Experimental investigation on basalt grid cementitious mortar strips in tension

Experimental investigation on basalt grid cementitious mortar strips in tension

Jennifer D'Anna[1], Giuseppina Amato[2], Jian Fei Chen[2], Giovanni Minafò[1], Lidia La Mendola[1]

[1]Department of Civil, Environmental and Material Engineering (DICAM), University of Palermo, Viale delle Scienze Ed. 8, Palermo, Italy
[2]School of Natural and Built Environment, David Keir Building, Queen's University Belfast, Stranmillis Road BT9 6AX, Belfast, Northern Ireland
email: jennifer.danna@unipa.it, g.amato@qub.ac.uk, j.chen@qub.ac.uk, giovanni.minafo@unipa.it, lidia.lamendola@unipa.it

ABSTRACT: Fibre reinforced cementitious matrix (FRCM) composite materials are currently receiving great attention for strengthening reinforced concrete and masonry structures, especially when specific preservation criteria need to be fulfilled. FRCM composites can be a convenient alternative to fibre-reinforced polymers (FRP) for their better resistance to high temperature and compatibility with stone and masonry structures. In this work an experimental study for the tensile characterization of basalt reinforced cementitious matrix (BRCM) strips is presented. Strips with one, two or three layers of grid were tested in tension to study the effect of reinforcement ratio on the tensile stress-strain response of the composite strips. The basalt grid and matrix (cementitious mortar) were also tested in order to compare the mechanical properties of the constituent materials to the response of the composite. Strength, stiffness, failure modes and response stages of the composite strips are discussed in the paper.

KEY WORDS: Basalt grid; FRCM; Tensile tests; Reinforcement ratio.

1 INTRODUCTION

Composite materials are widely used today as strengthening systems for existing concrete and masonry structures. Fibre reinforced polymers (FRP) materials externally bonded by means of epoxy adhesive represented in the last two decades a considerable technological innovation compared to the use of traditional materials and technique such as concrete and steel jacketing. More recently, in the effort to alleviate some drawbacks due to the organic nature of polymer-based composites, growing attention has been paid to fibre reinforced cementitious matrix (FRCM) composites as the inorganic cementitious matrix makes the composite more compatible to concrete and masonry, less sensitive to debonding phenomena at the interface and highly resistant to high temperatures.

FRCM materials show a complex mechanical behaviour in tension, which is affected not only by the fabric and matrix properties but also by the bond strength at the interface between the two components. For cement-reinforced composites, the bond behaviour between the fibres and the matrix is critical due to sliding phenomena and cohesive failures in the mortar. In the last decades many researchers have carried out tensile tests [1-4] and bond tests [1, 3, 5, 6, 7, 8] on FRCM composites. Composite materials made with natural [9], glass [4, 5, 9, 10], PBO [5, 6], carbon [1] and basalt [1, 2] fibres have been investigated. In most of the cases tests have also been carried out on the composite components: mortar [5, 10, 11] and textiles, [1, 2, 5, 6, 7, 11, 12], in order to investigate the contribution provided by the two components.

These studies have shown that the stress-strain behaviour response of FRCM under uniaxial loading can be divided into three stages [1, 2, 5, 9, 10, 12]: a first elastic uncracked branch, a second branch characterised by several jumps associated to cracking of the cementitious matrix and a linear branch up to failure with the whole tensile force been transmitted by the textile reinforcement.

The effect of reinforcing ratio has been analysed in many studies. For example Larringana et al. [2] presented an experimental work on basalt FRCM samples reinforced using four different reinforcement ratios. They showed that while samples reinforced with a single textile fabric showed a certain amount of stress redistribution after the crack development stage, the additional layers made the failure mode more brittle. The development of the crack pattern was also affected by the increase of the reinforcement ratio: the number of cracks was larger for strips with more multiple layers and the crack development stage was concentrated in a shorter interval of strain.

