BFRP: QUALIFICATION AND TEST

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Abstract
This article provides the first results of qualification and control tests over BFRP conducted at the material Laboratory of the ENEA Trisaia Research Center, in collaboration with HG GBF, a Chinese company specialized in bsalt fiber manufacturing. HG GBF has provided all the needed material required by ENEA to execute tests; in particular, given the basalt fiber application areas consistent with ENEA policy purposes, fabrics with different weave, nets, basalt fiber rebar from φ8 to φ16, chopped fiber of different length, continuous basalt fiber. Tests are carried out by ENEA primarily to understand and research about the properties of a material - basalt fiber - that in the western world is not widely used and known. In many cases research are in progress and however are still limited to a limited number of applications.

1 Introduction

Basalt fiber (BF), known as “the green industrial material of the XXI-century” is not a new material, but its applications are surely innovative in many industrial and economic fields, from building and construction to energy efficiency, from automotive to aeronautic, thanks to its good mechanical and chemical performances. In March 2010 ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development - and HG-GBF - a Chinese company world leader in basalt fiber manufacturing - signed a technical agreement which main targets was to improve the research related to innovative industrial applications of basalt fiber (BF) implementing in this way innovation programs. In general terms, the agreement with HG-GBF allows to ENEA to exploit the Chinese knowhow and materials, learning more about the basalt fiber potential in all its forms and applications, making a reference point in a virtuous cycle that links the producer to the end user through the validation and research done by an independent organization.

The resason of ever increasing interest for BF is principally in its various applications in the field of new materials, justified by several factors such as high tensile strength, elastic modulus, durability against acids, alkalis and environmental events, extended operating temperature range, low hygroscopicity, fire resistence, etc.[1].

ENEA, according to its mission, has focused its scientific interest mainly on the sectors of energy efficiency in building construction and automotive. In this context the Laboratory of Metrology and Material Technology of ENEA Trisaia Research Centre (UTTRI-TEM) has engaged parts of its human resources for testing and qualifing BF, in coordination with

HG-GBF, integrating the operational resources available in other ENEA Research Centers particularly focused to the materials sector and in some Italian public Universities.
To understand in a better way the properties of a material - basalt fiber - that in the western world is not widely used and known, ENEA's researchers together with the collegues of HG GBF have carried out different tests such as mechanical and durability characterization of basalt fiber rebars, characterization of BF insulating panels with particular reference to the thermal conductivity; characterization of basalt fabric for structural applications.
Some of these, like rebars tests, are still in progress because they need a long time for the execution with particular reference to the durability tests; others have already been performed. Following these experiences some research projects were launched and funded.
This paper presents the first results of this research activity.

2 Basalt fabric for structural application

The characterization of a fabric for the reinforcement of structural elements is principally obtained through the determination of a parameter set which knowledge is crucial for the dimensioning of the same reinforcement. In particular:

a) the area density ; it is the weight of a square meter of fabric and it is an indication of the total fiber quantity present in the fabric (g/m^2);
b) the width; it is the size of fabric across the direction of unrolling (mm, cm, m);
c) the unitary resistant section; it is calculated by dividing the fibers weight expressed in grams to the absolute specific weight of the material from which the fabric is constituted;
d) tensile strenght (Mpa);
e) elastic modulus;
f) elongation at break (%).

The first three can be calculated by simple geometric measuraments while for the last three are necessary mechanical tests. In our test, we have conducted a direct tensile test according to the guidelines of the American standard ASTM D3039 [5].
The fabric tested, provided by HG-GBF, was an unidirectional fabric made of single axis fibers or bundles of basalt fibers arranged all parallel to each other and held together by a network of BF filaments whose main geometric characteristics can be summarized as follows:

