Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 140 (2017) 159–169

Energy Procedia

www.elsevier.com/locate/procedia

AiCARR 50th International Congress; Beyond NZEB Buildings, 10-11 May 2017, Matera, Italy

Thermal and mechanical characterization of panels made by cement mortar and sheep's wool fibres

Tiziana Cardinale*, Giuseppe Arleo, Franco Bernardo, Andrea Feo, Piero De Fazio

ENEA - C.R. Trisaia, DTE-BBC – ss 106 jonica km. 419,500, Rotondella, 75026, Italy

Abstract

Green building and environmental sustainability are two important concepts for technicians and engineers. Among natural materials, usually considered as waste, sheep wool plays a fundamental role.
This paper is intended to learn more about the potential of these fibres inserted in cement mortar panels, investigating both the insulation properties and mechanical strength, trying to achieve an optimal compromise between these two aspects.
Therefore, in the laboratory of materials ENEA Research Centre Trisaia, several panels with different percentages of sheep wool were manufactured, tested and characterized according to technical standards.

Peer-review under responsibility of the scientific committee of the AiCARR 50th International Congress; Beyond NZEB Buildings.

Keywords: recycled material; cement mortar; sheep wool; thermal and mechanical characterization; periodic thermal transmittance

1. Introduction

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 10 pt. Here follows further instructions for authors.

One of the most important challenges of future buildings is the reduction of environmental impact and energy consumptions in all their life phases, from construction to demolition.

* Corresponding author. Tel.: +39 3471182729.
E-mail address: tiziana.cardinale@enea.it

1876-6102
Peer-review under responsibility of the scientific committee of the AiCARR 50th International Congress; Beyond NZEB Buildings
10.1016/j.egypro.2017.11.132

Nowadays the cement industry is responsible for 5-7% of global CO2 emissions [1]. In order to reduce them, recently in the field of eco-friendly practices, new technological solutions and new building materials have been developed [2] to protect natural resources [3]. So the concept of green materials involved both natural fibres and a big quantity of wastes. Natural fibres are used to improve mechanical performances of cement-based composites [4], in place of synthetic ones (e.g., PVA or polypropylene), because they ensure a better tensile strength, ductility and post-cracking behaviour [5] and, at the same time, they are increasingly appreciated thanks to the specific properties, the low price, the advantages for health and the recyclability.

The wastes are introduced as powder or filler or as aggregates in the concrete mix, with energetic, economic and environmental protection conveniences [6]. Even though the ingredients for the concrete manufacture are available almost everywhere, there could be opportunities to use some local wastes which have appropriate characteristics for concrete production [7]. According to their origins, natural fibres can be classified in ligno-cellulosic (from plants/vegetable), mineral (e.g. basalt fibres) and protein (from animals). These last fibres are grouped under the categories of hair (wool), fur (angora) and secretions (silk) [8].

In particular, sheep's wool, has begun to be marketed and promoted as an alternative material in civil engineering for both thermal and acoustic insulating applications [9].

It can be considered a renewable resource, as the average sheep produces between 2.3 and 3.6 kg of raw wool annually that must be sheared for the health of the animal, but in several regions it is not always adequately disposed or recycled [10], because it should to be considered a special waste, needing a sterilization treatment (at 130 °C) before its disposal.

In fact, about 75% of the wool (around 150 million tons per year), produced by the European sheep farms cannot be used by the textile industry.

Due to some mechanical treatments, performed in order to improve the workability, the quality of this wool is generally high.

According to available literature, there are few research regarding the sheep wool as addition in mineral composites, despite, as already mentioned, its use as reinforcement of cement in order to produce mortar or plaster involves several advantages.

This research intends to contribute to the management and reuse of sheep wool waste in order to reduce its impact on the environment; it is also focused on the possibility of using sheep wool fibres in the production of mortar, particularly for use as wall coatings, to create an additional and more sustainable market for a valuable resource.

To achieve this, mechanical behaviour and thermal conductivity of a cement mortar reinforced with wool fibres at three different fibre contents (2%, 5% and 7% by wt. of dry raw materials) were studied.

Nomenclature

λ	thermal conductivity of the specimen, *W/(m·K)*
d	specimen thickness, *m*
ΔT	temperature difference between the two faces of the test, *K*
A	area through which the heat passes, m^2
Φ	heat flux, W/m^2
N	calibration factor, *ND*
V	potential difference of the transducers, *V*
F	maximum load applied, *N*
f	flexural strength, N/mm^2
l	distance between the axes of the support rollers, *mm*
b	width of specimen, *mm*
d	depth of the specimen, *mm*
σ	compressive tension, *MPa*
ε	deformation, *mm/mm*

2. Materials and specimens preparation

Wool used in this work came by recycling waste containing raw wool unspun (old mattresses). The wool was firstly washed using water at 20 °C and detergent, in order to remove both impurities, such as dust and dirt and other substances virtually waterproofing, then left to air-dry for 24 hours.