De Santis et al. [10, 12] studies composites with five different mortars (from strong pozzolan mortar to relatively weak hydraulic lime mortar) and two types of reinforcement (glass-aramyd and ultra high tensile strength steel). They showed that strong mortars affect both the uncracked and crack development stages and lead to closely spaced cracks. This effect is less marked for composites with very stiff reinforcements. They also demonstrated that the crack pattern is affected by the layout of the textile, which influences the bond and interlocking between the textile and the matrix, while the failure mode is mainly governed by the reinforcement fabric.

The effect of different clamping systems on tensile characterization of FRCM composites has been studied in [1, 12]; the authors developed different options with the aim of achieving a uniform load distribution and avoid stress concentration in the gripping area. Carozzi et al. [5] compared the clamping method proposed in Annex A of AC434 [12] with an alternative clamping system. They concluded that the alternative solution was preferable as it limited the slip of fibres, giving the chance to explore the third stage of the FRCM stress-strain behaviour and to reach the ultimate stress of the textile reinforcement. On the contrary, the US Standard [12] limited the analysis to the first two phases.

In the present work an experimental study on the tensile characterization of basalt FRCM strips is presented. The tests were carried out at the Heavy Structure Lab of Queen's University of Belfast and are part of a larger study which aims at evaluating the confinement provided by both basalt reinforced cementitious mortar composites (BRCM) and basalt reinforced polymer composites (BFRP) on masonry rectangular columns. The constituent materials, namely fabric and matrix, were tested in order to compare the mechanical properties of constituent materials to the behaviour of the composite. The effect of different reinforcement ratio on the stress-strain response of the composite specimens was investigated, by testing samples reinforced with one, two or three grid layers.

2 MATERIALS: BASALT GRID AND MORTAR

The textile used as composite internal reinforcement consisted of a primed alkali-resistant basalt bidirectional grid with a nominal cell size of 6x6 mm. The mechanical properties of the grid provided by the supplier are presented on Table 1.

A two-component cement-based mortar, reinforced with glass fibres, was used as FRCM matrix. Both components, grid (Mapegrid B250) and mortar (Planitop HDM Maxi) are produced by MAPEI.

Table 1. Manufacturing specifications of the basalt grid.

Material	BFRP grid
Unit weight	250 g/m^3
Density	2.75 g/cm^3
Mesh size	6x6 mm
Tensile strength	60 kN/m
Elastic modulus	89 GPa
Equivalent thickness	0.039 mm
Elongation at failure	1.8 %

3 EXPERIMENTAL PROGRAM

3.1 Grid and mortar characterization

Monotonic tensile tests of basalt grid strips were carried out in accordance with ISO 13934-1 [13]. Five strips with dimension 260x13.5 mm were cut in the warp direction and provided of 80 mm aluminium tabs at the ends, in order to guarantee a uniform loading distribution. The strips were gripped over a length of 50 mm. The test were carried out using a Zwick Roell 100 kN universal machine in displacement control mode at a loading rate of 1 mm/min. Displacements were recorded using a videoextensometer and linear targets attached to the strip over a gauge length of 80 mm.

Three-point bending tests were carried out on six 40x40x160 mm mortar prisms according to EN 1015-11 [14].

3.2 FRCM strip preparation and test setup

A total of 10 basalt FRCM composite specimens were manufactured and tested, using different reinforcement ratios: one series of 5 specimens was prepared using one grid layer, one series of 4 specimens using two layers and one single specimen was prepared employing three layers.

Each specimen name is composed by "SP" followed by the specimen ordinal number and by the number of grid layers "L".

The test set up as well as the specimens dimensions were selected based on published research and existing regulations [15, 16, 17]. All strips had 40x8 mm cross-sectional area and length of 400 mm. Samples were cut from large 500x500 mm slabs prepared in wood formworks (Figure 1) in agreement with AC 434 American Standard [15].

