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Innovative mineral fiber insulation panels for buildings: Thermal and acoustic characterization

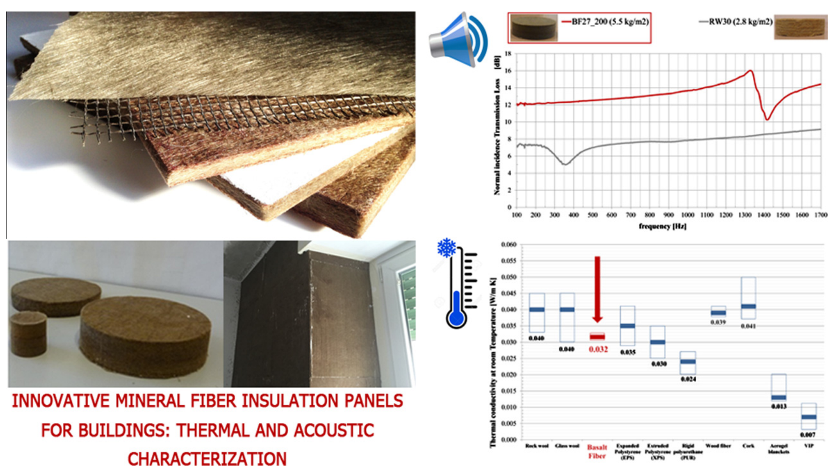
Elisa Moretti [a,*], Elisa Belloni [a], Fabrizio Agosti [b]

[a] Department of Engineering, University of Perugia, Via G. Duranti, 93 – 06125 Perugia, Italy
[b] Agosti Nanotherm s.r.l., Via San Giacomo 23, 39055 Laives, BZ, Italy

HIGHLIGHTS

- Innovative mineral fiber insulating panels were developed for building refurbishment.
- The thermal conductivity was in the 0.032–0.034 W/m K range, depending on the density.
- Very good acoustic behavior was shown, when compared to conventional solutions.
- The panel has also good mechanical resistance and high resistance to fire.
- The solution is suitable for building refurbishment, due to very low thickness.

GRAPHICAL ABSTRACT



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ABSTRACT

Thermal insulation of building envelope plays a key-role in energy saving: a growing interest is focused on new materials, such as the recycled and sustainable ones. Innovative mineral fiber insulating panels were developed and investigated as a strategy for building refurbishment. The thermal and acoustic properties were investigated in order to compare them to conventional solutions. The thermal conductivity was evaluated by means of a Heat Flow meter apparatus: it is in the 0.031–0.034 W/(m K) range, depending on the density. The acoustic absorption coefficient and the Transmission Loss values measured by means of Kundt's Tube showed a very good acoustic behavior, when compared to conventional solutions with similar chemical composition, but worse mechanical resistance, such as rock wool panels. The low value of thermal conductivity (0.0312 W/(m K) for a density of 165 kg/m^3), together with other characteristics such as acoustic insulation improvement, sustainability (very low presence of additives, such as resin), mechanical resistance, high resistance to fire, and finally easy application in buildings with very low thicknesses (9–27 mm) suggest this solution as a very useful one for building refurbishment, especially for historical buildings.

* Corresponding author. Tel.: +39 075 585 3694; fax: +39 075 585 3697.
E-mail address: elisa.moretti@unipg.it (E. Moretti).

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1. Introduction

As the energy use in building sector is a significant part of the total world energy consumption, it is important to improve the energy efficiency of buildings. In this context the concept of zero emission building and passive house has been introduced. In order to achieve the highest thermal insulation resistance, new materials and insulating solutions with low thermal conductivity have been developed [1]. Many Authors studied the thermal performance of different insulating materials, conventional and non-conventional ones, with natural or synthetic fibers, used for building envelopes [2–5]. Walker and Pavia [2] observed that aerogel and Polyisocyanurate boards provide the greatest wall transmittance reductions, while timber boards, cork, hemp lime, and calcium silicate panels are less efficient.

In particular, natural and recycled materials are becoming valid choices in place of traditional synthetic ones: natural fibers as kenaf, wood, cork, cane, cardboard, sheep wool, etc. are considered effective raw materials for producing insulating panels at a reduced cost. Other nonconventional products are manufactured by using residues of agricultural production and processing industries [6]. They are becoming increasingly popular thanks to many important advantages: low mass densities, cell structures, low thermal conductivity, high sound absorption properties, no harmful effects on health, large availability and sustainability (Life Cycle Analysis in terms of primary embodied energy and greenhouse gas emissions for the production of the material) [7–12]. They generally have good thermal insulation properties, similarly to traditional porous materials. Recycled cotton panels, as an example, have density and thermal conductivity very similar to the ones of expanded and extruded polystyrene (about 0.030–0.037 W/(m K)) and a high specific heat value (about 1.6 kJ/kg K). Insulating panels made of other materials such as sugar cane and rice have higher thermal conductivities (about 0.045–0.055 W/(m K)), but they are also interesting because of the large availability and the low costs [13].

