fibrous thermal insulations needs the use of additives that are to be controlled in order to avoid negative effects on indoor air quality.

This study can help to have a more precise comprehension about agro-waste research status in building field, demonstrating the potential energy improvement caused by bio-based building product. The authors have analyzed the hygrothermal properties of the insulating materials focusing in particular to the main vegetable fibers present in the Mediterranean area: hemp, straw and olive waste.

2. Hygrothermal properties

Different requirements such as thermal, mechanical, acoustic, hydraulic and economical have to be satisfied when considering a building materials.

Liu et al. [3] demonstrate that the thermal performances (thermal conductivity, thermal diffusivity, heat capacity) are the main properties investigated in the recent researches (Fig. 1). This is due to the need to reply to one of the main issue of the environment: the reduction of the energy consumption.

Palumbo et al. [12] determine the hygrothermal properties of six different bio-based insulation materials based on hemp, wood, wool, barley straw, corn pith. They demonstrated the dependence of thermal conductivity, thermal diffusivity and water vapour permeability of the different materials to the relative humidity of the environment.

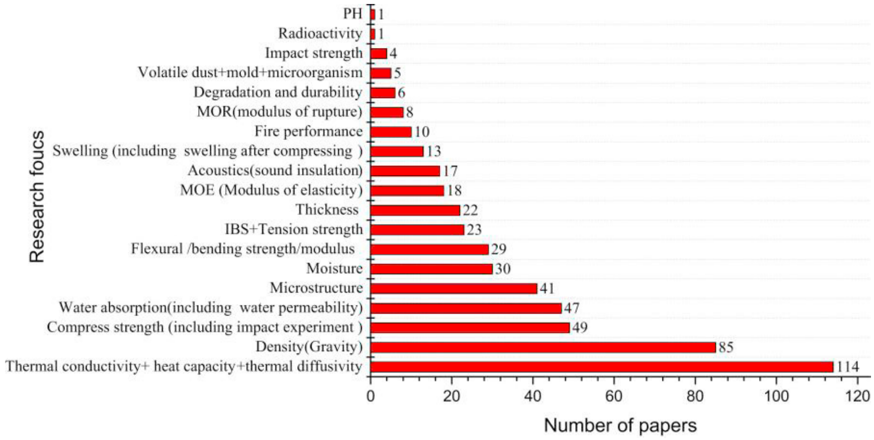

Fig. 1. Bio-insulation properties most commonly considered in literatures [3].

2.1. Thermal properties

Various studies show the thermal performances of hemp, straw and olive residues (Table 1).

Table 1. Summary of thermal properties considered in literatures.

Agro-waste	Application	Density ρ (kg/m^3)	Thermal conductivity λ (W/mK)	Specific heat c (J/kgK)	References
Hemp	Lime/Concrete	220-1000	0.06-0.542	300-1340	[13-18]
	Panel/Loose-fill	5-1280	0.033-0.138	1600-1700	[11],[19],[13],[20-21]
Straw	Lime/Concrete/Plaster	1123.89-2000	0.2261-1.35	1209.63-1821.19	[22-25]
	Panel/Brick	41.4-1690	0.038-0.32	900	[10],[12],[26-30]
Olive	Panel/Brick	970-1880	0.0841-0.76	-	[10],[31-34]
	Lime/Concrete	1147.94-2127	1	-	[35, 36]

Several researches [13-15; 19-20; 37-40] measured excellent thermal insulation properties of the hemp (Cannabis sativa). The attention on this fiber is due also to good mechanical properties, rapid growing (only 3.5 months), high dry biomass production (4–5 times higher than that produced by a forest of the same extension in one year) and high carbon storage potential.

Sassoni et al. [19] investigated new composite materials to be used as a wall plug for concrete or steel structures. They bonded hemp hurds with a novel hybrid organic–inorganic binder. According to the authors' results, the low density panels (ρ=330kg/m^3), designed as thermal insulators, exhibited a good thermal conductivity (λ=0.078W/mK), a quite good reaction to fire and relatively good mechanical properties.

Benfratello et al.[13] used hemp both for the realization of insulation panel (hemp fibres alone) and as a construction material (hemp bast and concrete mix). Such biocomposite had shown good insulation properties and acceptable mechanical resistance performance. The authors underlined that the biocomposite is 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 pre-existent building (Fig. 2).