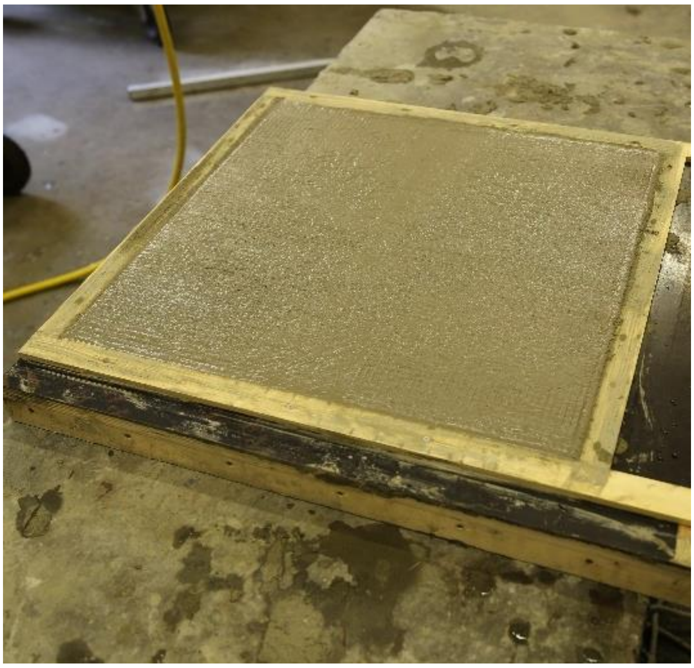

Figure 1. Composite slab.

After casting, slabs were cured for 28 days before been cut in strips with a circular saw. Aluminium tabs were glued to the ends of each specimen in order to avoid failure of specimens inside the gripping area. The strips were then sprayed with black and white paint to create a speckle in order to allow for contactless measurement reading during testing.

The tensile monotonic tests were carried out using a Zwick Roell 100 kN universal machine, in displacement control mode with a loading rate of 0.2 mm/min. A videoextensometer was used to measure the strain over a gauge length of 200 mm. Figure 2 provides a view of the test setup.

Figure 2. Test setup of composite strips

EXPERIMETAL RESULTS

3.3 Basalt grid and mortar

In Figure 3 the experimental stress-strain curves of the five basalt grid specimens are shown. The stress values were obtained considering the equivalent fibre thickness and the number of yarns in the strips. The curves showed a linear trend characterised by the brittle failure of some or all rovings in the strip width. Slipping phenomena inside the gripping area were not observed.

The average peak stress and strain obtained were 2240 MPa and 2. 7% respectively. The elastic modulus was 82. 8 GPa (Table 2).

The average mortar tensile strength from the three point bending tests is also given in Table 2. An average tensile strength of 7.27 MPa was calculated based on the cross-sectional area

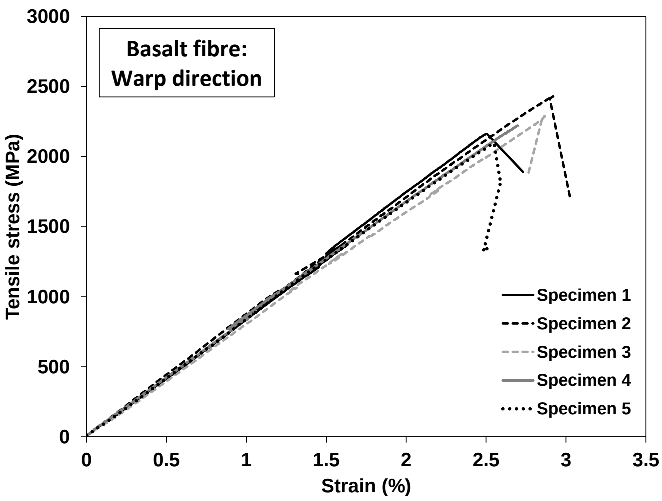

Figure 3. Basalt grid tensile test: stress-strain curves.

Table 2. Mechanical characteristics of Basalt grid and mortar

	Tensile strength	Young's modulus	Ultimate tensile strain
Basalt grid	2240 MPa	83 GPa	2.7 %
Mortar	7.27 MPa	-	-

3.4 Composite strip load-strain curves

The load-strain curves of the BRCM strips are plotted in Figure 4. The curves show a trilinear trend characterised by a first linear branch which ends when the first crack appears in the mortar. The second branch, characterised by several jumps and reduced stiffness, is due to the formation of several cracks in the matrix. Strips with two and three grid layers appear to give raise to a larger number of progressively closely spaced cracks compared to the one layer series. The slope of this linear branch also increases with the number of grid layers. Moreover specimens reinforced with one layer show a greater extension of this branch, compared to two and three layers samples.

