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FLEXURAL BEHAVIOUR OF BRICK MASONRY RETROFITTED WITH BRAIDED TEXTILE MESHES

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ABSTRACT

The vulnerability of unreinforced masonry walls (URM) under seismic events, causing huge loss of money and human lives, has revealed the enormous need for an efficient strengthening material. In this context, the present paper reports the development of a new reinforcing material for masonry walls based on braided fibrous structures. These fibrous materials were developed through braiding of polyester yarns around a core made of either glass fiber (core reinforced braid). Masonry walls were fabricated by placing these braided materials on the surface of clay brick walls in a mesh like configuration and covering with a mortar layer. This technique is designated as reinforced textile mortar retrofitting technique.
Keywords: textile reinforced mortar, brick masonry, seismic retrofitting

INTRODUCTION

Last seismic events in Southern Europe have highlighted the vulnerability in the most usual constructive typology in contemporary architecture: framed structures with masonry infills (Pompeu Santos, 2007, Lourenço et al., 2010). Contemporary structures have a good capacity to withstand these actions, given that they were considered for their design according to modern codes. Nonetheless, nonstructural elements as masonry infills show a high degree of damage even for medium magnitude earthquakes, causing casualties and high economic losses (Bertero and Broken 1983, Meharbi et al. 1994, Al-Chaar et al. 2002, Vintzileou and Tassios 1989). For decades, these elements have been considered as nonstructural and therefore they were not requested to have resisting conditions.

Given this, there is a large segment within the building stock in seismic prone areas that needs to undergo preventive action, especially for out-of-plane loads. This can range from a mere union of the infills to the frame structures to reinforce the elements, which can also be applied to the case of already damaged elements. The potential benefits go beyond the mere stability of nonstructural elements, as this would improve the behaviour of the whole structure to face seismic events. Following the use of textile reinforcement mortar as a retrofitting technique for masonry infill walls (Papanicolau et al., 2007; Papanicolau et al., 2008;) , some new fibre-based materials for structural reinforcement based on braiding techniques have been developed in the last years in the University of Minho, as an alternative to conventional FRP rods. These materials have several advantages, out of which it can be remarked the possibility of designing the composition according to mechanical requirements and the implication of low-tech (Mora, 2012)and low-cost procedures for its production.

The main purpose on this paper is to provide the results of the experimental campaign designed for the assessment of the performance of distinct meshes composed of braided materials with distinct quantity of fiber reinforcement and distinct spacing to work as retrofitting technique of brick masonry under flexural loads. The meshes with braided materials are composed of braided bars with two yarns of glass fibers spaced 6cm (2G6), four yarns of glass fiber with spacing of 6cm (4G6) and two yarns of glass fiber with spacing of 3cm (2G3) embedded in the rendering mortar of the specimens. The performance of these meshes was also compared with the behavior of different commercial meshes available in the market.

INNOVATIVE MATERIALS: BRAIDE FIBER-REINFORCED RODS

The application of textile materials is a technique with some years of research and development, with some commercial implementations already available. The used fibres are glass and carbon, due to the junction of good mechanical properties with durability and chemical resistance.

A second generation of this kind of materials is currently being developed on the aim of improving the behavior and effectiveness of the resisting fibers, by means of their use within composite materials, and especially within braided composite materials under the form of rods (Godinho et al., 2008). These were developed as an alternative for steel reinforcements, given its higher strength, its resistance to corrosion, the lower diameter and the possibilities offered by the insertion of a reinforcement structure to improve the bonding to the matrix. The further application of this technology is the retrofitting of masonry infill walls, still in early steps of assessment and main topic for this work. The resulting material is very similar to FRP rods, in the sense that they are a composite material with fibers within a resin matrix. They are called in bibliography braided composite rods (BCR). Its innovation is linked to the use of different materials within a composite trying to make the most of each one's properties. The resisting fiber, stronger, is inserted within a braided with low mechanical properties and cheap. This braiding, not being significantly resistant, should carry out two functions: (1) improving the bond among the mortar matrix and the fibers and (2) protecting the fibers from the potential chemical aggressivity of the matrix. Bonding is a major problem in the application of very strong materials for reinforcement. Failures by slipping of the fibers within the mortar or concrete matrix are very common, and it implies an ineffective use of the material, given that it is not allowed to develop its maximum stress.

Material Composition and manufacturing process

The composite material developed and presented in this paper can be briefly described as a braided fibrous materials made of polyester (polymeric fibers) around a core of fiberglass, with the addition of polyester resin to guarantee on the one hand bonding among them on the other hand the stability of the structure. Two different types of reinforcement will be produced in order to have a mean of parametrical comparison. They will be named from now as 2G and 4G, according with the number of yarns of fibreglass composing the core, namely two (2G) or four (4G). The choice on fibreglass instead of carbon is due to its lower cost, better availability and its better behavior in terms of ductility, given the higher stiffness and lower elongation in rupture of carbon, even if it has a higher tensile resisting force.