Filament diameter (μm)	Area density (g/m^2)	Width (mm)
13	3083	300

Table 1. Geometric property of basalt fabric used in test

Before the mechanical tests, it was necessary to proceed to the realization of appropriate specimens; infact the tensile tests are not performed directly on the reinforcement as it is, because it would be difficult to distribute the stresses uniformly over all the fibers. A sample of the composite is thus realized by impregnating the fabric with an epoxy resin. This step, apparently simple, is in reality very delicate. As it is known the texture of a fabric does not absolve any mechanical function but has simply the task of preventing loss or scrolling of fibers in addition to loss of alignment between the same before the same fabric is impregnated with the resin which will form the matrix. Any changes in the pattern of straight fibers before the "freezing" of their position through the impregnation and the subsequent solidification of the resin, in fact, may result in a reduction of the mechanical characteristics of the composite compared to those expected.
The next figures shows some of the steps fir the realization of the necessary specimens.
The unidirectional BF fabric was initially prepared in the form of strips of normed dimensions (fig. 1A). Then a fluid epoxy resin was applied to penetrate and impregnate fully

the support (fig.. 1B); the resin was spatulated to allow a proper filling of voids, covering the sample completely (Fig. 1C). The last step was to apply a possibly transparent cover treating the specimens with the technique of vacuum bag. (fig. 1D) in order to be sure that the resin had effectively penetrated and closed all the gaps.
After 48 hours at the ends of sampling were glued, by the same epoxy resin used in previous steps, aluminum wafers necessary for the transfer to the BFC of the stress transmitted by the jaws of universal machine.

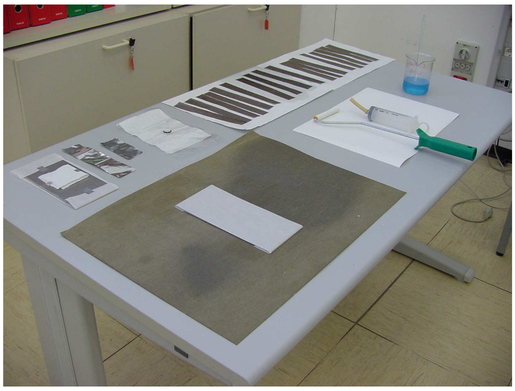

Figure 1A

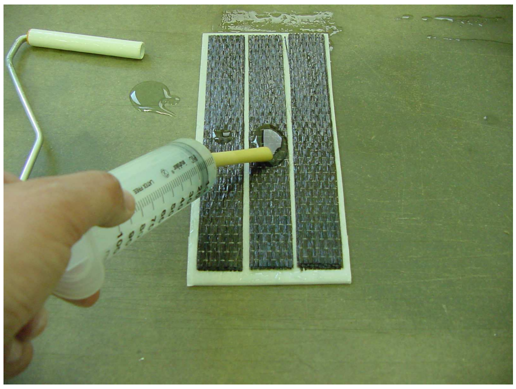

Figure 1B

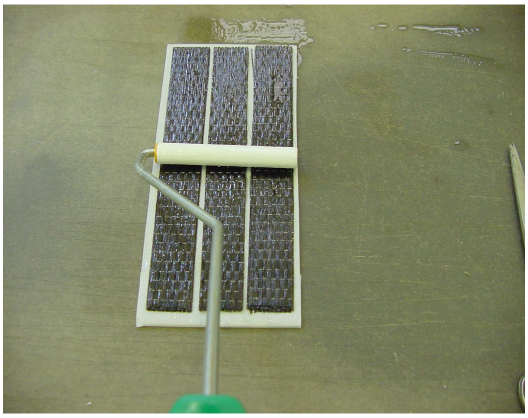

Figure 1C

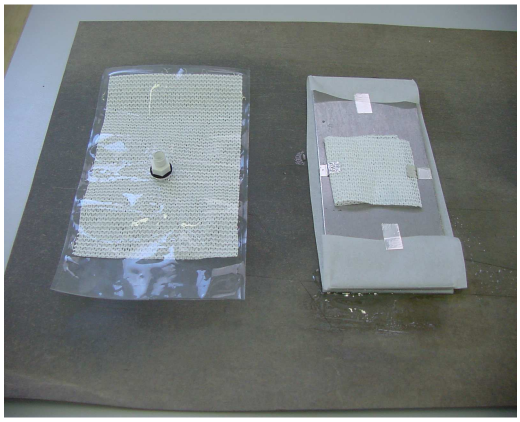

Figure 1D

The tests was performed by a mechanical testing system by Instron: the specimens were fixed through appropriate wedge action grips as shown in the next figure.

