MECHANICAL AND PHISICAL QUALIFICATION OF BASALT FIBER PANELS

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Abstract

This paper summarizes the experimental work carried out at the Material technologies Laboratory of the ENEA Trisaia Research Centre (UTTRI-TEM) for the energy performance characterization of basalt fiber panels with different thicknesses. In particular, the determination of the thermal conductivity with the heat flow meter methods, (in accordance with UNI EN 12667:2002), the determination of the physical characteristics of the material, such as compressive strength (in accordance with UNI EN 826:2013), the absorption of water in the short term (according to standard EN 1609). The final data may be used for a comparative evaluation of basalt fiber with traditional insulating materials and will be the basis for a future development of new panel, based on basalt fiber, able to guarantee thermal conductivity values lower than those existing with substantially contained economic costs.

1. Introduction

Energy saving is the most accessible and cost-effective form of alternative energy. The heating and cooling of buildings are a significant percentage of energy consumption, therefore, improving energy efficiency is possible to achieve the objectives of the program called "20-20-20" with which the EU countries intend, by the year 2020 , 20% improvement in energy efficiency, reducing by 20% the CO_2 emissions and use 20% renewable energy. A target obtainable on the buildings in which the structures that mark its volume are properly insulated.

In this context, the insulating materials and research related to them have a primary role. On the market there are various products that ensure energy performance in line with expectations for savings and environmental sustainability. Based on the current European legislation, enacted by the various states, they find a field of employment when they satisfy some basic requirements such as mechanical strength, fire resistance, relapse on health and environment, protection against noise, energy conservation, sustainable use of natural resources. The features listed above are owned by the basalt fiber (BF), a material not new but whose applications can certainly become innovative coming the fusion and subsequent spinning of basaltic rock, the most widespread on the Earth's crust. This material has very interesting physical-chemical characteristics: good chemical stability in both acidic environment than in an alkaline environment, a high degree of durability, strength guaranteed even at high temperatures up to 600 ÷ 700 ° C, a low moisture absorption, a good thermal and acoustic insulation, good mechanical properties, high resistance to fire and a production cycle with a lower impact energy than synthetic fibers. [1]

In recent years, research on this material has attracted particular interest for the countless potential that makes it usable in different application fields. The researchers of the ENEA UTTRI-TEM Laboratory focused their attention on those applications that meet the criteria of energy efficiency in the building industry, initiating testing experimental verification of the different basalt fiber products potential on the basis of current technical regulations [2].

This paper shows the final results of the investigation activity carried out on basalt fiber insulating panels expanding research also to mechanical behavior and water absorption in such a way to define the performance limits of the panels and then start activities for the improvement of their performance.

2. Basalt fiber panels tested

The tested materials are rigid insulating panels made up of basalt fiber, produced by HG GBF a Chinese company, world leader in production of this kind of material. The tested panels are obtained from the compaction of short BF without any further treatments and are supplied in a configuration of a square section of side approximately of 300mm and three different nominal thicknesses d_N as showed in the next table 1

Nominal thickness (cm)	Real thickness (cm)	Weight (g)
2.00	1.80	275.39
3.00	2.91	381.58
5.00	4.72	702.84

Table 1. Dimensional characteristics of tested basalt fiber rigid panels

Figure 1. Rigid basalt fiber panels

3. Experimental tests on Thermal conductivity

Thermal conductivity, expressed by the symbol λ identifies the aptitude of a material to transmit heat and represents one of its intrinsic property. It is defined as the amount of heat which, in a steady state, passes through a surface of one square meter of the material considered, with thickness of one meter, in one hour of time when the temperature difference between the two faces is one centigrade degree .