The BCR material is composed by 15 simple yarns and a braid (composed by 8 yarns) of high resilience polyester. In fact, a special disposition has been developed regarding the composition of the BCR material. The technique to made BCR involves braiding in the transverse and longitudinal directions forming a tubular structure. The yarns are in two groups of spindles and rotate in opposite directions, clock and counter- clock wise. With the aim of improving mechanical properties and for adding new functionalities, axial fibers can be added. This structure can be composed of different materials for achieving the required reinforcing behavior. Braiding angle is the most important parameter in characterizing a textile braided structure, influencing directly its behavior. Braiding angle is the angle between the longitudinal axis and the direction of insertion of the braiding yarns (Mora, 2012). In this case, this thicker yarn, which is used in the braiding machine in a rate of 15 normal to 1 thicker, is composed by a simple braid of 8 yarns.

(a) (b) (c)

Fig.1. Details about the manufacturing of the BRC; (a) distinct components of the BRC; (b) tensioning before the application of the polyester resin; (c) application of the polyester resin

The final step of the preparation of the rods implies tensioning them with 100N force, and then to stabilize them, as seen Fig 1b. The tensioning was done by attaching the braided rods to a stable structure on one end, and hanging weight on the other end. Once tensioned, san impregnation with resin is made, a process that is done manually as seen in Fig. 1c. The polyester resin is chosen because of its lower cost and toxicity compared to epoxy resins. It is activated through addition of 2% of Methyl Ethyl Ketone Peroxide. This is a technique aiming at ensuring the bonding and the unitary behavior of both braided fibrous and core, given that they will work together in the resin matrix and keeping the possibility of creating meshes by woving the individual BCR. For other research projects, the technique of resining was different (Godinho et al., 2008). Braided materials can be characterized mainly by two features: braiding angle and diameter. The diameter of the rods has been determined by its measure with a Vernier calipter with 0.05 mm accuracy for the measurement. The difficulty comes for the rugosity adherence of the BCR, which makes the diameter irregular. For each 2G and 4G 20 measures were taken in order to have a good average as characteristic feature. An average diameter of 2.05mm was found for 2G rods and an average diameter of 2.16mm was obtained for 4G rods.

The braiding angle is defined as the angle formed by the yarns braided around the core and the axis of the rod. This feature is important as bonding properties are highly affected by the characteristics of the braid and its rib structure. In previous studies by Godinho et al. (2008), it was observed that for each core-reinforced fabric, there is a braiding angle that ensures an optimum mechanical performance. For a braided fabric produced with six bobbins of polyester yarns and two simple braids, and a core reinforcement of 1800 tex fibreglass, this angle was stated in 23º-24º. This characterization was made with an optical amplifier and corresponding image-treatment software. The obtained data is an average of three measures, and the measured entity is as defined graphically in Fig. 2.

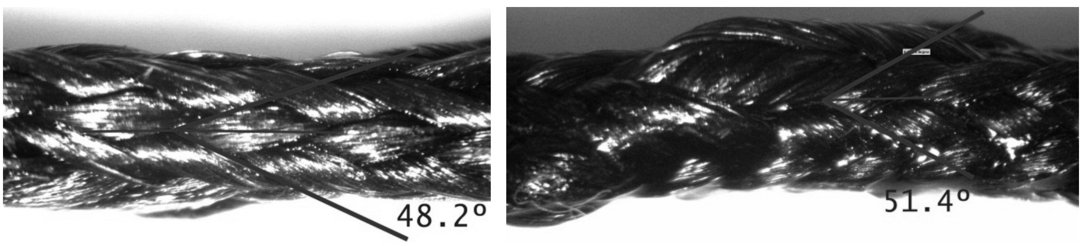
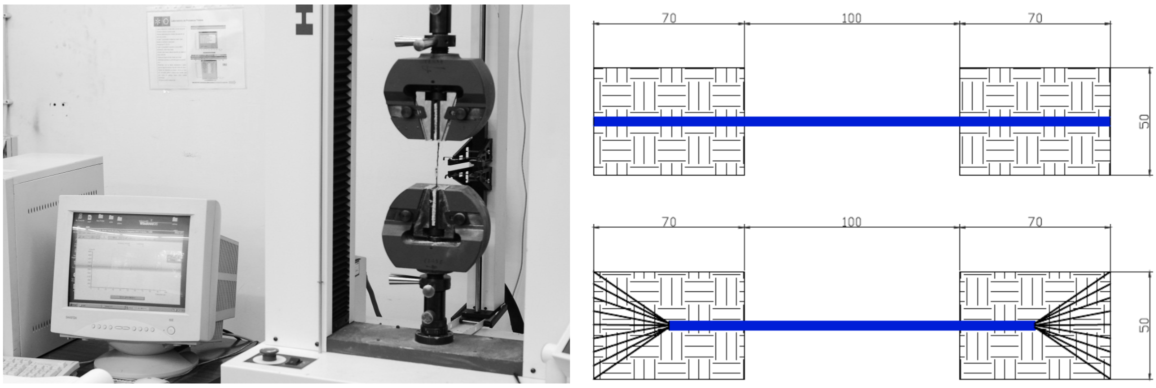