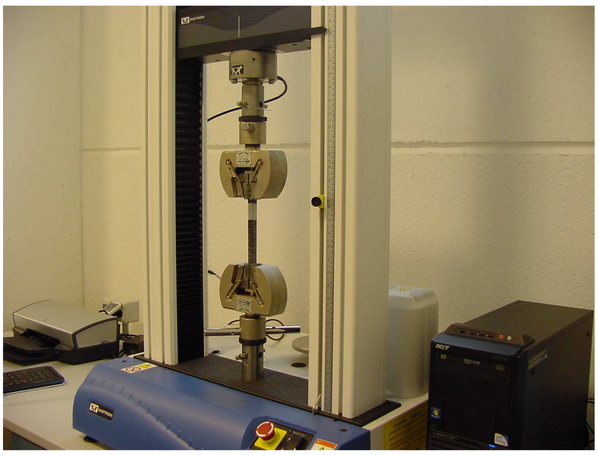

Figure 2: a phase of the mechanical test

As indicated by the ASTM 3039D the tensile stress and the elastic modulus of the BF fabric were determined by referring only to the cross section of the fibers without considering the contribution due to the stiffening resin. The next figure shows one of the diagram load/extension for one of the tested specimens; the behavior is linearly elastic until failure.

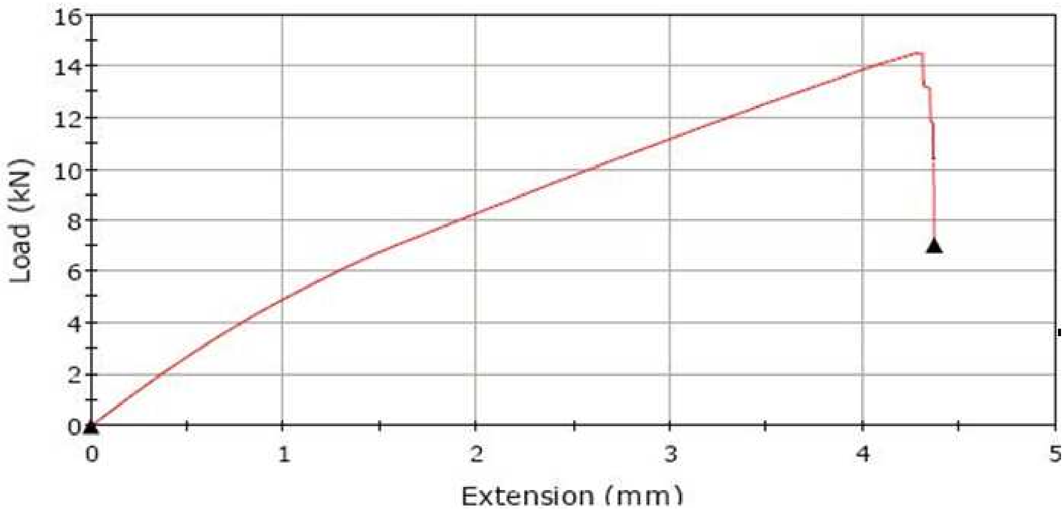

Figure 3: Specimen No. 4 - load /extension curve

The mean values of the mechanical parameters are summarized in the next table:

Tensile strength	1921 MPa
Modulus of elasticity	93 GPa
Deformation at break	2,15 %

Table 2: Mechanical property

3 Basalt fibers insulating panels

The aim of this test was to characterize the energy performance of an insulation basalt fiber panel, providing the necessary data to perform a comparative analysis with conventional insulation materials in building sector.

A proper analysis of its potential applications is based on the consideration that the energy efficiency of buildings primarily depends on the efficiency of the applied insulating material, indicated by thermal transmittance *U*.

This last one depends on the thickness (Δ_x) of the materials forming each layer of element and thermal conductivity (λ), a thermo physical property that determines the ability of a material to transfer heat. The value of the thermal conductivity is characterized by the quantity of heat passing per unit of time per unit area at a temperature drop of 1°C per unit length. In this way, the lower the λ factor, the better the material insulates.

The thermal characterization tests were carried out in accordance with the next Normative References:

1) *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". [2]
2) *UNI EN 13162:2009* - "Thermal insulation products for buildings –Factory made mineral wool (MW) products – Specification"[3]

The apparatus used for the experimental measurement of thermal conductivity λ is a heat flow meter of the type "single sample in a symmetrical configuration", model HFM 436/0 by NETZSCH.