In the third stage the strips regain a more regular, smooth trend, but with a lower slope than that showed in the first stage. This phase ends when the maximum load is reached.

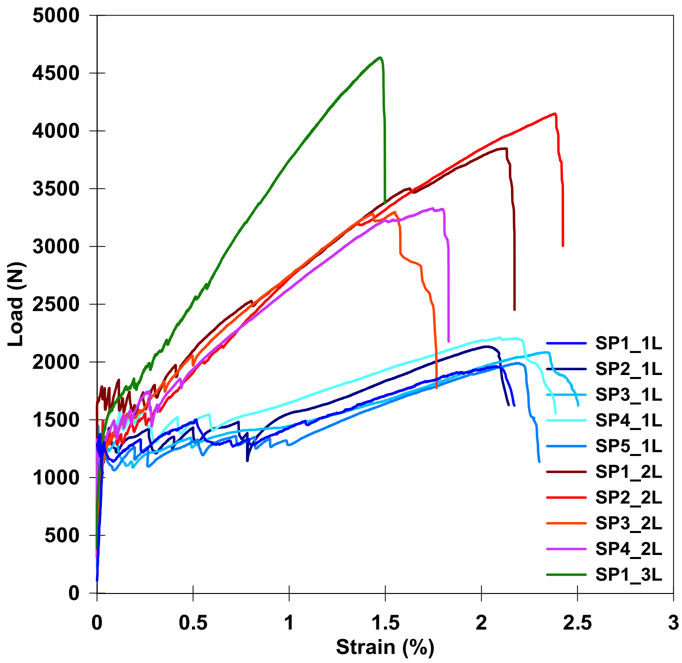

Figure 4. Load-strain curves of composite series.

Table 4 reports the average peak load (F) and strain (ε) values at the end of each stage, and the Young's modulus for the first and the third stage, for all the series.

Regarding the peak load values of the three stages, strips with higher reinforcement ratio showed higher strength as expected. However, the load increase was not proportional to the reinforcement ratio: +4% and +5% increment for stage 1 for SP_2 and SP_3 respectively compared to SP_1; +31% and 28% for stage 2; and +76% and +123% for stage 3.

Table 4. Average results for BRCM strips in Stage I, II and III

Series	Peak load [kN]	Peak stress [MPa]	Strain [%]	Young's modulus [GPa]
	F_I	σ_I	ε_I	E_I
SP_1L	1.363	875.7	0.035	3053
SP_2L	1.419	455.8	0.033	1565
SP_3L	1.437	307.8	0.040	776
	F_{II}	σ_{tII}	ε_{II}	E_{II}
SP_1L	1.419	911.8	0.90	/
SP_2L	1.862	598.2	0.43	/
SP_3L	1.822	390.1	0.22	/
	F_{III}	σ_{tIII}	ε_{II}	$E_{t,III}$
SP_1L	2.077	1334.3	2.15	34.22
SP_2L	3.655	1174.3	1.95	37.74
SP_3L	4.633	992.3	1.48	47.91

3.5 *Composite strip stress-strain curves*

The stress-strain curves of the BRCM strips are plotted in Figure 5. The tensile stress of the specimens was calculated dividing the measured load by the area of the internal reinforcement A_F calculated, for consistency with the procedure used for the textile, considering the number of yarns in the strips and the number of textile layers used as reinforcement. Stress values are reported in Table 4.