Fig.2. Visual aspect of the braided composite 2G and 4G rods

Mechanical characterization of BCR (Braided composite rods). Uniaxial tensile tests

The produced materials were tested according to ASTM 5034 (2009) in order to obtain their mechanical properties, namely breaking strength (equivalent to tensile strength), elongation and modulus of elasticity. This was done in a servo-controlled machine, following the common procedures in textile tests. The material is grabbed by the clamps and tensioned until breaking, being obtained the data of elongation related to the applied force.

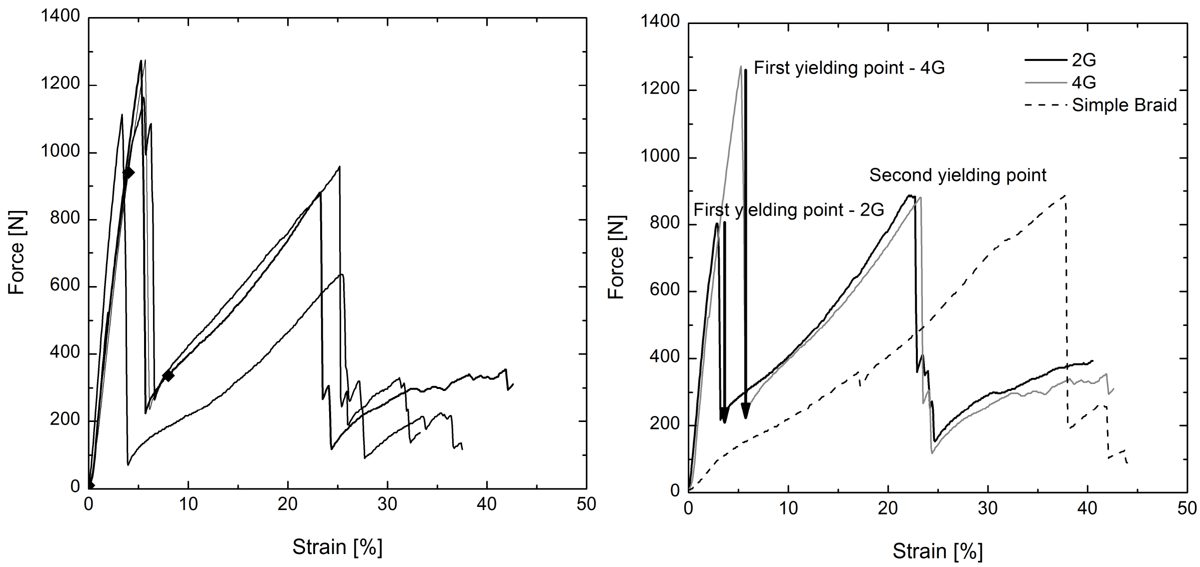
Samples of each 2G and 4G rods were prepared according to the standards and requirements of the testing machine. From previous experience it was learnt that it was not convenient to grab the rods directly with the clamps, being a better option providing them of holding plates on each end, made of a composite of fibreglass and epoxi resins, in order to obtain such a strength that the breaking occurs in the middle of the sample. The length of the samples was 100 mm, and the holding surfaces were 70x50mm^2. The equipment was a dynamometre Hounsfeld H100KS, and the test was carried under displacement control at a rate of 5mm/min. A preload of 10N was considered.



(a) (b)

Fig.3. Details of the tensile tests of the composite rods; (a) equipment; (b) BRC specimens

The typical behavior found for the composite rods under tensile loading is presented in Fig. 4. It is seen that the composite rods present a clear distinct behavior (2G and 4G) from the simple polyester braided rods (without reinforcing core). The composite rods exhibit considerable high stiffness than the simple braided rods, which is associated to the high stiffness of the reinforcing fibers. Besides, the reinforced composite braided rods present linear behavior until the maximum force is attained, whereas the pre-peak behavior of the simple braided rods is influence by the braded structure, leading to a different initial stiffness. This characteristic is associated to the braided angle of the textile structure. The maximum force of the composite rods is governed by the maximum force achieved by the glass fibers in the core, even if. the failure is not visible during the tests, as the fibers break within the polyester braid. Even if the post behavior should not be considered as representative od the composite structure, it should be noticed that there is a trend for the recovery of the tensile bearing force, which is associated to the bearing capacity of the polyester braided rods, whose tensile resistance is increasing for increasing deformation. In this case, very considerable axial deformations can be found. The recovery of the resisting force should be of the same order of the resisting force of the polyester braided, as shown in Fig. 4b. It should be noticed that the stiffness of the second branch is no more related to the stiffness of the composite rods and should be more close to the stiffness of the simple braided rods. It should be noticed that that for braided composite rods 4G, with double mass of the braided rod 2G, does not resist to the double force.