Also the acoustic features should be considered [14]: several measurements were carried out on samples of natural fibers by Berardi and Iannace [7]. The sound absorption coefficient was measured by means of Kundt's Tube, showing good sound absorption properties, especially at medium and high frequencies: it is possible to obtain significant sound absorption coefficients also at low frequencies by increasing the thickness of the panel or by incorporating air.

Moreover many studies tried to find a correlation between thermal resistance and sound insulation [15–18]. Nurzynski [15] demonstrated that it is difficult to find a simple relationship between acoustic and thermal insulation; some technical solutions that improve the thermal resistance of a panel can reduce the sound insulation. Massive homogeneous partitions can represent a good acoustic solution (high acoustic insulation properties thanks to high densities), but in order to obtain good thermal resistance it is better to have insulating systems with high porosity and incorporated air. In particular in [18] it was observed that the application of thermal insulating linings is effective for the thermal and sound insulation (for materials with high dynamic stiffness and internal damping), but in some cases it produces negative effects by decreasing the sound insulation in a specific frequency range.

Nevertheless some natural materials have a disadvantage: they have high wettability due to their open pore structures and they have to be protected against biological attacks (fungi, parasites, etc.) and fire (another advantage is the flammability). Zach et al. [19] studied the thermal behavior of natural insulating materials in different humidity conditions. It was observed that the reduction of wettability by the application of hydrophobic agents reduced the rate of degradation of the thermal insulation properties: the increasing of the thermal conductivity (λ) is about 43% in normal conditions (from the dried-up state to 80% of relative humidity); thanks to hydrophobic agents the increasing of λ is about 30%.

The basalt fibers represent an interesting solution among natural vegetable fibers. Basalt is a natural material that can be found in volcanic rocks originated from frozen lava [20–22]. It is cheaper than carbon fiber thanks to its large availability all over the world, especially in Russia, Georgia, Ukraine and China. It is not a new material but its applications are surely innovative in many industrial fields, in particular buildings, constructions and energy efficiency [23–26].

In general, basalt fibers have better tensile strength than glass fibers, greater failure strain than carbon fibers as well as good resistance to chemical attack, impact load, and fire. Sim et al. [25] investigated the applicability of the basalt fiber as a strengthening material for structural concrete, taking into account durability, mechanical properties, and flexural strengthening. Based on the experimental results, they concluded that the basalt fiber strengthening could be a good alternative to other fiber reinforced polymers (FRP) as strengthening systems, especially when moderate structural strengthening but high resistance for fire was required. Moreover, the prospective of the material in nuclear energy applications was widely investigated. The radiation shielding properties of a new proposed building material, a novel cement–basalt fiber mixture (CBM), was studied by Ipbükera et al. [26], highlighting a good potential for use in addition to heavyweight concrete for nuclear energy applications. Nevertheless, the applications of basalt fibers in building insulation and refurbishment is not yet properly explored.

The present paper is focused on the development of insulating panels based on a selected and particular basalt fiber as an innovative system for high energy efficiency in buildings, used for both internal and external coatings. The new system was developed by Agosti Nanotherm s.r.l. thanks to the work of a research team: they selected a specific kind of basalt fiber and developed an innovative production cycle in order to fabricate a panel for specific application in buildings, called Nobilum® panel [27,28].

The proposed panel was investigated in terms of thermal and acoustic performance. Thermal conductivity was measured at the Labs of the Agosti Nanotherm Company, whereas normal incidence sound absorption coefficient and Transmission Loss were evaluated at the Acoustics Labs of the University of Perugia [29]. In order to develop a new basalt fiber-based insulating panel for application in building refurbishment, different thicknesses and densities were considered in the analysis. Based on the experimental results, the proposed panels were compared to conventional insulating building solutions (Rock Wool, Glass Wool, Expanded and Extruded Polystyrene, etc.) taking into account not only the thermal performance, but also considering other important characteristics such as acoustic insulation, fire resistance, tensile and compressive strength, wettability, cost, in situ installation, and eco-compatibility. Finally the real potentiality of these panels was analyzed in terms of thermal transmittance by supposing the application of the materials to different kinds of existing walls.

2. Material and methods

2.1. Development of basal fiber insulating panels

Basalt is an igneous rock originated from frozen lava (melting temperatures of about 1500–1700 °C) [20–22]. Considering the chemical composition, SiO_2 and Al_2O_3 are the main constituents