The equipment used for the determination of the thermal conductivity was a heat flow meter model HFM436/3/0 produced by Netzsch, type " single sample with double configuration", placed in an air-conditioned laboratory at a temperature of 23 ± 2° C and relative humidity of 50 ± 5% in order to ensure compliance with the test conditions laid down by the UNI 13162:2012. [4]

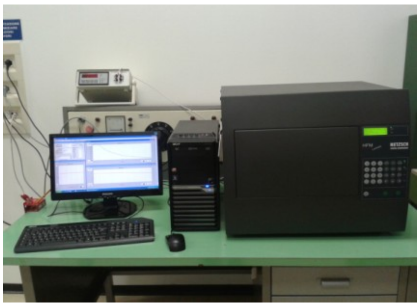

Figure 2. Heat Flow Meter instrument set in ENEA UTTRI-TEM Laboratory

Plate temperature range	Fixed 0° C to 40°C
Cooling system	Forced air
Specimen size (mm)	300x300x100
Thermal resistance range (m^2KW)	0.005 to 0.50
Repeatability	0.5%
Accuracy	± 1% to 3%

Table 2. HFM 436/3/0 technical specifications

3.1. Calibration test

As required by the standard UNI EN 12667 [3], the Heat Flow Meter (HFM) instrument calibration was made to ensure the accuracy of the measurements made on the samples. This step was performed using a standard reference glass fiber specimen having a known heat conductivity. The calibration test is related to a specific set-point values; it is important to define the value of the average temperature (T_{mean}) as well as that of the temperature difference ΔT between the upper plate and the lower one of the HFM instrument. It is necessary that there is a correspondence between the values T_{mean} and ΔT between the instrument calibration and experimental evidence test.

The calibration was done at three values of T_{mean}: 10° C, 20° C and 30° C and for all was imposed a $\Delta T = 20$ ° C. The final results, compared with the corresponding values provided by the user, are summarized in the next figure 3 which shows a clear obtained overlap. The values N of the calibration factor obtained with correspondence of three above indicated values of T_{mean} are used for testing and therefore it was not necessary to repeat the calibration for each experimental test.

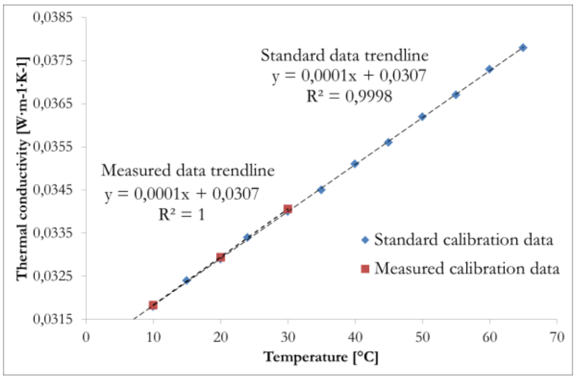

Figure 3. Graph comparing the measured calibration and the standard calibration instrument .

3.2. Test procedures

The test specimen was placed between two heated plates, set at different temperatures (ΔT). The heat flow (q), measured by a heat flux transducer, passes through the central part of the specimen (100 x100 mm), the only part used for the analysis. After reaching a thermal equilibrium, the test is done. The heat flux transducer output is calibrated with a standard. Named λ the heath conductivity of the specimen, d its thickness, ΔT the temperature difference across the sample and A the area through which the heat flows, the Fourier heat flow equation gives the relationship between these parameters when the test section reaches thermal equilibrium:

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

Two heat flow transducers measure the heat flow; their signal is proportional to the heat flow through the transducer. Therefore:

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

where N is the calibration factor that relates the voltage signal of the heat flow transducer to the heat flux through the sample. Solving for λ

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

3.3. Experimental activities

Before performing tests, the specimens were weighed, then placed in an oven with air circulation at a temperature T = 110 ° C and weighed at intervals of 1 hour. The conditioning period was equal to 4 hours because after this time was not detected any mass change; therefore it was decided to calculate the density value. The next table 3 shows the data recorded prior to conditioning of the masses (m_1), after 1 hour of conditioning (m_{c1}), after 4 hours of conditioning (m_2) and immediately after the test (m_3):

	m_1 (g)	m_{c1} (g)	m_2 (g)	ρ_2(kg/m^3)	m_3 (g)
d_N 2	275,39	274,67	274,65	167,10	275,86
d_N 3	381,58	379,69	379,69	142,70	382,89
d_N 5	702,84	700,46	700,42	162,26	703,27