(a) (b)

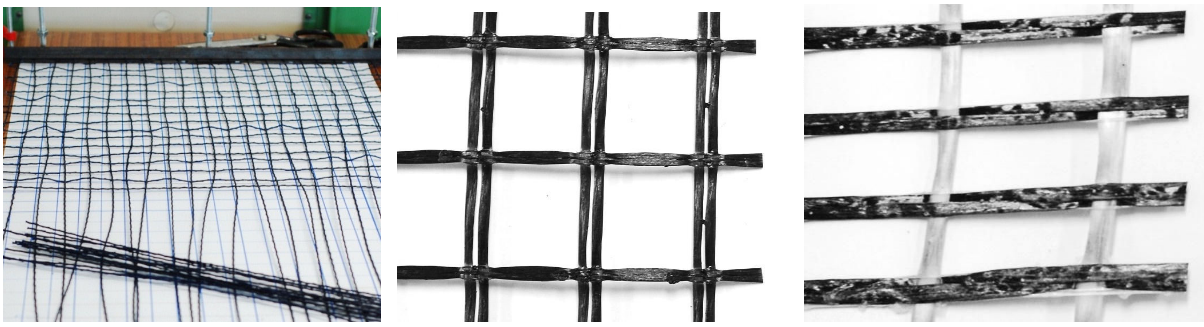
Fig.4. Typical behavior of the tensile behavior of the composite and simple braided rods: (a) tensile behavior of the composite braided rods4G and (b) comparison of the tensile behavior composite (2G and 4G) and simple braided rods

This nonlinearity in the tensile bearing capacity should be associated to different factors: (1) even if the deformation is solidary, the fibers in the core could be not perfectly aligned in the pre-tensile state, giving higher strains than expected, as the reinforcing fibers have to align in the beginning of the tensioning process; (2) nature of the fibrous materials, and the higher probabilities of having imperfect yarns, increased for materials with higher content of yarns. Besides, the scatter on the results can be explained by the semi-manual production of the braided rods.

Manufacture of BCR meshes

After the production of the reinforcements, the produced rods were assembled into a bidirectional mesh. A woven structure for the mesh was preferred to the simple superposition of the rods in perpendicular directions, due to a better self-stability of the mesh before its implementation and a better guaranteed bidirectional behavior. The meshes were assembled according to the defined measures, with spacing of 60 or 30 millimeters. The manual character of this procedure implied difficulties such as ensuring accurate constant spacing among the rods. The joining of the two perpendicular directions of yarns in the mesh was done by application of polystyrene resin on them, see Fig. 5a. To guarantee a correct application, the curing period was of 24 hours. The aim is to improve the natural stability of the mesh to ensure its application to the wall in correct conditions.

One of the purposes of this research is to assess the capacity of improvement of the bonding between the reinforcement fibers and the matrix mortar due to the use of braided materials. So far, commercial solutions consist just on the reinforced material, prepared to be inserted in the mortar matrix. To have a reference, two different commercial solutions were chosen to be used and be compared to the developed materials. The range of options was not very wide but, nonetheless, it was possible to choose two solutions different among them, being one more similar to our proposal in terms of resisting material and mass density, and the other different in material and disposition. The bidirectional mesh is composed by alkali-resistant fiberglass (CM1), see Fig 5b. The black color is due to the alkali-resistant treatment, based on bitumen. It is composed in both directions by two yarns of fiberglass per element, in one direction they are tightly together and in the other they are separated. The joints are somehow rigid, apparently made by pressure and heat. Its application is recommended with "high ductility mortars". The unidirectional mesh (CM2), see Fig 5c, is composed in the main direction are composed by two yarns of carbon fiber, slightly joined by a very thin fiberglass rolled around them. The yarns are slightly covered with a sandy-like granular element, probably to increase the bonding properties, though there is no mention to it in the technical data. The transversal elements are composed of fiberglass, in a much lower density, probably better for stabilizing the mesh than for really give a bidirectional behavior. The mesh is joined by woving, and its density guarantees its self-stability.