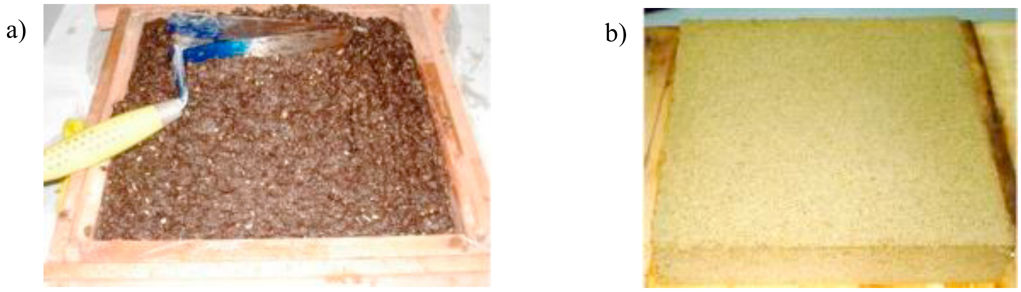

Fig. 2 (a) bast–water mixture in the mould; (b) lime-hemp mix [13].

Elfordy et al. [14] carried out a research on hemp concrete establishing that the thermal and mechanical properties, such as thermal conductivity, Young's modulus, compression strength, bending strength and hardness, increase when density increases (Fig. 3). In the building industry, it is necessary to find a compromise between thermal insulation and mechanical properties, depending on the type of construction. In a pre-built wood structure, low thermal conductivity (and low strength) materials can be used. On the contrary, if blocks contribute to the structural integrity of the construction, then denser and stronger blocks should be used, even if slightly lower insulation properties are achieved.

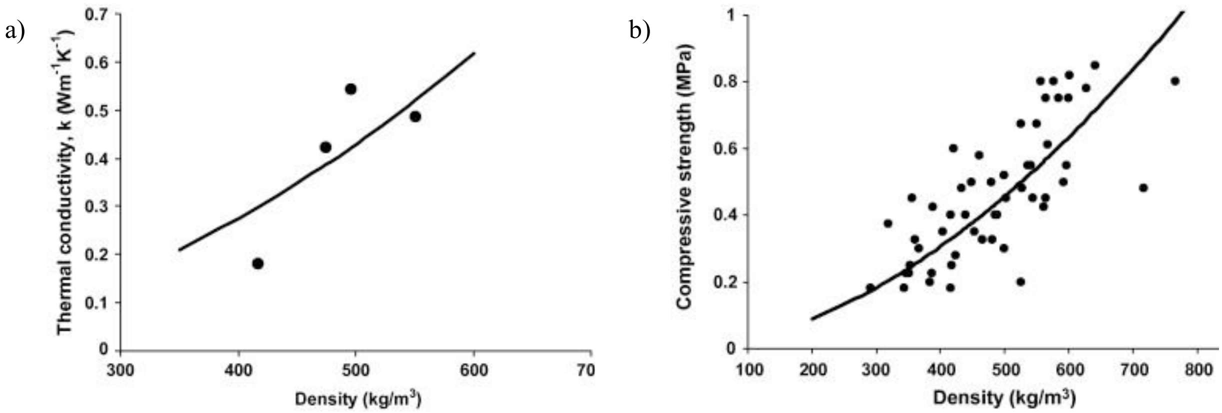

Fig. 3. (a) variation of thermal conductivity as a function of density; (b) variation of compression strength as a function of density [14].

Looking through the research about straw [22-26; 41-46] it was note that different types of straw are used in the building constructions.

Liuzzi et al. [22,26,41] carried out a research about the hygrothermal properties of some straw-based building materials (panels or bricks), mixed with different binders (lime, clay, water glass). Two types of fibers were used: wheat straw and bean straw. The results indicated that increasing the percentages of straw greater effects on the thermal properties can be appreciated.

Ashour et al. [23] testing earth plasters reinforced with straw fibers, has pointed out that the shrinkage of plasters is influenced by several factors, among which it should be considered curing temperature, fiber content, fiber type and plaster compositions. The highest shrinkage was observed for plaster reinforced with wood shavings, while the lowest shrinkage was observed for plaster reinforced with barley straw fibers. The plaster without reinforcement fibers shows extensive crack formation, which leads to disintegration of the specimens.