Figure 4A. Model HFM 436/0 of NETZSCH

	HFM 436/3/0 *Lambda™*
Plate Temperature Ranges:	Fixed, 0 to 40°C
Cooling System:	Forced Air
Plate Temperature Control:	Peltier System
Programmable Data Points:	1
Specimen Size:	300 x 300 x 100 mm³
Thermal Resistance Range:	0.1 to 8.0 m²·K/W
Thermal Conductivity Range:	0.005 to 0.50 W/m·K
Repeatability:	0.5 %
Accuracy:	± 1 to 3 %
Dimensions (LxWxH):	48 x 63 x 51 cm³

Figure 4B. Technical specifications

The operation scheme can be summarized as follows: it is constituted by a top heating plate, a below cooling one and two flow transducers of heat.
The insulating panel is placed, with horizontal position, between the two transducers on the lower plate in direct contact with the upper plate. These two transducers need to be calibrated using a standard sample with known characteristics; in this way it is possible to calculate a calibration coefficient, *N*.
The temperature difference ΔT between the two plates (T_{lower} and T_{upper} respectively for the lower and upper plate) generates a heat flow Φ passing through the basalt panel. When a thermal equilibrium is reached, defined *A* the surface of the sample (only a central portion of the sample *100 x 100 mm* is used for test) and Δ_x its thickness, the relationship between the involved parameters is expressed by the Fourier equation on the thermal conduction

$$\Phi = \lambda A \frac{\Delta T}{\Delta_x} \qquad (1)$$

The heat flux transducer output is calibrated with a standard. So, the heat flux Φ flowing through the specimen is proportional to the measured signal V of the heat flow transducer through a calibration factor N:

$$\Phi = NV \qquad (2)$$

Solving for λ it is possible to derive the thermal conductivity

$$\lambda = N \frac{V\Delta_x}{\Delta T} \qquad (3)$$

3.1 Testing procedure and results

Given that λ depends on the mean test temperature T_{mean}, that for the purposes of CE marking its values shall be measured at a mean temperature of 10°C, the tests were performed at the following mean temperatures T_{mean}:

- 10 °C (λ_D - conductivity declared in conformity with the UNI EN 13162 [3]);
- 20°C (temperature in winter conditions);
- 30°C (temperature in summer conditions).

The physical characteristics of the BF panel test were:

Dimensions	30 x 30 cm
Thickness	2,2 cm
Density	92,9 kg/mc

Table 3 . Geometric characteristics of BF panel

The heat flow meter calibration was performed using a standard fiberglass panel .The values obtained for the three test temperatures T_{mean} were compared with standard data annexed to the standard panel.

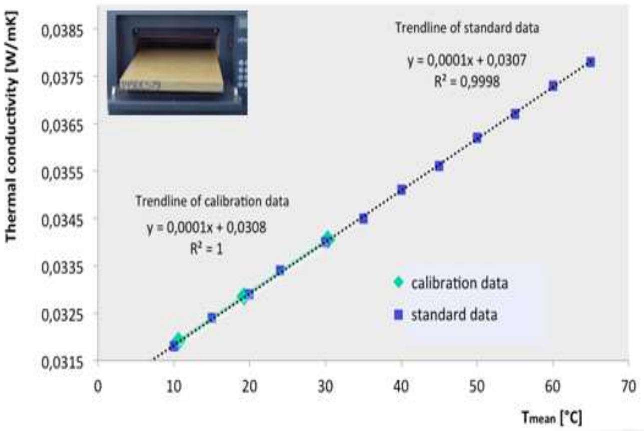

Figure 5. Calibration results

Figure 6. BF Panel specimen

The specimen has been subjected to three test cycles (Test A, Test B and Test C) for each of the test temperatures T_{mean} previously indicated and with a temperature difference between upper and lower plates, $\Delta T = 20°C$, in order to assess the accuracy of measurements.
The next graphs show the evolution of the value of λ during the test A run at 30° C of T_{mean} and the results obtained for the main parameters