(a) (b) (c)

Fig.5. Details about the meshes; (a) Proposed mesh; (b) commercial mesh CM1; (c) commercial mesh CM1

EXPERIMENTAL CAMPAIGN ON STRENGHTENED MASONRY

The evaluation of the effectiveness of the new materials developed as a retrofitting technique aiming at improving the out-of-plane behavior of brick masonry infill walls was carried out based on an experimental campaign composed of bending tests mobilizing the flexural resistance of masonry in the perpendicular direction to the bed joints. For this, distinct solutions for the retrofitting materials were selected, namely: (1) application of the textile composite meshes developed; (2) use two distinct commercial meshes as described previously. The idea is to reinforce the rendering mortar with the textile distinct meshes (TRM technique).

Masonry specimens and testing procedure

The geometry of the samples, the setting of the flexural resistance tests and the number of tests were defined according to standards EN-1052 (1999). For this work, the geometry of samples was reviewed in comparison with the previous work (Vasconcelos et al., 2012), as it is considered that the span that was considered for the flexural tests should be increased so that the results could be also more comparable with previous studies that have been carried out with larger spans. Therefore, the new dimensions will be designed according to UNE-EN-1052, according to the same type of bricks as the previous works, but trying to make the span for the flexural test double of the previous one, so that the relation thickness/span of the wall is closer to 10. Papanicolau and Triantafillou (2008) used specimens with a span to thickness ratio of 1300/85 (approximately 15) and Rupika (2010) used specimens with a span to thickness ratio of 930/7 (approximately 12).

The brick was selected as the most representative for simple partition walls or for simple leaves within composed enclosure walls in Portugal. The total thickness of the wall registered in codes (referring to isolation requirements) and in construction practice is of 12 cm. This solution, executed with the most usual measures of bricks and with bricks with horizontal perforation, leads to a brick of 30x20x11cm^3 (LxWxH). Given that the flexural tests will be done in the direction of the bed joints, it was necessary to have data for the compressive strength of the bricks in the direction of the holes. Four brick masonry units were tested in a loading machine with a capacity of 2000kN according to EN 771-2 00, using the corresponding load rate of 0.05 (N/mm^2)/s. The obtained average value must be normalized due to the dimensions of the unit. Given the height of 300 mm and the width 140 mm, the correction factor δ is 1.35, and the normalized strength in the parallel direction to the perforation, $f_{b,}$ is of 6.1 MPa.

The mortar for the bed and head joints is defined as a general purpose pre-mixed mortar used for laying the mortar units and is from class M10. The mortar for the rendering and implementation of the reinforcements is defined as rendering mortar, according to EN-998-1:2003. The quality of both mortars was controlled through samples taken during the construction of the specimens and then tested under flexure and uniaxial compressive strength. This procedure enables also to control also the quality of workmanship. The average compressive strength for laying brick units was 9.34 MPa, with the lowest value of 7.9 MPa, and the highest of 11.1 MPa. This value is slightly under the 10 MPa given by the specifications (M10), but again, it can be due to a higher quantity of water required to have a proper workability. The average flexural strength was of 2.94 MPa. For the render, the average compressive strength was of 9.18 MPa, higher than the minimum value provided by the producer and the average flexural strength of 3.45 MPa.

The construction of the samples was completed with the addition of the reinforcement materials, both commercial and self-produced, within a general purpose rendering mortar, as seen in Fig. 6a. Before the application of the retrofitting materials, the walls were swept to clean possible dust or imperfections that could affect adherence, and then spilled with water to avoid that the bricks absorbed the water of the mortar making it dry too quickly. The mesh was applied within the rendering mortar layer of approximately 12mm. In total, five different retrofitting schemes were tested. As mentioned in the previous section, the retrofitting meshes are characterized by the reinforcement density, spacing of the yarns and tensile capacity (Table 1). A calculation of the total tensile strength for each retrofitting mesh has been done. For the commercial meshes, this value is provided as tensile strength per metre, and will be adjusted to the tensile width of the walls, corresponding to the height of the samples and equal to 610 mm. In a simplified way, the resisting force taken by the proposed meshes is taken as the value resulting by multipliying the mean tensile force of each type of rod by the number of rods according to each retrofitting scheme. This is an approximate calculation and need to be confirmed by further tensile tests on the produced meshes, which is being made in a scope an additional experimental work.

(a) (b)

Fig.6. Details about the experimental program; (a) application of the BCR meshes; (2) setup for the flexural tests
Table 1. Definition of retrofitting schemes.