Fig. 1. Washed wool.

Fig. 2. Combed wool.

After this step, the wool was first combed and then shredded with a cutting mill Retsch ZM 200 by a blade that has allowed to cut the wool in lengths of 10 mm.

Fig. 3. Cutting mill Retsch ZM 200.

As known, a cutting process using a mill produces heat by increasing the temperature; this condition can cause a degradation of the wool. For this reason this step was conducted by treating the wool with liquid nitrogen in order to lower the temperature during the cutting phase. The final result in terms of shredded wool is shown in next figure 4.

Fig. 4. Shredded wool.

The obtained shredded wool was then used to produce specimens for tests. Four mixtures were produced: the first one was considered as the reference (REF), while the other three mixtures, indicated as SW2, SW5 and SW7, were produced by adding sheep wool fibres in amount of 2%, 5% and 7% per dry raw materials mass, respectively.

Table 1. Compositions of the mortar mixtures.

Component weight for specimens				
Mortar mixture	REF [g]	SW2 [g]	SW5 [g]	SW7 [g]
Cement	1213	1213	1213	1213
Sand	2965	2965	2965	2965
Lime	208	208	208	208
Water	472	745	1009	1272
Wool	--	88	219	307

All mixtures were prepared using Portland-composite cement CEM II/A RCK 42,5N, crushed sand 0,63 mm, lime and water. The water content was initially set to a value of 472 g in order to ensure a water/cement ratio of 0,4. However, on execution, it was necessary to increase the programmed quantity of water, in order to ensure the workability of the mix, greatly deteriorated due to the insertion of ever-increasing percentage of wool fibres.

For each kind of mixture, several specimens were realized:

- Two specimens (300x300x20mm) for thermal conductivity tests according to EN 12664:2002 [11]
- Three specimens (160x40x40mm) for mechanical strength tests according to EN 1015-11:2007 [12]

Fig. 5. Preparation of mortar.

The procedure adopted for the preparation of test specimens provides first of all the mixing of all solid raw materials (cement, sand and lime), and then the addition of water and wool. The mixture is then mixed with a concrete mixer impeller (800 rpm for 10 minutes).

Thermal test specimens were aged in wooden formworks in the form of rectangular panels for 28 days, while test specimens for flexural and compressive strength ac-cording to EN 1015-11 were aged in special moulds.

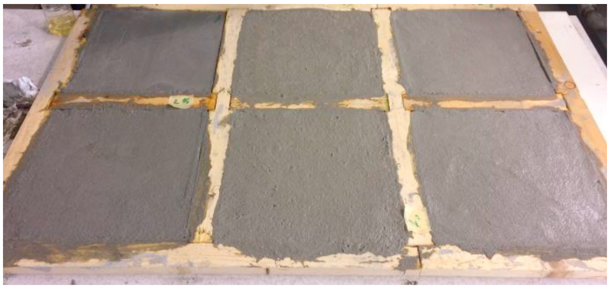

Fig.6. Thermal test specimens in wooden formworks.

Table 2 shows the calculated density of panels according to EN 1015-10 [13]. It decreases with increasing the wool fibres percentage inside mortar.

Table 2. Determination of density.

Mixture	Density [kg/m³]
REF	1697
SW2	1413
SW5	913
SW7	884

3. Thermal and mechanical tests

Experimental tests were performed to investigate thermal and mechanical proper-ties of mortar panels containing different percentages of shredded wool.

3.1. Thermal properties

The apparatus used for thermal conductivity measure was an heat flow meter in “single sample in a double configuration”, model HFM436/3/1 produced by NETZSCH, placed in a conditioned laboratory at a temperature of 23 ± 2 ° C and relative humidity 50 ± 5%, to ensure observance of the test conditions required by the standard EN 12664: 2002 “*Thermal performance of building and products – Determination of thermal resistance by means of guarded hot plate and heat flow meter methods – Dry and moist products of medium and low thermal resistance*”.

Fig. 7. NETZSCH heat flow meter HFM 436/0/1.

