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Mechanical characterization and thermal conductivity measurements using of a new 'small hot-box' apparatus: innovative insulating reinforced coatings analysis

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ABSTRACT

The insulation of the building envelope contributes to the reduction of annual energy consumptions. The development of new materials, such as fibre reinforced insulating coatings, could be useful in order to obtain an effective solution for the improvement of energy performance and for reinforcement of the walls.

The evaluation of the thermal and mechanical characteristics of building coatings with good thermal insulation properties and mechanical resistance is the aim of the present paper. A new experimental apparatus, Small Hot-Box, built at the University of Perugia, was used for the evaluation of the thermal conductivity of four different coatings (with and without a reinforced structure). No European standards are available for this innovative facility, but it takes into account some prescriptions of EN ISO 8990. The apparatus was calibrated with materials of known thermal conductivity. The thermal conductivity can be calculated with both the thermal flux meter and the Hot Box method. Good values of the thermal conductivity, in the range of 0.09–0.11 W/mK were found for all the samples, except for one (0.21–0.24 W/mK).

Mechanical tests were also carried out in laboratory on all the samples and results were used to evaluate the shear modulus and strength of the wall panels.

1. Introduction

Energy consumption for buildings heating and air conditioning represents on average 40% of energy consumptions in Europe [1]. Furthermore a relevant part of the building heritage in Europe is constituted by old buildings [2–4] with poor quality insulation materials. Therefore, recent regulations, as for example the EU Directive 2010/31 [5] on energy efficiency in buildings, aims at increasing target energy efficiency standards, considering both the single components and the entire building. The building envelope plays a fundamental role in energy balance. The evaluation of the building components thermal properties requires a high level of accuracy and many experimental methods for the thermal characterization of materials have been performed from research efforts all over the world. Several methods for measuring the thermal properties are well known; the guarded hot plate is the most common method used for the evaluation of the thermal conductivity of an homogeneous or multilayer material [6]. Many studies concerning the characterization of thermal properties of materials are available; André et al. [7] presented an experimental set-up based on the hot wire method for the thermal characterization of materials, while a tiny hot plate method is proposed by Jannot et al. [8,9] for the thermal conductivity measurement of heterogeneous materials [10].

Furthermore, for non-homogeneous structures, composed by different materials or components (such as doors, windows or French windows), or when the heat transfer is two - or three-dimensional, different techniques are used; the most common method for the thermal transmittance evaluation is the calibrated Hot-Box [11,12]. Since the seventies the guidelines for Hot Box design criteria are reported in EN ISO 8990 [13] and EN ISO 12567-1 [14]. In particular EN ISO 12567-1 specifies a method to measure the thermal transmittance of doors or windows, but also the thermal conductivity of homogeneous materials can be evaluated. The heat flux through the sample can be evaluated using thermal flux meters installed on the surface of the sample (Thermal Flux Meter Method, TFM). In this case the thermal conductivity of the panel will be calculated as the ratio between the thermal flux and the surface. The flux meter methodology is also considered in the UNI EN 1934:2000 [15]. At the University of Perugia (Department of Engineering), a Calibrated Hot Box was built in 2008, according to UNI EN ISO 8990 [13,16]. It is composed of two chambers (dimensions $2.5 \times 1.2 \times 3.2$ m height), the cold and the hot one [16–20].

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Nomenclature

A	panel surface (m^2)
e	error (%)
f_t	tensile strength (MPa)
G	shear modulus (MPa)
λ	thermal conductivity (W/mK)
P	power (W)
p	diagonal compression load (kN)
q	heat flux (W/m^2)
R_t	thermal resistance (m^2K/W)
s	thickness (m)
T	temperature (°C)

Subscripts

a	air
C	Cold side
f	fans
H	Hot side
HB	Hot Box method
i	input
m	mean
p	panel
r	resistance of the hot side
s	specimen
S	surface
tfm	thermal flux meter method
w	walls

Considering homogeneous materials, other experimental apparatus could be used: the guarded hot plate or heat flow meter method (EN ISO 12667 and ASTM C518-10 [21,22]). The heat flow meter apparatus is a comparative device and requires a reference material with known thermal properties for calibration. The heat flow meter apparatus establishes steady state one-dimensional heat flux through a test specimen between two parallel plates at constant but different temperatures [23].