Belhadj et al. [24] found out that the addition of barley straw considerably improves the thermophysical properties of sand concrete (thermal conductivity, specific heat and density). The thermal conductivity and the thermal diffusivity were reduced by 5.71% and 21.97% respectively.

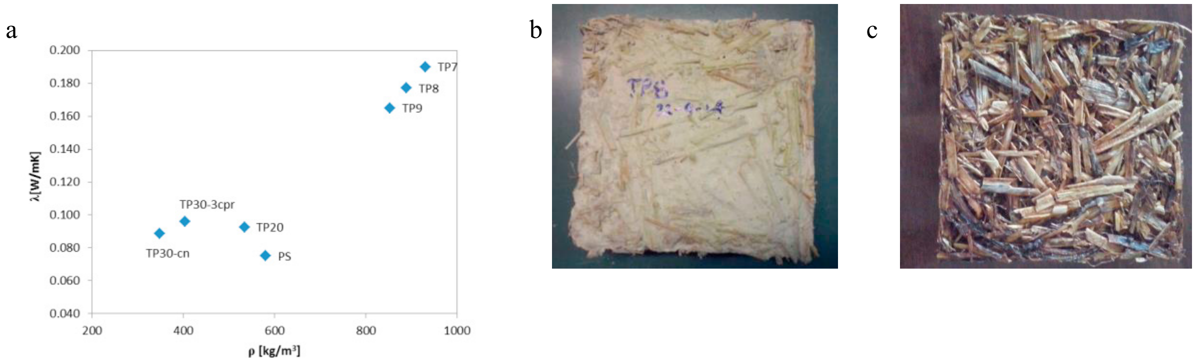

Fig. 4. (a) variation of thermal conductivity as a function of density; (b) barley straw and clay; (c) bean straw and water glass [26].

The economy of many South Mediterranean countries is mostly based on olive oil production and olive processing [35]. The major problems, which significantly affects the environmental sustainability are the crop residues and, considering the extraction process, the disposal of husk and vegetation water.

Barreca et al. [35] propose and analyse an original use of olive stone in order to improve the heat insulation performances of cement lime mortar and reduce its final density.

Some researchers [31, 47] used the olive mill solid residue (pomace) as an additive in lightweight fired brick production. La Rubia-García et al. [47] found that wet pomace can be considered an effective lightening additive since it increases the final material porosity. The hollows created by the combustion of the wet pomace during brick firing provide the insulating quality to the final product.

Several authors [48-49] studied also the potential of olive waste to be used with synthetic thermoplastics polymers. The importance of such materials as reinforcing fillers is due to their low density, non-abrasiveness, availability with low cost.

Binici et al. [32] studying some insulation materials produced with waste olive seeds, ground PVC and wood chips found out that the increase in olive seed ratio allows the decrease of the thermal conductivity coefficients of the final products. Mousa et al. [50] carried out a research on the influence of olive husk on the thermal stability of the PVC composites. They mix the U-PVC with olive husk at 180°C.

2.2 Hygric properties

Viitanen et al. [51] assert that bio-deterioration, e.g. mould, decay and insect damage in buildings, is caused when moisture exceeds the tolerance of structures which may be a critical factor for durability and usage of different building materials. For this reason it is fundamental to simulate the hygrothermal behaviour of the buildings and to assess the development of mould growth avoiding the eventual risk for bio-deterioration of materials.

Several researches [10, 15; 19-20; 26; 31-33; 35-38] described the hygric properties of various insulation materials (Table 2) by using different dynamic experiments and mathematical approaches [52-54].

Table 2. Summary of hygric properties considered in literatures.

Agro-waste	Application	Water vapor resistance factor μ (-)	Water absorption coefficient W_A (%)	References
Hemp	Concrete	5.42-5.71	60-85	[15]
	Panel	0.51-1.85	10.10-118.40	[19-20]
Straw	Panel/Brick	3.30-5.10	20.60-30	[10],[26]
Olive	Panel/Brick	-	10-32.50	[10],[31-33]
	Lime	10-20	23.69-31.57	[35]

Latif et al. [20] studying hemp insulation materials characterized them in terms of their hygric properties: adsorption–desorption isotherm, moisture buffer value, vapour diffusion resistance factor and water absorption coefficient. In relation to adsorption–desorption isotherm the insulation materials with more active area for monolayer water sorption showed higher water adsorption capacity during high water activity. Assessing μ values, significant variations among the insulation materials were appreciated. It is due to fibre processing, fibrous structure, tortuosity and porosity. The environmental conditions have also a great importance in this field.