Retrofitting material	Reinforcement density (g/m^2)	Spacing (mm)	Tensile Capacity (kN)
2G #6	57	60	9.2
2G#3	114	30	12.0
4G#6	114	60	18.4
CM1	225	25	27.4
CM2	200 (unidirect.)	20	57.1

Definition of the retrofitting schemes and test setup and test procedure

The test setup is composed of a steel frame connected to a reaction slab to which a hydraulic jack, with a load capacity of 500 kN connected to a load cell of 200KN is associated. The loading configuration was defined according to standard EN1052-2 99 for flexural strength of masonry. The deformation of the samples was measured through three LVDTs with a measuring capacity of 50 mm: one in the mid-span and one under each application of the load, as this were expected to be the most likely points for the formation of the cracks and thus the maximum deflection. The simple support structural scheme was achieved through the use of metallic rods, adding an interface in-between the rod and the sample composed by two layers of Teflon painted with mineral oil to avoid any unexpected effect of the friction at the supports, see Fig. 6b. In this case, the load-application control is through fixed displacement. The testing procedure is composed of three steps, according to the different expected mechanisms: (1) first step, with a velocity of 0.004 mm/s during the first 6 mm, corresponding to the lower rate achievable by the machine. This is due to the low displacement required for the cracking of the wall (after the first testing, estimated in the order of 1 mm); (2) second step, with a velocity of 0.01 mm/s during the next 4 mm, increasing the velocity as the reinforcement is loaded after the cracking of the wall; (3) last step, with a velocity of 0.02 mm/s, aiming to make time-affordable tests given the high deformation expected, especially for the braided materials.

Analysis of results

An overview of the obtained results will be provided on the purpose of analyzing the main features of the behavior that define each reinforcement typology. There will be a special interest on analyzing certain mechanical parameters that measure the effectiveness of each solution, namely cracking load, cracking load displacement, maximum loading and corresponding deflection and maximum deflection. Besides, it is important (1) to evaluate the post-peak behavior with increase or decrease of the loading capacity; (2) increase on the ultimate deformation; (3) evaluation of the failure mode, focusing on the existence of redistribution of load, being this a feature of the safety improvement provided by each solution. The typical load-displacement curves obtained for each masonry specimens are indicated in Fig.7.

The unreinforced masonry (Fig.7a) is characterized by a very brittle behavior, which is associated to the localized central crack involving the failure of the unit-mortar interface and the units, see Fig.8a. This is the typical failure mode already pointed out by recent researches (Vasconcelos et al., 2012). In average the maximum flexural load, corresponding in this case to the cracking flexural load, presents an average value of 8.48kN (Table 2), corresponding to the flexural stress in the perpendicular direction to the bed joint, f_{xi}, of 0.45MPa. The scatter on the flexural cracking load is low, which validate the accuracy of the experimental results.