The specimen is placed between two plates placed at two different temperatures (ΔT). The heat flux (q) which passes through the specimen is measured by heat flux transducers. With the achievement of thermal equilibrium the test ends. For the purpose of the analysis is considered only a central portion (100x100mm). In Fig. 8 in particular are highlighted a top hot plate and a lower cold plate equipped with two heat flux transducers.

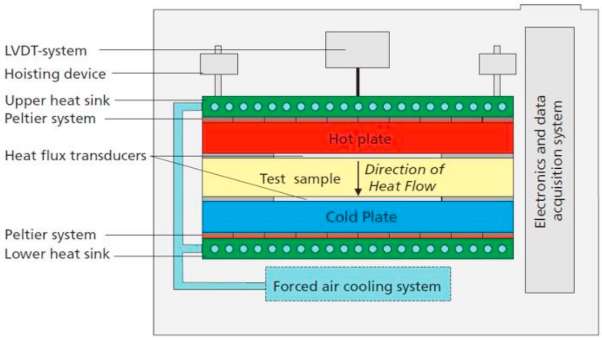

Fig. 8. Principle of operation of the apparatus for determination of thermal conductivity.

Indicated by λ the thermal conductivity of the specimen, d the specimen thickness, ΔT the temperature difference between the two faces of the test and A the area through which the heat passes, the relation between these parameters to achieve balance heat is expressed by the Fourier equation:

$$\Phi = \lambda \cdot A \cdot \frac{\Delta T}{d} \tag{1}$$

The two transducers measure the heat flow through the specimen (see Figure 8). The signal from a transducer (expressed in Volts (V)) is proportional to the heat flow through the transducer.

In the heat flow meter, the transducer area is the area through which passes the heat and is constant for all the specimens, then:

$$\Phi = N \cdot V \tag{2}$$

where N is the calibration factor that relates the potential difference of the transducers to heat flow through the specimen. Resolving isolating λ, the thermal conductivity is given by the following relation:

$$\lambda = \frac{N \cdot V \cdot d}{\Delta T \cdot A} \tag{3}$$

Mean temperature of equilibrium of tests was set to 10 °C and the ΔT between the plates is 20 °C. The following Table 3 shows the λ values obtained for all kind of tested specimens.

Table 3. Results of thermal conductivity tests.

Specimen	% of wool fibres	Thermal conductivity λ [W/(m²K)]	*(SW_i-REF)/REF* [%]
REF	0	0,381	--
SW2	2	0,288	-24,4%
SW5	5	0,138	-63,8%
SW7	7	0,107	-71,9%
Drywall panel	-	0,187	--

The analysis of obtained results highlights that the decrease of conductivity, if compared with that one of reference specimen (REF), is 24,4% in SW2, 63,8% in SW5 and 71,9% in SW7.

Table 3 shows also the thermal conductivity of a commercial drywall panel, considered as potential competitor of mortar panel with wool fibres with reference to the thermal performance.

3.2. Mechanical properties

To investigate the mechanical properties of mortar containing wool fibres, three samples (dimension 160x40x40 mm) for each mixture were prepared for flexural and compressive strength tests, according to EN 1015-11 "*Methods of test for mortar for masonry – Determination of flexural and compressive strength of hardened mortar*".

Fig. 9. Moulds and specimens for mechanical tests.

The test apparatus used for mechanical tests was a frame Dual Column Instron 3369 for both flexural and compressive strength.

Regarding flexural tests, the instrumentation applies the load at a rate specified in EN 1015-11 standard; in this phase load rate was set to 50N/s since for these plaster mortars a low resistance is expected.

Fig. 10. Three point flexural test on SW2_2 specimen.

It is useful to underline that a visual analysis of the samples SW5 and SW7 has highlighted that their lateral surfaces were not perfectly smooth and that wool fibres were partially grouped; these defects were more evident with increasing percentage of wool inside specimens.

Fig. 11. SW5_2 specimen during a three point flexural test.

Fig.12. SW7_1 specimen. Surface not linear due to wool fibres grouped.

For each specimen the maximum load applied (F) was recorded and expressed in Newton, then flexural strength (f) was calculated in N/mm2, to the nearest 0,05 N/mm2 using the following equation:

$$f = 1.5 \cdot \frac{Fl}{bd^2} \quad (4)$$

where

b = width of specimen (mm).

d = depth of the specimen (mm).

The average flexural strength was calculated to the nearest 0.1 N/mm2. The following Table 4 shows mean flexural strength according to EN 1015-11 for each kind of mixture:

Table 4. Results of flexural tests.