Table 3. Recorded specimen’s mass and density

The previous table shows how the mass value after conducting test tends to increase as a result of absorption of a small proportion humidity. The thermal conductivity tests were carried out with ΔT=20° C; about the values of T_{mean} the case study was not limited to the value of 10° C provided as a standard rule, but was extended to three different values:

a) T_{mean} = 10° C, as indicated by UNI EN 13162 "*Thermal insulating products for buildings. Factory made mineral wool (MW) products-Specification* ", which corresponds ideally to the winter weather conditions: ambient temperature of 0° C if outside and a temperature the of 20° C if inside an apartment.
b) T_{mean} = 30° C corresponding to the summer weather conditions: temperature equal to 40°C if outside and a temperature the of 20° C if inside an apartment.
c) T_{mean} = 20° C as an intermediate case.

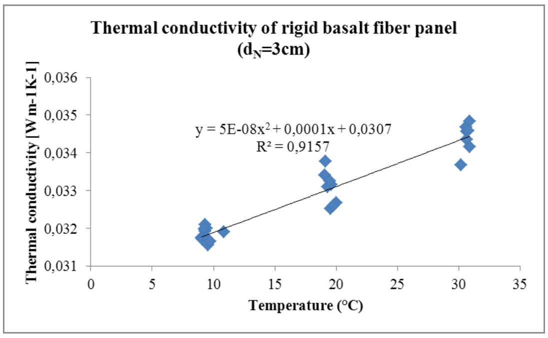

Figure 4. Results of thermal conductivity tests for a nominal thickness $d_N = 30$mm

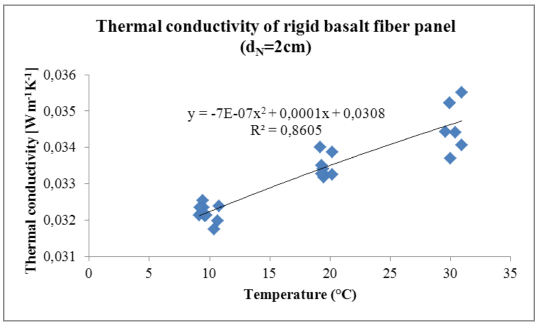

Figure 5. Results of thermal conductivity tests for a nominal thickness $d_N = 20$mm

For each specimen, the thermal conductivity values were calculated for a number of measurements n>10, performed during at least 10 days with a T_{mean} as indicated previously, then statistically processed to obtain the declared values of conductivity and thermal resistance. The reference formulas are:

$$\lambda_{90/90} = \lambda_{mean} + k \times s_\lambda \qquad s_\lambda = \sqrt{\sum_{i=1}^{n} \frac{(\lambda_i - \lambda_{mean})^2}{n-1}} \qquad R_{90/90} = \frac{d_N}{\lambda_{90/90}} \tag{4}$$

$\lambda_{90/90}$	is a 90% fractile with a confidence level of 90% for thermal conductivity;
λ_{mean}	is the mean thermal conductivity;
λ_i	is one test results of thermal conductivity;
k	is a factor related to the number of test results;
s_λ	is the estimate of the standard deviation of thermal conductivity;
$R_{90/90}$	is a 90% fractile with a confidence level of 90% for thermal resistance;
d_N	is the nominal thickness of the product;

The statistical value of thermal conductivity was rounded upwards to the nearest 0,001 $W\,m^{-1}\,K^{-1}$ and declared as λ_D. The statistical value of thermal resistance calculated from the nominal thickness d_N was rounded downwards to the nearest 0,05 $m^2\,K\,W^{-1}$ and declared as R_D

d_N	λ_{mean}	s_λ	λ_D	R_D
[cm]	[W m^{-1} K^{-1}]	[W m^{-1} K^{-1}]	[W m^{-1} K^{-1}]	[m^2 K W^{-1}]
5	0,0323242	0,0002193	0,033	1,50
3	0,0318175	0,0001705	0,033	0,90
2	0,0321929	0,0002253	0,033	0,60

Table 4. Final results obtained for the three analyzed nominal thicknesses

The value of λ_d obtained by test has allowed to report basalt fiber panel with the other insulating materials normally used in construction and has been possible to draw up a proper plotting as shown by the next figure.