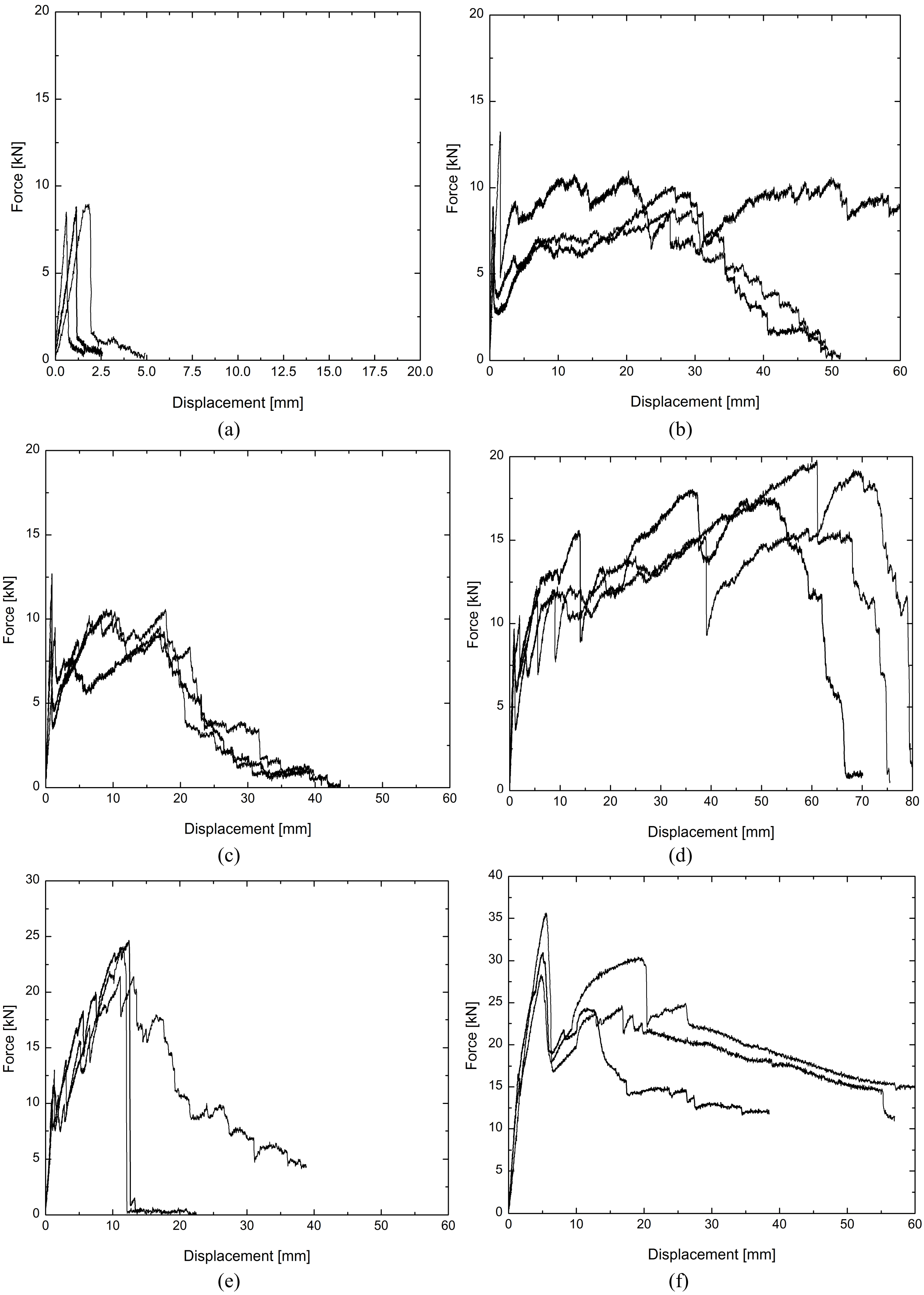


Fig.7. Typical force-displacement diagrams obtained in flexural tests; (a) unreinforced masonry; (b) masonry strengthened with mesh 2G#6; (c) masonry strengthened with mesh 4G#6; (d) masonry strengthened with mesh 2G#3; (e) masonry strengthened with mesh CM1; (f) masonry strengthened with mesh CM2

Table 2 . Loading and deflection indexes associated to the load vs. displacement curves

	URM	*2G#6*	*4G#6*	*2G#3*	*CM1*	*CM2*
Flexural cracking load (kN)	8.48	7.68	8.44	8.56	10.9	10.6
Cracking load deflection (mm)	0.165	0.149	0.235	0.265	0.145	0.198
Max elastic flexural stress (MPa)	0.450	0.408	0.448	0.454	0.579	0.563
Max flexural load (kN)		9.47	10.395	17.829	23.38	32.36
Max deflection calculated (mm)		68.287	42.826	86.583	12.59	large
Max flexural stress (MPa)		0.502	0.551	0.946	1.242	1.718
Load redistribution		NO	NO	YES	YES	YES

As expected, the material is very stiff, with a very low displacement until the peak load is attained. Even if the loading rate was set for the minimum possible for the used load cell, the samples broke in an average of 3 minutes, presenting an abrupt failure, resulting in the impossibility of obtaining any post-peak response. The response of the specimens strengthened with braided composite rod meshes present a similar behavior until the flexural cracking load is attained (Fig.7b-d), resulting in the opening of the first flexural crack. In average, the flexural cracking load obtained in the specimens 2G#6, 4G#6 and 2G#3 is similar to the load recorded in the URM specimens (Table 2).This means that the proposed meshes are not very effective in increasing the flexural cracking load. Besides, it is seen that after the first crack is opened there is a considerable reduction of the resisting flexural load in case of specimens strengthened with braided composite rod meshes, whereas the reduction is more controlled in case of Comercial meshes CM1 and almost inexistent in case of the CM2 mesh. Notice that the commercial mesh CM1 is composed of the same base reinforcing material than the innovative materials, glass fibres. However, reinforcement ratio is considerably higher when compared with the innovative materials developed here. On the other hand, the small spacing among the yarns guarantees a very uniform behavior. There is a very good redistribution of the load in case of use CM2, with the development of several thin cracks without a definite opening of any of them. The opening of these cracks implies lowerings on the load bearing capacity, even if a growing tendency until reaching a maximum load of about 23 kN is observed. The peak load is attained for a deflection of about 12 mm.