Mixture	Flexural strength [MPa]	*(SW_i-REF)/REF* [%]
REF	1,1	--
SW2	1,0	-9,1%
SW5	0,2	-81,8%
SW7	0,2	-81,8%

Comparison of flexural strength measured between the REF mortar and the other tested types shows a reduction of around 9,1% for SW2, while this reduction is more pronounced with a percentage of about 81,8% to SW5 and SW7.

Since for plaster mortars a low resistance was expected, in compression tests the load rate was set around to 50N/s, the minimum provided for by EN 1015-11.

For each specimen the maximum load applied (N) was recorded and expressed in Newton, then compressive strength (σ) was calculated to the nearest 0,05 N/mm2 as the maximum load carried by the specimen divided by its cross-sectional area.

Two graphs of compression tests are reported: the first one is related to REF specimen and the last one is related to SW2 specimen. The graph shows in x-axis deformation expressed in (mm/mm) and in y-axis compressive tension expressed in (MPa).

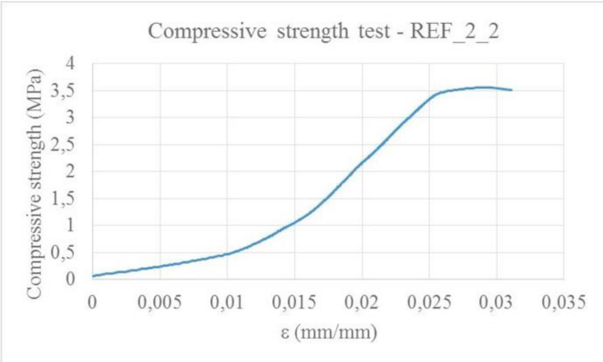

Fig. 13. Stress vs deformation curve in compressive test on REF_2_2 specimen.

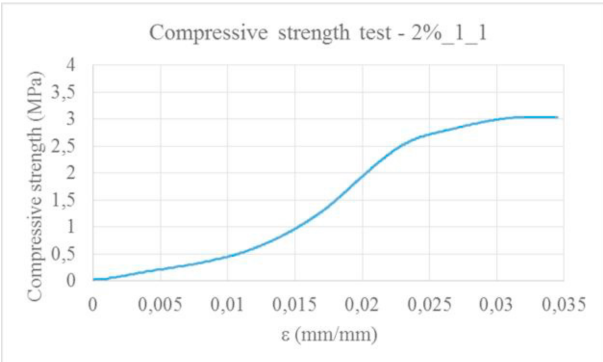

Fig. 14. Stress vs deformation curve in compressive test on SW2_1_1 specimen.

Finally, for all realized mixtures, mean of compressive strength has been calculated to the nearest 0,1 N/mm2. Following Table 5 shows mean values of compressive strength according to EN 1015-11:

Table 5. Results of compressive test.

Mixture	Compressive strength [MPa]	*(SW$_i$-REF)/REF* [%]
REF	3,4	--
SW2	2,9	-14,7%
SW5	0,4	-88,2%
SW7	--	--

Comparing the compression strength values with respect to the specimen REF, the specimen SW2 has a reduction of 14,7% while the reduction for the specimen SW5 is far more pronounced and reaches 88,2%.

Regarding the specimen SW7 all samples were discarded because the final material was very brittle and was not able to get a specimen for the compression tests.

4. Results and discussions

Experimental tests were performed to obtain thermal properties and mechanical properties of some mortar panels containing inside wool fibres in three different percentage.

Results of thermal properties tests, performed on four kind of different mixture and on a drywall panel, are shown in next figure.

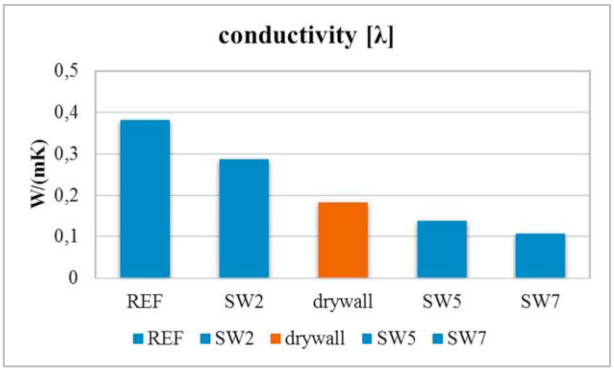

Fig.15. Comparison of thermal conductivity of mixture with commercial drywall.

Drywall panel specimen tested in HFM shows a conductivity higher than that of the samples containing percentage of the wool fibres of 5% and 7%, but lower than that of the specimen containing the fibres percentage of 2%.