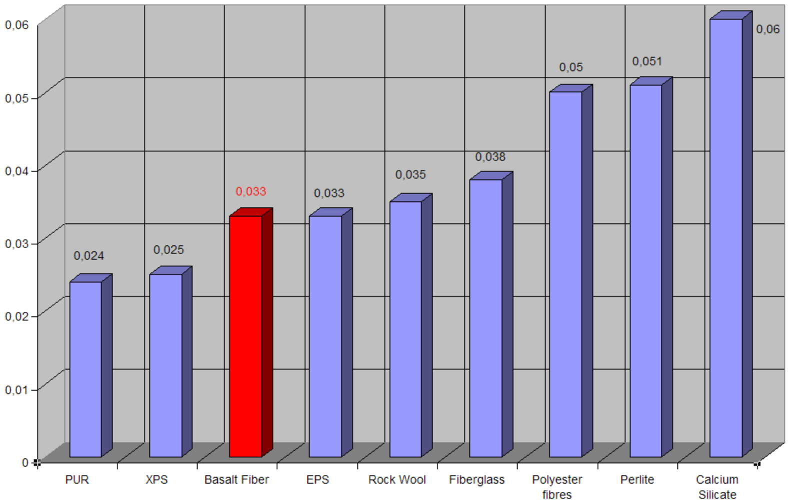

Figure 6 Relationship between the value of thermal conductivity (in red) of basalt fibers with the most common materials used in construction

4. Mechanical characterization test

On two types of basalt fiber panels tested for thermal conductivity, in particular those with nominal thicknesses d_N=20 mm and d_N=30 mm, were made some compression tests according to the UNI EN826: 2013 [5] in order to determine the compressive strength at 10% deformation. The used test apparatus was a frame *Dual Column Instron 3369*; dishes for compression were circular with a diameter of 160 mm.
The specimens, adjusted up to the size 100x100 mm, were stored for 6 hours at a temperature of 22° C in a conditioned room and the tests were conducted with the same ambient temperature and with a relative humidity of 50%.

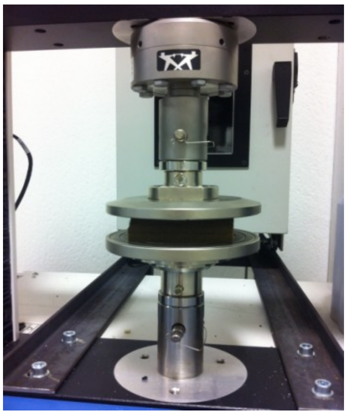

Figure 7. Compression testing machine

The specimens, placed in a central position between the compression plates, were submitted to the test with a constant speed of 1.8 mm / min (d_N = 2 cm) and 2.9 mm / min (d_N = 3 cm) until reaching the yield point or the deformation of the 10%.
The sampling of the values of strength and deformation was carried out with a frequency of 100Hz and the results were in turn represented graphically in charts.

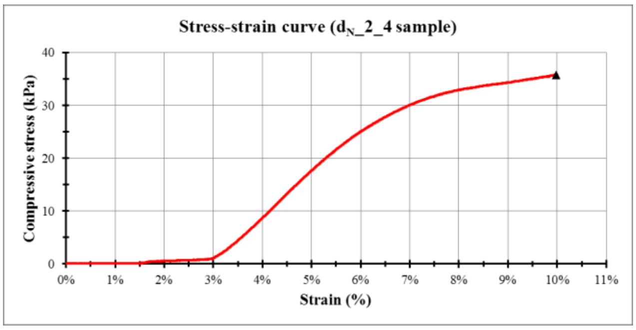

Figure 8. Stress-strain curve compression test for specimen number 4 with d_N = 2 cm