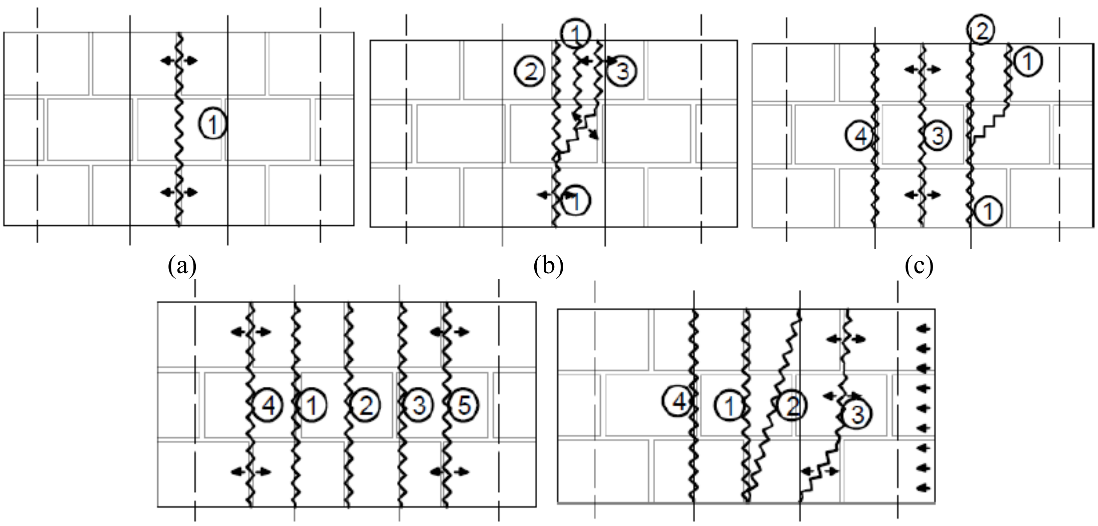


Fig.8. Crack patterns at failure; (a) masonry strengthened with mesh 2G#6; (b) masonry strengthened with mesh 2G#6; (c) masonry strengthened with mesh 2G#6; (d) masonry strengthened with mesh CM1; (e) masonry strengthened with mesh CM1

After the reduction of the flexural strength there is a recover for a value close to the flexural cracking load in case of specimens strengthened with 2G#6 and 4G#6. In case of mesh 2G#3 there is a progressive increase on the flexural load for more than the double of the flexural cracking load. The great advantage of the BRC meshes (2G#6 and 4G#6) is the improvement on the behavior after the cracking load, as the specimens are able to recover great percentage of the flexural resistance for high values of lateral deformation, even if no advantage was observed in the crack distribution, see Fig. 8a-b, in relation to unreinforced masonry. On the other hand, the mesh 2G#3 results in effective force redistribution, being the crack patterns clearly more distributed, see Fig8c.

It is observed that the BRC meshes present a more ductile behavior than the mesh CM1, in which two specimens failed abruptly after the achievement of the maximum load. In case of the specimens reinforced with the BRC mesh 2G#3, the increase on the flexural resistance load in accompanied by the increase on the deformation. Contrarily to the other BRC meshes, in this case it is possible to observe that there is a more effective redistribution of forces being the mesh also effective in increasing the resistance, see Fig. 8d. It should be noticed that the ductility measured as a function of the maximum displacement is also higher in case of BRC mesh 2G#3, being practically similar to the ultimate deformation exhibited by the specimens strengthened with mesh CM2. The use of this commercial solution lead to an enhancement of the first cracking load, of around 20 % compared to the unreinforced samples. The most remarkable feature of its behavior is the quick redistribution of the loads and the developing of several thin cracks. The formation of cracks does not imply the dropping on the load bearing capacity, but just a lowering of the stiffness (cracked stiffness). In this case it is observed a distributed crack pattern, even if in the failure sliding of the carbon fibers was recorded.

CONCLUDING REMARKS

The comparison among the different retrofitting solution must take into account the differences between the used solutions. The samples with the innovative material are comparable among them, given that they have a progressively increasing tensile capacity, and this is noticeable in increasingly better properties. The commercial solutions, having a much higher mass and tensile capacity, give better results in general, though the features of their behavior are different. Therefore, the comparison among the solutions should be regarded more in a qualitative than in a quantitative scope.

However, for the quantitative comparison the following statements can be remarked: (1) the composite reinforcements do not provide any noticeable improvement in the elastic range, meanwhile the commercial products increases the maximum elastic flexural stress (load at first crack) in about 26% for CM1 and 24% for CM2 commercial solutions; (2) the maximum load increases progressively with the amount of reinforcement, though not in a linear way.
The improvement on the flexural maximum load can be estimated in terms of load bearing capacity (directly related to flexural stress) when compared to the load obtained in unreinforced masonry specimens: (1) 2G#6, improvement on the maximum flexural load of of 11%; (2) 4G#6, improvement on the maximum flexural load of of 22.6%; (3) 2G#3, improvement on the maximum flexural load is of 110% but it is mobilized for very large deformations. If the range of deformations for which the maximum load is achieved for the other solutions is considered, the improvement can be estimated as 36%; (4) CM1 improvement on the maximum flexural load of of 175%.; (5) CM2, improvement on the maximum flexural load of 281%.

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