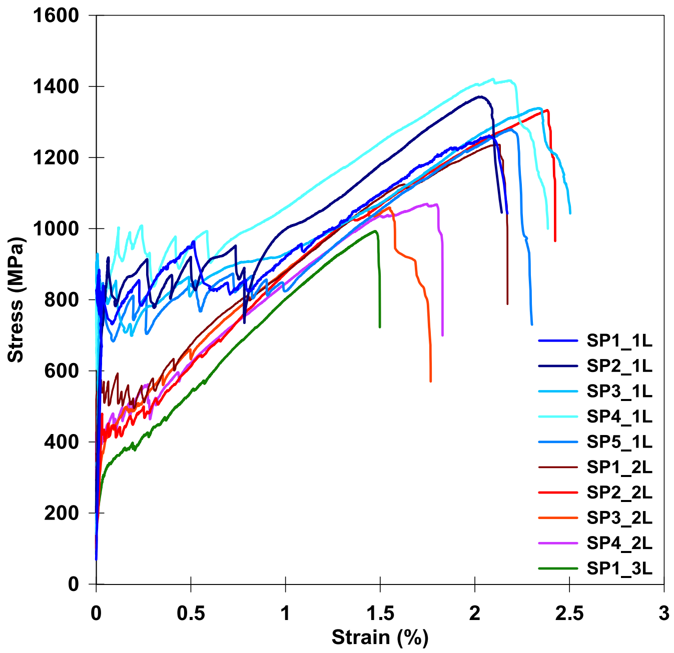

Figure 5. Stress-strain curves of composite strips.

Regarding the reinforcement ratio the stress-strain curves show that the strip strength decreases when the reinforcement ratio increases. This occurred for the first and second branch and in a less marked way for the third branch (load at failure). The two layers reinforced series compared to the one layer series show a decrease of -47%, -34%, -11% respectively for stage I, II and III. The three layer reinforced specimen compared to one layer series presents a strength decrease of 64%, 57% and 25% respectively for stage I, II and III.

In regard to strain values, the average of the three series are quite close for stage I (0.035%, 0.033%, 0.040%). For stage II there is a marked reduction of maximum strain between the one layer specimens and the two and three layer specimens with a drop of 53% and 76% respectively. Finally, curves show a reduction in stage III strain equal to 9% and 31% respectively.

The Young's modulus value in stage III increases with the number of grid reinforcement layers, but all the series present a large reduction of stiffness if compared with the value obtained from basalt grid strips (59%, 54%, 42% for one, two and three layers respectively).

Also the values of tensile strength in stage 3 ($\sigma_{t,III}$) are widely lower compared to the tensile strength of the basalt grid. The average tensile strength shows a reduction of 40%, 47% and 55% for one, two and three layers reinforced specimens respectively. These results indicate that the FRCM strips did not fully exploited the nominal capacity of the fibres. Both stiffness and strength reductions, although not so marked, were observed by other researches [1, 2] and could be related to stress concentration due to geometric defects of the grid, especially misalignment of the rovings, possible eccentricity in the application of the load to the fibres, wear of the fibres ate the vicinity of cracks edges. As the effective width of the grid strip was also more than twice smaller than the composite strip width size effect due to the geometric defects are also to be expected.

Considering the geometrical cross sectional area of the strip the average cracking stress for strips with one layer of reinforcement is 4.16 MPa, that is lower than the mortar strength obtained through three point bending tests (7.3 MPa). This has already been shown by other authors [12].

3.6 *Crack pattern*

In Figure 5 photos of three samples of SP_1L, SP_2L and SP_3L series at the end of testing are shown.

Figure 6. Crack pattern of composite specimens at failure.

The crack development observed during tensile tests on BRCM composites was characterized by cracks transversal to the direction of the applied load, clearly identifiable in the response curves and visible during testing. The photos show how the number of cracks increased with the increase of the reinforcement layers. The crack development stage extended up 0.9% strain for SP_1L and ended at 0.43% and 0.22% for SP_2L and SP_3L specimens. A similar strain reduction was observed in [2].

4 CONLUSIONS

The tensile tests carried out on composite BRCM strips with one, two or three layers of grid showed that:

- BRCM strips are characterised by a trilinear curve: uncracked response (stage I), crack development (stage II) and cracked response until rupture (stage III).
- The tensile strength values of basalt FRCM strips are widely lower compared to the tensile strength of the dry grid (-40% for 1 layer).
- The Young's modulus of the curves decreased with the number of layers in stage I (-49% and -75% respectively for 2 and 3 layers) and increased in stage III (+10%, +40%).
- The number of cracks increased with the increase of reinforcement ratio.
- The maximum strain in stage II reduced considerably (-53%) from strips with one layer to strips with two layers.