Whian [55] and Jolly [56] observed the relationship of relative humidity and moisture content of straw.

Liuzzi et al. [23] demonstrated that a general improvement of the hygrothermal performances of unfired clay plasters with addition of straw can be achieved. The addition of straw to the basic mixture allows to reach a significant improvement of the sorption capacity.

As previously mentioned Palumbo et al. [12] studied the role of temperature changes on the hygrothermal performance of some bio-based materials. In all cases the thermal conductivity increases with relative humidity. Results indicate that the changing rate of thermal conductivity in hemp composites is higher than in the rest of the materials, which implies a higher sensitivity of the materials to moisture changes.

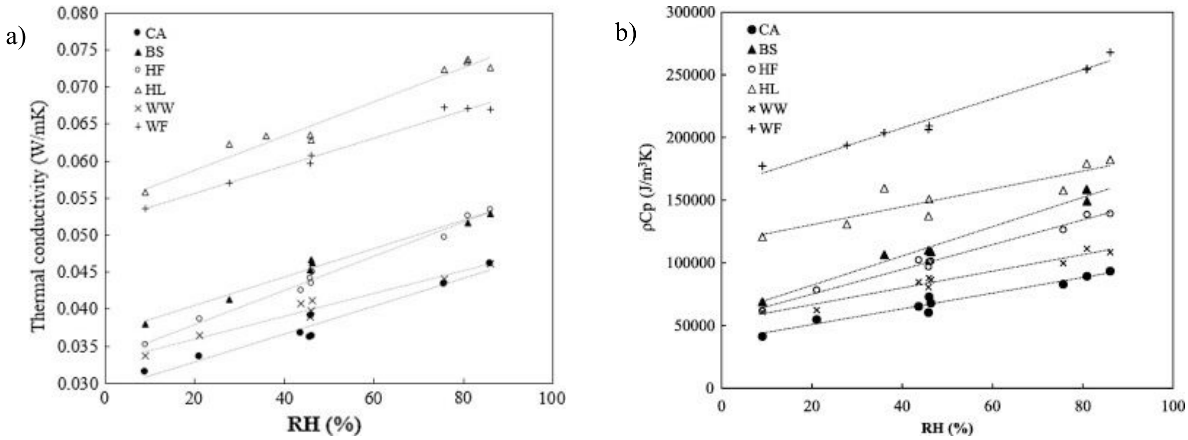

Fig. 5. (a) variation of thermal conductivity with relative humidity for six samples; (b) variation of the product ρC_p with relative humidity for six samples [12].

Barreca et al. [35] show that the addition of olive stone causes a decrease in density but also an increase in water absorption. This characteristic has to be taken into account because it may invalidate the improvement in the cement lime mortar thermal performances, since water has a high thermal conductivity value.

Walker et al. [15] demonstrated that the type of binder influenced the capillary absorption of hemp concrete; this is probably due to hydrates filling micropores in the binder.

3. Conclusions

The present work reports an up to date review of some building insulation products made with vegetable fibers derived also from agro-waste in the Mediterranean area.

Recycling of such wastes into sustainable, energy efficient construction materials is a suitable solution for the problem of pollution and natural resource conservation for future generations.

Main hygrothermal properties of the fiber-based building materials have been reviewed according to recent literature. Hemp, straw and olive waste products have shown the potential to develop energy efficient and cost effective sustainable construction materials along with enhanced hygrothermal behaviour. Several researchers determined the hygrothermal properties of bio-based insulation materials demonstrating the dependence to the fiber contents. The environmental conditions have also a great importance in this field. For this reason some studies underlined that it is fundamental to simulate the overall hygrothermal behaviour of the buildings. From the various literatures it is noted that products/composites produced from various agro-waste materials, have low thermal conductivity and high hygric performances. The principal problem of these materials is their durability. Further researches have to be done in order to prevent mold growth and make their use more suitable.

The generated small database about hygrothermal performances will eventually be beneficial to the manufacturers or researchers to develop innovative construction materials.

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