In this context, in the present study measurements with a new experimental apparatus, named Small Hot-Box, were carried out. The experimental system has been designed and built at the Laboratory of Thermal Science, University of Perugia. The apparatus allows the evaluation of the thermal conductivity of homogeneous materials, but the operating principle arises from the Hot-Box method. The advantage of the apparatus with respect to Hot-Box is the possibility of testing homogeneous materials with smaller samples (300 × 300 mm); with respect to the Hot Plate apparatus, it can provide a thermal transmittance value measured in conditions similar to the in-situ ones.

Fibre reinforced insulating coatings were characterized with the innovative apparatus. The mechanical properties of the same samples were also evaluated, in order to show the influence of the fibres on the mechanical resistance.

Retrofitting techniques for masonry constructions are extensively found in the existing literature. FRP (Fibre-Reinforced Polymer) systems are increasingly used to strengthen masonry structures: reinforcement is frequently bonded to the surface of existing walls, where it provides tensile strength and prevents the opening of cracks [24–27].

The use of FRPs without epoxy adhesives is less well established [28,29]. Only recently the use of non-organic matrixes has been the subject of research, and it could be a valid alternative to the use of epoxy matrixes. Mechanical tests were conducted in laboratory on 1.2 × 1.2 × 0.24 m brickwork panels. All wall panels were subjected to shear strength and test results were used to evaluate the shear strength of the masonry before and after the application of the strengthening made of a G-FRP (Glass Fibre-Reinforced Polymer) reinforced insulation coating applied on both panel sides.

Insulation coatings can be used in many applications, such as refurbishment of old buildings, on internal as well as external surfaces, and they should offer a non-invasive method for reinforce historic buildings and saving energy without altering their forms. Fibre-Reinforced Polymers (FRP) are composed of high-strength fibres (such as glass) embedded in a polymer resin (such as polyester), durable (thanks to the resin), and lightweight. Glass fibre reinforced concrete is a composite material made of components with different mechanical properties: cement mortar and G-FRP in place of metal grids. Cement avoids buckling of glass fibres when compressing them, glass fibres improve the tensile strength and ductility. This solution is very diffused in order to improve the shearing strength of the walls [30,31]. Thermal insulation plasters, as the samples investigated in the present study, consisting in innovative reinforced coatings made of mortar and G-FRP, try to combine good mechanical and thermal properties for building refurbishment. Innovative coating solutions are therefore in development, such as aerogel-based high performance insulating plasters, but a limited number of studies exists in this field, probably due to the high costs of the innovative system [32,33].

2. Materials and methods

2.1. Description of the samples

Four mortars with different chemical compositions were investigated, each one with and without G-FRP, for eight samples in total. The G-FRP grid is characterized by a 66 mm square mesh inserted into the matrix. It is produced by Fibre Net (Udine, Italy)

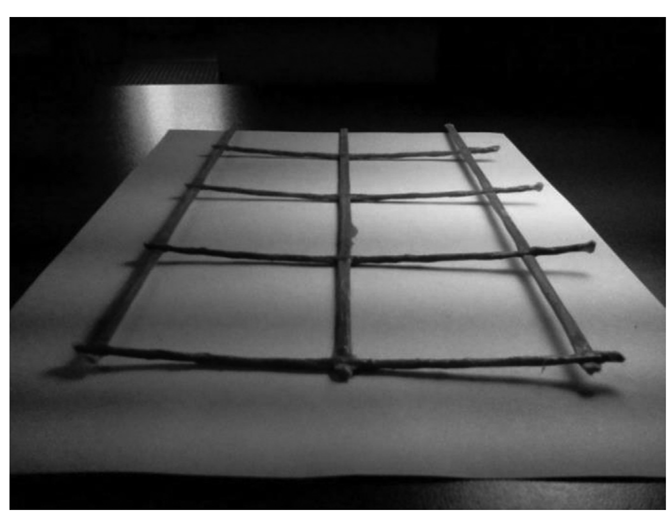

Fig. 1. G-FRP grid.