REFERENCES

[1] De Felice, G. et al. (2014),"Mortar-based systems for externally bonded strengthening of masonry", *Mater. Struct.*, 47, 2021–2037.

[2] Larrinaga, P., Chastre, C., Biscaia, H. C., San-José, J. T. (2013), "Experimental and Numerical Modelling of Basalt Textile Reinforced Mortar Behavior Under Uniaxial Tensile Stress", *Mater. Des.*, 55, 66–74.

[3] Ghiassi, B., Razavizadeh, A., Oliveira, D. V., Marques, V., Lourenço, P. B. (2016), "Tensile and bond characterization of natural fibers embeeded in inorganic matrices", *RILEM Bookseries*, 12, 305–314.

[4] Bilotta, A., Ceroni, F., Nigro, E., Pecce, M. (2017), "Experimental tests on FRCM strengthening systems for tuff masonry elements", *Constr. Build. Mater.*, 138,114–133.

[5] Carozzi, F. G., Poggi, C. (2015), "Mechanical properties and debonding strength of Fabric Reinforced Cementitious Matrix (FRCM) systems for masonry strengthening", *Compos. Part B Eng.*,70, 215–230.

[6] Alecci, V., De Stefano, M., Luciano, R., Rovero, L., Stipo, G. (2016), "Experimental Investigation on Bond Behavior of Cement-Matrix-Based Composites for Strengthening of Masonry Structures", *J. Compos. Constr.*, 20, article number: 04015041.

[7] Roscini, F., De Santis, S., de Felice, G. (2016), "Structural Analysis of Historical Constructions - Anamnesis, diagnosis, therapy, controls", *Proceedings of the 10th International Conference on SACH*, Leuven, Belgium, 384–390.

[8] Olivito, R. S., Codispoti, R. & Cevallos, O. A. (2016), "Bond behavior of Flax-FRCM and PBO-FRCM composites applied on clay bricks: Experimental and theoretical study", *Compos. Struct.*, 146, 221-231.

[9] Cevallos, O. A., Olivito, R. S. (2014), "Effects of fabric parameters on the tensile behaviour of sustainable cementitious composites", *Compos. Part B Eng.*, 69, 256–266.

[10] De Santis, S., de Felice, G. (2015), "Tensile Behaviour and Durability of Mortar-Based Strengthening Systems with Glass-Aramid Textiles", *Key Eng. Mater.*, 624, 346–353.

[11] Codispoti, R., Oliveira D. V., Olivito R. S., Lourenco P. B. (2015), "Mechanical Performance of Natural Fiber-Reinforced Composites for theStrengthening of Masonry", *Compos. Part B Eng.*, ELSEVIER, 77, 74–83.

[12] De Santis, S., De Felice, G. (2015), "Tensile behaviour of mortar-based composites for externally bonded reinforcement systems", *Compos. Part B Eng.*,68, 401–413.

[13] ISO 13934-1, (April 2013). "Textiles – Tensile properties of fabrics – Part 1: Determination of maximum force and elongation at maximum force using the strip method". CEN – European Committee for Standardization.

[14] EN 1015-11, (1999). "Methods of test for mortar for masonry – Part 11: Determination of flexural and compressive strength of hardened mortar".

[15] AC 434. (2012), "Proposed Revisions to the Acceptance Criteria for Masonry and Concrete Strengthening Using Fiber-reinforced Cementitious Matrix (FRCM) Composite Systems".

[16] Lignola GP, Caggegi C, Ceroni F, De Santis S, Krajewski P, Lourenço PB, Morganti M, Papanicolaou C(C), Pellegrino C, prota A, Zuccarino L. (2017), "Performance assessment of basalt FRCM for retrofit applications on masonry", *Compos. Part B Eng.*, doi: 10. 1016/j. compositesb. 2017. 05. 003.

[17] RILEM Technical Committee 232-TDT (Wolfgang Brameshuber) Mater Struct (2016) 49: 4923. doi:10. 1617/s115270160839z.