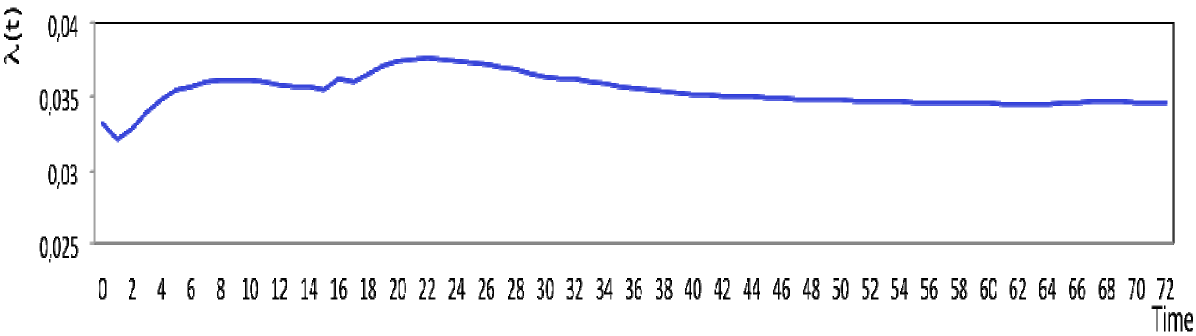

Figure 7 : λ trend - Test *A* : T_{mean} = 30° C

	FB 10-20			FB 20-20			FB 30-20		
	Test A	Test B	Test C	Test A	Test B	Test C	Test A	Test B	Test C
Thermal conductivity (W/mK)	0,033	0,032	0,032	0,033	0,033	0,033	0,035	0,034	0,035
T_{mean} (°C)	9,28	9,98	9,41	20,21	19,66	19,39	30,94	30,43	30,89
ΔT (°C)	19,99	19,99	19,98	20,07	19,7	19,9	20,06	19,95	20,07

Table 4: Test results

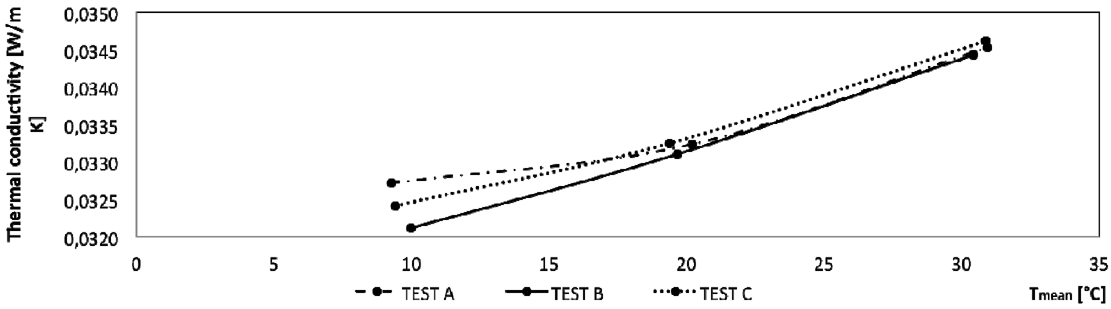

Figure 8. Graphic of λ performance at different T_{mean} values

Based on the obtained values it has been possible to calculate the average value of λ_D and the standard deviation **σ**, one relating to the different T_{mean}.

T_{mean} [°C]	λ [$Wm^{-1}K^{-1}$]	σ_[$Wm^{-1}K^{-1}$]
10	0,03253	0,000252
20	0,03421	0,000158
30	0,03403	0,000303

Table 5: Average value of λ_D and standard deviation **σ**

This test therefore allows to classify the panel basalt fiber compared to other materials normally used in the thermal insulation, according the next table.

Insulation material	λ (W/mK)
Calcium silicate	0,060
Expanded cork panels	0,045
Mineral fiber panels	0,045
Foam glas	0,041
Cellulose	0,040
Polyethylene foam	0,040
polystyrene foam	0,040
Fiberglas	0,038
Rockwool	0,035
Basalt Fiber	**0,033**
Polystyrene expanded (EPS)	0,033
Extruded polystyrene foam	0,025
Polyurethane foam (PUR)	0,024

Table 6: Position of BF compared to other insulating materials

4 Conclusions

The shown tests are only some of those held at ENEA laboratories. ENEA's researcher of TEM laboratory are carrying out tests for stress corrosion, durability tests on unidirectional fabric and on concrete reinforced with chopped BF, mechanical characterization tests of BF rebars. In this regard, particularly interesting are the first data on the behavior of self monitoring smart BF rebars containing sensing optical fiber dstributed in the manufacture process.

The relative results will be presented during the ECCM Conference

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