Results of mechanical tests can be summarized in a reduction of flexural strength and of compressive strength more limited for SW2 if compared to REF. Not the same for SW5 and SW7 specimens; they have very pejorative characteristics.

Analysing the described tests results it is possible to state that an increase of the percentage of wool in the cement mortar increases the thermal properties but strongly penalizes the mechanical characteristics of the material. This last aspect is also attributable to the greater amount of water that has been necessary to add to the mixture, which gradually increasing the percentage of fibres, to facilitate the workability of the mortar.

Of course, a potential use of these panels cannot be divorced from a higher mechanical strength. For this reason it will be used within the mixture of cementitious mortar other natural fibres with the task to strengthen this particular aspect; this application will be part of a future research activity.

5. Conclusions

Sheep's wool is a resource and not waste. Taking advantage of its special thermal insulation properties, there are various commercial types of insulating panels made entirely of sheep wool.

Starting from these consideration ENEA researchers have investigated the possibility to consider this resource in an unconventional way; using it as a material able to pro-vide an added value certainly in terms of heat insulation, but also mechanical strength, to mortar panel. In fact, these kind of panels for building have normally a poor thermal insulation and a sufficient mechanical characteristics often depending on the particular composition of the mixture.

This research has tried to highlight the possibility to increase both thermal and mechanical aspects of the cement mortar panels and to identify what was the best percent-age of wool fibre to meet both requirements.

Among the various combinations tested, the percentage of 2% of wool fibre is the one that has had better results even if not completely satisfactory.

In any case it was still demonstrated that the addition of small percentages of wool fibres allows the composite material to increase its thermal insulation capacity with respect to the material without fibres.

Surely many other investigations are necessary, but we can say that the insertion and reusing of sheep wool can certainly be a potential advantage in economic and environmental terms.

References

[1] Fantilli A. P., Sicardi S., Dotti F. The use of wool as fibre-reinforcement in cement-based mortar. In: Proceedings of the *1st International Conference on Bio-based Building Materials*, Clermont-Ferrand, France, ICBBM; 2015, pp. 341-346.

[2] Asprone D., Durante M., Prota A., Manfredi G.. Potential of structural pozzolanic matrix–hemp fibre grid composites. *Construction and Building Materials* 2011; 25 (6): 2867-2874.

[3] Bărbuță M., Toma I.O. et al.. Behavior of short hybrid concrete columns under eccentric compression. *Archives of Civil and Mechanical Engineering* 2013; 13: 119-127.

[4] Hamzaoui, R., Guessasmam S., Mecheri, B., Eshtiaghi, A.M., Bennabi, A. Microstructure and mechanical performance of modified mortar using hemp fibres and carbon nanotubes. *Materials and Design* 2014; 56: 60–68.

[5] Vikan H.. Concrete workability and fibre content. *Sintef Building and Infrastructure Report*; 2007.

[6] Grădinaru C.M., Bărbuță M., Șerbănoiu A.A., Babor D. Investigations on the mechanical properties of concrete with sheep wool fibres and fly ash. *Bulletin of the Transilvania University of Braşov*; 2016.

[7] Imbabi, M.S., Carrigan, C., McKenna, S. Trends and developments in green cement and concrete technology. *International Journal of Sustainable Built Environment*, 2012; 1:194-216.

[8] Valenza A., Fiore V., Nicolosi A., Rizzo G., Scaccianoce G., Di Bella G. Effect of sheep wool fibres on thermal-insulation and mechanical properties of cement matrix. In: Proceedings of the *1st International Conference on Bio-based Building Materials*, Clermont-Ferrand, France, ICBBM; 2015, pp. 40-45.

[9] Štirmer N., Milovanović B., Sokol J.M.. Cement composites reinforced with sheep's wool. In: Proceedings of the International Symposium on Eco-Crete; 2014, pp. 271-278.

[10] Corscaddena K.W., Biggsb J.N., Stilesb D.K.. Sheep's wool insulation: A sustainable alternative use for a renewable resource? *Resources, Conservation and Recycling*, 2014; 86: 9–15.

[11] CEN. 2001. Thermal performance of building materials and products - Determination of thermal resistance by means of guarded hot plate and heat flow meter methods - Dry and moist products of medium and low thermal resistance. EN 12664 Standard. Bruxelles: European Committee for Standardization.

[12] CEN. 2007. Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar. EN 1015-11 Standard. Bruxelles: European Committee for Standardization.

[13] CEN. 2007. Methods of test for mortar for masonry - Part 10: Determination of dry bulk density of hardened mortar. EN 1015-10 Standard. Bruxelles: European Committee for Standardization.