The tables below show the results of compression tests and in particular the resistance values in terms of compressive force in correspondence to a crushing of 10% (F_{10}) and Compression stress in correspondence of a crushing of 10% (σ_{10}).
It follows that the average value tension resistance is equal to 64.975 *kPa*, for d_N = 2 cm and 53.469 kPa for d_N = 3 cm. Finally, using coding according to EN 13162, which provides that no test result must be less than the stated value of CS (10), these products will have CS (10) ≥ 40kPa.

specimen	Geometric size				Resistance value	
	L1	L2	t	A	F_{10}	σ_{10}
	[mm]	[mm]	[mm]	[mm^2]	[N]	[kPa]
BAS_2_1	100	100	18	10000	683,530	68,353
BAS_2_2	100	100	18	10000	698,400	69,840
BAS_2_3	100	100	18	10000	446,130	44,613
BAS_2_4	100	100	18	10000	805,380	80,538
BAS_2_5	100	100	18	10000	615,320	61,532

Table 5 - Results of compression tests conducted on basalt fiber panel with a nominal thickness d_N=2 cm

specimen	Geometric size				Resistance value	
	L1	L2	t	A	F_{10}	σ_{10}
	[mm]	[mm]	[mm]	[mm^2]	[N]	[kPa]
BAS_3_1	100	100	29	10000	539,560	53,956
BAS_3_2	100	100	29	10000	709,700	70,970
BAS_3_3	100	100	29	10000	459,480	45,948
BAS_3_4	100	100	29	10000	478,250	47,825
BAS_3_5	100	100	29	10000	486,470	48,647

Table 6- Results of compression tests conducted on basalt fiber panel with a nominal thickness d_N=3 cm

5. Partial measure of water absorption.

At the laboratory UTTRI-TEM it was also carried out an experimental activity concerning the partial measure of the water absorption of basalt fiber panels with different thicknesses, supplied by HG GBF, in accordance with the UNI EN 1609:2013 - *Determination of water absorption for a short period for partial immersion* [6].
From the original analyzed basalt fiber panels, 4 specimens of average size 20 x 20 x 2.91 cm were obtained according to the UNI EN 1609:2013. All the specimens were conditioned for 6 hours at 23 ± 5° C and then weighed for the determination of the initial mass with an accuracy of 0.1 g. The specimens were placed in a container and on them was applied a load to keep

them sufficiently immersed only with the lower part. During all the test the water level was kept constant. At the end of the test, after a phase of rapid drying, the specimens were weighed to determine the mass after 24 hours

The partial absorption of water, *Wp* expressed in kg/m^2, was calculated using the following formula:

$$Wp = m_{24} - m_0/Ap \tag{5}$$

where m_0 and m_{24} respectively indicate the mass specimens at the beginning and after 24 h, while Ap is the area of the lower surface of each specimen.

Figure 9. Specimens immersed in water for 24 h.

All the obtained result are outside of the maximum values in the standard and the same is for lower values of panels thickness. This result was obviously expected considering that the panels are made through compression of the basalt fibers and the different layers are obtained by compressing several layer minimum, then with large amounts of air inside them. A slight improvement has been by increasing the compression degree but it is evident the need to adopt new techniques to make these panels compatible with the presence of water without reducing the other properties, both physical and mechanical.

Conclusions

From the above, it is possible to observe how the basalt fiber panel may well satisfy most of the requirements listed at the beginning of this work.

The laboratory UTTRI-TEM is now committed to implement new solutions to make this rigid panel even more powerful in terms of energy efficiency and environmental sustainability.

References

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[3] UNI EN 12667:2002 Thermal performance of building materials and products - Determination of thermal resistance by means of guarded hot plate and heat flow meter methods - Products of high and medium thermal resistance

[4] UNI EN 13162:2012 Thermal insulation products for buildings –Factory made mineral wool (MW) products – Specification

[5] UNI EN 826 Thermal insulating products for building applications. Determination of compression behaviour.

[6] UNI EN 1609 Thermal insulating products for building- applications Determination of short therm water absorption by partial immersion.